UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
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R E P O R T

ON

THE INTERNATIONAL WORKSHOP ON COMPOSITE MATERIALS AND WASTE MINISATION:

FIBRE REINFORCED MATERIALS BASED ON LOCAL RESOURCES
4-8th AUGUST, DAR ES SALAAM, TANZANIA

ORGANISED WITH FINANCIAL SUPPORT FROM THE UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANISATION (UNIDO)

INTERNATIONAL WORKSHOP ON COMPOSITE MATERIALS AND WASTE MINIMISATION:
FIBRE REINFORCED MATERIALS BASED ON LOCAL RESOURCES

Dar Es Salaam, Tanzania
4th-8th August, 1997

Organised by:
The International Centre for Science and High Technology (ICS)
P.O. Box 589, Via Grignano 9
34014 Trieste, ITALY

Sponsored by:
United Nations Industrial Development Organisation (UNIDO)

Jointly hosted by:

The Faculty of Engineering
University of Dar Es Salaam, TANZANIA

and

The Eastern and Southern African Mineral Resources Development Centre (ESAMRDC), Dar Es Salaam, TANZANIA

ICS PROGRAMME COORDINATORS

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WORKSHOP LOCAL ORGANISING COMMITTEE:

Dr. E.T.N. BISANDA	-	University of Dar Es Salaam
Mrs. T.K. MWASHA	-	ESAMRDC
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1.0 INTRODUCTION

In the fast changing scenario of the construction industry requiring to link production of building materials with a sustainable and environment - friendly development, the building materials industry is under pressure and is unable to cope with the new demands from different industrial sub-sectors. This has led to a growing concern for developing and promoting alternative building materials.

One of the strong options is to promote development and utilisation of composite materials based on local renewable resources such as natural fibres and plant materials including the recycling of industrial by - products, and utilisation of agricultural wastes.

At the same time, research and development undertaken on alternative building materials and waste exploitation has not only shown but also effectively demonstrated that the use of some of these wastes and of local renewable resources can reduce the use of expensive materials such as cement, bricks, steel and wood. Furthermore, it has been shown that expensive synthetic fibres can be replaced by natural plant fibres to produce reinforced composites with the desired mechanical strength and durability.

Taking the above into account, the International Centre for Science and High Technology (ICS) within the framework of UNIDO, proposed an international programme on development manufacturing and application of materials based on local resources and recyclable by-products.

The major objective of the programme is to promote the exchange of know-how and enhance both science and technology among participating countries in the areas of product design, manufacturing, testing and evaluation. Special efforts are being undertaken in the field of natural fibre-reinforced materials and waste minimisation to build-up know-how and manpower capabilities for the high industry and housing sectors. The programme will also focus on providing infrastructural support for product developments, the technology transfer and management of technological change in developing countries.

The International Workshop on Composite Materials and Waste Minimisation was held at the Eastern and Southern African Mineral Resources Development Centre (ESAMRDC), Kunduchi Beach, Dar Es Salaam, Tanzania from 4th to 8th August, 1997. The Workshop was officially opened by the Vice President of the United

Republic of Tanzania, Dr. Omar Ali Juma. It was attended by participants with medium to low scientific background coming from countries such as : Uganda, Kenya, Ghana, India and Tanzania.

The contents of the workshop, were illustrated by means of lectures and dealt with the state of the art, future directions, standardisation and commercial exploitation aspects of plant fibre-based composite materials as shown on appended papers. Lectures were given by worldwide outstanding and contributing lecturers on the topics.

Majority of the participants were sponsored by ICS. For the sake of enhanced visibility and for a larger dissemination, the workshop invited external self financing participants.

The workshop was addressed to Scientists working in the field of new materials and entrepreneurs, and was aimed at:

- bridging the gap between the materials science and technology of composites based on natural materials;
- exchanging knowledge and experience on aspects of design, production, testing and application of these materials;
- enhancing the industrial use of environmentally friendly natural materials and create new opportunities for business;
- facilitating the transfer of technology in advanced and new materials to developing countries while also promoting South-South co-operation.

The workshop was conducted in English.

From various presentations made during the workshop, capabilities exhibited and interest and awareness created, there is a growing evidence that the new composites using natural fibres, industrial and agricultural wastes, low value woods and plantation timbers shall be the building materials of the 21st century.

2.0 ORGANISATION AND CONDUCTION OF THE WORKSHOP

2.1 The Opening Ceremony

The workshop started on Monday 4th August, 1997 with an opening Ceremony in which the Vice President of the United Republic of Tanzania, Dr. Omar Ali Juma made the opening speech. The ceremony was also attended by The Vice Chancellor of the University of Dar es Salaam, Prof. Mathew Luhanga, The Dean, Faculty of Engineering, Prof. Peter Materu, The Director General of the ESAMRDC, Dr. Antonio Pedro and the Ambassador of Italy in Tanzania, Torquato Cardilli.

In his opening speech, the Vice President challenged workshop participants to propose solutions to the growing problems of deforestation and suggest ways of obtaining low cost building materials for the growing needs of human shelters in developing countries.

2.2 Lectures

Briefly, the following is a summary of the lectures presented:

2.2.1 The ICS's New Materials programme
By Prof. Sergio Meriani

The New Materials Programmes Co-ordinator, Prof. S. Meriani, gave a brief introduction of the structure of ICS, its objectives and mission towards science and technology transfer in the area of New Materials. Emphasis was made on the current programme which is aimed to assist developing countries to utilise their natural resources for production of useful engineering materials that are environmentally friendly. The present programme had four major components:

(i) A scientific workshop on composites, held in Bergano, Italy in March 1997.

(ii) A Scientific workshop on composites based on natural resources and waste minisation, Dar Es Salaam, Tanzania.

(iii) A fellowship programme, in which fellows from developing countries spend one year in Italy on industrial attachment. Two fellows have been selected from Tanzania under the programme.

2.2.2 The Potential of Agricultural Wastes for Composites Manufacture in Tanzania.

By Dr. E.T.N. Bisanda, University of Dar es Salaam, Tanzania.

The Lecturer presented data showing the amounts of agricultural wastes produced annually in Tanzania. Their potential for use in biocomposites manufacture was discussed. Examples of available technologies that may be employed to produce biocomposites from agricultural wastes were mentioned. This was generally felt by participants to be an area with immense opportunity for farmers and entrepreneurs who would wish to start producing building materials from agricultural wastes.

2.2.3 Natural Fibre Biocomposites: Production and Applications in North America:

By Prof. P.V. Mtenga , Florida A&M University, USA.

The Lecturer gave an impressive presentation on the growing production and application of biocomposites in North America, due to increased concern on environmental conservation and the unlimited range of shapes and sizes of products that can be made from biocomposites, to replace wood and timber. The lecture produced statistics on quantities of waste generated and recoverable from various sources, while illustrating the unlimited resource of agricultural wastes available for biocomposite production in North America.

The structural applications of biocomposites in the North America was highlighted, clearing showing a growth in preference for biocomposites.

2.2.4 Cellulose Based Polymers for Plastic Composite Materials

By Patricia Truer, CSIR, Pretoria, South Africa

The Lecturer introduced the natural fibres, giving the classifications and characteristic of several common natural fibres. The processing of fibres and the manufacture of natural fibre composites was briefly outlined. The lecture also discussed the major advantages and limitations of natural fibres in composites. Poor wettability, intermolecular hydrogen bonding and water absorption were seen to be the main challenges that have to be overcome in order to take full advantage of plant fibres in composites.

Polymers that are suitable for matrix materials were mentioned. Potential marketable products from natural fibre reinforced composites were highlighted, and emphasis was made on industrial applications. The presenter concluded by urging co-operation among researchers from developing countries, especially in Africa, to work together using skills and resources within their countries to achieve industrial development.

2.2.5 Steam Exploded Natural Fibres and Reinforcement for Polymeric Based Composites

By Dr. M. Avella, IRTeMP, Italy

The Lecturer presented an overview on the steam explosion process, which is used to produce fibres from any vegetable sources. The process involves subjecting the ligno cellulosic material to high temperature stream (200 - 250°C) at high pressures (14 - 40 bar) for a few minutes (1 - 5min). When the materials is subjected to a sudden change of pressure to atmospheric pressure, the epidermal tissue of the material is destroyed, and the amorphous material (liqnin, pectin and lemicellulose) separating individual fibres is also destroyed, liberating neat cellulose fibres. The cellulose fibres thus produced can be used as reinforcement for plastics.

This technology was identified as very ideal for developing countries like Tanzania with abundant resource of agricultural wastes containing large amounts of cellulose. The cellulose produced can be used with both thermosetting and thermoplastic matrices. Processing techniques include extrusion, injection and compression moulding.

2.2.6 The Structure of International Information System aimed at Implementing Technology Co-operation Programme in the area of Composite Materials from Natural Resources

Dr. T.N. Gupta, Director BMTPC, India.

The Lecturer presented the structure of the data base on availability of local resources along with their current uses. The network structure was also presented, showing how various regional centres will be linked to the system. At least four countries in Africa have shown willingness to participate in the creation of the data base. These include Tanzania, Ghana, Kenya and South Africa. The main reason for this effort was shown to be the fact that there are vast amounts of data on natural fibre composites, which are scattered around the world. However, there was no consistency in the reported information, nor are there any system of standardisation to ensure compatibility and comparability of various sources.

Hence, extensive efforts are necessary to generate multiple co-ordinated data on the fibres, composites, and process technology to form a sound technological base.

2.2.7 Development and Industrial Application of Natural Fibre Reinforced Composites - The Indian Experience.

Dr. Mohan Rai, Building Materials Consultant, India

The Lecturer started by stating the high position that India has placed on the utilisation of plant fibre and industrial wastes on the production of building materials. The vegetable fibres abundantly available in India include Coir, Rice husks, Groundnut husks, Rice and Wheat straw, Jute, Bagasse, Corn corbs and stalk, and Saw mill wastes. Others are Pineapple and Palmyrah. India has already developed and commercialised several composite systems for the construction industry. Some mechanical properties of commercial roofing sheets made from fibre reinforced composites in India were presented. Comparative costs for the various materials were also shown. Recently, efforts have also been made to produce 'hybrid' composites that constitute of glass fibre and plant fibres, to take advantage of the high strength and water resistance of the glass fibre in outdoor structural applications. Finally, a list and addresses of commercial fibre reinforced composite manufacturers in India was given.

2.2.8 The Performance of Cotton-kapok Fabric Polyester Composites

Mr. L.Y. Mwaikambo, Sokoine University, Morogoro, Tanzania

The Lecturer introduced the utilization of Kapok fibre in the group of plant fibres that have potential for use in biocomposites. The fibres, obtained locally in coastal areas of Tanzania, have been largely ignored as a commercial product, after the introduction of synthetic foamed plastics for use in mattresses and upholstery stuffing. By blending the fibre with cotton, it was possible to produce a fabric that has been successfully used in making composites with Polyester, Cashewnut Shell Liquid (CNSL), and Polypopylene matrices. The lecture illustrated the mechanical properties of the composites, the Scanning Electron Microscope (SEM) micrographs of fibres, and SEM fractographs of fractured tensile test specimen. The Differential Scanning Calorimetry (DSC), thermogram of cotton and kapok fibres and the Dynamic Mechanical Thermal Analysis (DMTA) response of a cotton-kapok fabric polyester composite were also shown.

2.2.9 Interfacial Debonding of Natural Fibre Reinforced Composites (NFRC)

By Prof. Akwasi Ayensu, Ghana

This presentation illustrated the mechanisms and processes involved in interface behaviour of natural fibre reinforced composites. Interface behaviour was seen to be the controlling factor in the mechanical behaviour of the composite. A theoretical model based on Eshelby's equivalent method and experimental data was developed to estimate the total work of fracture. It was shown that the work of fracture largely depended on the pull out energy, which is a reflection of interfacial strength.

The lecturer also presented some performance data on coir - polyester composites to illustrate the influence of surface modification of fibres on the interface behaviour in terms of flexural properties.

2.2.10 Utilisation of Wood Wastes and Residues in Particle boards

Dr. B. Chikamai, KEFRI, Kenya

The Lecturer presented the current developments in Kenya, on the utilization of wood wastes and residues for the manufacture of particle boards. It is estimated that more than 340,000 cubic metres of wood are being generated as non-commercial thinnings in Kenya.

About 67,350 cubic metres of saw dust is generated while another 197,560 cubic metres end up as factory waste in the form of slabs and bark. It has been estimated that at least 44% of the wood ends up as residue and waste in

East Africa. While some of the residues and wastes are being used as fuel, most of the residues such as sawdust remain under-utilised. The production of particle and chip boards is seen as the best alternative to minimise waste. The Kenya Bureau of Standards, has established the specifications required for chipboards. The presentation highlighted the opportunities available for increased use of wood wastes and residues, through establishment of integrated factories close to the sawmills.

2.2.11 Development of Wood Adhesives for Tanzania Plywood and Particle-board Factories

By G.C. Mwalongo, TIRDO, Dar es Salaam, Tanzania

The Lecturer presented some recent work by researchers at TIRDO, in which an adhesive has been developed from wattle tannin and cashew nut shell liquid (cave). The adhesive is now being commercially applied in particle-board and plywood manufacture. The presentation gave comparisons in terms of performance of the new adhesive compared to traditional Urea Formaldehyde binders used by the plywood and particle board industry. The new adhesives have shown to have improved weather resistance, and have lower formaldehyde emissions compared to commercial Urea Formaldehyde resins. The Cashew Nut Shell Liquid was used as an emulsifier and improved the bond strength and pot-life of the tannin based resin.

2.2.12 Timber and Wood-based Composites

Dr. P. Bonfied, BRE, U.K.

The Lecturer presented the state of the art in the mechanics of wood based board materials. Wood is a natural polymeric composite material with a complex structure. The characteristic difference in board types is the particle size. Board can be produced with oriented particles, using a variety of binders to give variations in density and material properties. The lecturer presented the various types of boards including chipboard (or particle board), medium density fibreboard (MDF), oriented strandboard (OSB), cement-bonded particleboard and plywood. The resins that are commonly used are melamine formaldehyde (MUF), Urea formaldehyde (UF) and high alkaline cured phenol formaldehyde (PF).

Long-term performance tests (creep) and fatigue have been used to evaluate the performance of the wood base composites. European standard requirements of wood-based panels to be effective from 2004 have been published. These require the use of limit state design and prototype testing methods and specifications. The Lecturer stated that his organisation was willing to assist developing countries in testing and standardising wood based composite materials.

2.2.13 Economical solutions to the Durability of Portland Cement Mortars reinforced by vegetable fibres

By Dr. G.M. Kawiche, BRU, Dar es Salaam, Tanzania

The Lecturer presented past experiences at the Building Research Unit, on their evaluation of Portland cement motors reinforced by sisal fibre. The presence of an alkaline environment and high humidity are detrimental to the durability of plant fibre in a cement matrix. This has been the greatest limitation to the use of cement - sisal composites in the tropical region of East Africa. The approach taken by researchers at BRU has been to protect the fibres by impregnating them with reagents that would form a protective layer to exclude water and moisture penetration or to seal the matrix pores so as to reduce permeability and reduce alkaline solution formation, or a combination of the two. The lecturer presented some experimental results on the behaviour of cement - sisal composites with various admixtures. It was concluded that the use of tannin and colophony result in insoluble compounds with most metal salts, that are chemically stable and insoluble - and show good alkaline reduction, pore sealing and reduction of water absorption in both the mortars and the fibres.

2.2.14 Alternate Cements based on Lime Pozzolanes

Mr. W. Balu-Tabaaro, Dept of Geological Survey & Mines, Uganda

This lecture focused on the potentials in Uganda for the utilisation of volcanic ash to produce lime-pozzolan that can be used as substitutes to Portland cement. The situation in Uganda and most African countries, show that the supply of building materials especially cement is far below the demands of the growing population. The production of portland cement is expensive, and the rural population cannot afford its high cost. Pozzolana cement has been identified as a cheap cement for rural population. Its basic raw materials are limestone and volcanic ash which are abundant in some parts of Uganda.

The lecture also presented possibilities of using artificial pozzolans from agro-waste ashes such as coffee husk ash, Bagasse husk ash, rice husk ash and saw dust ash. Data on the performance of various natural pozzolans from volcanic ash and burnt clay were presented. The blending of Portland cement with pozzolans was seen to be the best combination that results in good performance and low cost.

2.2.15 The Potential of Coconut shells for Activated Carbon Production in Tanzania

By T.K. Mwasha, ESAMRDC, Dar es Salaam, Tanzania

The Lecturer presented the potentials that exist in Tanzania for the production of activated carbon from coconut shells.

Activated carbon is an important industrial material. This product has a potential of being used by the gold mining industry which is fast expanding in Tanzania. There is also an export potential. Most of the coastal regions of Tanzania and the offshore islands of Zanzibar, Pemba and Mafia are covered by coconut plantations. At least 239,361 hectares are under coconut cultivation, giving an estimate production of 532.7 million nuts per year. There are a few copra processing factories in Zanzibar, Mafia, and Bagamoyo. These produce about 1,500 tonnes of shells annually. Shell charcoal is used as a culinary fuel in smithies, bakeries and laundries. It has high adsorption capacity for gases and colouring matter and can therefore be used as a refining agent both as a deodoriser and a decolouriser. The production process for making activated carbon was presented, and it was shown that it can be adopted locally, if there are willing investors. An analysis for the domestic and export markets was also presented.

2.2.16 Short Presentations by Workshop Participants

(i) Use of coir fibres in the Development of Building Components

By M.S. Kalra, Centre Building Research Institute, Roorkee - 247667, India

The presentation illustrated current progress in the utilisation of coir for making various building components. These include coir-cement panels, walling blocks, purlins, etc. The coir-cement composite panels produced conformed with ISO:8335-1981, and possess better fire resistance and exterior durability as compared to commercial wood based products. The composite system has potential to be developed into light weight walling and roofing components as well as structural components.

(ii) Development of Cementitions binder Using Industrial Waste "Red Mud".

By Rewashankar Ahiwar
Regional Research Laboratory (CSIR), Bhopal, India.

This presentation was on the recent experiences on the utilisation of red mud, a by-product from the Aluminium extraction process. It was stated that almost 3 to 4 million tonnes of red mud are generated in India annually. The red mud can be calcinated with rice husk ash and clay to produce a low cost cementitious binder with wide applications in building construction. The presenter briefly presented some properties of red mud cementitious binder tested according to ISO:4098-1983.

2.3 Exhibitions

The following Institutions presented exhibitions:

(i) Building Materials & Technology Promotion Council, New Delhi, India: (Dr. T.N. Gupta):

- An assortment of various products made from plant fibre reinforced composites. These included coir-polyester, coir-cement, Red mud - coir, Jute-Polyester, rice-husk-cement, MDF, sisal-polyester.

- Participants were impressed by the level of technological development and commercialisation of plant fibre reinforced composites in India.

(ii) Eastern and Southern African Mineral Resources Development Centre, Dar es Salaam, Tanzania:
(Mrs. T. Mwasha)

- An assortment of various ceramic products, which included domestic ware, electrical insulators, etc; made from local resources.

(iii) Faculty of Engineering, University of Dar es Salaam
(Dr. E.T.N. Bisanda)

- An assortment of various agricultural wastes that may be used for Biocomposite production

- Experimental composite samples from sisal - Polyester, sisal - CNSL, Kapok/cotton - polyester, Kapok/cotton - CNSL, Kapok/cotton - Polypropylene. Also samples of Briquettes from coffee husks produced at Tanganyika Coffee curing factory, Moshi, were demonstrated.

2.4 Closing ceremony

The Acting Director General of COSTECH, Mr. Mlaki thanked ICS for collaborating with the Local Organisers in holding the workshop; UNIDO for financing the participation of overseas and local participants; ESAMRDC for providing host facilities and the participants for their active participation and deliberations.

Dr. Gupta on behalf of the participants thanked UNIDO for financing the workshop and ESAMRDC for the provision of conference facilities.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The following are some observations from the workshop presentations and exhibitions:

- Considerable amounts of data have been generated on plant fibre reinforced composites from various parts of the world. These need to be co-ordinated in a data base.

- There are still large amounts of agricultural wastes, industrial wastes and plant fibres which are being wasted annually in developing countries. Efforts should be geared towards utilisation of these wastes and residues to minimise waste.

- Most of the R & D work on biocomposite technologies has yet to be commercialised. Techno-entrepreneurs should be encouraged to commercialise these results.

- Plant fibres absorb moisture and are not fire resistant. These are the major limitations to the long term behaviour of plant fibre-reinforced composites.

The following are the major recommendations:

- Natural fibres are not available in the required length and form (filaments, mats, ribbons, fabrics, non-wovens, etc.). Attempts should be made to develop processes to obtain fibres in the required form using cost effective processing technologies.

- The resin matrix is still the most expensive component in biocomposites. Attempts should be made to reduce resin consumption. Suitable cheaper resins from lignocellulosie materials should also be developed.

- The fire resistance of composites, particularly with polymeric matrices and plastics should be improved.

- Physical, mechanical, thermal, electrical, optical, tribological and environmental properties of natural fibre composites and 'hybrid' composites should be evaluated completely, using standard procedures.

- Long term-time dependent properties of natural fibre and 'hybrid' composites must be evaluated.

- Detailed basic studies on interfacial behaviour and other factors affecting strength and performance must be undertaken to facilitate future developments and modern applications of natural fibre reinforced composites.

- To provide sufficient quantities of fibres, large scale extraction methods should be developed to replace the present cottage industry methods.

- . National and provincial governments should provide increased assistance for further R&D and fiscal and non-fiscal incentives for encouraging investment in production of composite materials based on wastes and natural fibres.

- . Techo-economic feasibility studies should be conducted to identify composite materials technologies that can be commercialised and initiate a meaningful action plan.

- Each country should establish an organisation to coordinate the promotion of Building Materials Technologies, involving all key ministries and departments.

- Efforts should be encouraged to transfer proven Technologies from India and developed countries, to African countries, which have vast resources of agricultural wastes and plant fibres.

4.0 FINANCIAL REPORT

The Eastern and Southern African Mineral Resources Development Centre received US $ 38,000 out of US $ 40,000 from UNIDO as ICS-UNIDO initial contribution for the accomplishment of the First International Workshop on Composite Materials based on Natural Resources and Waste Minimisation (Tanzania).

The Centre also received Ths. 500,000 from the Tanzania Commission for Science and Technology as contribution towards the organisation of the workshop.

Out of the US $ 38,000 received from ICS/UNIDO the workshop spent US $ 33,979.48 as shown in the statement of expenditure (Table 1)leaving a balance of US $ 4,095.15 including bank interest. The balance of US $ 4,095.15 together with the remaining disbursement from UNIDO of US $ 2,000 and the contribution from The Commission for Science and Technology is being committed for the remaining ICS workshop activities as per budget and statement of expenditure below.

Table 1: STATEMENT OF EXPENDITURE

DESCRIPTION	BUDGET	EXPENDITURE	VARIANCE
A) Preparatory Phase			
Stationery, correspondence, Telephones, faxes, photocopies	1,250	3,465.92	(2,215.92)
Secretarial services	500	591.47	(91.47)
Committee Expenses	2,500	2,440.00	60.00
SUB- TOTAL	**4,250**	**6,497.39**	**(2,247.39)**
B) Workshop Execution Phase			
Secretarial Services	500	640.00	(140.00)
Conference Hall	free	-	-
Projector	free	-	-
Transport	750	1,798.94	(1,048.94)
PA System	200	-	200.00
Documentation (photocopies)	300	960.00	(660.00)
DSA for 18 international participants	4,500	1,870.00	2,630.00
DSA for 7 international lecturers	2,800	4.080.00	(1,280.00)

DSA for 4 Tanzanian participants	1,000	1,400.00	(400.00)
Lecturers' Honoraria	600	520.00	80.00
SUB- TOTAL	**10,650**	**11,268.94**	(618.94)
C) Travel support			
C1) Lecturers			
3 from Europe at US $ 2,000	6,000	3,928.00	2,072.00
1 from USA at US $ 2,000	2,000	1,820.00	180.00
1 from South Africa at US $ 1,000	1,000	629.00	371.00
1 from Kenya at US $ 300	300	332.00	(32.00)
1 from India at US $ 1,500	1,500	2,096.00	(596.00)
from Ghana and Uganda	-	1,378.24	(1,378.24)
C2) Participants			
7 from Kenya & Uganda at US $ 300	2,100	664.00	1,436.00
6 from Southern Africa at US $ 700	4,200	-	4,200.00
3 from West Africa at US $ 1,000	3,000	-	3,000.00
2 from India at US $1,500	1,500	2,189.00	(689.00)
SUB- TOTAL	**23,100**	**13.036.24**	**10,063.76**
TOTAL A+B+C	**38,000**	**30,802.57**	**7,197.43**
Contingencies	2,000	-	2,000.00
TOTAL	**40,000**	**30,802.57**	**9,197.43**
OTHER EXPENSES			
Bank charges	-	405.73	(405.73)
Catering Services	-	2,771.18	(2,771.18)
SUB- TOTAL	-	**3,176.91**	**(3,176.91)**
GRAND TOTAL	**40,000**	**33,979.48**	**6,020.52**

COMMITTMENTS FOR THE REMAINING ACTIVITIES RELATED TO ICS WORKSHOP:

DESCRIPTION	AMOUNT (US$)
Preparation of Report 15 mandays @50	750.00
Printing and binding of reports 10 copies @30	300.00
Postage of reports @ 100x6	600.00
Production of workshop Proceedings	
Word Processing, 10 mandays @ 50	500.00
Editorial, 15 mandays @ 50	750.00
Typesetting,15 mandays @50	750.00
Proof reading 10 mandays @50	500.00
Printing,100 copies @ 20	2,000.00
Postage of proceedings to workshop participants @ 20	1,000.00
SUB TOTAL	**7,150.00**
Add: Contingencies	500.00
TOTAL	**7,650.00**

SUMMARY :

Cash received by ESAMRDC from UNIDO		38,000.00
Add:	Bank Interest	74.63
SUB-TOTAL		**38,074.63**
Less:	Actual Expenditure	33,979.48
	Actual Balance	**4,095.15**
Add: i)	Contribution from the Commission for Science and Technology (Ths.500,000)	800.00
ii)	Contigency funds at UNIDO	2,000.00
SUB TOTAL		**6,895.15**
less:	Commitments	7,650.00
	Net balance (deficit)	**(754.85)**

EASTERN AND SOUTHERN AFRICAN
MINERAL RESOURCES DEVELOPMENT CENTRE

02400/108698/02
ACCOUNT NO.

RECONCILIATION OF ACCOUNT WITH STANBIC BANK IN US $ CURRENCY
AS OF 14 AUGUST 1997

	VOUCHER NO.	AMOUNT	TOTAL AMOUNTS
BALANCE AS PER BANK STATEMENT			5,390.00
LESS: OUTSTANDING CHEQUES		1,294.85	
DEPOSITS NOT RECORDED BY US:			
INTEREST NOT RECORDED BY US:			
OTHER RECONCILING ITEMS:			
ADD: BANK CHARGES NOT YET RECORDED			4.095.85
DEPOSITS NOT CREDITED BY BANK			
OTHER RECONCILING ITEMS:			
			4.095.15

BALANCE AS PER ACCOUNTING RECORDS
(US$ Equivalent)

(Signature)

STANBIC BANK TANZANIA 5501 DETAIL ACCOUNT INQUIRY RUN

FROM ACCOUNT 02400/108698/02
TO ACCOUNT 02400/108698/02 TRANSACTION FROM DAY 01/07/19

ACCOUNT NUMBER : 02400/108698/02 ESAMRDC
ESAMRDC/ICS

BOOK BALANCE: 5,390.00CR
CLEARED BALANCE: 5,390.00CR MATCHING A/C:
UNCLEARED AMT : 0.00 MATURITY :
LIMIT [SNCTION]: 0 SIGNATURE CD: C
INTEREST RATE %: 3,0 CR 0,0 DR INDICATORS :
ACCR. INT GROSS: 24.22CR NETT: 24.22CR MEMO 1:
Y-T-D INTEREST : 82.92CR MEMO 2: 0000000
SERVICE CHARGE : 0.03DR MEMO 3: 0000000

DATE	VALUE DATE	TYPE	REFERENCE	AMOUNT	BALANCE
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10/07/1997	10/07/1997	CHP	2AM0100601	8.50DR-	37,951.50CR
17/07/1997	17/07/1997	CHQ	2S21838901	1,162.98DR	36,788.52CR
22/07/1997	22/07/1997	CWC	2RM2227401	1,000.00DR	35,788.52CR
22/07/1997	22/07/1997	COM	2RM2233701	15.00DR-	35,773.52CR
29/07/1997	29/07/1997	CWC	2RM2278401	2,000.00DR	33,773.52CR
29/07/1997	29/07/1997	COM	2RM2281801	30.00DR-	33,743.52CR
31/07/1997	31/07/1997	IAP		74.63CR	33,818.15CR
31/07/1997	31/07/1997	SF		15.00DR-	33,803.15CR
01/08/1997	01/08/1997	COM	2RM2325701	144.00DR-	33,659.15CR
05/08/1997	05/08/1997	COM	2RM2348701	150.00DR-	33,509.15CR
07/08/1997	07/08/1997	CWC	2RM2369701	3,000.00DR	30,509.15CR
11/08/1997	05/08/1997	GPC	ZMO	10,000.00DR	20,509.15CR
11/08/1997	01/08/1997	GPC	ZMO	9,600.00DR	10,909.15CR
13/08/1997	13/08/1997	CSP	2S72069101	2,771.18DR	8,137.97CR
14/08/1997	14/08/1997	CWC	2NS3399001	1,215.56DR	6,922.41CR
14/08/1997	14/08/1997	COM	2NS3399201	18.23DR-	6,904.18CR
14/08/1997	14/08/1997	CHQ	2GM1987701	1,514.18DR	5,390.00CR

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37,960.00CR	0.02DR	TT B/O UNITED NATIONS IND
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36,788.52CR	41.10CR	ESAMRDC
35,788.52CR	56.43CR	CASH CHQ: 031443
35,773.52CR	56.43CR	1.5%COMM FGN CASH
33,773.52CR	77.30CR	CASH CHQ: 031444
33,743.52CR	77.30CR	1.5%COMM FGN CASH
33,818.15CR	0.00	INTEREST TO DATE (NET)
33,803.15CR	0.00	SERVICE FEE
33,659.15CR	2.82CR	1.5%COMM FGN CASH
33,509.15CR	14.04CR	1.5%COMM FGN CASH
30,509.15CR	19.62CR	CASH CHQ: 031448
20,509.15CR	17.95CR	ESAMRDC
10,909.15CR	13.15CR	ESAMRDC
8,137.97CR	18.60CR	CHQ 31451
6,922.41CR	19.28CR	CASH CHQ: 031453
6,904.18CR	19.28CR	1.5%COMM FGN CASH
5,390.00CR	19.28CR	ESAMRDC

Appendix 1

Programme and Abstract

INTERNATIONAL CENTRE FOR
SCIENCE AND HIGH TECHNOLOGY

International Workshop on Composite Materials and Waste Minimization: *Fibre reinforced materials based on local resources*

Dar Es Salaam, Tanzania
4th-8th August, 1997

PROGRAMME AND ABSTRACTS

SPONSORED BY THE UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION
(UNIDO)

INTERNATIONAL WORKSHOP ON COMPOSITE MATERIALS AND WASTE MINIMIZATION: *FIBRE REINFORCED MATERIALS BASED ON LOCAL RESOURCES*

Dar Es Salaam, Tanzania
4th-8th August, 1997

Organized by:

The International Centre for Science and High Technology (ICS)
P.P. Box 586, Via Grignano 9
34014 Trieste, ITALY

Sponsored by:

United Nations Industrial Development Organization (UNIDO)

Jointly hosted by

The Faculty of Engineering
University of Dar Es Salaam, TANZANIA

and

The East and Southern Mineral Resources Development Centre (ESAMRDC), Dar Es Salaam, TANZANIA

MONDAY, 4th August, 1997

08.30 - 10.00	REGISTRATION Conference Room, ESAMRDC, Kunduchi Beach *(Please bring all travel tickets for reimbursement)*
10.00 - 11.00	TEA BREAK
11.00 - 12.00	OPENING CEREMONY (Dr Pedro, Director ESAMRDC) *Welcome Speech:* Dr A. Kigoda, Minister for Energy and Minerals. *Opening Speech:* Dr Omar Ali Juma, Vice President, United Republic of Tanzania *Vote of Thanks:* Prof. Mathew Luhanga, Vice Chancellor, University of Dar Es Salaam.
12.00 - 13.00	KEYNOTE TALK Prof. S. Meriani, Programme Diector, ICS
13.00 - 14.00	LUNCH
14.00 - 15.00	KEYNOTE LECTURE: *Dr T.N. Gupta, Director BMTPC, India* **Structure of International Information System aimed at implementing Technology Cooperation Programme in the area of Composite Materials from Natural Resources.**
15.00 - 15.30	DISCUSSION
15.30 - 16.00	TEA BREAK
17.00 - 19.00	COCKTAIL RECEPTION *Silversands Hotel*

TUESDAY, 5th August, 1997

08.30 - 09.30	LECTURE ***Dr Mohan Rai,*** *Building Materials Consultant, India* **Development and Industrial Application of Natural Fibre Reinforced Composites - The Indian Experience**
09.30 - 10.00	DISCUSSION
10.00 - 10.30	TEA BREAK
10.30 - 11.30	LECTURE ***Prof. P.V. Mtenga*** *Florida A&M University, USA* **Natural Fibre Biocomposites: Production and Applications in North America**
11.30 - 12.30	DISCUSSION
12.30 - 14.00	LUNCH
14.00 - 15.00	LECTURE ***Dr E.T.N. Bisanda*** *University of Dar Es Salaam, Tanzania* **The Potential of Agriculture Wastes for Composites Manufacture in Tanzania.**
15.00 - 15.30	DISCUSSION
15.30 - 16.00	TEA BREAK
16.00 - 17.00	EXHIBITIONS

WEDNESDAY, 6th August, 1997

08.00 - 09.30 LECTURE
Dr Patricia Truter, CSIR, Pretoria, South Africa
Cellulose Based Polymers for Plastic Composite Materials

09.30 - 10.00 DISCUSSION

10.00 - 10.30 TEA BREAK

10.30 - 11.30 LECTURE
Dr M. Avella, IRTeMP, Italy
Steam - Exploded Natural Fibres as Reinforcement for Polymeric Based Composites

11.30 - 12.30 DISCUSSION

12.30 - 14.00 LUNCH

14.00 - 14.30 LECTURE
Mr L.Y. Mwaikambo, Sokoine University, Tanzania
The performance of Cotton-kapok fabric Polyester Composites

14.30 - 15.00 LECTURE
Prof. Akwasi Ayensu
University of Cape Coast, Ghana
Interfacial Debonding of Natural Fibre Reinforced Composites (NFRC)

15.00 - 15.30 DISCUSSION

15.30 - 16.00 TEA BREAK

16.00 - 17.00 LECTURE
Dr B. Chikamai, KEFRI, Kenya
Utilization of Wood Wastes and Residues in Particleboards

17.00 - 17.30 DISCUSSION

THURSDAY 7th August, 1997

08.30 - 09.30	LECTURE *Mr G.C. Mwalongo, TIRDO, Tanzania* **Development of Wood Adhesives for Tanzania Plywood and Particleboard Factories**
09.30 - 10.00	DISCUSSION
10.00 - 10.30	TEA BREAK
10.30 - 11.30	LECTURE *Dr P. Bonfield, BRE, U.K.* **Timber and Wood-based Composites**
11.30 - 12.30	DISCUSSION
12.30 - 14.00	LUNCH
14.00 - 14.30	LECTURE *Dr G.M. Kawiche, BRU, Tanzania* **Economical Solutions to the Durability of portland cement mortars reinforced by vegetable fibres.**
14.30 - 15.00	LECTURE *Mr W. Balu-Tabaaro, Dept. of Geosurvey, Uganda* **Alternate Cements based on Lime Pozzolanes**
15.00 - 15.30	DISCUSSION
15.30 - 16.00	TEA BREAK
16.00 - 17.00	LECTURE Mr T.K. Mwasha, ESAMRDC, Tanzania **The Potential of Coconut Shells for Activated Carbon Production in Tanzania**

FRIDAY, 8th August, 1997

08.30 - 10.00	GENERAL PRESENTATIONS **Short presentations by Participants - experiences in their countries**
10.00 - 10.30	TEA BREAK
10.30 - 11.30	WORKSHOP EVALUATION
11.30 - 12.30	CLOSING CEREMONY (Dr E.T.N. Bisanda) Opening Speech, ***Prof. Meriani,*** *ICS* Remarks by a Representative of Participants Closing Speech : ***Dr Y. Kohi,*** *Director General, COSTECH* Vote of Thanks: Mrs T.K. Mwasha
12.30 - 14.00	LUNCH

KWAHERI

Structure of International Information System Aimed at Implementing Technology Cooperation Programme in the Area of Composite Materials from Local Resources

by
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With building materials industry under pressure and unable to cope up with the demand in most developing countries there is a growing concern for developing and promoting alternative building materials. Considering a potential option of developing and promoting composite materials from local resources, UNIDO has initiated an interregional programme of cooperation between the willing Asian and African countries to promote use of composite materials based on local resources such as wastes from forestry, agriculture, horticulture, agro-based industry, natural fibres and plant materials etc. The programme, inter alia, aims at capacity building in the developing countries in the areas of design, manufacturing, testing and evaluation of composite materials. The programme will basically cover all activities vital for systematic development of composite materials based on local raw material resources for application in housing and building sector.

One important component of this programme as identified by the Scientific Planning and Coordination Meeting (SPCM) is to establish a database on the availability of local resources along with their properties and current uses in the country-specific situations. Such a database will help in identifying large common resources of interest to several developing countries which need greater attention both in terms of research and commercial exploitation. The database or the information system would be so structured as to help various countries to develop projects on (a) research and development, (b) prototype/demonstration units, and (c) manufacturing plants of composites using local skills and local infrastructure. The regional nodal points for storing data will be proposed at selected institutes located in a developing region. The information would be so formatted as to transfer the knowledge base to all participating countries. The selection of a regional nodal point for storing data will be governed by the criteria such as availability of natural fibres and other local raw materials in the region and the capability and degree of interest of the specific institution selected for the purpose. Besides establishing the nodal regional points for the database these institutes will also be strengthened for undertaking research, development and technology transfer activities related to a particular group of fibres or useful local resources available in the operating zone of the institute. The database will be so designed as to help in assessing the status of technology, cost benefit analysis, and other parameters required for promoting the manufacture of composites using local raw material resources. The UNIDO and ICS at Trieste should catalyse preparation of such local assessments and project reports for strengthening local manufacturing base involving the people and the enterprises in different regions where these resources are located. A strong database having components which will be discussed at the workshop will help in setting up design, prototype manufacturing and testing centres and even full scale demonstration plants to manufacture composites from local resources. The database will also include information on current status of avilability of local resources, R&D, standardisation, capacities for testing, design of pilot and full scale demonstration plants etc.

It is proposed to include data and information on the following topics in the database.

1. Name, source & production process of the local resource/resource material
2. Annual production/availability
3. Present and proposed mode of disposal/utilisation
4. Chemical, physical and mechanical properties
5. Characterisation of locally available organic or inorganic wastes having potential for being used as raw material composites.

Three categories of raw materials will include the following:

1. Local plant based resources grown in small geographical regions:

   (e.g. natural fibres, plant material other than wood, local grasses and reeds, local shrubs etc.)

2. Local mineral based resources available in small geographical regions
   (e.g. granite, mica, clay, sand, quartz, bauxite, laterites, stones, lime shells etc.)

3. Industrial/agricultural/forestry wastes, by-products or residues available on sustainable basis in sufficient quantities.

Development and Industrial Applications of Natural Fibre-Reinforced Composite Building Materials - Indian Experience

by
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Tel: 91-1332-73632 Fax: 91-1332-74020

The fibre-reinforced building materials and components found wide acceptability all over the world as light weight, strong and durable materials, particularly those using glass, polymer and steel fibres. But these materials, in the face of energy shortage are also now becoming quite unaffordable and hence there has been a continuous search for alternative locally available low-cost reinforced fibres. Natural fibres such as sisal, coir, jute, bagasse etc. have been extensively studied in India and several other countries for their physical and mechanical properties and their suitability for reinforcing to produce roofing, partitioning and panelling materials. Although such composites do possess some intrinsic deficiencies in fire-resistance and long range durability, they compensate with their high specific strength, low density, high toughness and good thermal insulation.

Various approaches have been adopted in India in improving the alkali resistance and overall durability of vegetable fibres in portland cement or in modified cement. The composites developed could match with the glass fibre reinforced polymer composites yet complete standardization of design aspects with respect to appropriate aspect ratio, orientation and wetability characteristics of only a few fibres has been completed. In fact, the Indian experience has further confirmed that the success lies in specific characterization studies on each fibre, using hybrid-composition, adopting pre-treatment of the fibres to evolve the selective technology. This may be using the most compatible matrix which sometimes is developed from an industrial waste or byproduct.

Indian R & D laboratories possess some of the best instrumental and pilot-plant, facilities which qualify them to be chosen as nodal institutions where vegetable fibres from different countries of Africa and Asia could be evaluated for generating a comprehensive data base. The best organised quality-assurance, quality controls and standardization systems and methodology adopted by the Bureau of Indian Standards and B.M.T.P.C. have helped in the formulation of a number of IS specifications on fibre-reinforced composite building materials. These institutional facilities could be extended to other developing countries also.

Some of the most versatile composites, with vegetable fibres as reinforcement, being commercially produced in India e.g. jute-fibre-polyester; sisal-polyester-red mud; fibre-pulp-bitumen; bagasse/rice husk cement; coir-fibre-magnesium oxychloride and coir-byproduct gypsum binder composite materials are being used for roofing, flooring, partitioning door, frames and shutters, ceiling and partitioning applications. These materials have created a great public awareness and specific interest about their versatility for building constructions. This paper has highlighted some of the above efforts and also presents an analysis of future prospects.

Natural Fiber Biocomposites: Production and Application in North America

by
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Tallahassee, Florida 32310, USA

Natural fiber based building products are gaining popularity in North America. The gain of popularity is been driven mainly by the following: 1) the need of finding a more environmental friendly products and process, which include recycling of cellulose based materials, 2) the utilisation of lesser used wood species and other fibrous resources, and 3) the global concerns on "green house" gasses, which lead to the necessity of developing more efficient uses of natural resources worldwide. These natural fiber based products have found broad applications as substitutes for asbestos in the reinforcement of thin cement products. They have shown to have low and desirable technical properties. A number of production plants are already in existence in North America.

In this paper, the author will overview of the production, major properties and application of these natural fiber based building products in North America.

The Potential of agriculture wastes for Composites manufacture in Tanzania.

By
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Tanzania as an agricultural based economy, produces vast amounts of agricultural wastes, most of which are neglected, or are burnt, posing a hazard to the environment. There are also vast areas covered by non woody fibrous materials such as bamboo and papyrus, which are not making any significant contribution to the economy. Most of the rural populations depend on wood and timber products for construction and fuel. This increasing demand for construction materials and fuelwood has caused a depletion of the vital tropical rain forests, and has led to desertification in most areas surrounding human settlements. The results to the ecosystem and the environment are immeasurable. A decrease in annual rainfall, leading to poor agricultural productivity, has caused a rise in rural to urban migration, while generally the annual national food production is not marching with the population growth. Meanwhile, despite efforts by the government and non-governmental institutions to plant trees, more trees are still being cut than are planted.

Recent research developments have shown that most of the agricultural wastes possess high value plant fibbers, and can therefore be used for making boards, panels, tiles, etc. for construction purposes. They can similarly be pulped to produce fine mechanical or chemical pulp to be used in paper and fiberboard production. Some of the non-fibrous wastes can be fermented to produce biomass (methane, ethanol, etc.) for domestic and industrial applications, while others may be converted into activated carbon or briquettes to serve as energy sources.

The paper attempts to show the magnitude of annual agro-wastes generation from various key agricultural activities. An attempt is also made to show other valuable outputs besides the main crop products, that may be processed from a few selected agricultural crops. Examples of available technologies that may be employed to produce biocomposites from agriculture wastes are also cited. It is concluded

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that the conversion of agricultural waste into useful products would increase the income of farmers, create new employment opportunity, protect the environment, and contribute significantly to the national economy.

Cellulose Based Polymers for Plastic Composite Materials

by
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Natural fibres consist mainly of celluloses. The fibrils present in the fibres are all aligned, irrespective of the origin. Such alignment can be utilized to render maximum tensile and flexural strengths and also improve rigidity if utilized as a 'Filler' in plastics. The fibres can also increase the electrical resistance, thermal and acoustic insulation.

Natural fibres are abundantly available resources, can be renewed, have a low cost compared to most synthetic fibres, are biodegradable and environmentally friendly. The cultivation of plants with technically usable fibres (such as coconut tree, sisal, flax, etc.) can have an added benefit of alleviating unemployment for the local people.

All types of renewable cellulose fibres such as cotton, wood, flour, sisal, bagasse, kenaf, jute, and waste newspapers could be used as natural biofibres in thermo plastic composites.

Fibres can be modified by physical and chemical methods. Physical treatments change the structural and surface properties of the fibres and therefore also influence the mechanical properties. Physical methods can include stretching, calendering, thermo treatment and electric discharge (corona, cold plasma). Electric discharge is a technique to change the surface oxidation activation (change the surface energy of the fibres).

Chemical treatments methods are mainly used to improve the compatibility of the fibres (strongly polarized) with polymers (mainly hydrophobic). The methods can include the use of coupling agents, change in surface tension (methods to decrease the hydrophillicity), impregnation of the fibres, etc.

Properties can be further improved by using small amounts of additives to improve the dispersion of the polar fillers in the non polar matrix polymer and enhance bonding between the filler and polymer. The utilization of fibres is e.g. the automotive industry in various vehicle components such as headrests, door linings and insulation materials is an area that needs to be investigated.

By the year 2000 we expect to recycle 7% of the total stock of post-consumer plastic waste, the other 93% will still continue to be discarded in landfields unless another solution can be found. Degradable plastics will begin playing a critical role in helping solve environmental problems over the next 10 years.

Biodegradable plastics are needed for many consumer use applications, such as disposable plates, utensils, composting bags, disposable packaging, agricultural films, etc. The main focus of scientists for developing biodegradable polymers and composites are on :- 1) developing biodegradable plastics based on natural polymers from renewable resources , and 2) developing synthetically produced biodegradable polymers.

There is considerable interest in the use of natural polymers: e.g. starch as a biodegradable annually renewable substitute for non biodegradable plastics.

To improve the biodegradation of starch and cellulose fibres, enzymes have been used. New methods of modification of starch are developed using enzymes. Modified natural polymers have improved biodegradation.

Modified and unmodified starches, cellulose fibres waste and protein waste are used for developing environmentally biodegradable plastic compositions.

Steam-Exploded Natural Fibres as Reinforcement for Polymeric Based Composites

by
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Institute of Research and Technology of Plastic Materials (IRT&MP) - CNR Via Toiano, 6 - 80072 Arco Felice (NA) - ITALY

The twin issues of environmental defence and resources conservation have led to a renewed interest of the utilization of biomass as precursor of polymeric materials.

Vegetable fibres are now being increasingly applied as reinforcement to plastic materials mainly because of their high specific properties, low cost, biodegradability and renewability. The possibility of these fibres to act as good reinforcing agent is dependent on their cellulosic content, fibre size and a strong fibre/matrix interfacial adhesion.

In the last years there has been a growing interest in light, strong and cheaper natural fibre reinforced composite materials in addition to the development of high performance composites reinforced with synthetic, strong, stiff fibres such as glass, carbon etc.

This work has been developed to illustrate our results concerning the preparation and characterization of polymeric based materials reinforced with natural fibres such as straw, hemp, sorghum and broom.

Different fibre extraction processes were applied in order to achieve effective reinforcement action/characteristics on the fibres. In particular, steam explosion treatment was applied to obtain high fractionated lignocellulosic materials, providing also good reactivity.

Thermal, morphological and mechanical characterization of the composites were performed, with particular attention being addressed on the interfacial adhesion between the matrices and fibres.

Also, water absorption tests have been carried out to evaluate the effect of water molecules on the mechanical properties of the composites.

The Performance of Cotton - Kapok - Polyester Composites

By
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Cotton - kapok fabric, at a ratio of 2:3, have been incorporated, in unmercerised and mercerised form, with polyester resin in various fibre volume fractions. A simple manual lay - up technique was used in fabricating the composites. A hand operated hydraulic electrically heated press was used and the composites were cured at 100 °C for 60 minutes and post cured over night in the oven at 80 °C.

Mechanical properties such as tensile strength, tensile modulus and impact strength, and flexural properties of unweathered composites have been evaluated.

Composites with unmercerised fibres were found to have higher fibre volume fractions than composites prepared using mercerised fibres. Also, tensile strength of the composites had similar relationships with composites produced using mercerised fibres but having, on average, higher tensile modulus than composites manufactured using unmercerised fibres.

The impact strength was found to decrease with increase in fibre volume fractions for, both, composites with or without mercerised fibres. Reductions in flexural strength and modulus were observed with weathered composites. The specific strength of the composites was found to be comparable to the specific strength of other vegetable fibre reinforced resins.

General the results obtained in this work show that cotton - kapok fabric has the potential of being used as a reinforcement to polymeric materials, producing composites having similar property characteristics to other vegetable fibre reinforced resins.

Interfacial Debonding of Natural Fibre Reinforced Composites

by
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The mechanisms and processes involved in interfacial debonding and fracture of natural fibre reinforced composites have been investigated. The pull out theory which depends upon factors such as lateral deformation, Poisson's effect and non-unformity of fibres was used to determine the fracture toughness. The total fracture energy is a contribution from the surface energy, redistribution energy and pull out energy. The fracture mode is complex as it involves fibre splitting, decohesion, crack formation and propagation. The surface energy term originates from the creation of three new surfaces terms, i.e., fibre, matrix and fibre-matrix interface.

Using Eshelby's equivalent inclusion method, the transition stresses between the three stages of stress-strain curves were predicted. The first stage of the curve is linear and indicates that bonding of matrix interface is essentially perfect and both phases deform elastically. The second and third stages are non-linear. During the second stage, microcracks are initiated from fibre ends and extend to the matrix. In the third stage, the microcracks become abundant, interlink or coalesce into macrocracks which propagate to fracture. The transition from second to third stage occurs when crack extends further in the matrix, and an expression for the critical stress for a penny shaped crack to propagate as a Griffith-type crack was derived.

The propagation of stress corrosion cracks in aligned NFRC were also investigated by using the concept of strain energy release rate as primary parameter to derive values of stress intensity factor for plan strain.

Utilisation of Wood Wastes and Residues in Particle Boards

by
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The rising cost of solid timber, increasing trend towards maximising use of scarce wood resources and the need to produce dimensionally stable products that are cost effective has led to fast growth of the wood panel industry. World production of panel products has increased tremendously from a mere 10 million m3 in 1950 to more than 140 million m3 at present. Among the various panel products, particle boards are the fastest growing with an estimated annual production of 57 million m3 (or 37%).

Particle boards are manufactured from wood chips using binders under heat and pressure. Raw material requirement is less stringent compared to other panel products like plywood. Virtually, any species of wood can be used depending on availability and costs. Additionally, wood wastes and residues are often utilised providing a known composition mix is prepared.

The use of industrial wastes and residues for production of particle boards is one area that is the focus for economical and efficient use of forest resources in developing countries. The level of production of these wastes and residues is quite alarming. In Kenya for example, it is estimated that logging wastes contribute 262,600m^3 (48%) of wood volume while saw dust is in the order of 82,750 m^3 (15%) of the wood. The need for increasing their use in the production of particle boards, among others, ranks high in the country.

This paper presents an overview of the particle board industry in the world with emphasis in the use of wood wastes and residues in the developing countries. It provides a case study of the level of wood wastes and residues production in Kenya and initiatives in their utilisation for particle board production. The quality of locally produced particle boards from these resources and the future scope are examined.

Development of Wood Adhesives for Tanzanian Plywood and Particleboards Factories Using Cashewnut Shell Liquid and Wattle Tannin

by

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In the late eighties Tanzania Industrial Research and Development Organization (TIRDO) conducted a survey in Industries to identify problems. The Organizational intention was to get the true picture of what is happening in industries so as to provide the appropriate advice and assistance where possible.

Among bottlenecks noted during the survey was the serious shortage of binder (wood adhesives) in the plywood and particleboards factories. The shortage of adhesives was caused by lack of foreign currency for ordering the binder from abroad.

Responding to the situation, TIRDO proposed a project for developing wood adhesive formulations using cashew nut shell liquid (CNSL) and wattle tannin extract both available in abundance herein Tanzania.

The objective was to develop high quality, cheap and ease to process adhesives which are environmentally friendly.

Under the sponsorship of the International Development Research Centre (IDRC) of Canada, TIRDO in collaboration with Forintek Canada Corp. managed to develop tannin based plywood and particleboards adhesives. The adhesives are easy to process and apply. Plywood adhesive involves simply mixing the tannin solution with a small amount of urea formaldehyde (UF) solution or urea and formalin emulsified in sunflower oil or CNSL while the adhesive for particleboards requires hydrolysis of the tannin solution first and then mixing the ingredients as in the plywood adhesive. Both are done at ambient temperature.

The adhesives have been tested at laboratory and industrial scale. The wattle tannin based adhesives have proved to be weather resistance and emit less formaldehyde compared to the commercial UF resin.

In industrial wattle tannin bonding paraformaldehyde is used as a hardener, but in the TIRDO process it was replaced by a cheaper formalin solution emulsified in sunflower oil or CNSL to reduce the high vapour pressure of the formalin solution.

CNSL as emulsifier improved the internal bond strength and increased the life span (pot-life) of the particleboards tannin adhesive, also it was used in lesser quantities compared to sunflower oil. Therefore tannin-CNSL based particleboards adhesive found to be a promising product and it is now being commercialized at Tembo Chipboards Ltd. in Tanzania here in Tanzania.

Wood-Based CompositeS

by
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This paper provides an overview of the major types, properties and uses of wood-based composites used in construction and other applications. The future development of these materials is also considered. The main characteristics that differentiates wood-based composites is particle size. Further distinction can be made relating to resin type, wood species, density and manufacturing processes employed and it is these parameters that control the nature, grade and quality of the resultant material. the main types of wood-based products are particleboards, fibreboards, oriented strand board, plywood and cement bonded particleboard. Within each of these main types, there are many grades and qualities. Each of these have different performance characteristics and will respond differently to external factors such as moisture, temperature, duration of load, loading mode and level. This offers users the ability to select a material that most closely matches the performance requirements of the application. Other wood-based composite products such as glulam and laminated veneer lumber and other analogous materials have been developed and have found application as both beam and panel materials. The future for these materials looks bright, particularly for enhanced or new innovative wood-composites which make more efficient use of the wood resource. Improvements can be achieved by more efficient use of the processed wood, binder systems, chemical modification, composite lay-up and processing.

Economical Solutions to the Durability of Portland Cement Mortars Reinforced With Vegetable Fibres

by

A. L. Mtui, E.M. Kwanama and Dr. G.M. Kawiche
Building Research Unit,
P.O. Box 1964,
Dar es Salaam, Tanzania.

Composites of Portland Cement Mortars Reinforced with Vegetable Fibres are known to be suitable product for alleviating the problems of high-cost housing. But the same composite is faced with the problem of durability, originating from the mineralization of such fibres due to some factors inherent to them as well as to their surroundings.

Recently, Doctorate Laboratory Studies completed by one of the authors from BRU; at the Department of Civil Engineering in the E.T.S. de Ingenieros de Cominos, Canales Puertos of the Polytechnical University of Madrid - Spain; have shown existence of economical methods of solving the problem of the mineralization of the fibres through fibre impregnation, mortar pore sealing, cement alkalinity reduction, etc. All these without notable impairing of the mechanical properties of the mortar or the fibre. The said methods are based on the use of organic compounds from timber. Said compounds scan be obtained naturally or as by products of small scale industries. Moreover its extraction needs no special skills and once known will attract other areas of use.

The paper presents the theoretical approach to the problem and the selection of the compounds. Then followed by laboratory tests results to confirm the claims, followed by recommendations and conclusions. In the recommendation the use of such compounds are also included in the other building materials such as mud construction for the elimination of the problem of plastering. Also such compounds can be used to remove heavy metals from industrial waste waters. All this put together will help to attract interpreneurs in this field and hence the alleviation of poverty in the society.

Alternate Cements Based on Lime Pozzolanes

by
Eng. W. Balu-Tabaaro,
P.O. Box 9, Entebbe, Uganda.

The potential use of Kisoro volcanic ash, Bunyaruguru tuffs and Kajansi burnt clay in production of lime-pozzolan and other blended cements has been experimentally investigated in the laboratory. Field trials of the various cement mixes have been carried out to assess their technical performance.

Various samples picked from the project area proved positive under the pozzolanicity test. Grindability test carried out in 3 x 3 ft ball mill at 33 r.p.m. 45% ball charge and feed of 400 kg gave the power requirements for production of pozzolan cement at 125 kWh per ton. The blended cements exhibited mortar strengths between 13.2 and 29 MPa.

Field trials of the cements indicate that Lime Pozzolan Cements serve as good binders for masonry units and blended cements showed good performance in general concrete work.

The economic evaluation of lime-pozzolan and blended cements was assessed based on a 675 ton/annum production capacity, using a mill installed at Geological Survey and Mines Department. Savings of up to 45% in the cement cost for low cost housing can be achieved.

With these positive results, a seminar to present the results of this research was conducted at Lake Victoria Hotel, Entebbe. Various stakeholders including academicians, businessmen, bankers, policy makers and non-governmental institutions took part. As a result, some few companies have picked up the idea and are in process of setting up lime-pozzolana cement production plants in Kabale, Kisoro and Bunyaruguru areas. Hima cement factory is also studying the possibility of setting up a facility for the of production of Portland-Pozzolana cement.

The Potential of Coconut Shells for Activated Carbon Production in Tanzania

by
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Coconut is the most important oil crop in the entire coastal belt of Tanzania. The coconut shell is a valuable raw material for a number of industries and is considered as a valuable which is suited for manufacture of superior quality activated carbon. Activated carbon is a material very much sought after in the world market for water treatment, depolarisation, solvent recovery, air treatment, precious metal recovery and for military and nuclear purposes. At present all activated carbon requirements in Tanzania and the Southern Africa Subregion are met by imports. Activated carbon is traded internationally in several categories and contracted prices are confidential. Critical to competition are quality, price and delivery terms. The activated carbon customer have a choice to buy from a variety of sources, hence command a strong bargaining power. While coconut shell based activated carbon is preferable in many applications, the problem encountered with its processing is that it has to compete with coal and other carbonaceous materials which are comparatively cheaper. With the support of appropriate technology shell based activated carbon may be in a position to compete price-wise and qualitywise in the domestic and export market for selective application in pollution control devices and in chemical, food and mining industries.

Though a valuable commodity, in Tanzania the shells available at homesteads do not serve any purpose because they are not concentrated at any point. The shells wherever they are available are burned as domestic fuel or even wasted. Further processing of shells is not carried out in the country. Coconut shell based activated carbon is mainly preferred in the mining industry for recovery gold due to its resistance to abrasion. With potential development in the mining industry in Tanzania activated carbon has great potential. There is also export potential for coconut shell based activated carbon in the

Southern African Subregion. Production of shell charcoal may be initiated in Zanzibar by the Waste Heat Process in order to determine the suitability of the charcoal for production of activated carbon. In order to move forward a study should be carried out to quantify the markets and raw materials supplies.

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Appendix 2

Opening and Closing Speeches

EASTERN AND SOUTHERN AFRICAN MINERAL RESORUCES DEVELOPMENT CENTRE (ESAMRDC)

WELCOME ADDRESS BY THE DIRECTOR GENERAL OF THE ESAMRDC
ON THE OCCASION OF THE "FIRST INTERNATIONAL WORKSHOP
ON COMPOSITE MATERIALS AND WASTE MINIMISATION"
AT THE ESAMRDC, DAR ES SALAAM, TANZANIA
ON 4 AUGUST 1997

Your Excellency, the Vice-President of the United Republic of Tanzania,
Dr. Omar Ali Juma,

Distinguished Guests,

Dear Participants,

Your Excellencies,

On the occasion of the "First International Workshop on composite Materials and Waste Minimisation" to be held here at the Eastern and Southern African Mineral Resources Development Centre is my single privilege and honour to welcome you all to our humble premises.

As you might all know the ESAMRDC was established in 1977 under the auspices of the United Nations Economic Commission for Africa to provide specialised services for the development of mineral resources of its member States through economies of scale.

We are now restructuring our institution to develop services and products which are relevant to the current environment, and to a wider spectrum of customers, which includes governments, the private sector, research institutions, community based organisations and other stakeholders.

The objectives of the establishment of the ESAMRDC were redefined to include inter alia the provision, co-ordination and harmonisation of mineral resources development support services within the sub-region and the establishment of correspondent sub-regional networks of programmes and services. We are implementing an ambitious programme of capacity building and institutional strengthening which will further increase our ability to serve the sub-region.

We would like to be seen as an hub from where specialised know-how and technologies can be pooled together and accessed in a cost-effective and competitive manner to service the sub-region.

It is with that understanding that we were very pleased when we were asked to host this very important workshop. It is within our mission and values to facilitate the exchange of data and research results, to promote networking, strategic links, twining and other mutually supportive and beneficial inter-institutional collaborations between and among research institutions.

After this important event we therefore hope that we can establish with the ICS Network privileged working relations.

My only and most important task now is to invite His Excellency Dr. Omar Ali Juma to officially open the workshop.

Thank you.

TANZANIA COMMISSION FOR SCIENCE AND TECHNOLOGY
(COSTECH)

SPEECH BY
THE DIRECTOR GENERAL OF TANZANIA COMMISSION FOR SCIENCE AND TECHNOLOGY (COSTECH),
DR. YADON M. KOHI, AT THE CLOSING CEREMONY OF THE
INTERNATIONAL WORKSHOP ON COMPOSITE MATERIALS AND WASTE MINIMISATION HELD AT ESAMRDC KUNDUCHI DAR ES SALAAM
ON 8TH AUGUST, 1997

Dr. Antonio Pedros, The Director General of Eastern and Southern Africa Mineral Resources Development Centre (ESAMRDC);

Prof. Sergio Meriani, The Programme Coordinator of the International Centre for Science and High Technology (ICS);

Dr. E. Bisanda, Associate Dean of Faculty of Engineering, University of Dar es Salaam;

Distinguished Guests, Ladies and Gentlemen.

It is with great pleasure, that I would like to acknowledge my sincere thanks to the organisers for inviting me to come and preside over the closing ceremony of this workshop. I am pleased to know that this workshop has been successfully concluded, and that it has been well attended both by local and international participants.

TANZANIA COMMISSION FOR SCIENCE AND TECHNOLOGY

(COSTECH)

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I wish also to acknowledge our thanks to the United Nations Industrial Development Organisation (UNIDO), who have supported this programme through the International Centre for Science and High Technology (ICS), based in Trieste, Italy. Their decision to move this workshop closer to the end user of biocomposites technology, is highly commendable, and we suggest that this approach should be among their focus in future programmes.

The organisation of an international workshop of this dimension is not an easy task. Tanzania, like many developing countries, does not have a good communication network. Neither does it have sufficient resources for hosting such an event. Nevertheless, ESAMRDC, in collaboration with the Faculty of Engineering of the University of Dar es Salaam, have done a commendable job in organising this event. I am sure this was made possible through individual efforts and commitment of the local organising committee, which I would like to commend most sincerely.

Distinguished Guests, Ladies and Gentlemen,

During the last five days, you have been listening to lectures and have had a lot of discussions on the workshop theme. Different lecturers have given talks on various topics, which I am sure you have appreciated. Most of our tropical developing countries are endowed with vast amounts of natural resources, which either lie unexploited, or are being wasted because of lack of know-how and poor scientific and technological infrastructures. There are also many environmental concerns associated with misuse of our natural resources. The damage to the ozone layer resulting from gaseous emissions is posing a threat to the very existence of mankind and other creatures on earth. The increasing rate of depletion of the rain forests due to increasing population and higher demands for fuel wood and timber, have affected the rainfall patterns in this part of the world, and have had an adverse effect on the production of food and water supply. I am pleased to note that some of

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in the protection of our environment. The utilisation of agricultural wastes for production of biocomposites, is likely to have an effect in the short and long terms. We have seen how these technologies have worked in Europe, where, after prohibiting the burning of agricultural wastes, a lot of new materials have been produced from straw and other wastes, avoiding utilisation of timber and thereby maintaining the eco-system. I must therefore commend you for coming up with such dynamic suggestions and solutions.

Distinguished Guests, Ladies and Gentlemen

Your workshop theme of Composite Materials and Waste Minimization, links very well with a concept which is being persued by my organisation, The Tanzania Commission for Science and Technology (COSTECH), on the exploitation of agro-industrial wastes for zero emissions under the Zero Emission Research Initiative (ZERI).

ZERI for short, offers potential opportunities in the total utilisation of vast volumes of biomass and byproducts of industrial wastes. What are otherwise considered as problems such as waste disposal, water hyacinth and sea weeds, could be turned into opportunities with modest additional input in research efforts within the framework of ZERI. ZERI projects aim at zero emissions where raw materials become 100% productive, through the introduction of non-traditional process lines for by products and wastes. This is achieved by forming a cluster of industries and technologies which are integrated in the traditional processes to convert wastes into useful products.

A good example of ZERI application is the integrated farming system designed to comply with economic and ecological principles, with full integration of livestock, aquaculture and agro-industry. In such a system all wastes are treated as valuable resources and completely reutilised within the system. According to Prof. George Chan, a United Nations University - ZERI Consultant, whom we work very closely together in this programme, farmers in Vietnam have managed to raise their income from US$200 to US$6000 per annum by converting a hector of their rice fields into integrated farms. This kind of system has been in use in China for more than 500 years. There is no any reason why such systems should not be promoted in our societies. If we consider that ZERI makes a Contribution to environmental protection; Raises productivity of raw materials in industrial processes; Increases employment opportunities; Increases income generation through introduction of non-traditional products; and Enhances sustainable activities at respective enterprises; we will work hard to see that such systems are encouraged in developing countries. My institution is working very closely with the United Nations University (UNU) based in Tokyo, Japan in the implementation of ZERI projects in Tanzania. Local participating institutions include Faculties of Engineering and Sciences of the Univesity of Dar es Salaam, Institute of Marine Sciences in Zanzibar, Tanzania Sisal Authority, DarBrew, and the Mwanza Beer Breweries. We are certain that we will be able to fullfil this programme.

Distinguished Guests, Ladies and Gentlemen

Success on projects and programmes similar to ZERI and those related to this Workshop, require cooperation of stakeholders and full government encouragement. The role of government is to balance what is socially desirable against what is economically possible, through adoption of standards and limiting pollution concentrations through official regulations. Such regulations may stimulate consideration of recovery or reutilization of wastes and could be instituted as part of the national policy on environment. The government could also introduce some incentives which will encourage adoption of ZERI concept and other effective waste utilisation systems in industries, through such methods as tax exemptions on non-traditional products, or subsidies for funding Research and Development (R&D) by industrieswishing to diversify their industrial processes in order to recycle their industrial wastes. The government could also promote awareness among the general public by disseminating information on the need to recycle biomass, as well as industrial wastes, in order to protect the environment and to maximize utilization of resources. We should therefore work very closely together with our governments in seeing to it that good scientific ideas are promoted and used for the development of our societies.

Distinguished Guests, Ladies and Gentlemen,

Before I conclude let me take this opportunity to mention one more specific issue about the organisation I head, which I believe is relevant to your future collaborative activities.

COSTECH is the apex national body for research coordination and promotion. It also plays an important role in the development and promotion of Science and Technology in this country. In undertaking its promotion role in research and in Science and Technology, a National Fund for the Advancement of Science and Technology (NFAST) was established two years ago with the bulk of its sources coming from the government and donor organisations. So far the Fund has been operating with a modest sum of TShs. 300m/- per year. However, high level consultations are underway to increase the Fund and reach at least 1% of the Gross Domestic Product (GDP) by the year 2000. This is in accordance with the 1980 Lagos Plan of Action of the Heads of State of Africa under OAU. A big portion of the Fund (65%) is dedicated to support research and the remaining portion is used to support R&D institutions, schools, fellowships, training, information, as well as seminars and meetings such as this one we are about to close. In order to guide beneficiaries to the Fund we have a research grants manual and a brochure on NFAST.

During the brief period of the existence of NFAST, we have been able to support good research projects in Agriculture and Livestock, Public Health and Medicine, and Natural Resources. We hope that in future we shall support good research projects fromthe field of material sciences (composite material). We have also been able to support scientists to travel abroad for meetings and to organise local scientific meetings. I must admit that the volume of applications we receive far exceeds the available resources at present and sometimes we are compelled to apply a quota system in order to support as many sectors of the economy as possible. It is my hope that workshop participants from Tanzania will use this opportunity to prepare research proposals and submit them for possible consideration under NFAST.

Distinguished Guests, Ladies and Gentlemen,

The Tanzania Commission for Science and Technology is interested in seeing increased collaboration among developing countries in advancing this technology of biocomposite materials. As you have seen for yourselves during the lectures and exhibitions, a lot of developments in biocomposites technology have already taken place in India and other countries. We think it is through this kind of activities, that we get opportunity to exchange information, and I am sure, future activities will focus on exchange of information after the data base being worked out by ICS is complete.

We desire that the recommendations made during this workshop are implemented expediently, so that we can start to benefit in the shortest possible time, from the innovations and advances already available. We are prepared to foster linkages between the research institutions and industry so as to facilitate smooth technology transfer and commercialisation.

Having made these few remarks, I now wish to express my best wishes to all workshop participants especially those who have come from foreign countries. We expect that you shall be our ambassadors in your countries, and you are always welcome to return for scientific joint activities like these, or even as tourists. With these few remarks, I now wish to declare this workshop closed.

Thank you.

Appendix 3

Papers presented

The Potential of Agriculture Wastes for Composites Manufacture in Tanzania.

By
E.T.N. Bisanda
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Abstract

Tanzania as an agricultural based economy, produces vast amounts of agricultural wastes, most of which are neglected, or are burnt, posing a hazard to the environment. There are also vast areas covered by non woody fibrous materials such as bamboo and papyrus, which are not making any significant contribution to the economy. Most of the rural populations depend on wood and timber products for construction and fuel. This increasing demand for construction materials and fuelwood has caused a depletion of the vital tropical rain forests, and has led to desertification in most areas surrounding human settlements. The results to the ecosystem and the environment are immeasurable. A decrease in annual rainfall, leading to poor agricultural productivity, has caused a rise in rural to urban migration, while generally the annual national food production is not marching with the population growth. Meanwhile, despite efforts by the government and non-governmental institutions to plant trees, more trees are still being cut than are planted.

Recent research developments have shown that most of the agricultural wastes possess high value plant fibbers, and can therefore be used for making boards, panels, tiles, etc. for construction purposes. They can similarly be pulped to produce fine mechanical or chemical pulp to be used in paper and fiberboard production. Some of the non-fibrous wastes can be fermented to produce biomass (methane, ethanol, etc.) for domestic and industrial applications, while others may be converted into activated carbon or briquettes to serve as energy sources.

The paper attempts to show the magnitude of annual agro-wastes generation from various key agricultural activities. An attempt is also made to show other valuable outputs besides the main crop products, that may be processed from a few selected agricultural crops. Examples of available technologies that may be employed to produce biocomposites from agriculture wastes are also cited. It is concluded that the conversion of agricultural waste into useful products would increase the income of farmers, create new employment opportunity, protect the environment, and contribute significantly to the national economy.

Introduction

Tanzania is a developing country which is currently faced with the challenge to improve the living standards of her people without destroying the environment. Most of the Tanzanian populace live in rural areas where their livelihood has traditionally depended on agriculture. Higher demand for wood fuel and building materials has led into depletion of the country's vital rain forests further reducing rainfall and hence cultivable agricultural land. Excessive cutting of the forests has left some areas without any large trees for the supply of building materials. Despite many concerted efforts by the government and non governmental institutions to plant trees, still more trees are being cut than are being planted.

In general, there is an acute shortage of construction materials for the fast growing populations of Africans south of the Sahara. Most of the traditional houses in rural areas are made from wood, clay and are usually covered by grass thatch. In urban areas, roofing is usually made from corrugated iron, ceramic tiles, and sometimes asbestos-cement corrugated sheets. The internal constructions for ceiling and partitioning walls are usually made of fibreboards, hardboards, and sometimes linings of soft or hardwoods. As the population in the sub-Saharan region increases, there is a parallel increase in the consumption of wood, both for fuel and shelter requirements. The increased demand on wood-based products is now leading to a high rate of depletion of natural forests and woodlands, with consequent lessening in rainfall and an increase in desertification of the region. The environment and ecosystem are also being affected, as the wildlife survival gets threatened as man moves deeper and deeper into the rain forests and woodlands in search of timber, fuelwood and good farmlands.

To address the twin issues of deforestation and transfer of technology, and appropriate technologies are required. The development of plant fibre reinforced composites through technology transfer is an appropriate solution that is environmentally friendly, to the problem of dwindling wood resources. The sub-Saharan region boasts and abundance of a wide variety of plant fibre materials, including sisal, cotton, coir, kapok, flax, banana, pineapple, palm leaf, papyrus, etc. These fibres can be used to reinforce polymeric or ceramic matrices to produce useful composite materials. Only a few of these fibres are being exploited commercially.

Mclaughlin and Tait (1980) postulated that the fibre bundle behaved like a composite material constituting of a strong crystalline phase of cellulose and a tough amorphous phase constituting the matrix. It was first assumed that the microfibrillar spiral angle θ of the inner secondary wall in a particular cell is constant. The second assumption was that the cells within a particular species are identical. It was first postulated that if E_c is the Young's modulus of the microfibril making a spiral angle θ, its component in the axial direction E_a is:

$$E_a = E_c \cos^2\theta \qquad (1)$$

They then applied the rule of mixtures to derive the Young's modulus of the fibre, E_f as:

$$E_f = w_c E_c \cos^2\theta + w_{nc} E_{nc} \qquad (2)$$

where E_c and E_{nc} are the Young's modulus values for the crystalline and non-crystalline regions, w_c and w_{nc} are their weight fractions respectively.

Commercially viable plant fibre sources

Sisal fibre

Of the nine examples cited above, only sisal fibre and cotton are currently produced and processed for commercial purposes. Sisal fibre has shown to possess excellent mechanical and physical properties and has been successfully used to reinforce cement, thermosets (polyester, epoxy, phenolic) and some thermoplastics.

Sisal fibres are commercially available as white, hard fibres, 0.8 to 1.2 meters long and about 0.1 to 0.3 mm thick. The fibre bundle is extracted from the leaves of the sisal plant (*Agave sisalana*). The structure of sisal fibre has been studied and reported by several authors [Barkakaty, 1976; Mukherjee et al, 1984; Nutman, 1937; Bisanda, 1988]. A commercial sisal fibre bundle consists of several individual fibre cells bound together by a cementing natural polymer thought to be lignin. The cell wall is dominated by microfibrillar bands that form spirals about the fibre cell axis An analysis of the fibre composition [Barkakaty, 1976] reports that the dry fibre is made up of cellulose (78%), lignin (8%), hemicellulose and pectines (10%), waxes (2%) and ash (1%).

The amount of sisal fibre extractable from the sisal leaf is only 4% of the total weight of the leaf and 2% of the total weight of the sisal plant. There is currently an increasing trend of growth in the demand for hard fibres like sisal but the cost of production shall remain high as long as only 2% of the plant is useful. Attention is now being focused on the solid and liquid wastes from the sisal plant, where biogas, fertilizer and ethanol are being produced experimentally.. The fibre tow and flume which come as waste during the decortication process are being processed into 'gunny' bags for packaging of grain and cereals. The woven material is cheap and can also be used to produce laminate composite panels with sound mechanical and physical properties (Bisanda, 1983).

Cotton

Cotton is one of the major export crops of Tanzania. The cotton fibre is produced mainly for the textile industry, where it is in high demand worldwide. However, the use of cotton cloth for producing composite materials has been practiced for certain special purpose applications. The stem and stalks left in the field have yet to find any useful applications, and are usually burnt in the field.

Kapok

Kapok fibre is a cellulosic plant fibre locally known as 'sufi' or generally referred to as 'silk cotton'. It resembles cotton in many respects, but it is lighter, is water repellent and has a slippery smooth feel. The traditional uses of kapok include mattress/pillow stuffing, upholstery and thermal insulation. However, the market for kapok in these conventional applications has declined considerably over the past 20 years due to developments in synthetic materials such as foamed plastics. Most peasant and plantation owners have almost abandoned the crop and only a small quantity is being harvested for local use. Recent research findings by the author has shown that it is possible to produce 'hybrid' textile material by mixing kapok and cotton at the ratio of 3:2 in favour of kapok. Such textile materials can either be deployed as clothing or a reinforcement for composites in polymeric matrices.

Coir

Coir is the fibrous material surrounding the nut of the coconut fruit. Coconut plantations are widespread along the coastline of East Africa, and copra, is the main export product from coconut. In Tanzania, Zanzibar and Mafia Island are the main producers of copra. During the processing of copra, thousands of tonnes of the fibrous waste, coir, are produced. Some limited efforts are being made to commercialize the coir through production of ropes, mats, brushes, and composites. Experiences in India and the Far East have shown that coir is a useful reinforcement to certain ceramics and polymers (Owolabi, et al. 1983). Coconut pith and coir waste have been utilized as fillers in natural rubber products like rubber cork, teamat, cellular sheet, partition board, packaging materials and other very low density products (Chandran et al, 1995).

Papyrus

Cyperus papyrus of the family *Cyperaceae* is widely distributed over tropical Africa, particularly in the region of the great lakes. It forms one of the principal plants of the great swamp vegetation of the area. Papyrus stalks are up to 3m high. Traditionally, the stalks were used to make boats, woven baskets, and its fibre provided materials for sails, matting and rope. Ancient Egyptians used its pith for making paper. The papyrus fibre can be used as reinforcement to polymeric matrices giving light weight composites for general purpose engineering applications.

Bamboo

Bamboo belongs to the grass family *Bambusoideae*. It is a natural lignocellulosic composite, in which cellulose fibres are embedded in a lignin matrix. The average length of bamboo fibres is about 2 mm, and the average diameter is between 10 and 20 mm (Jain, 1992). The structure, mechanical properties and fracture performance of bamboo and bamboo reinforced composites are widely reported (Chuma, 1991, Jain 1992; Jain, 1993). In India, bamboo is reported to have been used in grid shells for the construction industry (Vasavada, 1986). Bamboo has also been identified as a suitable reinforcement material for rainwater cistern (Robles-Austriaco, 1991). It is also being used by the pulp and paper industry for the production of paper and fibreboards.

Major sources of agro-wastes

Thousands of tons of agricultural wastes are produced annually from the various agricultural and industrial activities. Some of these waste products have potential to be used to produce green polymers as well as composite materials.

As modern techniques for farming improve the agricultural production, there is growing concern of the mountains of agricultural wastes produced, which are often being burnt, and contributing considerably to global warming. In the early 1990's, the EC passed legislation banning the burning of agricultural wastes in the whole of Europe. This has led into evolution of new technologies which convert these waste into useful materials, making them potential sources of cellulose an pulp for the production of paper and fibreboards. Currently, almost 60% of furniture materials in U.K. is made of medium density fibreboards (MDF) from wheat straw.

In Africa, there have been considerable developments in the utilization of agriculture wastes as a source of biomass. Table 1 shows some of the properties for some selected agricultural wastes and their advantages in biomass production.

TABLE 1: PHYSICAL CHARACTERISTICS OF MAJOR AGRICULTURAL AND FORESTRY WASTES (Massaquoi, 1986)

CROP	Bulk Density (kg/m^3)	Moisture Content (% wet basis)	Ash Content (%)	Calorific Value (MJ/kg)
Rice husk	107	11.87	20.3	12.75
Rice straw	320	17.91	17.9	13.5
Cocoa pods	-	19.27	10.2	14.2
Coffee husk	575.7	17.35	9.4	15.35
Peanut shells	429	16.35	14.2	15.46
Palm kernel shells	1315.57	12.02	1.3	16.4
Palm fruit fibres	826	11.48	-	23.21
Woody remains of palm fruit bunches	-	10.2	-	18.2
Bagasse	-	50	11.3	9.39

The chemical composition of some of these wastes have been determined and are shown in Table 2 below.

TABLE 2: CHEMICAL COMPOSITION OF SOME SELECTED AGRO-WASTES.

COMPONENT	Rice Husks	Rice Straw	Corn Cobs	Bagasse
Hemicellulose	11	16	40	19
Cellulose	37	38	38	38
Lignin	21	12	8	22
Ash	19	16	1	3
Other	12	18	13	18

Some Cases of waste utilization

Bagasse

This is the fibrous residue of sugar cane after the sugar juices have been extracted. Currently, nearly all bagasse produced in Tanzanian sugar industries is used to fuel the same industry with very low efficiency. Fig 1, shows the various products that can be produced from sugar cane.

Rice husks

It is known that about 20% by weight of the harvested paddy grain is made up of husk surrounding the kernel. Rice husk has been found to possess some pozzolanic properties, and if added to a lime donor, it can produce Portland cement or hydrated lime (de Gutierrez, 1994; Okpala et al, 1993). Rice hull consists of silica in hydrated amorphous form and cellulose which yield carbon when thermally decomposed (Singh et al, 1993). Rice husk has also been used as a filler for reinforcement or rubber, thereby improving its mechanical properties (Jain et al, 1994). A number of uses as reinforcement to cement and plastics have also been reported in India (Gupta, 1996). Rice husks have been identified as a potential source for the production of silicon nitride, silicon carbide or a mixture of both (Kuskonmaz et al, 1996). Generally, a rice farm has potentially many outputs as illustrated in Figure 2.

Coffee Residues

Coffee is one of the major export crops of Tanzania. In 1996/97, the coffee crop is expected to total 41,000 tonnes worth 92m US dollars. Coffee beans are extracted from a cherry which is more than half moisture when ripe. The outer soft skin is usually removed by semi- automatic or manual pulping processes. The beans are sun-dried to a moisture content of 15-30%. The endocarp or parchment (husk) is usually removed by a hulling machine before export. The husk removed is 20% by wt of the bean. Currently Tanzania produces two types of coffee, namely Arabica and Robusta types. In the Arabica type, the external soft cover of the coffee fruit is removed mechanically, the beans are soaked in water for a few days to allow for fermentation of the sugary surface, they are then cleaned and dried. The fermented pulp is often used as fertilizer to coffee plantations. The dry beans are usually graded before being sold to cooperatives or private buyers, who take the product to coffee auction markets after removing the hull. In East Africa, the Robusta coffee is grown in the West lake (Kagera) province and Uganda. The fruits are usually dried without pulping, and then hulled mechanically. The hulling from robusta coffee is usually taken back to coffee plantations as fertilizer, and is not as whitish as that from Arabica. The processing of coffee and resulting outputs are illustrated in Figure 3.

Usually one tonne of fresh cherries yields about 0.16 tonnes of pressed pulp and 0.05 tonnes of husk. The Bulk density of air dry pulp (24% mcwb) is 168 kg m^{-3} and oven dry pulp is 128 kg m^{-3}.

Sisal waste

Sisal was introduced to Tanzania in 1893, and has since largely been grown for the production of hard fibres, mainly for ropes and cordage. In the 1960's, Tanzania was the leading producer of sisal. Thereafter, production dropped drastically, reaching its lowest levels in the late 1980's.

It is known that in sisal, hard fibres extracted by wet decortication amount to only 2-3% of the total leaf weight. The leaves are about 50% the weight of the plant. The remainder of the plant (bole, pole, roots) together withe decorticate solid and liquid waste are discarded. Thus sisal fibre production represents one of the most serious resource under-utilisation. On the other hand, the sisal industry posses severe damage to the environment, because of the toxic discharges into water sources, of liquid wastes. It is estimated that wet decortication is 20 to 30 times as polluting as average domestic waste, or 4 to 6 times as polluting as sewage.

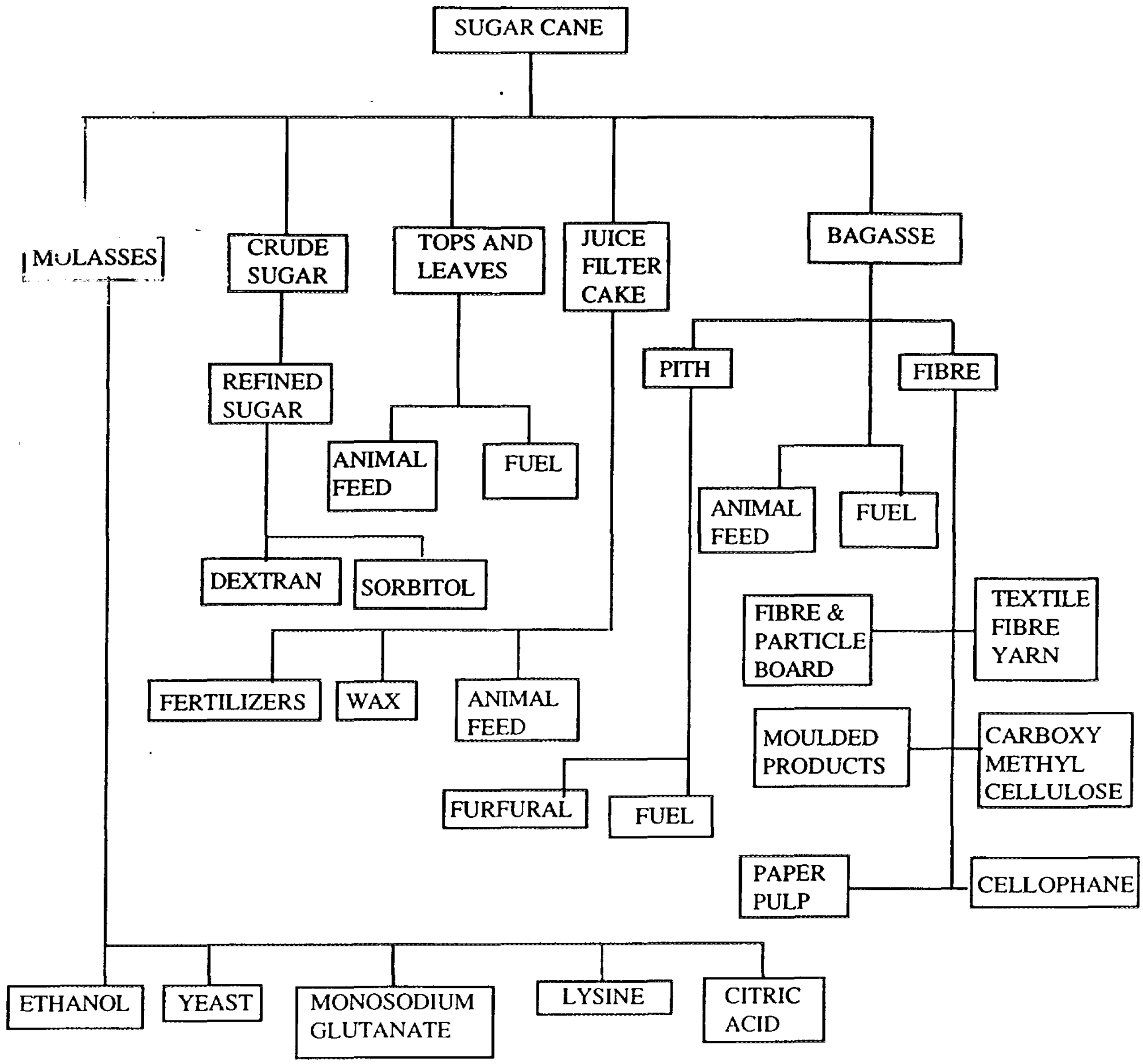


FIG.1: POTENTIAL PRODUCTS FROM SUGAR CANE

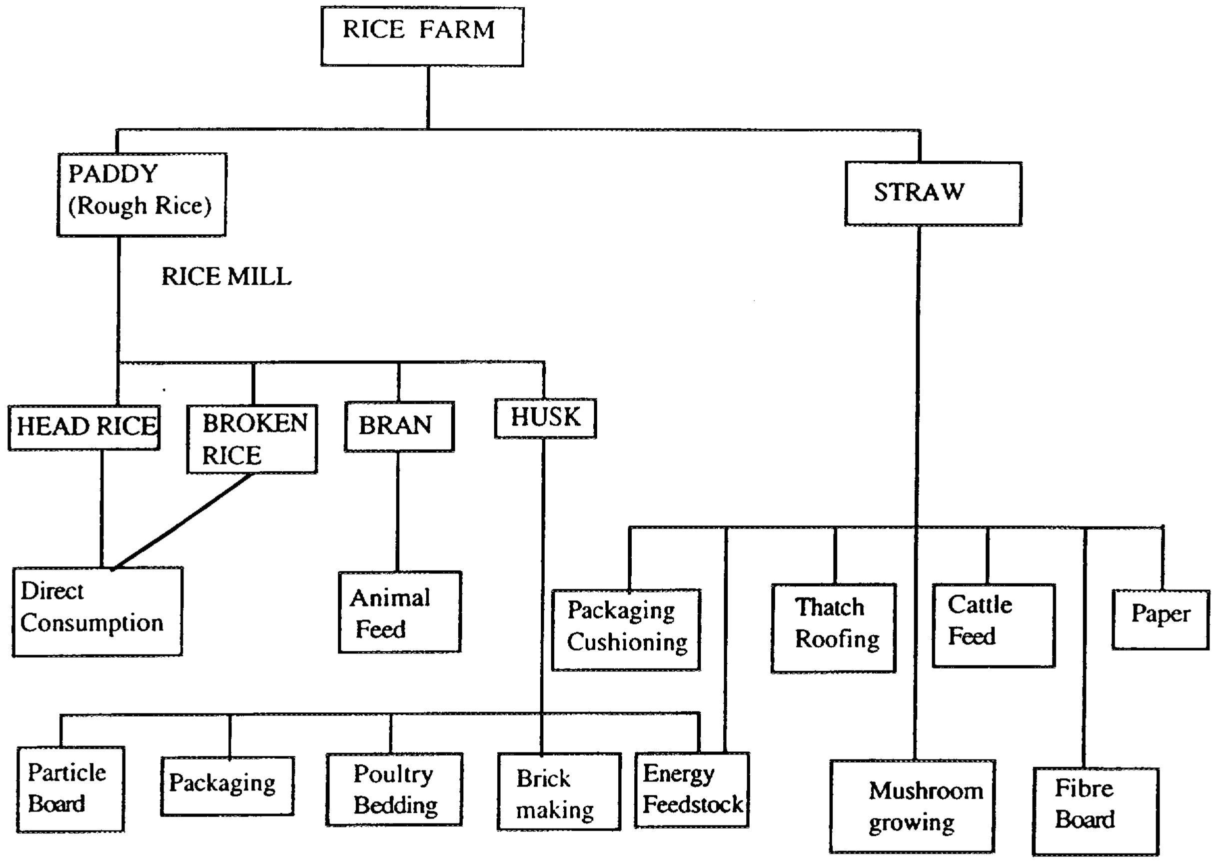


FIG.2. OUTPUTS FROM A RICE FARM

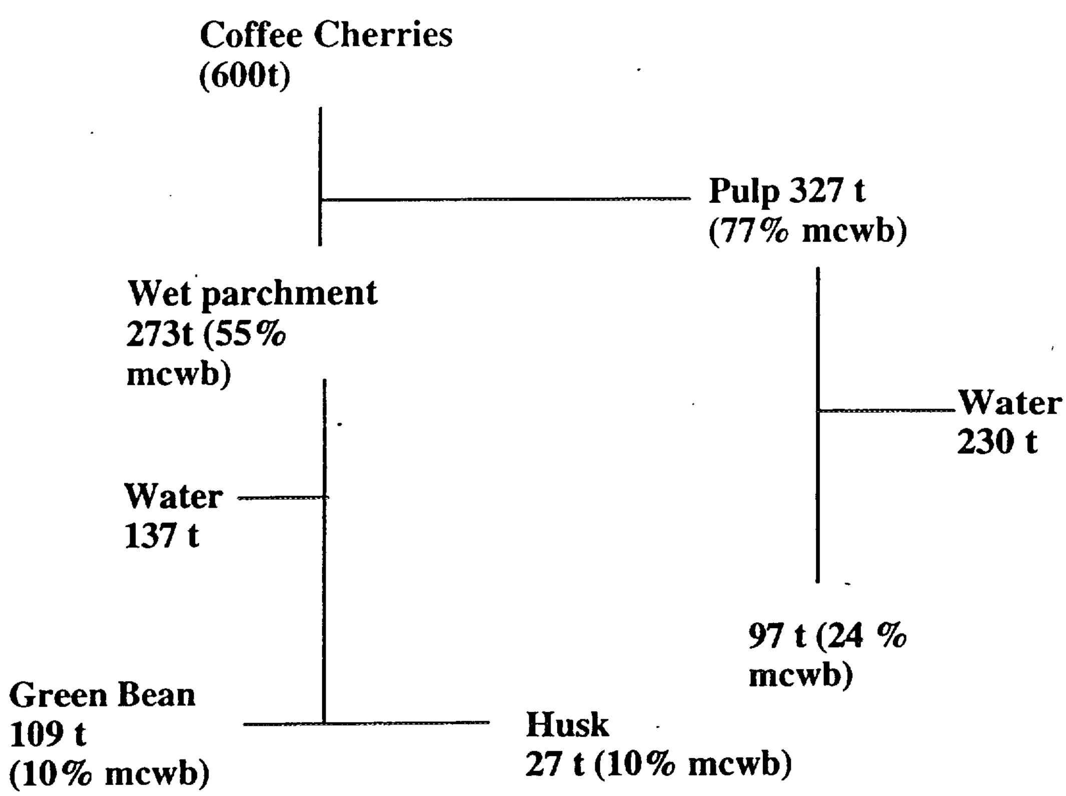
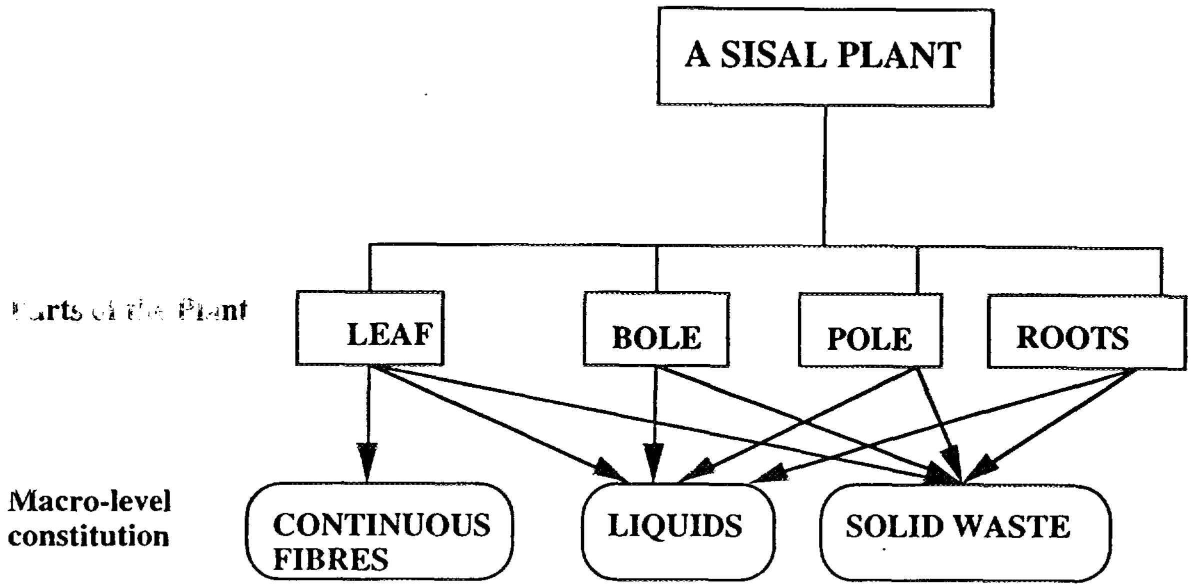


FIG.3. THE PROCESS OUTPUTS FROM COFFEE



Traditional and current end-uses	**Twine, Rope, Bags, Carpet, Brushes**	**None**	**Building poles**

Potential end products	**Composite panels Geotextiles Chemical pulp**	**Biogas Alcohol Organic acids Hecogenin**	**Chemical pulp Thermo-mechanical pulp Animal food Fertilizers Wax**

FIG. 4. POTENTIAL OUTPUTS FROM A SISAL PLANT

The potential outputs from a sisal plant are illustrated in Figure 4. Generally speaking, the only solution to the ailing sisal industry is through innovative exploitation of the useful resources potentially available in the discarded waste. The potential outputs have been identified as:

- Chemical extracts from sisal juices (organic acids, lipids, chlorophyll, alkanoids, saponins, etc.
- Sugars from sisal bole juice, which can be fermented and distilled to yield industrial chemicals including ethanol, citric acid, lactic acid, etc.
- Steroids which may be used to produce hecogenin for the pharmaceutical industry.
- Animal feed from the non - fibrous waste
- Biogas and fertilizers
- Chemical and thermomechanical pulp for the production of paper and fibre boards.

Coconut waste
The potentials of the coconut tree have been recognized widely. Almost every part of the tree has some useful application. The coconut fruit gives a high value product, copra, which is used as food and as an oil source. The liquid contained in young fruits is a healthy drink, which is very popular. The fruit is covered by a fibrous mass, which yield coir fibre. The coconut husk or shell, has been found to yield good quality activated carbon when briquetted. The stem is a tall trunk which has been successfuly used for production of timber and pulp for furniture, construction and other domestic end-uses. The leaves are traditionally used for thatched roofing. These potential outputs of the coconut plant are summarised in Fig.5.

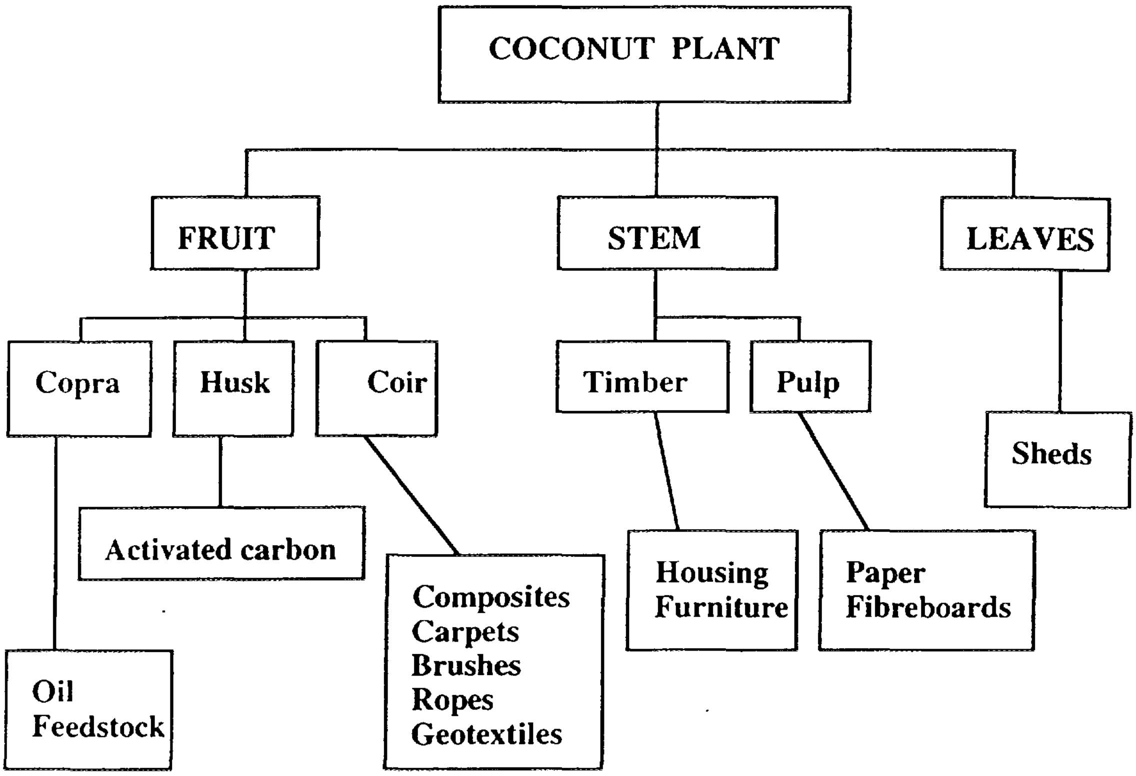


FIG.5. POTENTIAL OUTPUTS FROM THE COCONUT TREE

Maize waste
Maize or corn is the main staple food in Africa South of the Sahara. Huge amounts of maize waste are produced annually in the form of maize stalks and corn cobs. In some parts of East Africa, especially in the Kenyan Rift Valley Province, these wastes are converted into animal feed. In other places, they are either left for foraging animals or are burnt. It is known that the maize cob contains valuable amounts of hemicelluloses (mainly starches) and cellulose. The starch is an extractable ingedient in high demand in the phamarceutical industry and it has many industrial and domestic applications.

Estimation of Agro-wastes potential

The residues from agricultural crops are usually the stubble, straw, chaff and waste grain. It is important to leave at least 50% of the residues in the field for foraging animals and for soil conservation. In order to estimate the quantities of agricultural wastes produced, we can either use average crop yield per hectare when the total planted areas are known, or we can rely on annual production statistics. Sometimes we may have to use a combination of these two methods. Table 3 shows the production of major crops in Tanzania between 1990 and 1996.

In a first approximation of agro-waste quantities, a 50% residue recovery is assumed. In this approach, the Harvest Index (HI) is used to measure the ratio of grain yield to the total above ground yield, because of losses in harvest due to pests, animals, proliferage, etc. The Harvest Indexes in Table 4 have been confirmed with Ethiopian State agronomists

Various sources have given different values of the yield per hectare. The Report of the Commission of inquiry into the Agricultural Industry in Zimbabwe, gave the values of Yield shown in Table 5. Table 6 shows the estimated planted areas for various crops in Tanzania. These statistics can be used to estimate the residue produced annually.

TABLE 3. PRODUCTION OF MAJOR CROPS IN TANZANIA
(Economic Operation Report, June 1996, Bank of Tanzania)

CROP	'000 tonnes					
	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96
Coffee	37.7	52.2	56.3	48.5	43.5	52
Cotton	49	76.5	68.8	48.4	44.5	84.2
Tea	18.1	18.3	21.3	22.4	24.8	25
Cashewnuts	28.7	41.2	42.3	46.6	63.4	82
Tobacco	11.8	16.5	23.3	24	22.4	28
Sisal	36	24.2	24.3	30.5	25.5	30
Maize	2,332	2,226	2,282	2,159	2,567	2,638
Paddy	624	394	641	614	723	681
Wheat	84	64	59	59.4	75	61
Pulses	425	312	406	186.7	374	384
Banana	750	794	800	834	651	631
Cassava	1,566	1,778	1,708	1,415	1,492	1,478
Potatoes	291	257	260	277	451	446
Sugar	118.5	108.5	121.4	123.9	104.6	116.8

TABLE 4: HARVEST INDEXES AND RECOVERABLE RESIDUE ESTIMATES (Energy Dept Paper no. 26.; June 1985)

CROP	HARVEST INDEX	RESIDUE (Per tonne of Grain recovered)	RECOVERABLE RESIDUE (Per tonne of Grain Recovered)
Wheat	0.38	1.63	0.82
Barley	0.40	0.75	0.40
Sorghum	0.40	1.50	0.75
Maize	0.38	4.00	2.0

TABLE 5 (a). THE YIELD OF MAIN CROPS IN ZIMBABWE

CROP	YIELD (kg/ha)
Maize	695
Munga	385
Groundnuts	481
Sorghum	493
Rapoko	493
Cotton	722
Beans	304
Sunflower	401

TABLE 5 (b). THE ESTIMATED YIELD OF SOME CROPS IN TANZANIA

CROPS	AREA PLANTED (ha)	PRODUCTION (tonnes)	YIELD (kg/ha)
Maize	1,368,246	2,362,658	1727
Paddy	274,428	477,389	1740
Sorghum	389,643	415,415	1066
Bulrush Millet	207,841	221,388	1065
Beans	228,418	142,675	625

TABLE 6. ESTIMATED PLANTED AREA FOR VARIOUS CROPS IN TANZANIA

GROUP	CROP	AREA PLANTED (Hectares)
CEREALS	Maize	1,368,246
	Paddy	274,428
	Sorghum	389,643
	Bulrush Millet	207,841
	Finger Millet	29,211
ROOTS AND TUBERS	Cassava	188,243
	Sweet Potatoes	59,571
	Irish Potatoes	1,500
	Others	1,760
OIL CROPS	Sunflower	23,124
	Simsim	8,615
	Groundnuts	91,825
	Palm Oil	3,962
	Coconut	1,829
	Cashewnut	19,476
LEGUMES	Beans	228,418
	Cow Peas	10,419
	Green Peas	3,169
	Pigeon Peas	8,441
	Chick Peas	26,437
	Bambara Nuts	7,380
	Peanuts	3,566
FRUITS	Banana	81,910
	Other Fruits	2,975
VEGETABLES		4,110
OTHER CROPS		306,555

The second approach, is to use statistics available for the annual average production for each crop. Using the estimated recoverable waste factors, one gets a more realistic estimate of the amount of the waste available. It is known that there are great variations in YIELD from place to place as clearly shown in Table 5 (a) and (b) for Zimbabwe and Tanzania. The waste factor is defined as the ratio of the weight of the waste to the weight of the primary product. Table 7 gives some waste factors established for a variety of crops.

: WASTE FACTORS FOR SELECTED AGRICULTURAL WASTES (Massaquoi, 1986)

WASTE	PRIMARY PRODUCT	WASTE FACTOR
Rice husk	Paddy rice	0.325
Rice straw	Paddy rice	3.78
Dead natural vegetation	Paddy rice	2.6
Cocoa pods	Cocoa beans	1.0
Coffee husk	Coffee seeds	1.0
Peanut shell	Peanuts	1.0
Palm kernel shells	Kernel	1.85
Palm fruit fibres	Palm Oil	0.95
Woody remains of palm fruit bunches	Palm Oil	1.48
Bagasse	Sugar	3.3

TABLE 8: SOME ESTIMATES OF IMPORTANT AGRICULTURAL WASTES PRODUCED IN TANZANIA DURING 1996.

WASTE	PRIMARY PRODUCT	WASTE FACTOR	Primary Product Production ('000 tonnes)	Estimated amount of Waste ('000 tonnes)
Rice husk	Paddy rice	0.325	681	221
Rice straw	Paddy rice	3.78	681	2,574
Coir	Copra	0.70	3.3	2.31
Coconut husks	Copra	2.0	3.3	6.6
Coffee hull	Coffee seeds (Arabica)	0.2	52	10.4
Bagasse	Sugar	3.3	116.8	385.4
Sisal Tow and Flume	Sisal fibre	2.0	30	60
Corn cobs	Maize	0.25	2,638	659.5
Corn stalk	Maize	2.0	2,638	5,276
Groundnut shells	Groundnuts	0.60	9	5.4
Wheat straw	Wheat	3.50	61	213.5
Cashew nut shell	Cashew kernel	0.30	82	24.6
Sawdust	Timber	0.45	86	38.7

Technologies required for waste reclamation for the manufacture composites

Various technologies for composite processing are available, and their selection depend on the type of product desired and the binder or matrix material. Hot compression moulding is commonly used for products that are made using thermosetting polymer binders. To be able to produce composites with continous fibres, it is important to first obtain a woven mat which would give a more non directionality of properties. Random mats or multidirectional woven mats can be easily produced using available technologies. In most cases, the agricultural wastes mostly consititute of pulpy materials. As such, conventional pulping techniques must be employed to produce the desired type of pulp, which would then be used to produce the pulp based materials such as paper and fibre boards.

Proper binding materials must be selected to meet the desired requirements in terms of mechanical strength, water resistance, micro-organism resistance and aesthetics. Nearly all plant fibres are hydrophillic, hence chemical modifications of the fibre surface may be necessary in order to overcome the problem of water and moisture absorption. Furthermore, the fibre surfaces require to be cleansed of any waxy or oily substances which would interfere with the creation of a solid interface between the fibres and the matrix.

Moulding techniques such as hot compression are easily employed to produce laminated composites. However, other techniques such as injection moulding and extrusion are possible especially when working with non continuous fibre and themoplastic matrices. Nearly all conventional techniques for composite manufacture can be employed on plant fibre reinforced composites.

Conclusions

From the foregoing discussions and presentations, the following conclusions can be made:

1. Tanzania produces a significantly high amount of agricultural wastes, which can be utilized profitably if used for biocomposite manufacture.

2. The processing of agricultural wastes into useful composites is possible using available technologies.

3. The introduction of biocomposites from agricultural wastes is likely to reduce the demand for timber, and this will have significant impact on environmental conservation.

REFERENCES

BARKAKATY, B.C. (1976): "Some structural aspects of sisal fibers", *Journal of Applied Polymer Science*, **20**, 2921-2940.

BISANDA, E.T.N. (1988): "The prospects for sisal reinforced composite materials and their impact on the Tanzanian economy", *The Tanzania Engineer*, **2** (3), 36-41.

CHANDRAN, K.R.; KURIAKOSE, A.P. (1993): "Utilization of coconut pith and coir as fillers in natural rubber vulcanizates", *Kautschuk und Gummi Kunststoffe*, **46** (1), 29-33.

CHUMA, S.; OHGAMA, T.; KASAHARA, Y. (1991): "Composite structure and mechanical property of Mousou bamboo", *Journal of the Society of Materials Science*, Japan, **40** (448): 21-26.

de GUTIERREZ, R.M.; DELVASTO, S.A. (1994): "Production of high strength cements fro rice husk ash" *Journal of Resource Management and Technology*, **22**(3), 127-130.

GUPTA, T.N. (1996): "Composite materials using local resources", *New and Advanced Materials*, **3**, 3-30.

JAIN, A.; RAO, T.; SAMBI, S.S., GROVER, P.D. (1984): "Energy and Chemicals from rice husk" *Biomass and Bioenergy*, 7 (1-6), 285-289.

JAIN, S.; JINDAL, U.C. (1992): "Mechanical behaviour of bamboo and bamboo composite", *Journal of Materials Science* **27**, 4598-4604.

JAIN, S.; KUMAR, R. (1993): "Development and fracture mechanism of the bamboo/polyester resin composite", *Journal of Materials Science Letters* **12**(8), 558-560.

SAYGINER, A.; TOY, C.; ACMA, E.; ADDEMIR, O.; TEKIN, A.(1996): "Studies on the formation of silicon nitride and silicon carbide from rice husk", *High Temperature Materials and Resources,* **15** (1-2), 123-129.

MASSAQUOI, J. (1986): "A methodology for assessing the energy potential of crop residues", CSC Technical Publication Series no. 188, 163-178.

McLAUGHLIN, E.C.; TAIT, R.A. (1980) : "Fracture mechanism of plant fibres", *Journal of Materials Science,* **15**, 89-95.

MUKHERJEE, P.S. & SATYANARAYANA, K.G. (1984): "Structure and properties of some vegetable fibres, Part 1: Sisal fibre", *Journal of Materials Science,* **19**, 3925-3934.

NUTMAN, F.J. (1937): "Agave fibres", *Empire Journal of Agriculture,* **5**, 75-111.

OKPALA, D.C. (1993): "Some engineering properties of sand concrete blocks containing rice husk ash", *Building and Environment,* **28**(3), 235-241.

OWOLABI, O.; CZVIKOVSZKY,T.; KOVACS, I. (1985): "Coconut fiber reinforced thermosetting plastics", *Journal of Applied Polymer Science,* **30** , 1827 - 1836.

ROBLES-AUSTRIACO, L. (1991): "Bamboo reinforcement for rainwater cistern", *Journal of Ferrocement* **21**(1) , 25-29.

VASAVADA, R. (1986): "Grid shells using bamboo as lightweight structural material", LSA 86: Lightweight Structures in Architecture, Proc. 1st Int. Conf., Sydney, Australia, Aug. 24-29, 1986, Unisearch Ltd, Kensington, Australia.

Natural Fiber Composites: The North America Scene

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INTRODUCTION

In the U.S., increasing concern for the protection of the environment has focused greater attention on the development of composites as a means of using resources more efficiently. Perceived exploitation of forest resorces and destruction of wildlife habitat has led to legislation restricting access to old growth forests thus limiting the supply of high quality veneer and sawlog timber. At the other end of the scale, concern for depletion of available landfill space and the volume of this space being taken by wood-based materials has lead to major efforts to recycle wood-fiber based materials. As a result, wood-based composite materials are being developed for a wide variety of applications. In some cases these are direct substitutes for lumber and plywood. In other cases, they are gaining acceptance as new and improved options in the buildings materials markets.

Composite Classification

A number of terms have been adopted to describe wood based composites. These range from fairly generic terms to specific products. A commonly used classification focuses on the binder and the form of the aggregate fiber. Binders are classified as either organic or inorganic. Organic binders include naturally occuring carbon based substances such as wood lignin, recycled plastics or polymeric resins. The aggrigate fiber in these composites may be in the form of fiber or particles. An example of an organic bonded wood fiber composite is medium density fiberboard (MDF) as compared to the commonly used organic bonded particle composite called oriented strand board (OSB). The most common inorganic binder is Portland cement. Inorganic bonded wood fiber composites are normally high density, comprising less than 20% wood fiber by weight and are commonly used for cladding applications (siding, shingles, etc). Inorganic bonded particle composites come ina wide range of densities with wood contents ranging as high as 60% by weight. The most common use is as sound adsorbing, fire resisting interior panels. Laminated veneer lumber, plywood and glulam are also composite products. There is currently research being done to improve the performance of glulam by using high strength fiber reinforced plastic composites as a tension lamination. These products, however, are not designed to use recycled or low quality organic fiber based materials and will not be discussed here.

Advantages of Composites

The primary advantage of composites over solid wood is flexibility. By combining wood with other materials, it is possible to design a composite which exhibits the best properties of each. Composites can be molded to specific shapes, eliminating the need for more expensive machining. Finally, it is possible to vary the density of composites to give a range of properties with regard to energy adsorption and transmission. Thus, for applications where solid wood has some limitations, it may be possible to obtain superior performance using composites.

Organic Wood Composites.

One of the most popular organic bonded wood composites used in the US is is oriented Strand board (OSB). There are currently 65 plants manufacturing OSB in North America. Roughly 60% of residential structures built in the US in the past 2 years have OSB roofing and wall sheathing and 25% use OSB as floor sheathing. OSB is not made using recycled material, but it does use particles from low quality/ small diameter trees.

Plastic-wood composites are gaining in popularity. For many extruded or molded plastic products, it has been found that adding wood fiber improves stiffness and impact resistance. The automotive industry uses these composites for interior trim. Flat panels made using thermosetting resins, recycle plastics and wood fiber are pressed in heated molds to form door and rear deck panels. Plastic lumber is also being produced for applications such as decks , exterior trim and outdoor furniture where exposure to rain and sun leads to maintenance problems for wood.

Inorganic Wood Composites

Inorganic bonded composites can be designed for a variety of applications which require special performance attributes with respect to sound transmission, energy dissipation, and resistance to fire, decay and insects. Low density cement/ wood - particle composites are commercially produced for commercial/industrial applications requiring both acoustic adsorption and fire resistance. These materials are also used for highway sound barriers where a low density face is used to limit soud reflection and a high density core is used to limit sound transmission. A major market for whgh density cement/wood fiber composites is as a replacement for cedar shake shingles in hot dry climates where wild fires are a constant threat. Some companies are exploring the energy dissipating properties of low density particle composites for applications such as mine support cribs, shear walls in seismic zones and highway crash barriers. The cement environment imparts a pH which is too high for termites to digest thus making this an ideal material for use in termite prone areas.

Acceptability of Composites

Cewment bonded Wood Composites (CBWCs) are not new to the U.S. Asbestos cement board has been used for at least 70 years. White (1991) reports on the efforts to market wood-cement products in theUSA. According to White (1991) the parameters that influence the home owner in deciding to use biocomposites include: 1) aesthetics; 2) application familiarity; 3) any bad publicity, such as those associated with asbestos; 4) availability; 5) fire rating 6) long term appearance 7) strength; 8) pricing; 9) warranty.

Products that have gained acceptance include cladding, roofing and interior wall and ceiling panels. James Hardy Co did some development work on cellulose reinforced cement panels in the 1940's when there was a shortage of asbestos due to demands of WWII. After asbestos gained recognition as a health hazard, cellulose fibers became a more importnat rawmaterial for the James Hardy roof shingle and siding products. Cement bonded excelsior panels, a low-density cement-bonded wood particle product, have also been around for close to 70 years and has a well established, though not extensive market as an interior panel.

Processing Issues

Processing issues include raw materials availability, the form of the wood componet, binders and the forming processes. In this section of the paper these issues will be addresed in reference to the North American scene.

Sources of Raw Materials (current and future sources)

There are numerous sources of raw materials for use in wood based fiber composites. These sources range from virgin fibers derived from low value woods to recycled fibers associated with Municipal Solid Waste (MSW). Approximately 1/3 of the US land area is forested, providing 280 million metric tonnes of wood per year. Management of this resource requires thinning small diameter, trees which have little use as lumber but could be chipped or crushed for use in wood fiber composites. Roughly one-half of all industrial material used in the U.S. is wood-based. Recent estimates (McKeever, 1997) suggest that 61 million metric tons of solid wood waste material is generated each year in the form of manufacturiing, construction and demolition waste. Composites research in the US is looking for ways to add value to these resources by developing wood fiber composite products. In this section a general overview of some of this sources will be presented.

Low value woods

In many parts of North America, there are some tree species that have remained un-exploited by the wood industry. This may be due to the geographical spread and concentration of the species, making it uneconomical to exploit. In the manufacture of CBWCs the whole tree is utilized, as opposed to the trunk only as is in most traditional wood industry. In addition, municipal brushwood (tree trimmings) can be used as a source raw material for these CBWCs.

Forest thinning

In course of its growth, a forest needs thinning at various stages. The thinned stems are often small diameter containing a large portion of juvenile wood which is undesirable for production of structural lumber. Some of this material is harvested, processed into chips and used in the manufacture of paper or composite panels. While this source of fiber is readily available, it is not the major focus of composites research as there is a steady though limited value market for it.

Manufacturing waste

Waste wood from manufacturing facilities is normally fairly clean. In many instances, this is wood that has been sawn and dried. It rarely contains impurities such as bark, dirt or nails. It sometimes contains glue lines but that is not a problem for the composites. A problem that does surface when using manufacturing waste with cement binders, however, is inhibition of cement hydration due to an over abundance of free sugars or extractives in the wood. These problems can be solved but the solution adds cost in terms of processing time and chemical additives. In the U.S. a company called Fastwall produces a cement bonded wood composite building block from recycled wood pallet material by treating the wood particles with a processes which coates the particles with kaolin clay, thus restraining the interaction between the wood sugars and cement. Wood sugars are not a problem for plastic-wood composites.

Construction waste

Construction waste is normally a good source of material for cement-wood composites. The most popular construction lumber species are softwoods. In addition to the low sugar and extractive content of these species, the fact that they are often kiln dried makes them even more compatible with the cement binder. A pilot study conducted by Wolfe (1996) showed that cement bonded wood waste could be used with no special treatment to produce a product that could meet requirements for use as highway sound barriers. Data from this study also indicated that these materials could possibly be used to prevent excessive damage in seismic and wind zones by serving as shock absorbing, energy dissipaing elements.

Demolition waste

Demolition waste presents added problems in that it often contains impurities that must be removed prior to processing for use in particle or fiber composites. This material often contains metal, masonry, glass and bituminous materials which can create problems with procesing equipment as wiell as detracting from product controls. Most research efforts dealing with the development of value added products from waste is concentrating primarily on the use of clean waste materials. .

There exist large quantities of wood based material that need to be disposed at the end of their intended use. These include utility poles, railroad ties, army ammunition boxes, lumber from decking, and many other sources. Most of these wood based products are treated with preservatives. The preservatives may leach from the wood when placed landfills, causing ground water contamination. As a result there are strict regulations covering the disposal of this products.

According to Felton and De Groot (1996), approximately 6 x 10^6 m^3 of wood treated with chromated copper arsenate (CCA), pentachlorophenol, an creosote and disposed annualy. Currently, about 1.3 x 10^6 m^3 per year of creosote-treated railroad ties and 2 x 10^6 m^3 of utility poles treated with pentaclorophenol and creosote are available for recycling. In recent years there has been a significant increase in the use of CCA-treated dimension lumber in housing and decking. Assuming a 30-year lifetime, it means that in the near future there will be a increase in the volume of CCA treated lumber that has to be disposed. The analysis of the current utilization trend, the volume of treated wood products that has to be disposed is estimated to grow to 19 x 10^6 m^3 by the year 2020. I general it can be said that there exist large volumes of preservative treated wood. Of these, wood treated with CCA and similar inorganic preservatives has the highest potential for use in CBWCs. Other preservatives (the oil based preservatives) poses some bonding problems. However, health concerns during processing and environmental durability are still under investigation.

Municipal Solid Waste (MSW)

In the United States, nearly 70 million tons of different paper and paper board products are discarded each year. This waste is included in a general category of MSW, which is a mixture of various types of wastes. Table 1 presents According to Rowell (1994), most of these waste paper products cosists of a fiber matrix to which some inorganic or organic chemical compound is added to enhence the utility of the product. This means that most of these wastepaper contains contaminants. These contaminats include adhesives, inks, dyes, metal foils, plastics and many more other contaminants. In order for these waste to be used in the manufacture of biocomposites some of the contaminants must be separated. However, the composite produced from thses wastepaper fibers are usually colored, painted or overlaid. Therefore the recovered fibers do not require extensive cleaning or refinement. Table 1 below, extracted from Rowell (1994), shows the various componets of MSW in the USA.

Table 1. Wood based solid waste in the USA, 1993 (from McKeever 1995)

Source of Material	Generated	Recoverable	
	Amount (10^6 metric tons)	Amount (10^6 metric tons)	%
Municipal solid waste (MSW)			
Solid wood			
Wood waste	12.4	6.7	54
Woody yard trimmings	28.2	13.6	48
Total	40.6	20.3	50
Paper and paperboard	70.6	28.0	40
Total MSW	111.2	48.3	43
Construction and demolition ((C&D)			
New construction waste			
Solid wood	6.1	5.4	88
Paper and paperboard	0.2	0.2	89
Total	6.3	5.5	88
Demolition waste			
Solid wood	22.7	6.8	30
Paper and paperboard	0.3	~ 0*	2
Total	23.0	6.8	30
Total C&D			
Solid wood	28.8	12.2	42
Paper and paperboard	0.50	0.2	40
Total	29.2	12.3	42
Primary timber processing			
Solid wood residues	74.5	4.3	6
TOTAL, All sources			
Solid wood	143.9	36.8	26
Paper and paperboard	71.1	28.2	40
Total	215.0	65.0	30

Fibers from agricultural by products and wastes.

Examples of these agricultural by products include banana fibers and cereal (millet, wheat, corn etc.) stalk fibers. Sisal waste in the form of decorticated solid mass and sisal boles also form a large group of agricultural wastes with large fibrous potential. Studies conducted on sisal pulp-cement composites (Coutts, 1992), showed that building materials with superior properties can be produced from this composite system. In most parts this agricultural by products are disposed off by burning, therefore creating among other things "green house gasses (CO_2)".

Fibers from grasses and other wildly growing vegetation.

In many areas there exist wild growing tall grasses that can be used a natural fiber source. The major categories of these wild fibrous plants are bamboo and papyrus. *Cyperus papyrus* of the family *cyperaceae* is widely distributed over world, as the region of the Great Lakes of Africa. It forms one of the principal plants of the great swamp vegetation of the area. Papyrus stalks are up to 3 m high. Ancient Egyptians used its pith for making paper. Traditionally, the stalks were used to make boats, woven baskets, and its fiber provided materials for sails, matting and rope. Again, competition from other "superior" materials, has made *Cyperus papyrus* a less attractive material for its original use. In many parts of the world, the only significant use of *Cyperus papyrus* is the use of its stems in thatched roofs. These thatched roofs have to be replaced in about every two years. This takes valuable work force that would have otherwise been used for other economic activities such as fishing and agriculture. Converting these fibers to more durable composites will help in this regard. Other tall grasses, such as elephant grass, are extensively used as thatch in many parts the world.

Production and Consumption of Biocomposites in North America

As a result of stiff competition that exist between manufacturers, most companies are reluctant to give out statistics on the production details. As a result we can tell exactly the production exact figures of CBWCs. However, we can estimate production based on news releases and information available on the World Wide Web for the major manufactures of CBWCs.

One such major manufacturer of CBWCs is James Hardie, a leader in the manufacturing of fiber-cement siding, tile underlayment and roofing products. These products include HARDIPLANK lap siding, HARDIPANEL vertical siding, HARDISOFFIT soffits, HARDIBACKER tile underlayment, and HARDISLATE roofing. According to company brochure, builders have discovered that these unique products are today's answer to enhancing the durability of their projects, while increasing the aesthetics and reducing overall maintenance. James Hardie has three plants in operation (in Plant City, Florida; Fontana, California and Cleburne, Texas). A new plant is under construction at Frederickson, Washington, which will bring James Hardie's over-all North America annual production capacity to over 83.6 million m^2 (900 million sq.ft).

Louisiana-Pacific Lumber is another major player in the manufacturing of CBWCs. Primarily a wood products processing and distribution company, it is one of among those who are diversifying their products so as to be in a competitive advantage as the timber resources dwindles.

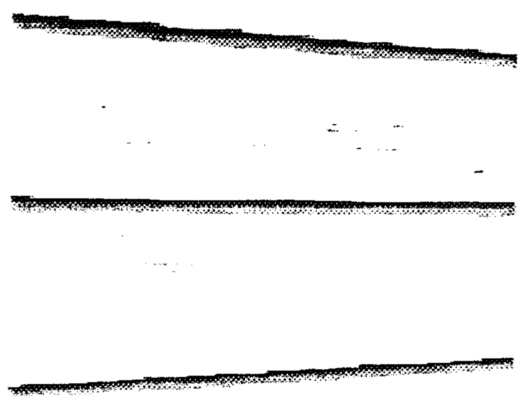
Another manufacturer of CBWCs is FireFree/Re Con Building Products, whose specializes in roofing products. According to Blaney (1997), the current annual production capacity of this company is 18,600 m^2 (200,000 sq.ft) with 23,200 m^2 (250,000 sq.ft) annual capacity under construction.

Product Properties

There have been a number of studies on inorganic bonded wood and fiber composite materials (Moslemi(editor), 1991; Michell, 1986; Coutts and Warden, 1985; Lee, 1985).

Available Commercial Products and Applications

Hardiplank and Hardipanel Fiber-Cement Siding

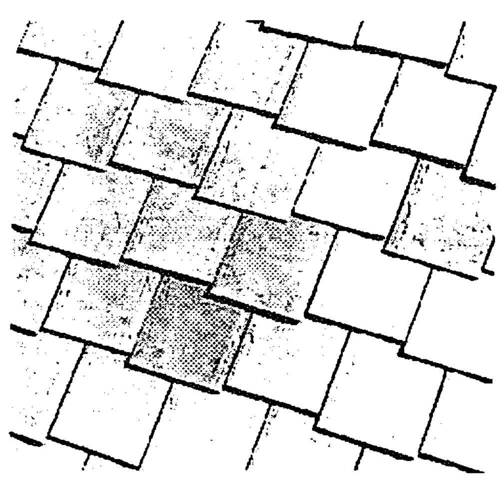


These fiber-cement sidings are the durable, attractive alternative to traditional wood, brick, stucco, vinyl and wood composites. Providing the look of wood and durability of fiber-cement, Hardiplank and Hardipanel sidings resist damage from extended exposure to humidity, rain, snow and salt air. They will not crack, rot or delaminate, and are able to withstand termite attacks and gale-force winds. Although they install easily like conventional wood, Hardiplank and Hardipanel sidings are non-combustible, and are backed by a 50-year limited, transferable product warranty.

Hardibacker Fiber-Cement Tile Underlayment

Hardibacker fiber-cement underlayment provides the substrate you need for all your ceramic tile installations. It is more durable than wood, gypsum-based backerboards and other cementitious products, and is non-combustible. Supported by a 20-year limited product warranty, Hardibacker will not swell, peak at the joints or deteriorate when exposed to water. For easy installation, Hardibacker scores and snaps from a single side so it cuts faster and cleaner than other boards. Hardibacker is 1/4" thick and available in 3'x5', 4'x4', and 4'x8' sheets.

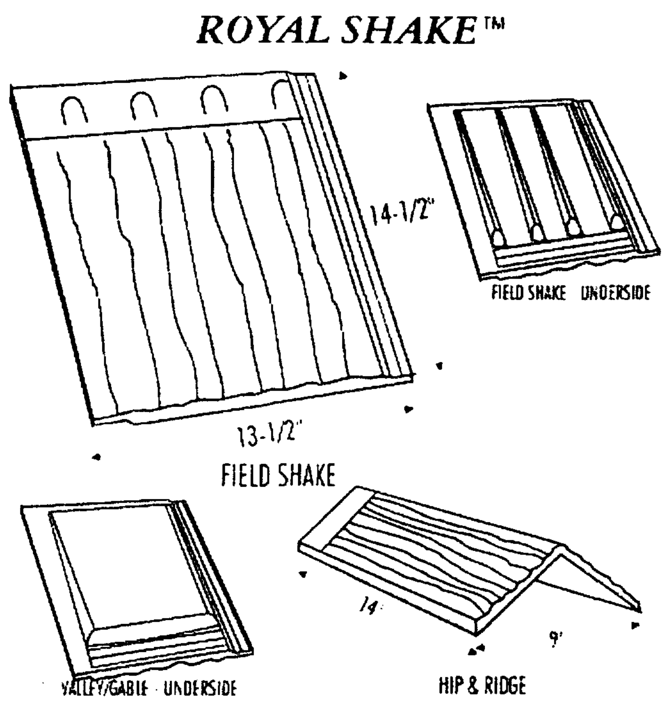
Hardislate Fiber-Cement Roofing



Hardislate fiber-cement roofing provides the beauty of natural slate and the durability of fiber-cement without the heavy weight. It resists the damaging effects of sun, heat, moisture, hail and termites, as well as withstanding gale-force winds. Designed to complement all architectural styles, Hardislate is recommended for reroof and new construction projects. Hardislate is non-combustible, and can be installed to achieve a Class A fire rating in accordance with ASTM Test Method E-136 Standards. Hardislate carries a 50-year limited transferable product warranty.

Royal Shake

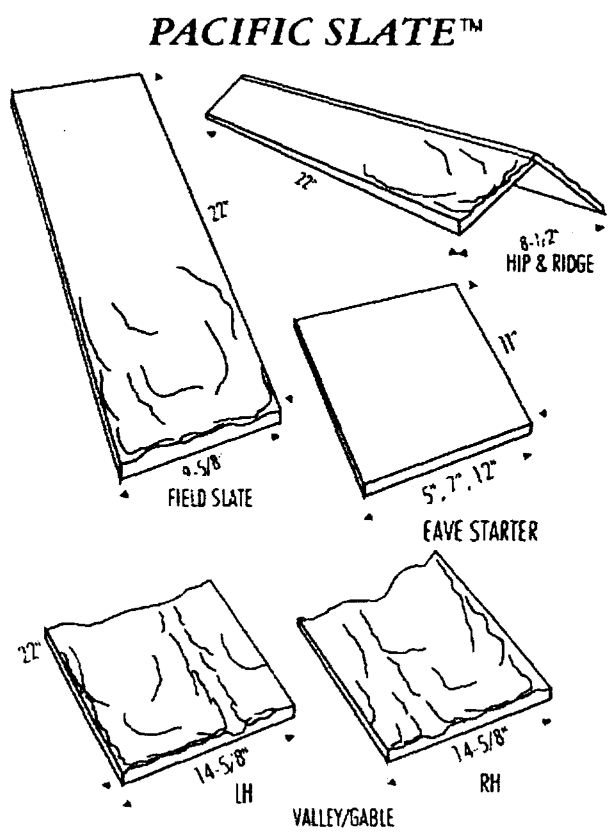
These are roofing CBWCs made by American Cemwood. They weigh about 480 Lbs per square (100-sq. ft.). They have very good impact resistance and are Class "A" fire rated. The are supplied with a 30 years transferable manufacturer warranty.



DRAFT: FOR WORKSHOP FLOOR ONLY

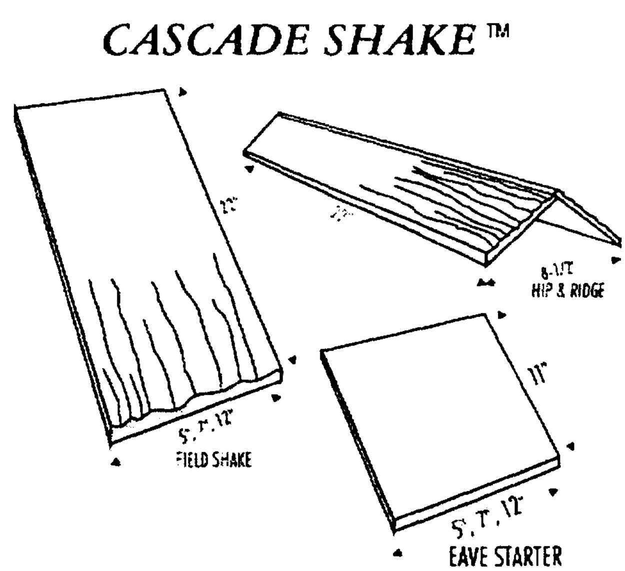
Pacific Slate

Manufactured by American Cemwood, they are 22" long and up to 9-3/4" in width. They weigh about 620 Lbs. Per square (100-sq. ft.). They have very good impact resistance and are Class "A" fire rated. They can be applied over spaced or solid sheathing and are supplied with a 30 years transferable manufacturer warranty.



Cascade Shake

Manufactured by American Cemwood, they are 22" long and available in three standard widths (12", 7" and 5"). They weigh about 580 Lbs. Per square (100-sq. ft.) and have authentic shake profile. They have very good impact resistance and are Class "A" fire rated. They can be applied over spaced or solid sheathing and are supplied with a 30 years transferable manufacturer warranty.



Conclusions

Based on the reception of Biocomposites in North America the following conclusions can be inferred:

Biocomposites are viable products that a revolutionizing the way we use our natural, renewable, fiber sources in the construction industry. In many parts of Africa natural fibers are been used as thatch, which is highly vulnerable as far as fire hazards and biodegradation is concerned. This technology can be adopted very successfully here.

African countries lagged behind, in part, because they had not made the right investments where it mattered most. It is important for African governments to put in place the policies needed to ensure that resources are utilized wisely, without causing adverse impact on the environment. Investment in biocomposites will reduce to a great extent housing shortage problems as well as provide employment in this new industry.
Research to particularize the processes and the product to Africa is needed. Given the right incentives, the major players in other parts of the world may play an important role in introducing developing the technology in Africa

Bibliography

Coutts, R.S.P.; Warden, P.G., 1992: "Sisal pulp reinforced cement mortar", **Cement Concrete Composites**, v 14 no 1, p. 17-21.

Fuwape, J.A., 1994: "Natural adhesive bonded particle-board's", **Bioresource Technology**, v.48 no.1, p. 83-85.

Hernandez-Olivares, F.; Oteiza, I.; de Villanueva, L., 1992: "Experimental analysis of toughness and modulus of rupture increase of sisal short fiber reinforced hemihydrated gypsum", **Composite Structures**, v.22 no. 3, p. 123-137.

Singh, M.; Verma, C.L.; Garg, M.; Handa, S.K.; Kumar, R., 1994: "Studies on sisal fiber reinforced gypsum binder for substitution of wood", **Research and Industry**, v. 39 no.1, p. 55-59.

Campbell, M. D.; Coutts, R.S.P.; Michell, A.J. and Wills D.., 1980. "Composites of Cellulosic Fibers with Polyolefins or Cement. A short review." Industrial Engr. and Chemical Engr. Product Research and Development, Vol. 19 pp 596-601

Coutts, R.S.P and Kightly, P. 1984. " Bonding in wood fiber-cement composites". Journal of Material Science, 19 (1984) pp 3355 - 3359.

Coutts, R.S.P. and Warden, P.G., 1985. " Air-cured, wood pulp, fiber cement composites". Journal of Materials Science Letters 4 (1985) pp 117 - 119.

Hachmi M. and Moslemi A. A. 1989. "Correlation between wood-cement compatibility and wood extractives". Forest Products Journal 39(6):55-58.

Lee, A.W.C. 1985. "Effect of cement/wood ratio on bending properties of cement bonded southern pine excelsior board". Wood and Fiber Science, 17(3) pp 361-364

McKeever,D. 1997, Resource Potential of Solid Waste Wood in the United States: The Use of Recycled Wood and Paper in Building Applications, Forest Products Society, Madison, WI.

Michell, A.J. and Wills, D. 1977. "Cellulosic fibers for reinforcement". A paper presented at 31st APPITA Annual Conference, Surfers Paradise, Australia 1977.

Moslemi A., 1991. Editor, Proceedings of the second International Inorganic Bonded Wood and Fiber Composite Materials Conference, Idaho, October . 1990. Published by For. Pro. Res. Soc. 1991.

Soroushian P., Shah Z and Marikunte S. 1992. "Use of kraft and recycled fibers in fiber-cement products". Proceedings of the 3rd International Inorganic-Bonded Wood and Fiber Composite Materials Conference Sept. 28-30, 1992. Published by the Forest Products Society.

Steam-Exploded Natural Fibres as Reinforcement for Polymeric based Composites

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1. INTRODUCTION

In the last years the vegetable fibres such as wood, straw, flax ... are starting to substitute, for some applications, standard materials commonly used to reinforce plastics (glass, carbon, kevlar fibres).

This fact could lead soon to the occurrence of new plantations with high value for rural industries.

The composites obtained by utilising fibres deriving from agriculture are called biocomposites and present with respect to those reinforced with synthetic fibres the following advantages:

- lower density
- high specific properties
- low energy content
- no-cancer producing materials
- low costs
- partially biodegradability

The achievement of such materials is important also owing to the growing interest in terms of environmental protection. As matter of fact, recently, the industry has been constricted to revalue its economical reasons of efficiency and productivity by introducing new parameters such as resources protection, products and process compatibility with the environmental and the subsequent reutilization of wastes deriving from the production. A possible procedure to achieve composites having as matrices polymeric materials and as reinforcement vegetable fibres has to include the following steps:

- choice of suitable plants for fibres
- cultivation extraction and manufacture of the fibres
- choice of plastics
- compounding of fibres with plastics
- processing of materials

These natural fibres composites can find applications in various sectors such as automotive, agriculture, furniture and building.

Some examples of uses are tasted below:

- stuffing material
- panels for building applications
- thermoinsulator material
- panels for automotive industry
- containers, boxes and pipes
- biodegradable containers (when biodegradable matrices are used)
- noise-absorbing panels

Finally these materials can be utilised in the design such non-structural elements also as substitute of glass and asbestos fibres.

2. EXTRACTION AND MANUFACTURE OF VEGETABLE FIBERS

The achievement of vegetable fibres able to be used as reinforcement for plastics, obviously, has to include an extraction process and manufacture of the biomass obtained from the plants.

As matter of fact the cellulose fibres have to be separated from the other components such as lignin and hemicelluloses that can produce a worsening of fibres properties due to their amorphous state.

Thus, when the parts of plants containing the lignocellulosic materials (bast, leaves and seeds) are collected, they have to be undergone to some chemical or physical treatments in order to obtain fibres richer in cellulosic content which will be mixed together with plastic materials.

Today two types of extraction more commonly are used:

A) Chemical extraction

B) Innovative physical extraction by means Steam Explosion Process (SEP)

A) Chemical extraction

Sodium hydroxide solutions are utilised to extract lignin and hemicellulos and others bonding substances to release cellulosic fibres. The concentration of the alkaline solutions and the extraction conditions depending on the type of plant and also on its age.

The maceration is effected by boiling the biomass in open boilers or in autoclaves under low pressures (2-3 atms.). Generally 30 kgs of sodium hydroxide are dissolved in 1,500 lts of water. Subsequently, if necessary, other maceration can be repeated. At the end of process, usually, 600-700 g of sodium hydroxide have been used for 1Kg of extracted fibres.

The temperature and pressure parameters have to be optimised according to the type of plant and the size of fibres that it is desired.

In order to separate the products deriving from the dissolution in sodium hydroxide, the lignocellulosic fibres have to undergo different washing cycles.

The following different ways can be made:

- by cold water shower;
- by repeated immersions in washing tanks;
- by mechanical washing-machines.

Finally the fibres have to be dried and eventually cut.

The extraction by alkaline medium above described can be easily effected and does not ask particularly expensive reagents or high specialised labour.

B) Physical treatment by steam explosion process

A recent alternative process to obtain appropriate vegetable fibres to be used in the plastic industries, is called Steam Explosion Process (SEP). Such procedure allows to prepare good properties fibres having characteristics tailored according to the specific requirements; moreover SEP, with respect to the chemical extraction, presents a clearer technology since it does not use chemical reagent such as sodium hydroxide.

This process consists to put into contact the lignocellulosic materials with high temperature steam (200 - 250 °C) and at high pressures (14 - 40 atms) for few minutes (1 - 5 mins)

In Fig. 1 a schematic diagram of a pilot plant for steam explosion is shown. The lignocellulosic material is "shooted" from an autoclave at high pressure to an atmospheric pressure tank, giving rise to a destruction of epidermal tissue of the material and separating the amorphous components (lignin, pectin and hemicellulose). In this way it is possible to obtain neat cellulose fibres with a low contents of other components. As matter of fact the SEP destroys the composite structure of material and, in the same time, increasing the anisotropy of cellulosic fibres and their reactivity, allows the utilisation of exploded fibres as reinforcement for plastics.

Finally the fibres, after the explosion treatment, are collected and put into an oven at 80 °C to eliminate the residual water. Furthermore a milling procedure can be effected to obtain fibres having appropriate lengths.

Of course the SEP treatment presents a more expensive starting cost than chemical extraction, but it permits the achievement of fibres with better performances, reactivity and repeatable results.

3. PLASTICS / NATURAL FIBERS COMPOUNDING

The compounding process between polymeric matrices and vegetable fibres is the most important step to obtain natural fibres composites. As matter of fact, the extracted vegetable fibres have to be mixed with plastics materials without damages m order to preserve their mechanical performances. Moreover it must be underline that a good dispersion of the fibres in the matrix and an optimum fibre/matrix interfacial adhesion have also to be obtained. Only in this way it is possible that the strength loaded on the composite is supported by fibrous reinforcement.

As above described the use of vegetable fibres to reinforce polymers can be proposed both for:

A) thermoplastic matrices;

B) thermosetting matrices.

A) Thermosetting Matrices

The technology that can be used to obtain thermosetting based composites reinforced by natural fibres is not more different than standard methodologies of glass fibres reinforced resins.

The thermosetting polymers more used are: polyesters and epoxies resins. Generally glass or carbon fibres are utilised to reinforce them The alternative use of vegetable fibres can allow to achieve lighter, cheaper and partially biodegradable manufactured and to avoid the use of cancer-producing fibres glass. In fig. 2 some vegetable fibres reinforced hand-made (pipe and panel) products are shown.

The technology that permits to obtain thermosetting based composites reinforced by natural fibres consists into a good dispersion of fibres in the liquid resin (before the curing reaction); furthermore by adding the appropriate initiator and catalyst the solid composites is achieved. An important advantage of the utilisation of vegetable fibres is that not need the coating of coupling agents as fibres glass technology. As matter of fact the vegetable fibres are able to interact with polar matrices by means the numerous OH groups present on the cellulosic component, especially when exploded fibres are used.

B) Thermoplastic matrices

Also the thermoplastic materials can be reinforced by natural fibres: however it is necessary the presence of polar groups in its structure. Therefore some thermoplastic matrices that can be used are: polyester, nylon, PVC, modified polypropylene with maleic anhydride etc.

The technologies that can be utilised to prepare thermoplastic based composites with natural fibres are the same of synthetic fibres reinforced composites: extrusion, injection or compression moulding etc.

4. CONCLUSIONS

This paper shows the possibility to achieve polymeric based composites by using as reinforcements fibres deriving from agriculture world. A larger utilisation in the next years

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The technologies that can be utilised to prepare thermoplastic based composites with natural fibres are the same of synthetic fibres reinforced composites: extrusion, injection or compression moulding etc.

4. CONCLUSIONS

This paper shows the possibility to achieve polymeric based composites by using as reinforcements fibres deriving from agriculture world. A larger utilisation in the next years of these materials, probably, will lead to upgrade plantations whom deriving the fibres, that now are underestimated, opening up new horizons to the rural sector.

As previously described the natural fibre composites can find large applications in various sectors such as automotive, agricultural, building, etc. owing to the fact that they are economical low in processing energy, renewable and strong.

REFERENCES

1. P. Zadorecki, A. J. Michell, Polym. Compos. **29**, 69 (1989)
2. J. F. Kennedy, G.O Phillips, P. A. Williams, "Wood processing and utilization" Ellis Horwood England 1989.
3. B. Focher, A. Marzetti, V. Crescenzi, " Steam explosion techniques" Gordon and Breach Sci. Publ. U.S.A. 1991.
4. M. Avella, B. Focher, E. Martuscelli, A. Marzetti, B. Pascucci, M. Raimo, J. Appl. Polym. Sci. **49**, 2091 (1993).
5. M.Avella, R dell'Erba, B. Focher, A. Marzetti, E. Martuscelli, Die. Angewandte Makrom. Chemie.**233**, 149 (1995).

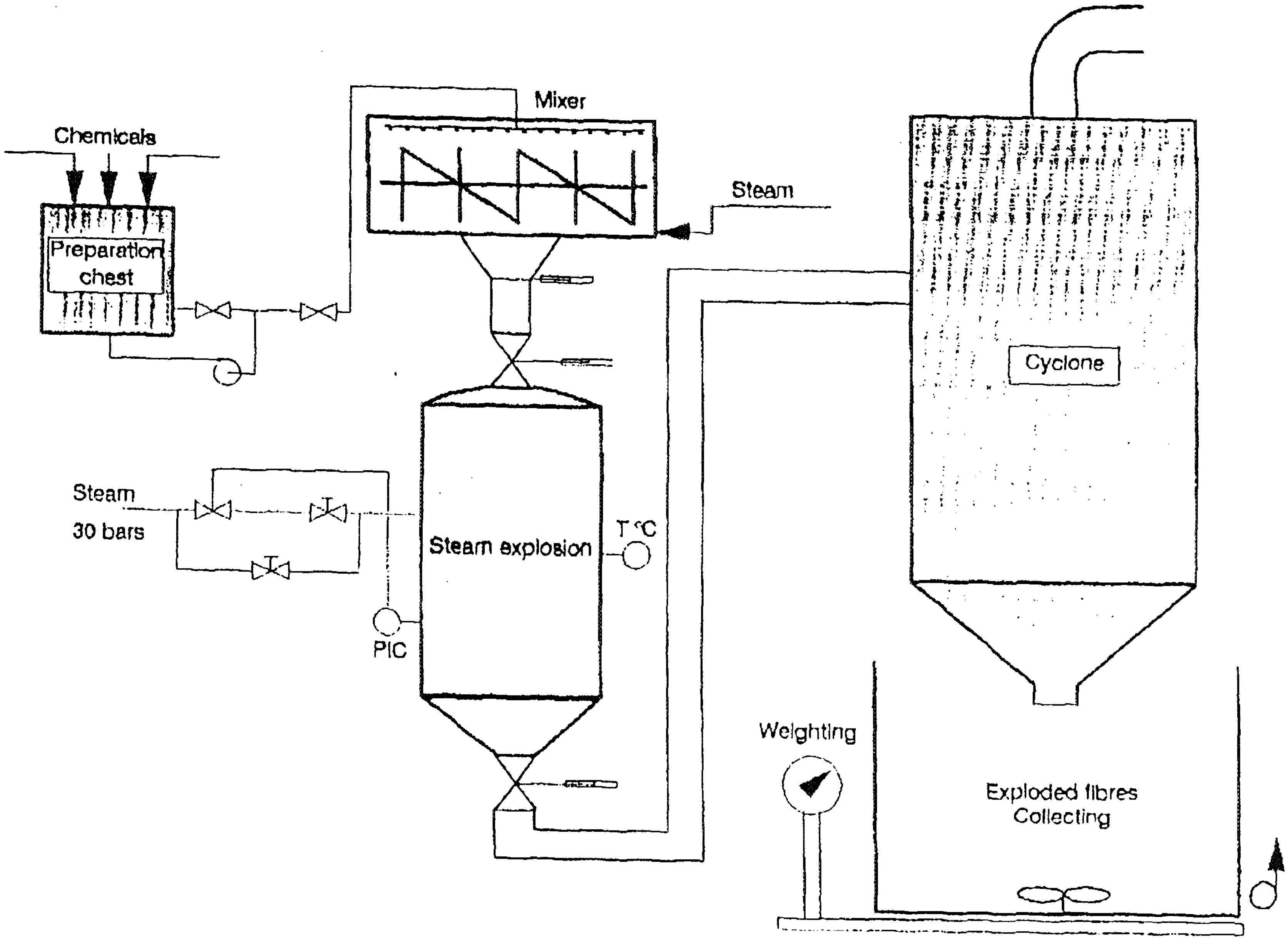
Chemicals
Preparation chest
Mixer
Steam
Cyclone
Steam
30 bars
Steam explosion
T °C
PIC
Weighting
Exploded fibres
Collecting

FIG. 1

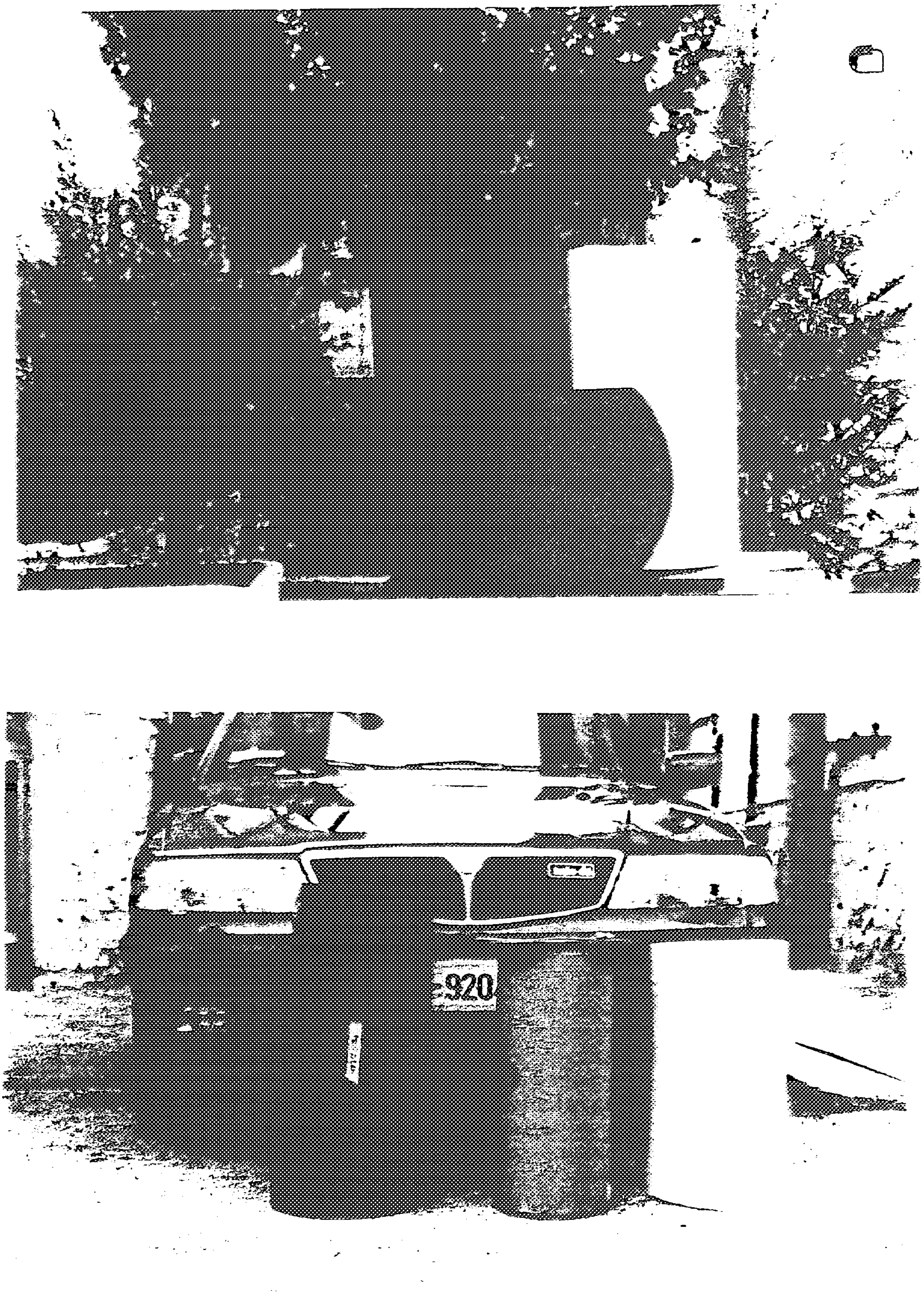

FIG. 2

STRUCTURE OF INTERNATIONAL INFORMATION SYSTEM AIMED AT IMPLEMENTING TECHNOLOGY COOPERATION PROGRAMME IN THE AREA OF COMPOSITE MATERIALS FROM LOCAL RESOURCES

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ABSTRACT

With the traditional building materials industry under pressure and unable to cope up with the demand in most developing countries there is a growing concern for promoting alternate building materials. Considering a potential option of the utilisation of local resources, UNIDO has initiated an interregional programme of cooperation between the willing Asian and African countries on composite materials based on wastes from forestry, agriculture, horticulture, agro-based industry, natural fibres and plant materials etc. The programme, inter alia, aims at capacity building in the developing countries in the areas of design, manufacturing, testing, and evaluation of composite materials in the housing and building sector.

One important component of this programme as identified by the Scientific Planning and Coordination Committee Meeting (SPCM) relates to establishing a database on the availability of local resources along with their properties and current uses in the country-specific situations. Such a database will help in identifying large common resources of interest to several developing countries which need greater attention both in terms of research and commercial exploitation. The database or the information system would be so structured as to help various countries to develop projects on (a) research and development, (b) prototype/demonstration units, and (c) manufacturing plants of composites using local skills and local infrastructure. The regional nodal points for storing data will be.proposed at selected institutes located in a developing region. The selection of a regional nodal point for storing data will be governed by the criteria such as availability of natural fibres and other local raw materials in the region and the capability and degree of interest of the specific institution selected for the purpose. Besides these institutes will also be strengthened for undertaking research, development and technology transfer activities related to a particular group of fibres and other local resources available in the operating zone of the institute. The UNIDO

and ICS at Trieste are expected to catalyse preparation of such local assessments and project reports for strengthening local manufacturing base.

It is proposed to include the following information in the proposed database:

(1) Name, source & production process of the local resource/ resource material; (2) Annual production/availability; (3) Present and proposed mode of disposal/utilisation; (4) Chemical, physical and mechanical properties; and (5) Characterisation of locally available organic or inorganic wastes having potential for being used as raw materials for composites.

Three categories of raw materials will include the following:

(1) Local plant based resources grown in small geographical regions, (e.g. natural fibres, plant material other than wood, local grasses and reeds, local shrubs etc.); (2) Local mineral based resources available in small geographical regions, (e.g. granite, mica, clay, sand, quartz, bauxite, laterites, stones, lime shells etc.): and (3) Industrial/agricultural/forestry wastes, by-product or residues available on sustainable basis in sufficient quantities.

INTRODUCTION

Fibre reinforced composites have already made a place in the diversified applications as structural and non-structural material. The uses of fibres such as glass, carbon, boron, and kevlar in the matrices of polymers, metals, ceramics etc. have been found to possess unlimited applications in components for aircrafts, aerospace, machine tools, optical and electrical goods, artificial bone and biomedical materials where costs are not the limiting factor. However, the unique properties of mechanical strength and toughness of fibre (particularly glass fibre) reinforced polymer composites induced hopes of making the best use of these materials also for buildings and other related structures. Within the last 15 years the world over, including many developing countries, glass fibre reinforced polymer composites became very popular and socially and aesthetically acceptable new class of materials. Consequently it is being pointed out that at least for door and window frames, shutters, furniture, partitions and ceilings a real answer has been found in GRP as substitute for ever depleting timber resources.

It was, however, quickly realised that GRP like materials would not be a cost-effective material for low-cost housing options for millions of homeless people. One of the strong options suggested has been to use waste fibres from forestry, agriculture, horticulture and agro-based industries alongwith most compatible matrix among cement, bitumen, gypsum plaster and polymer. Research and development on the physical and mechanical properties on about a hundred locally available vegetable fibres showed that coir, jute, sunhemp, sisal and banana were highly promising and also extensively available in most developing countries. The present position is that only polymer matrices with vegetable fibre reinforcements have achieved significant market penetration. Apart from the thermosetting polymers such as epoxy, polyester, phenolformaldehyde etc. used commonly now several thermoplastic resins such as polysulphide, polyether sulphone, polyetherimide and polyether-ether-ketone have also been considered suitable. The advantages in using the thermoplastics are their unlimited shelf-life and freedom from difficulties in accurate proportioning of thermosetting resins and their hardeners and accelerators during production processes.

Yet another area of significance is to explore the utilisation of industrial and mineral wastes and byproducts for development of the binders equivalent in specific properties of cement, bitumen, gypsum plaster and hydraulic limes. These binders have proved their well established compatibility with some selected fibres used as chopped, powders and in woven and mat like products in the composites, such as bricks, boards, ceilings and roofing felts. Hence, the increasing use of inorganic wastes-based binders with fibres, transform into well proven products which incorporate the objectives of utilisation of locally available fibres as well as waste minimization.

THE GAP IN KNOWLEDGE AND DATA-BASE APPROACH

Despite many encouraging achievements in R&D there remain some serious problems and shortcomings in the use of vegetable fibre reinforced composites. These may be listed as follows:

a) Poor wettability of the fibres in various matrices.
b) The non-uniform degree of pretreatments of the fibres; loss on alkali boiling.
c) Wide variations in the physical and mechanical properties of a fibre from the same source.
d) Often the elasticity modulus of the fibre of vegetable origin (Ef) is lower than elasticity modulus of the matrix (Em), placing limitations on design uniformity.

e) Poor fire resistance of the vegetable fibre-polymer combinations.

f) Non-standard processes of extraction of the fibres.

One must look into the uncertainty of the degree of pretreatments required for the fibres and their poor wettability. For example, most abundant coir fibre does not go well with polyester matrix because of the variable thickness of a waxy fatty acid on the fibre, which must be got rid of with alkali treatment. The variability in the strength and stiffness of some fibres from different sources within the same area has a factor of one as to three. For design considerations of a composite it is important to understand the role played by orientation of the fibres placed in the matrix which takes care of the anisotropic influence in mechanical properties. As the most fibres will have varying cellulose and lignin contents they very significantly influence the mechanical properties. The effects of aspect ratios (l/d) and excessive moisture absorption of the fibres also tell upon the unpredictable mechanical properties and poor performance of the composites on outdoor exposure.

The above problems as well as several plus points in the development and extension of vegetable fibre reinforced composite materials for housing were discussed in the last 2-3 workshops and the expert group meetings organised under the UNIDO-ICS programme at Trieste and Bergamo. It was broadly agreed to explore further and to arrive at some definite base consisting of a store house of most reliable data on some of the best vegetable fibres and their use for developing building materials and components. Further supplementary information should be collected on the selection of most suitable matrix for each fibre to develop low energy and low capital-intensive technologies for production of the composite building materials, in selected developing countries of Asia and Africa.

This paper puts forward a minimum common programme, to begin with, on the following points for consideration and discussions in the present workshop:

(i) To finalise a list of commercially important fibres and their sources.

(ii) To assess the availability, transportation, processing of the fibres, and their cost to make them in the usable forms.

(iii) Chemical and physical properties and their variability of the selected fibres, indicating the most important criteria by which the best fibres could be selected by process of elimination.

(iv) Present status of vegetable fibre (or hybrid with glass fibre) reinforced composites in polymer and inorganic matrices and the costs of production in some selected countries of East Africa, West Africa, Indian Sub-Continent and Far-East Asia.

(v) Compilation of the known engineering properties of the composites; details of production technologies; plant and equipment and the sources of procurement.

(vi) Introduce a DATA-BASE characterisation system for the above (i) to (v).

It is the data base which would lead to generation of new resources and predict the direction of future developments-in materials for sustainable housing. A CAD software may have to be specially developed in visualizing the designs of structural components for the required applications in buildings. Infact, a beginning in this direction has been initiated by the BMTPC at the Regional Research Laboratory Bhopal (India) for the sisal fibre reinforced red mud-polyester composites.

MANUFACTURING REQUIREMENTS OF COMPOSITES

It is perhaps a wrong notion that glass fibre or carbon fibre reinforced composites are the most durable and adaptable materials for housing applications. Vegetable fibres provide several advantages and flexibility in production processes of various products. In fact, it is ultimately the cost and market acceptability which matter the most and there are a few important points related to the design and production technologies:

1. **High productivity:** This includes short cycle times, low labour, low energy and low capital requirements.
2. **Minimum materials cost:** It should be taken care of by using least number of value-added operations, for example, low cutting and low pre-treatment costs.
3. **Maximum geometrical flexibility:** The design criteria would be simplified if there is freedom to place the fibre in any geometrical orientation while casting and pressing alongwith the matrix.

4. **Maximum property flexibility:** It is ideal that the fibres and matrix combinations provide a scope to design the products for various structural requirements.
5. **Minimum finishing requirements**: The composites manufactured should not require elaborate protective and finishing treatments which add to costs considerably.

A database on compilation of the technical details of the manufacturing technologies and their economics aspects are very important to provide guidelines for the production of composites of high quality and reliability at affordable costs.

AVAILABLE INFORMATION

A large volume of literature consisting of books, research papers, conference proceedings and encyclopedia are available on various vegetable fibres and fibre-reinforced composites. World production figures of the fibres have been estimated. But there is no break-up given for different countries. Chemical composition, moisture absorption and physical characteristics of some natural fibres have also been tabulated. But all these data are mostly based on isolated experimental efforts, and the sources mentioned indicate that they were not the average figures or the range of results obtained *(Ref. Annexures 1,2,3,4,5,6 & 7)*. It was mentioned in some scattered literature and reports that many serious efforts were made in the development of vegetable fibre-cement composite roofing sheets and tiles. But no information appears to have been updated for the last 10 years. The production capacities were very small and mostly at the pilot plants. It is not known why many of the well-drawn schemes were abandoned. Now with the advancement in theoretical and practical science of fibre-reinforced composite materials it is very essential to look once again into the present status of various stories of success of production and application. It is, therefore, proposed to finalise a plan to select a few countries which are most potentially situated to produce vegetable fibres and also possess the minimum required infrastructure of laboratory facilities and manpower. The details of this proposal is given below:

PROPOSED PARTICIPATING COUNTRIES

India, Kenya, Tanzania, Nigeria, Bangladesh and Philippines.

Some other countries may also be encouraged to join the proposed team. Table-1 gives the names of the countries, the institutions and the fibres allotted.

Table-1: Countries, Institutions and Fibres

Name of Country	Institution	Fibres on which information to be collected
1. India	Regional Research Laboratory, Hoshangabad Road, Habibganj Naka, Bhopal	Sisal, Coir
2. Kenya	Kenya Building Research Centre, PO Box.30260, Nairobi	Sisal, Sunhemp
3. Tanzania	Faculty of Engineering, University of Dar-Es-Salaam, Dar-Es-Salaam	Sisal, Coir
4. Nigeria	Nigerian Building & Road Research Institute, PMB 12568, 15 Awolowo Rd. Ikoyi, LAGOS	Jute, Banana
5. Bangladesh	Housing and Building Research Institute, Barus Salaam, Mirpur, Dhaka	Jute Banana
6. Philippines	Building Research Service, University of the Philippines, NEC, 182, Dilliman, Quezon City 1101	Sunhemp, Banana

POSSIBILITIES OF USING LOCAL RAW MATERIALS FOR MAKING CONSTITUENTS OF COMPOSITES

Many of the developing countries are quite unfortunate in not possessing petroleum which is the chief source of synthetic polymeric resins. Importing petrochemicals and intermediates would not help as the costs would go very high. Hence inorganic matrices such as cement, gypsum plaster, lime-pozzolana may have to be used and for this purpose special attention has to be given to produce the pretreated fibres or incorporate additives to make them mutually compatible and ensure long range performance. Each country generates many industrial, mining and mineral wastes which form alternative raw materials for producing inorganic cementitious/hydraulic binders. Hence, supplementary information on the following waste materials may also have to be collected. These are supported by better scientific back-up information.

1. Flyash/fuel ash (from thermal power stations)
2. Blast furnace slags (from steel plants)
3. Byproduct gypsum (eg. phosphogypsum)
4. Red mud (from aluminium industry)
5. Waste lime sludges (from chemical, sugar, paper, tanning industries)
6. Limestone wastes/marble waste
7. Natural pozzolana
8. Laterite waste, and
9. Mine tailings

While much of the report discusses the use of local resources for low performance composites principally for applications in housing and household goods, there is considerable potential of using these resources for making constituents for high performance composites. Rice husk, which is a very large resource all over the developing world, has been pyrolyzed under controlled conditions to yield Silicon Carbide whiskers which are used as reinforcements in high performance composites, including those for aerospace applications. Even today, rice husk based silicon carbide whiskers, and composites from these whiskers are being manufactured in the US and Japan. It is imperative that in the future, such breakthroughs on development and manufacture of high value added constituents from local raw materials of developing countries, occurs in developing countries themselves.

Attempts have been made in Japan to pyrolize plant based natural fibres to make carbon fibres, similar to fibres currently used in high performance composites. Research has been done in India on using microbial techniques to release cellulose fibres and ultrafine silica from rice husk, the cellulosic fibres and silica generated by this process can be used for high performance composites. The conventional process of pyrolizing rice husk leads to total loss of fibres and coarse ash which issued as an additive to cement. Research and development efforts are needed to convert local raw material resources into constituents of high performance composites like fibres, whiskers and particulates, and eventually incorporate these into composites.

Opportunities also exist in the manufacture of matrix materials for composites from local raw materials. A variety of polymers can be made from local plant based materials. An example of work done in India included synthesis of polymers (which can be used as a matrix material for composites) from cashew nut shell liquid, and many more such opportunities remain untapped to date.

STRUCTURE OF DATABASE

Annexure 8 and 9 present two proposed database structures which could be the base for compilation of data on the related fibres and inorganic waste materials. The selected participants may have to meet or correspond to come to an agreement about the methods to be selected for determining various physical, chemical and mineralogical properties listed in the data base structures. The participating scientists may collect the samples of the allotted vegetable fibres and the waste materials, from their own countries and possibly from a few neighbouring countries. The completed proforma then should be sent to a nodal laboratory. Regional Research Laboratory Bhopal (India) could fulfil the role of the nodal organisation as this laboratory has a long and varied expertise and is equipped with necessary instruments and infrastructure which have been further updated and strengthened by the BMTPC, New Delhi.

The Annexure-10 indicate a very simple structure for computerisation of the proposed Database while Annexure-11 show the storage system and Annexure-12 briefly give the network with connectivity between local, regional and central operational locations. The proposed structured, which I wish to discuss at the workshop aimed at following four categories of users. All participants are welcome to give their observations, comments and suggestions for strengthening the proposed structure and operational aspects of the system.

User of the System

1. Research and Development Departments
2. Product Designers
3. Manufacturers
4. Actual End-users of the Products

PROPOSED ACTIONS

The UNIDO can help by developing sample project reports on setting up industries on manufacture of composites using local raw material resources. These projects reports should include overall technology assessment, cost-benefit analysis and rate of return analysis from a local standpoint. Quite frequently the pure financial rates of return from a composites industry based on local resources may not be high, yet the industry may be very desirable from the viewpoint overall improvement of quality of life of the population of that region. The present programme should catalyze preparation of such local assessments and project reports with local viewpoints, involving the people of the regions where these resources are located. The overall cost-benefit analysis from the viewpoint of local population where these resources exist will often justify the setting of industries manufacturing composites from local resources. Table-2 lists the elements of a possible project to promote the manufacture of composites from local raw materials. This includes setting up design, prototype manufacturing and testing centres and even full scale demonstration plants to manufacture composites from local resources.

Table-2 Elements of a Project Proposal for cooperation between India and other developing countries.

-	Establishment of a Database on availability and properties of natural fibres and composites made from these composites
-	Research to complete the database required for manual or computer aided design of components from these composites
-	Deputing scientists and industrialists from participating developing countries to research and manufacturing institutions in India for lectures, seminars, demonstrations (selected scientists from developed countries be invited)
-	Deputing scientists from India to participating developing countries for local evaluation of resources for composites and infrastructure for manufacture and testing of composites in different countries; for demonstration of techniques of manufacture of composites;
-	Establishment of design, prototype manufacturing and testing centre in India to develop transferable technology for developing countries;
-	Financing the establishment of full scale demonstration plants to manufacture composites from local resources initially in India, and subsequently in other developing countries.

CONCLUSIONS

1. Development and use of vegetable fibre reinforced composite building materials are one of best answers for meeting the requirements of low cost building materials in developing countries.

2. In the last 2 decades many sincere efforts have been made to introduce vegetable fibre reinforced composites in many countries of Africa and Asia but the progress is very meagre. The reasons lie in the lack of perfections of the scientific and technological inputs.

3. The variability of the physical and chemical properties of the fibres restricted the reliability of the components produced in the face of poor out-door performance. Hence, extensive efforts are necessary to generate multiple coordinated data on the fibres, which could form a sound technological base.

A CAD approach to formulate tailormade compositions would be greatly helpful.

4. Polymer matrix has been found most compatible with vegetable fibres so far. But lack of petroleum resources and periodical enhancements of petro-chemicals prices limit their use to only a few countries. Industrial and mineral wastes could fulfil the need of producing inexpensive alternative binders of consistent quality.

5. Some good progress however, has been achieved in the development and applications of vegetable and glass fibres (hybrid) and polymer composites in production and marketing of building materials for walling, roofing and joineries. Even cement and gypsum matrices have been found quite successful in a few products.

6. It is, therefore, proposed to intensify a system of data-base on the collection and storage of the characterisation - oriented information on some of the most promising vegetable fibres, matrices, engineering design aspects of composites, technological details - large and small scale production process and plant and equipment. For this two sets of database structural proforma have been suggested, with some modifications to be included later.

7. With the growing interest in the development of new materials amongst developing countries, UNIDO should initiate a programme to select some institutions distributed geographically in developing countries through which the data-base information system on the above aspects of fibre-reinforced composite building materials could function, maintaining a continuity and the information should be stored at a nodal laboratory for utilisation by all developing countries.

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REFERENCES

1. Gupta T.N.. Proposal for an interregional programme of cooperation between Asian and African countries in areas of fibre reinforced composite materials based on local resources. submitted to ICS, Italy, 1995.

2. Gupta T.N.. Composite materials using local resources, New and Advanced Materials - Emerging Technology Series. 3/1996. UNIDO, Vienna. 1996.

3. Concise Encyclopedia of Composite Materials. ed Anthony Kelly. Pergamon Press. Oxford. U.K.. 1989.

4. FCR Fibre Concrete Roofing by H.E.Gram et.al. SKAT. Intermediate Technology Publications. Stockholm. Sweden

5. Composite Materials & Structures Proceedings. Jan 6-9. 1988. IIT Madras. Editors K.A.V.Pandalia. S.K.Malhotra. Fibre Reinforced Plastic Research Centre. Madras

6. New Composite Materials from Natural Hard Fibres by H.Belmores et.al.. Ind.Eng.Chem.Prod.Res.Dev. 20(1981)-555-561

7. Impact Properties of Sisal-glass Hybrid Laminates by C-Pavitran et.al. J. of Materials Science 26(1991) 455-459

8. Jute Reinforced Polyester, Project for UNIDO/Govt. of India. Plastics & Rubber International 14(1979). 23-28

9. Natural Fibre-Polyester, Composites by K.G.Satyanarayana et.al. Cement & Concrete Composites. 12(1990). 117-136

10. Composite Materials form Local Raw Material Resources by P.K.Rohatgi. Advanced Workshop on Industrial Composites Design and Application Nov.1994. Trieste. Italy.

11. Promotion of Composite Building Materials prepared by Chemical Industries Branch Industrial Sectors and Environment Division for the Advanced Workshop on Industrial Composites Design and Application, Trieste, Italy, 30 Oct - 4 Nov. 1994

12. Polymer Natural Fibre Composites by P.K.Rohatgi et.al., Encyclopedia of Composites. Editor S.Lec, VCH Publication (1990)

13. The Use of Natural Organic Fibres in Cement, some Structural considerations, Appropriate Technology Centre for Education and Research. PO Box.43844, Nairobi. Kenya

14. Composites from Recycling Materials by R.M.Rawel and J.A.Young quist 25th Particle Board Composite Materials Symposium, 9-11 April. 1991. Pullman, WA

15. Cellulose Fibre Reinforced Cement Composites State-of-the-Art by P.Soroushian and S.Marikunte. Oct(1991) Conference in Laval University. Canada

16. Advanced Composites. Design. Materials. and Processing Technologies. 2-5 Nov., 1992. Chicago. USA. Published by ASTM International Materials Park, Ohio 44073-0002

17. Composite Materials and Structures by KAV Pandalai. S.K.Malhotra. Fibre Reinforced Plastics Research Centre. Indian Institute of Technology, Madras. India (Tata Mchrow Hill Publishing Co.Ltd., New Delhi - 1987. 4/12. Asaf Ali Road. New Delhi-110 002

18. Composite Materials Technology. Ed.P.K.Mallick & S.Newman. 200. Modison Avenue, New York. NY 10016. Oxford University Press, 1990

19. Fibrous Plants of India (Fitted for Cordage. Clothing & Paper). with an account of cultivation & preparation, 1983. Flax. Hemp & their substitutes by J.Forbes Royle. Soni Reprints Agency. 3843. Gali No.13. Shanti Mohalla. Gandhi Nagar. Delhi-31

20. Identification of Vegetable Fibres by Dorottry Catling & John Grayson, 11 New Fetter Lane, London, 1982, Chapman & Hall, London/New York, London EC404EE

21. Fibre Reinforced Cement & Concrete, Editor R.N.Swamy, E&FNSPON, Chapman & Hall, 2-6 Boundary Road, London SE18HN (UK)

22. Rohatgi, K., Prasad, S.V., Rohatgi, P.K., "Release of Silica-Rich Particles from Rice Husk by Microbial Fermentation," J. of Materials Science Letters, Vol.6 (1987) 829-831.

23. Rohatgi, K., Trivedi, J.P. and Rohatgi, P.K., "Research Imperatives in Microbial Leaching of Bauxite and other Silica Bearing Minerals using Heterotrophic Bacteria." J of Scient. & Ind. Research, Vol.43, June (1984 302-305.

24. Chander R., Rohatgi, K. and Johri, B.N., "Agro-wastes from Paddy and Sugarcane Cultivation as a Resource for Materials," Journal of Scientific and Industrial Research, Vol44, (1985) 607-612.

25. Morehouse, W., "Biotechnology and the Third World: Panacea or Recipe for Social Disaster," Background Paper for the 10th Symposium on Law and Development at the University of Windsor, Ontario, Canada, Nov.5-8, (1986).

26. Swaminathan, C.V., and Rao, G.V., "Biotechnology: Problems of Policies and Needs," Bio-Technology, 56-63.

27. El Nawawy, A.S., "The Promise of Microbial Technology," Impact of Science on Society, Vol.32, No.2, (1982) 157-167.

28. Program Advisory Note (PAN) on: New Materials and Economic Development, UNDP Publication, (1990) (Compiled by P.K.Rohatgi, Tien, J.K. and Chinsman, R., New York).

Annexure- 1

Commercially important fibre sources

Fibre Source	World Production 10^3 tonnes	Origin
Wood	1,750,000	Stem
Bamboo	10,000	Stem
Cotton lint	18,450	Fruit
Jute	2,300	Stem
Kenaf	970	Stem
Flax	830	Stem
Sisal	378	Leaf
Roselle	250	Stem
Hemp	214	Stem
Coir	100	Fruit
Ramie	100	Stem
Abaca	70	Leaf
Sum hemp	70	Stem
Banana	200	Stem
Elephant grass	Abundant	Stem
Nettles Palmyrah	-do-	Stem
Broom	-do-	Stem
Oil palm fruit linseed/_____ oil seed	-do-	Fruit
Rice husk	-do-	Fruit/grain
Rice straw	-do-	Stem
Wheat straw	-do-	Stem

Chemical constituents and moisture absorption of some natural fibres
(Data has been given on percentage of dry fibres)

Fibre	Cellulose (%age)	Hemi-cellulose (%age)	Lignin (%age)	Moisture regain at 65% RH	Transverse swelling in water (%age)
Banana	60 - 65	6 - 8	5 - 10	10 - 15	16 - 20
Sisal	63 - 67	11 - 13	8 - 12	11	18 - 20
Jute	61 - 63	13	5 - 13	12.5	20 - 22
Sum hemp	71 - 78	18	4	10.5	18 - 20
Ramie	83 - 87	3.5	0.5	6.5	12 - 15
Flax	90 - 72	14	5.5	7	20 - 24
Mesta	60	15	10	13	20 - 22
Palmyrah	40 - 45	15	42 - 43	10 - 12	-
Pine apple leaf	81	-	12	10 - 13	18 - 20
Cori	43	<1	45	10 - 12	5 - 15
Cotton lint	90	6	-	7	20 - 22
Straw	40	28	17	-	-
Wood	45	23		-	-

Note: The figures given in Annexures 1 and 2 often differ from author to author

Annexure-3

Types of fibres and their characteristics

Fibres can be classified as shown below:

Fibre type	Length mm	Diameter mm	Density kg/m^3	Young's Modulus GPa	Tensile Strength MPa	Elongation at break %	Water absorption %
Kenaf	30-750	0.04-0.09	NA	22	295	NA	NA
Coir	50-350	0.1-0.4	1440	0.9	200	29	130-180
Sisal	1000-1300	0.2-0.3	1450	26	570	3	60-70
Bagasse	NA	0.2-0.4	1250	17	290	NA	70-75
Bamboo	NA	0.1-0.4	1500	27	575	3	40-45
Jute	1800-3000	0.1-0.2	1500	32	350	1.7	200-220
Flax	500	NA	1540	100	1000	2.0	70
Elephant Grass	NA	NA	NA	5	178	3.6	NA
Water-reed	NA	NA	NA	5	70	1.2	NA
Banana	NA	0.08-0.25	1350	1.4	92	5.9	100-150
Musamba	NA	NA	NA	0.9	83	9.7	NA
Piassava	NA	NA	NA	6	143	6.0	110
Mesta	NA	0.2	1470	12.68	150-590	-	130
Pine apple	NA	0.2-0.8	NA	34.5	413-1627	-	100-130
Polypropylene	NA	NA	910	6.8	586	210	2
Glass	0.08 - 0.15	20 - 50	2700	76	1240	3.5	4
Steel	5-200	0.1 - 0.4	7860	207	700-2100	3.5	NA
Asbestos	<15	<0.2	2550	159	210-2000	2.5	7-18

Note: The data on characteristics of fibres differ from author to author.

Annexure- 4

Natural-fibre-cement/polymer composites experimented and trial production in different countries of Africa, South-east Asia and South and Central America

Country		Fibre used	Produced since	Production capacity of sheet/tiles (m^2/day) for roofing
Africa				
Mozambique		Sisal	1985	4
Zambia		Sisal	1984	13
Tanzania		Sisal	1978	20
Kenya	(I)	Sisal	1983	18
	(II)	Sisal	1985	17
Zimbabwe		Elephant grass	1979	17
Ghana		Palm nut	1985	NA
Malawi		Sisal	1980	15-60
S.E.Asia				
Bangladesh	(I)	Jute	1983	9
	(II)	Jute	1983	8
India	(I)	Coir	1982	21
	(II)	Coir	1982	-
Indonesia		Jute	1982	-
Sri lanka		Coir	1984	NA
Central and S.America				
Dominican Republic	(I)	Sisal	1984	16
	(II)	Sisal	1982	-
Nicaragua		Sial	1984	80
Soloman Island		Coir	1984	4
Haiti		Sisal	1984	40
Guatemala		Sisal	1981	NA
Colombia		Sial	1982	NA

Annexure-5

Bending strength properties of natural and glass-fibre reinforced composites

Fibre/Matrix	Sp-gr	Bending strength, GPa	Bending modulus, GPa	Fibre volume fraction, %
Random wood/phenolic	1.2	0.110	8.0	65
Woven jute/polyester	1.2	0.090	8.0	50
Filtered jute polyester	1.2	0.100	10.0	60
Cotton/epoxy	1.56	0.170	8.0	55
Parallel jute/epoxy	1.20	0.450	43.5	70
Parallel kernaf/epoxy	1.20	0.420	59.0	70
Pulruded glass/epoxy	1.70	0.690	47.0	70
Random glass/epoxy	1.90	0.172	10.5	70

Note: The above data are for commercial products in advanced countries.

Annexure-6

Engineering properties of some polyester resin bonded composites

Fibre in composite	Density kg/m^3	Tensile strength MN/m^2	Flexural strength MN/m^2	Modulus of elasticity GN/m^2	Impact Resistance seg m/m^2	Water absorption %
Glass	1500-1900	241.38-689.6	344-680	6.9-41.38	3116-8476	0.2-1
Cotton fabric	1400	34.5-689.5	62.1-124.1	2.76-4.14	257.5-428	0.8
Banana fabric	1215	27.96-35.92	50.6-64	3.33-3.34	329.2-748.5	1.33-1.9
Coir	1160	18.61	38.15	4.045	391	1.36

Note: These data are on experimental samples and show wide variations

Typical specific strength properties of some composites

Composite	Sp.Gr	Specific tensile strength (GPa)	Specific tensile modulus (GPa)	Energy content GJ/t
Natural fibre	0.6-1.2	1.60-2.95	10-150	4
Glass	2.6	1.35	50	50
Kevler	1.4	2.71	90	25
Carbon	1.8	1.71	150	150

Annexure-8

I. SECONDARY RESOURCE MATERIALS
(Natural Fibres/Agricultural Wastes & Residues)
(Data base)

1. **Name of the secondary** resource/waste material (Fibre) :

2. **Source/Production process** :

   Natural/byproduct :

   Country :

   Organisation :

   Telephone :

   Fax :

3. **Annual production (million tonnes/year)** :

4. **Mode of disposal** :

   Present utilisation

   Future plans, if any

No.	Particulars		Test Method/Standards
5.	**Physical Properties**		
	Colour		
	Specific Gravity		
	Bulk density (kg/m^3)		
	Length (mm)		
	Diameter (mm)		
	Water absorption (%)		

No.	Particulars		Test Method/Standards
	Moisture regain at 65% RH		
	Transverse swelling in water (%)		
6.	**Mechanical properties**		
	Specific tensile strength (GPa)		
	Specific tensile modulus (GPa)		
	Young's modulus (GPa)		
	Impact resistance		
	Elongation break (MPa)		
	Fibre modification property Ability to receive coating		
7.	Fibre volume fraction (%)		
8.	Energy content (Kcal/kg)		
9.	**Chemical Analysis (%) by weight**		
	Cellulose (%)		
	Hemicellulose (%)		
	Lignin (%)		
	Sugars (%)		
	Organic Extractives (%)		
	Colour washability (%)		
	Ash on incineration (%)		
	Inorganic matter in ash (%)		
	Silica (SiO_2) (%)		
	Al_2O_3 (%)		
	Fe_2O_3 (%)		
	CaO (%)		
	MgO (%)		
	Any other (%)		

No.	Particulars		Test Method/Standards
10.	**Chemical Properties**		
	Reaction to acids		
	Reaction to alkali		
	Reaction to organic solvents		
11	Resistance to heat (Softening, M.P.)°C		
	Fire Property (Fomability) (Combustibility)		
	Fungal decayability		
	Resistance to pests/termites		
12.	Toxicity behaviour		
13.	Visible health hazards		
	In production		
	In handling		
	In Transportation		
	In use		
14.	Resistance to UV (% loss in wt.)		
15.	Resistance to decay in water (% loss in tensile strength/month)		
16.	Durability		
	on heating/wetting/cooling (% wt. loss) charring/brittleness		
	on natural exposure (% wt. loss)		
	on weatherometer tests (% wt. loss)		
17.	Microstructure properties		
	Fibre distribution system		
	Scanning electron microscope studies		

No.	Particulars		Test Method/Standards
	Fibre orientation property		
18.	Insulation properties (1) Heat (2) Sound		
19.	Dielectric properties (mv/m)		
20.	Utilisation potential		

II. SECONDARY RESOURCE MATERIALS

(Inorganic)

(Data base)

1. **Name of the secondary resource/waste material** :

2. **Source/Production process** :

    Natural/byproduct :

    Country :

    Organisation :

    Telephone :

    Fax :

3. **Starting year of production**
    Annual production (millions/year)

4. **Mode of disposal** :

    Present utilisation

    Future plans, if any

No.	Particulars		Test Method/Standards
5.	**Physical Properties**		
	Colour		
	Specific Gravity		
	Bulk density (kg/m^3)		
	Surface area (cm^2/g)		
	Lime reactivity (N/mm^2)		
	Setting time (hr)		

No.	Particulars		Test Method/Standards
	Water absorption (%)		
	Deleterious matter (%)		
	Carbon/organic matter (%)		
	Silt & Clay (%)		
6.	Hardness		
7.	Radioactivity level		
8.	Durability Tests		
	Heating/Cooling cycles % wt. less		
	Weatherometer exposure % wt. less		
	Alkali-aggregate reaction		
9.	**Chemical Analysis (%) by weight**		
	Loss on ignition		
	Silica (SiO_2)		
	Aluminium Oxide (Al_2O_3)		
	Iron Oxide (Fe_2O_3)		
	Magnesium Oxide(MgO)		
	Sulphur Trioxide (SO_3)		
	Alkalies (Na_2O)		
	Any other		
	Total		
	Trace elements (%)		
	Heavy Metals (%)		
	Pollutants generation		
	Toxic constituents		
10.	**Visible Health Hazards**		
	In handling		
	In transport		
	In use		

No.	Particulars		Test Method/Standards
11.	**Mineralogical Constituents**		
	X-ray diffraction		
	Main Minerals		
	Accessory Minerals		
12.	**DTA/TGA analysis**		
	Endotherm & mineral		
	Exotherm & Mineral		
	Weight loss (%)		
13.	**Microscopic studies**		
	Structure		
	Main minerals		
	Minor Minerals		
14.	**Microstructural properties (SEM)**		
	Porosity		
	Structure		
	Mineral orientation		
15.	**Thermal properties**		
	Specific heat, J/g°C		
	Thermal expansion co-efficient mm/mm°K x 10^{-5}		
	Thermal conductivity Kcal/hr.m. °c/cm^2		
16.	Resistance to Heat, M.P.°c		
17.	Resistance to UV		
18.	Utilisation Potential		

DEVELOPMENT AND INDUSTRIAL APPLICATIONS OF NATURAL FIBRE-REINFORCED COMPOSITE BUILDING MATERIALS-INDIAN EXPERIENCE

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ABSTRACT

The fibre-reinforced building materials and components found wide acceptability all over the world as light weight, strong and durable materials, particularly those using glass, polymer and steel fibres. But these materials, in the face of energy shortage are also now becoming quite unaffordable and hence there has been a continuous search for alternative locally available low-cost reinforcing fibres. Natural fibres such as sisal, coir, jute, bagasse etc. have been extensively studied in India and several other countries for their physical and mechanical properties and their materials. Although such composites do possess some intrinsic deficiencies in fire-resistance and long range durability, they compensate with their high specific strength, low density, high toughness and good thermal insulation.

Various approaches have been adopted in India in improving the alkali resistance and overall durability of vegetable fibres in portland cement or in modified cement. The composites developed could match with the glass fibre reinforced polymer composites yet complete standardization of design aspects with respect to appropriate aspect ratio, orientation and wetability characteristics of only a few fibres has been completed. In fact, the Indian experience has further confirmed that the success lies in specific characterization studies on earch fibre, using hybrid-composition, adopting pre-treatment of the fibres to evolve the selective technology. This may be using the most compatible matrix which sometimes is developed from an industrial waste or byproducts.

Indian R & D laboratories possess some of the best instrumental and pilot-plant facilities which qualify them to be chosen as nodal institutions where vegetable fibres from different countries of Africa and Asia could be evaluated for generating a comprehensive data base. The best organized quality-assurance, quality controls and standardization systems and methodology adopted by the Bureau of Indian Standards and B.M.T.P.C.

combinations of insoluble oxides of iron, silica and titanium, in polyester type thermosetting resins. Other fillers like carbon black or waste china clay in polyethylene matrix has also been widely used in making various types of composites for sheets, blocks, water storage tanks etc. In the use of dispersoids a lot of researches have been conducted regarding their particle size, beneficiations, pretreatments and use of silanes, pyrophospato titanates or triacryl zirconates.

Success has however been achieved in India only in the utilization of a few vegetable fibres - like coir, jute, sisal, bagasse and rice husk. Yet it has been a considerable hard work in developing the correct methods of preparation of these fibres, their alkali-boiling effects, pretreatment, coatings, the orientation of the placements coupled with their compatibility with the matrices. Comparatively still less success has been achieved in the use of cement matrix than polymer matrix and lastly hybrid fibres using glass fibre along with vegetable fibres have produced composites of good mechanical properties and durability on exposure to Indian climatic conditions.

Inorganic wastes and byproducts have been used with considerable confidence in the particulate composites and also in the developments of hydraulic binders, for example using byproduct phosphogypsum, flyash, waste lime sludges and mining tailings. Whereas the rules of mixtures, when coarse particulates are used, adequately predict the resultant properties, the voids and unblocking the slip are effectively compensated by using the inorganic binders along with chopped (< 2 cm length) vegetable fibres to produce bricks, blocks, roofing sheets and boards. Many non wood fibre composites have come up in India possessing equivalent properties of medium density wood fibre boards and are being used for insulation, walling, door frames and shutters with excellent results.

This paper consists of descriptions of Indian scenario and experience on the following aspects :

(a) Availability of vegetable and allied fibres in India,
(b) Vegetable fibre-reinforced composite building materials-traditional and conventional and modern alternatives,
(c) Names and addresses of some important manufacturers of vegetable fibre reinforced building materials.
(d) Indian standard specifications on vegetable fibre reinforced composites, and
(e) Research and development facilities in India.

have helped in formulation of a number of IS specifications on fibre-reinforced composite building materials. These institutional facilities could be extended to other developing countries also.

Some of the most versatile composites, with vegetable fibres as reinforcement, being commercially produced in India e.g. jute-fibre-polyester; sisal-polyester-red mud; fibre-pulp-bitumen; bagasse/rice husk-cement; coir-fibre-magnesium oxychloride and coir-byproduct gypsum binder composite materials are being used for roofing, flooring, door frames and shutters, ceiling and partitioning applications. These materials have created a great public awareness and specific interest about their versatility for building constructions.

This paper has highlighted some the above efforts and also presents an analysis of future prospects.

INTRODUCTION

Composites are, by definition, those combinations of two or more materials which produce unusual properties of stiffness, strength, hardness, weight, high temperature and corrosion resistance or electrical conductivity, and which can not be attained by the individual material. There have been spectacular developments in the composites and the twenty first century belongs to this class of materials. Along with the rest of the world India is credited to have made good progress in composites required for the space craft machine tools, electronics, biomaterials, high temperature ceramics applications etc. This workshop and the title of the paper do not provide scope for the descriptions of the above contributions made by the Indian Space Research Organization (ISRO), Defence Research and Development Organization (DRDO), National Physical Laboratory (NML), Indian Institute of Technology and National Aerospace Laboratory (NAL). Hence excluding the R & D in the areas of so called 'Advanced Composites' this paper confines to the fibre reinforced composites for housing and building applications in India.

Indian building materials scientists have been concentrating in all the three classes of composites viz. (1) particulate, (2) fibre and (3) laminar with the twin objectives of the utilization of locally available inexpensive vegetable fibres and the wastes and byproducts of industrial, mining and mineral sources. In the development work for timber substitutes one of the approaches has been to combine some metallic oxides as dispersoids into the fibre-reinforced polymer composites. Use of red mud, a very finely divided waste material from aluminium industry has recently been found as a good dispersoid as red mud is the acts as reinforcement. Such pozzolana mortars exhibit much better adhesion property than normal cement-sand mortar. Similarly chopped coir fibre or rice husk used with fly ash-lime binder in making steam-cured building bricks contributes to higher transverse strength and impact resistance of the bricks than that of flyash-lime bricks without the fibre.

Fibre-Reinforced Building Materials in India

(A) Traditional and conventional

1. Chopped vegetable fibres (Rice husk straw, wheat straw) and mud matrix
2. Bamboo (split) and pulp with mud and/or cement as panels for walls and concrete for posts, roofs, rafters, electric poles etc.
3. Hesian woven cloth and bitumen felts for roofing, waterproofing and dampproofing and mastics, (flexible and rigid).
4. Paper pulp/pine needle pulp boards impregnated in bitumen for roofing sheets (corrugated), (various colours),
5. Hesian backing and fibres with polymers as linoleum sheets as flexible flooring and tiles (also using wood flour),
6. Coconut fibres (retted and unretted) with cashew nut shell liquid phenolic resin or cement for corrugated roofing sheets,
7. Coconut pith with cement or bitumen for insulation boards (roof slabs) and expansion joint filler.
8. Coconut chips with phenolformaldehyde resin for making particle boards
9. Wood wool (max 12% resin content) with magnesium oxychloride cement for boards mechanically pressed (walls, partitions, ceiling) and corrugated roofing sheets (with water-proof protective coating).
10. Wood wool (max 12% resin content) with Portland cement or Portland pozzolana cement or Portland blast furnace slag cement as corrugated roofing sheets (mechanically pressed) and slabs for partition, ceiling, walling etc. (fibre treated for alkali resistance).
11. Sawdust/wood flour and magnesium oxychloride cement door and window frames.
12. Matting cloths with polymer for venetian blinds.

(B) Modern Alternatives

13. Coconut fibre/jute fibre/sisal fibre and gypsum plaster cast as boards for partition, ceiling and wall panel.

14 Coconut fibre/jute fibre/sisal fibre and glass fibre with gypsum plaster for solid and perforated building blocks.

15. Poplar wood with polymer for making door shutter, door and window frames; rubber wood also like wise used as substitute for timber.

16. Vegetable fibre/pulp-red mud (waste of aluminium industry) and PVC for flat and corrugated roofing sheets and tiles (red mud as filler gives good colour)

17. Sisal fibre and glass fibres, red mud - polyester for sheets, door shutter, boards and frames for roofing, joineries and partitions.

18. Jute fibre polyester/epoxy with red mud for panels and sheets, wall cladding, partitions and door shutters.

19. Cotton stalks pulp and PVC for medium density fibre board (equivalent to wood fibre particle boards).

20. Bagasse and UF/PF resin (pressed) into panels and blocks.

21. Rice husk and Portland cement particle board

22. Coir fibre (chopped to 1-1.5 cm length) with fly ash and lime or cement to make bricks and blocks for walling (hot water or steam cured)

23. Multiblend fibres and multiblend cements into bricks, panels, blocks; (flyash, blast furnace slag, red mud, phosphogypsum).

24. Paper mill waste sludge and black liquor (lignosulphonic acid binder) for making boards and blocks with lime waste as filler.

The above list, under modern alternatives, also shows the utilization of wastes and byproducts which are inorganic in nature, (examples are fly ash, waste lime sludges, BFS, red mud and phosphogypum) along with vegetable fibres.

CONTRIBUTION OF THE BUILDING MATERIALS AND TECHNOLOGY PROMOTION COUNCIL

With the growing public awareness towards saving timber; (about 4 million m^3 timber is annually consumed in housing in India) the Central Public Works Department banned the use of timber in all Govt. building since April 1993. During 1993-95 the Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Affairs and Employment promoted a number of alternative fibre reinforced composites through collaborative efforts of the research laboratories and the industry. There are at least four new products commercialised.

AVAILABILITY OF VEGETABLE FIBRES

All over the world there may be many vegetable fibres supposed to possess physical and engineering properties suitable for use in fibre-reinforced composites. However, in India, there are only a few fibres which have been used extensively, and their estimated quantities are given in Table 1. Table 1A shows the cellulose and lignin contents and some other properties of a few fibres available in India, along with those of sisal and coir. But, inspite of large availability not much success has been achieved, in the utilization of other fibres as compared to sisal, jute, coir and bagasse.

Since availability of coconut in India is the second in abundance, after Philippines, in the world, the coir fibre has been investigated most extensibly. More importantly, coir fibre has been recognised as highly durable fibre in all types of matrices viz. polymer, bitumen, cement, gypsum, flyash-lime, mud etc.

VEGETABLE FIBRE-REINFORCED COMPOSITE BUILDING MATERIALS

Walls and roof of mud houses using chopped straw and vegetable fibres are quite common in rural India, and this practice is likely to continue for another 50-60 years or even more. In many hilly regions, on slopes and forest areas, houses using split bamboo, rice husk-mud mortar and thatch roofs continue to be constructed on the traditional designs with a lot of aesthetic appeal. In addition many other types of vegetable fibre-reinforced building materials are quite in vogue in India. Many new products and related technologies have been introducted in recent years. But people in general continue with mud-fibre composite construction practices as a matter of tradition only.

(A) Traditional and Conventional Composites

(B) Modern Alternative Composites

Almost all types of fibre-reinforced composites mentioned under (A) and (B) use only vegetable fibres except in some of them glass fibres also are used along with vegetable fibres. Some typical properties of the composites are given in Tables 2 to 14. Tables 2 and 3 show the properties of coir-cement panel and roofing sheet respectively. Tables 4,5,6,7 and 8 present the comparative properties of fibre reinforced products and other traditional composites. In fact most of the fibres were selected as process of elimination under rigorous evaluation of alkali resistance and brittleness on long exposure.

The rice husk and calcined clay or lime-sludge based composite mortar materials for buildings utilized partially burnt rice husk, containing a portion of unburnt husk which

(i) Jute fibre-red mud-polymer composites (FRPC)
(ii) Sisal fibre-red mud-polymer composites (SRPC)
(iii) Cotton fibre-phenolic resin medium density fibre board (MDF)
(iv) Poplar/rubber wood laminated split lumber (P/RLSL)

Most of these products are becoming very popular for making door frames, window frames and door shutters. (Tables 7 & 8). The comparative cost (in US $) of various door shutters manufactured and used commercially and also their comparative superior technical properties have helped in very large-scale demand. The BMTPC also promoted the utilization of largely grown rubber wood and poplar wood as substitute to wood, with resin bonding and preservatives. Table 9 and 10 show mechanical properties of laminated rubber split lumber and poplar wood veneer lumber. Table 11 and 12 give the properties of fibrous gypsum plaster boards and Table 13 and 14 contain the properties of rice husk-lime-pozzolana composite masonry mortars which could also act as substitute for industrially important substitutes to wood particle boards, with better fire resistance, biodurability termite proofness and water resistance. The BMTPC has been able to extract several tax concessions and incentives from the Govt. of India for various new materials which are either timber substitutes or utilize the wastes.

DISCUSSIONS

Many sincere efforts, coupled with international collaborations, have resulted into a fairly good degree of success in the production and use of vegetable fibre-reinforced building materials in India and in other Asian and African developing countries. The products, such as roofing sheets, wall panels, door and window frames satisfy the standard specifications and performance criteria under many rigorous conditions. However, the dream that abundance of vegetable fibres would make the fibre-reinforced products within the reach of the poor people has hardly been realized.

The fibre such as coir, jute, bagasse, bambaoo, rice husk and sisal have all found diversified applications in textiles, paper and paper boards and alternative fuels. These applications have pushed up their market prices besides the cost of procurement, extraction, pre treatments and processing. The polymeric binders have been found more compatible than inorganic cementitious binders but in a country like India which imports 25% of its pertoleum requirements, the cost of synthetic resins revised upwards too often is a discouraging factor. In addition manual methods of casting roofing sheets, tiles and building blocks do not meet the expectations of quality in comparison to those of the materials produced mechanically, and this factor also becomes responsible for higher costs. Thus in spite of the vegetable fibre reinforced composites building materials meeting acceptability they donot always prove economical compared to the products made from steel, aluminium, asbestos-cement and secondary timber.

INDIAN STANDARD SPECIFICATIONS OF FIBRE-REINFORCED BUILDING MATERIALS

The Bureau of Indian Standards (BIS) and the Building Materials and Technology Promotion Council (BMTPC) have drawn up technical expertise from R & D organizations and the industry in bringing out new standard specifications on vegetable fibre-reinforced building materials. India has many standard specifications on the glass fibre reinforced polymer bonded composite materials. The products which are covered under the standards are : pipes, fittings, electrical conduits, water vapour barriers, doors and windows frames, shutters, flooring and wall tiles, thermal insulation sheets, panels, decorative laminates, sanitary plumbing, fibre boards, GRP glazing, roof lighting materials, sealants, foams, bath fixtures, prefabricated shelters and cabint etc.

The above specifications, therefore, have been very helpful in formulation of the standard specifications on vegetable fibre reinforced materials, such as : corrugated coir-wood wool cement roofing sheets, (IS:12866), fibrous gypsum plaster board (using waste phosphogypsum) (IS:8273), medium density fibre boards and products (IS:12406), hesian backed bitumen bonded roofing felts (IS:7193), flexible-fibre-PVC flooring and tiles (IS:3461 and IS:3462), structural plywood, using nonwood (IS:10701), linoleum sheets and tiles using hesian backing and wood flour (IS:653), magnesium oxychloride-sawdust-bagasse flour flooring (IS:658) and wood wool slabs (IS:3308) grey straw mill board (IS:2617), boards from other lignocellulose (IS:2380), jute spinning frame board (IS:13721), sisal products (IS:11058), jute-polyethylene composites (IS:13649), jute canvas (IS:10039), cellulose-polyester (IS:3416) etc. There are many more under active process of formulations.

Thus India has a well established strong base in standards formulations.

RESEARCH AND DEVELOPMENT ORGANIZATION IN INDIA WORKING IN COMPOSITES FOR BUILDINGS

India possesses a good network of research and development organizations. Regional Research Laboratories, Bhopal, Jorhat and Trivandrum were set up with advanced R & D facilities for work on fibre-composites. Jute Research Institute, Calcutta, Indian Plywood Research and Training Institute, Bangalore, Forest Research Institute, Dehradun and many other institutes dealing with rice, tea, coconut, sugar and bagasse, bamboo, paper and boards materials and polymer materials have their own specialization. In addition as mentioned in the beginning some other premier R & D institutes such as the National Aerospace Laboratory, Defence Metallurgical Research Laboratory, Indian Space Research Organisation, National Physical Laboratory, Indian Institutes of Science and Indian Instiites of Technology (7 Nos.) specialize in composites for non-building purposes.

CONCLUSIONS

It is said that there is rather a slow progress in vegetable fibre reinforced building materials and components. Many of the problems have been analysed and presented in various papers, books and experts deliberations. In fact a strong data base on vegetable fibres, their properties and potentials is urgently required to be established. Data-base can be scientifically managed to generate and develop alternative resources. Such a data-base must be able to cater to the needs of any user from all developing countries. It is high time to understand the important point underlying sustainbility that human race must live on income from our biosphere and not eat into the capital. This can be achieved with a proper planning, integrated action programmes and inputs of science and technology. It is in this way that the earth could be spared from impending environmental disaster, and save the mankind from further sufferings.

Table 1 : Availability of agriculture wastes in India/Year

S. No.	Waste	Source	Estimated production in 2000 A.D. (million tonnes)
1.	Coconut husks byproduct	Coir Industry	2.5
2.	Rice husk	Rice Mills	25.0
3.	Ground nut husk	Oil Mills	3.0
4.	Rice and wheat straw & Reeds	Farms	Abundance
5.	Jute sticks	Jute Mills	3.5
6.	Bagasse	Sugar Industry	5.0
7.	Saw mill waste	Saw Mills	Abundance
8.	Corn cobs + stalks	Farms	Abundance

Table 1A : Properties of some veg fibres

Fibre	Cellulose Content %	Lignin Content %	DIA. μm	UTS MN/m^2	% Elongation Max.	Modulus
Banana	64	5	50-250	700-780	3.7	27-32
Sisal	70	12	50-200	530-630	5.1	17-22
Pine-Apple	85	12	20-80	360-749	2.8	24-35
Coir	37	42	100-450	106-175	47	3-6
Talipot	68	28	80-800	143-263	5.1	10-13
Palmyrah	40-50	42	70-1300	180-250	2.8	4-6

Table 2 : Physical properties of coir building panel

1.	Size ($X10^{-2}m$)	300 x 100 x 5
2.	Bulk density (kg/cm^3)	0.5 - 0.65
3.	Texture	Smooth
4.	Moisture absorption (%) (24 hrs.)	10
5.	Bending strength (MPa)	0.88 for 0.05 m thickness
6.	Thermal Insulation ($k\ cal / m^2 / h / c^0$)	0.082 to 0.090
7.	Sound absorption (NRC)	0.32

Table 3 : Physical properties of corrugated roofing sheets

		Coir-cement	**A.C.**
1.	Pitch of corrugation (mm)	145	146
2.	Depth of corrugation (mm)	48	48
3.	Length (M)	1.5 to 2.0	1.5 to 3.0
4.	Breadth (m)	1.0	1.05
5.	Thickness (mm)	7	6
6.	Weight (kg/cm^2)	11.0	13.0
7.	Water absorption (24 hrs) (%)	1.0 (with water-proffing)	25 (max.)
8.	Breaking load	Coir cement gives equal strength at 0.6 m spacing as compared to 1.0 m spacing to A.C. sheet.	
9.	Thermal Insulation ($KCal / m^2 / h / c^0$)	0.09	0.24

Table 4 : Properties of veg fibre-polyester composites

Fibre Used % wt.	SP Modulus GN/m^2	SP Strength MN/m^2	Density kg/m^3	Flex. Str. MN/m^2	Impact Str. $X10^3 J/m^2$
Banana 23%	2.02	38.60	1106	88.4	17.40
Chopped Banana 25% wt	2.34	43.25	1000	92.10	10.00
Chopped Sisal 25% wt	1.90	34.25	1150	86.40	30.00
Chopped Coir 25% wt	1.40	14.10	1132	31.20	11.10
Chopped Glass 30% wt	1.75	41.60	1210	89.60	9.30

Table 5 : Physical properties of jute fibre and glass fibre reinforced polyester composites before and after weathering for seven years

Properties	Unweathered jute fibre reinforced sheet	Weathered jute fibre reinforced sheet	Unweathered jute fibre reinforced sheet	Weathered jute fibre reinforced sheet
Bulk densit kg / m^3	1160	1025	1300	1250
Fibre content %	12-15	-	28-32	30-35
Water absorption % (24 hr.)	2.35	3.23	1.03	1.28
Flexural strength MN / m^2 Dry	23	11.60	107	103
7 days soaking	34	19.10	74.10	-
Tensile strength MN / m^2	24.20	9-20.6	76.00	63.00

Table 6 : General properteis of some commercial roofing sheets made from fibre reinforced composites, in India

Property	Using waste paper board and asphalt	Pine shingle waste pulp & asphalt	Redmud waste and PVC	Cut stell wire and cement
Density kg / m^3	700-1100	900-1100	200-400	-
Dimensions (mm)	1200x750x4	400x150x10	2000x1000x3	1500-1800
Flexural strength (MPa)	80-85	15-20	50-60	1200x750x10
Permeability of water	Nil	Nil	Nil	Trace
Water absorption (%)	8-10	8-10	0.2-025	5-10

Table 7 : Comparative cost of alternate door shutters (Size of doors = 2.00x1.00m)

Door	Red mud polymer door	M.S. door	Timber (Teak)	P.V.C.	Medium density fibre
Cross Section	Door frame 105mm x 60mm flush/panel door-shutter 30mm	Door Frame 105mmx60mm shutter-frame 30mmx30mm, pane particle board with laminates	Door frame 100 mm x 75 mm, shutter frame style and top rail 100 mm x 35 mm, lock rail 150 mm x 35 mm, Panel timber 18 mm	Door frame 40 mm x 57 mm, shutter frame 60 mm x 24 mm, Panel 20 mm	-
Initial cost of shutter including frame	US $ 70.00	US $ 75.00	US $ 114.00	US $ 140.00	US $ 56.00
Cost per year life of product (including maintenance cost and cost of capital @18%)	US $ 9.00	US $ 18.00	US $ 22.00	US $ 26.00	US $ 10.00
Costs indicated above are based on 1995 market rates in India					

Table 8 : Comparative technical features of RFPC and other materials

Sr. No.	Test conducted	Unit	RFPC	MDF	PVC	Teak	Particle board
1.	Density (Tested as per IS:2380 part III:1977)	g/cc	1.72-1.76 (1.65-1.7)	0.5-0.9	1.3-1.58	0.62-0.64	0.5-0.9
2.	Moisture content	%	0.2-0.38	5-8	N.A.	10-12	5-15
3.	Modulus of rupture (Tested as IS:2380 part IV:1977)	N / mm^2	85-95 (min 28)	12.5-15	68-110	11.6-14	12.5-15
4.	Tensile Strength (Tested as per IS:2380 part V & VI:1977)	N / mm^2	22-24 (min.17)	0.6-0.7	N.A.	N.A.	0.4-0.45
5.	Compression perpendicular to surface	N / mm^2	78.48-101	N.A.	N.A.	2.5-4	N.A.
6.	Compression parallel to surface	N / mm^2	44-51	N.A.	N.A.	6.4-8.8	N.A.
7.	Water absorption (Tested as per IS:2380 part XVI:1977)						
	2 hours	%	0.15-0.4 (Max. 10%)	6-10	N.A.	N.A.	6-10
	24 hours	%	1.1-1.5 (Max. 10%)	10-12	0.04-0.4	N.A.	17-20
8.	Swelling in water (Tested as per IS:2380 part XVII:1977)						
	Length	%	0-0.36 (Max. 5%)	0.3-0.35	N.A.	N.A.	0.45-0.5
	Width	%	0-0.47 (Max. 5%)	0.3-0.35	N.A.	N.A.	0.45-0.5
	Thickness	%	0-1.38 (Max. 10%)	3.5-4	N.A.	N.A.	6.5-8
9.	Fire retardency (Tested as per BS:476 part V:1979; BS; 476 Part VII:1987)	Second	Self extinguishing in 15 seconds	N.A.	N.A.	N.A.	N.A.
Note : Figures in brackets show Codal values							

Table 9 : Mechanical and physical propertis of laminated rubber lumber

Property	Average value for LSL	Value for solid rubber wood
Sp. gr.	0.56	0.5 to 0.66
Volumetric shrinkage %	5.21	N.A.
Modulus in rupture (kg / cm^2)	720	570
Modulus in elasticity (kg / cm^2)	70800	72000
Compressive strength parallel to glue line (kg / cm^2)	326	320
Compressive strength perpendicular to grain (kg / cm^2)	80	N.A.
Shear strength parallel to glue line (kg / cm^2)	119	N.A.
Screw holding strength (kg.) (Parallel to glue line)	165	176
Nail holding strength, kg. (prallel to glue line)	98	93

Source : BMTPC, New Delhi, India, Internal Report, 1995

Table 10 : Mechanical properties of poplar wood veneer lumber and teak

	Poplar wood	Teak
Moisture content %	8.2	12
Sp. gr.	0.704	0.551
Compressive strength perpendicular to grain (kg/cm^2)	183	83
Maximum shear strength (kg/cm^2)	176	92
Modulus of elasticity (kg/cm^2)	870	665
Screw holding power (kg)	260	N.A.
Nail holding powder (kg)	200	N.A.

Source : BMTPC, New Delhi, India, Internal Report, 1995

Table 11 : Chemical properties of water resistant gypsum binder

Constituent	% by wt.
Loss on ignition	4.11
SiO_2 + insoluble in HCL	8.5
Al_2O_3	9.00
CaO	37.30
MgO	1.80
SO_3	39.65
P_2O_5	0.15
F	0.09

Table 12 : Properties of glass fibre-reinforced gypsum binder composite

Property	Gypsum-binder composite (glass 4%)	Gypsum plaster composite (Jute 4%)
Bulk density kg/m^3	1.628	1.20
Consistency, %	65	45
Flexural strength (kg/cm^2)		
3 days	121.7	35.5
7 days	132.1	35.6
28 days	2220.0	36.0
Tensile strength (28 days) (kg/cm^2)	180	27.5
Impact strength (28 days) (kg/cm^2)	186	92.5
Thermal conductivity $Kcal/mh^0c$	0.09	0.08

Table 13 : Properties of rice husk clay pozzolana

Coarsely ground material	Surface area 260 m^2/kg (Blaines)
Compressive strength of mortar (1L:1P:1S)	0.98 M Pa
Finely ground material	Surface area 800 m^2/kg (Blaines)
Compressive strength of moratar (IL, IP, IS)	6.86 M Pa

Table 14 : Properties of hydraulic binder from rice husk lime sludge

Finely ground material	Surface area 800 m^2/kg (Balaines)
Compressive strength of mortar	4.9 M Pa
Setting time :	
Initial	60-70 minutes
Final	480-600 minutes

Annexure - 1

Commercial fibre reinforced composites in India

Sl. No.	Name of the coposite	Type of the building materials	Name and address of the manufacturer
1.	Red mud-PVC jute fibre	Corrugated roofing sheet panels	Lotus Roofing Pvt. Ltd., Sedurapet P.O. Pondicherry-605 101
2.	Jute Fibre-polyester	Panels	Jupiter Board Industries 93, Pilkhana Road, Berhampore, Mushidabad-742 101 (WB)
3.	Redmud-polyester sisal-glass fibres	Panels, tiles, roofing sheet	Neolux India Ltd. 75, Altanta, 7th Floor, 209, Nariman Point Bombay - 400 021
4.	Bitumen bonded paper fibre or pulp	Corrugated roofing sheet and shingles	Light Roofing Ltd. No. 2/87, GST Road Chettipunniyam 603 200
5.	Agro fibre-polyurethane	Panles	Alliance Board ltd. P.O. Dadri (Distt. Ghaziabad), U.P.
6.	Gypsum plaster-fibre jute/sisal & glass	Partitions Door Shutters	Ganesh Agro Industries Pvt. Ltd. 636, Mundka, Delhi - 110 041
7.	Borotik (rubber wood)	Door shutter partition	Borox Morarji Ltd. Jolley Bhawan No. 2, New Marine Lines Bombay 400 020 (India)

Contd...

Sl. No.	Name of the coposite	Type of the building materials	Name and address of the manufacturer
8.	Coir-oxychloride-fibre composite	Ceiling, partition, panels	Anutone Boards (P) Ltd. Bangalore (India)
9.	Rice husk cement board	Wal panelling, false ceiling, partitioning, door/window shutters, roofing panels, flooring	Padmavathy Panel Boards Pvt. Ltd. 114, 4th Cross Ist, N Block Rajaji Nagar Bangalore - 560 010 India
10.	Bagasse PF board	Wall panelling, false ceiling, partitioning, door/window shutters, flooring furniture	Western Bio System Ltd. ECO HOUSE 65/2-A, Akarshak Opp. Nal Stop, Karne Road, Pune - 411 004
11.	Cement bonded particle board (non-wood)	Partitioning, wall lining, false ceiling, roofing, flooring, doors, panelling	NCL Industries Ltd. 7th Floor, Raghava Ratna Towers, Chirag Ali Lane, Abids, Hyderabad-500 001
12.	Phosphogypsum-plaster-coir fibre board	Thermal and sound insulatio board	IDL-Salzban (India) Ltd. Bombay (Factory Vizag)
13.	Jute-felt-flyash-cement polymer	Roofing sheet	Texlite Roofing Pvt. Ltd. Malyavaram (A.P.)
14.	Medium density fibre board (non-wood)	Chaukhats, doors, mouldings, furniture, partitioning, panelling, flooring, ceiling	NUCHEM Ltd. E-46/12, Okhla Industrial Area, Phase-I, New Delhi - 110 020 and Best Boards Ltd., Gajraula Distt. Moradabad, U.P.
15.	Stramit board	False ceiling, doors, partitons, non load bearing walls, flooring walls, flooring roofing, wall cladding	Ballarpur Industries Ltd. Thapar House 124, Janpath New Delh - 110 001

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TITLE OF PAPER

THE PERFORMANCE OF COTTON - KAPOK FABRIC - POLYESTER COMPOSITES

AUGUST 6, 1997

BY

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ABSTRACT

Cotton - kapok fabric, at a ratio of 2:3, have been incorporated with unsaturated polyester resin in various fibre volume fractions. The fabric was also treated with 5 % sodium hydroxide with the aim of improving fibre - matrix adhesion. A sim[illegible]nual lay up technique was used in fabricating the composites. A hand operated hydraulic electrically heated press was used and the composites were cured at 100 °C for 60 minutes and post cured over night in the oven at 80 °C.

Mechanical properties such as tensile strength, tensile modulus, impact strength, and flexural properties of composites not subjected to weathering conditions and weathered composites have been evaluated. Composites with untreated fibres were found to have higher fibre volume fractions than composites prepared using treated fibres. The tensile strength of the composites with untreated fibres were found to be higher than the tensile strength of composites prepared by using treated fibres but, having, on average higher tensile modulus than composites manufactured using untreated fibres.

The impact strength was found to decrease with increase in fibre volume fractions for, both, composites with or without alkali treated fibres. Reductions in flexural strength and moduli were observed with weathered composites. The specific strength of the composites was found to be comparable to the specific strength of other vegetable fibre reinforced resins.

1. INTRODUCTION

Natural fibres are attracting more attention as reinforcements to thermoset and thermoplastic matrices. The increasing demand for these cellulose materials as fillers in a wide variety of matrices is essential because of their desirable properties such as low cost, renewal, biodegradability and high specific properties compared to the conventional matrix fillers like glass and carbon fibres which are expensive and not renewable besides being environmentally undesirable.

A large variety of natural fibres is available in Tanzania (Table 1). Most of these fibres have not been optimally utilised, except cotton and sisal fibres which are the country's main cash crops. At present, nearly all the fibres are utilised for conventional applications, for instance, for the production of yarns, ropes, mats, apparels and upholstery etc. However, in recent times, many of these conventional uses of natural fibres are threatened by plastics and synthetic fibres like glass and nylon fibres. This has generated the need to develop new uses for natural fibres [1-2].

The application of natural fibres as reinforcement to polymeric matrices have been extensively researched, and it is now possible to produce plastic composites using natural fibres for applications such as roofing, panelling, food grain silos and low cost housing units. Natural fibre reinforced composites are is now being seen as the most appropriate and cost effective building materials [3].

A research was initiated at the University of Dar Es salaam to determine the application of cotton - kapok fabric[4] as reinforcing material in unsaturated polyester resin. The fabric was mercerised in slacked form with 5 % sodium hydroxide. The aim was to improve the fibre's wetting ability by extracting the non - cellulose substances, mainly wax and pectin. The extraction of these non - cellulose substances reveals the microfibrillar character of rough parallel ridges which adds to the fibre - matrix frictional forces, enhancing the fibre - matrix adhesion. Mercerisation without tension allows total conversion of cellulose I to cellulose II to take place, and it increases the strength uniformity along the fibre length and improves accessibility of reactive sites to binding chemicals[5].

The cotton - kapok fabric - polyester composites have been manufactured using untreated and treated fabric. Some of the composites with treated fabric have been subjected to accelerated weathering conditions.

This paper reports on the mechanical and thermal properties of cotton - kapok fabric - polyester composites and fibres.

Table 1: Natural fibre available in Tanzania and the annual production.

Fibre	Production (tonnes)	Possible production (tonnes)	Price (US $/kg)
Cotton	126,000	200,000	2.00
Sisal	30.5	< 50	0.74
Kapok	20	800	0.20
Wood	Abundant	-	-
Coir	0.1	-	0.85
Rice husk	Abundant	-	-
Rice straw	Abundant	-	-
Wheat straw	Abundant	-	-
Bagasse	Abundant	-	-
Elephant grass	Abundant	-	-
Groundnut hull	Feasible	-	-
Flax	Feasible	-	-
Banana	Abundant	-	0.1
Broom	Abundant	-	-
Bamboo	Abundant	-	-

Note : The price of glass fibre is about 3.00 US $/kg

2. EXPERIMENTAL PROCEDURE

2.1 Materials

Cotton - kapok fabric was manufactured at Morogoro Canvas Mill, Tanzania[4]. The fabric had a weave construction of 7 x 7 warp/weft respectively with an area density of 97.23 g/m^2 and breaking strength of 180 N/50 mm. The unsaturated polyester was obtained from Hankel Plastics Ltd in Dar Es salaam Tanzania. No specifications of the polyester matrix were given by the supplier.

A 30 sq. mm^2 hand operated electrically heated hydraulic press was used for compression moulding and a mould with internal measurement of 250 x 60 x 60 length, width, and height respectively was used to manufacture the composites. It had vents as exit pathway for the excess expelled resin during compression. The mould was made out of mild steel plates.

2.2 Method

2.2.1 Characterisation

2.2.1.1 Scanning electron microscope analysis (SEM)

A Philips SEM 501 scanning electron microscopy was used to study the fibres and the tensile fracture surface of the composite samples. Prior to the analysis, the samples were metallised with a Au/Pd alloy, by means of a Polaron sputtering apparatus. The equipment was set to make a coating of 18.2 nm thickness.

2.2.1.2 Dynamic mechanical thermal analysis (DMTA)

Dynamic mechanical measurement were carried out by means of a dynamic thermal analyser (DMTA MK III Polymer labs) operating in a single cantilever bending mode at a frequency of 1 Hz. The samples in a form of small bars (15 x 5 x 5) mm were investigated in the temperature range from 20 °C to 200 °C.

2.2.1.3 Differential scanning calorimeter analysis (DSC)

A Mettler type differential scanning calorimeter was used. It was set to operate between 0 °C and 300 °C. This range of temperature was considered sufficient to record the thermal characteristics of the fibres and composites. Samples of fibres and composites weighed between 5 mg and 10 mg and were enclosed in an aluminium container and sealed. The container were then punctured with a needle to provide escape pathways for the volatile substances. The equipment was operated in a nitrogen environment.

2.2.2 Surface treatment of fibres

The surface treatment of fibres was performed in fabric form. The fabric was first soaked in commercial petrol for 4 hours at room temperature. It was then washed in distilled water, rinsed and left to dry in doors for 24 hours. The dried fabric was soaked in a hot solution of 5 % sodium hydroxide for 2 hours, after which it was thoroughly rinsed in distilled water and left to dry indoors for 24 hours.

2.2.3 Moulding of composites

A convenient gel time for the unsaturated polyester was determined using a timer and observing the gel time of polyester when mixed with a hardener and thoroughly stirred. This provided ample time between the time to prepare the resin - fabric mixture and placing the soaked fabric in the mould for compression before complete gelling of the resin occurs, as this would impede complete compression to the desired composite thickness

Cotton - kapok fabric pieces were accurately weighed and soaked in polyester resin which had been mixed with a hardener. Excess resin was squeezed before moulding. A mould release agent was smeared onto the mould surfaces to facilitate the removal of the composites. A set of resin soaked fabric layers were then placed into an open - ended mould. A maximum of 40 minutes was sufficient to enable the laying of resin soaked fabric layers before hot curing started. A plunger was immediately fitted and pressed to a pressure of about 3 GPa for 60 minutes. The composites were then removed from the mould and post cured in the oven at 80 $^{\circ}$C.

2.2.4 Weather degradation test

A simple accelerated test was performed by immersing the composite sample into boiling water for 2 hours as per ASTM D 570 - 77. Flexural properties of the composites were then determined.

2.2.5 Testing of composites

2.2.5.1 Tensile properties

The tensile testing of rectangular plain specimen was carried out using Zwick tensile testing machine type 1141 in accordance with ASTM D 3039. The specimen were pre - conditioned to remove excess water, and placed in the desiccator maintained at room temperature with a relative humidity of 50 ± 5 %.

The sample were tested at a cross - head speed of 5 mm/min. and break time of 20 seconds. The tensile strength, modulus and elongation at break of the composite were calculated from the load - elongation curve. At least five specimen were tested for each set of samples and the mean and standard deviation values were reported.

2.2.5.2 Impact strength

The Charpy - type impact tests were performed using the pendulum impact testing machine on samples of 7 x 3.29 mm in dimension. The specimen were not notched because introducing a notch at right angles to the plane of fabric layers would involve cutting through one or more layers. Impact loads were applied in a direction at right angles to the fabric. This orientation was chosen to represent lateral impact to a laminate panel in commercial use. The tests were carried out in accordance with ASTM D 256 - 92; for each composite, five specimen were tested. No impact test was performed on weathered composites.

2.2.5.3 Flexural (bending) properties

Flexural properties were determined on weathered and non - weathered composites. ASTM D 790 method 1 - Procedure A was used. The strain was maintained at 1.3 mm/min. and a span - to - depth (thickness) ratio of not more than 8 was applied.

3. RESULTS AND DISCUSSION

3.1 Tensile properties

The load - elongation curves for various fibre volume fractions are shown in Fig. 1 (a and b) The curves are similar and in both cases the composite with more volume fraction has higher breaking load than composites with less fibre volume fractions. A point of inflexion in the curves indicates the failure of critically stressed fabric layers as a result of the lower fracture strain of fibres to the resin matrix.

The tensile properties such as tensile strength at break, tensile modulus and elongation at break were calculated from the load - elongation curves. The results are reported in Table 2 and Table 3 for composites produced using untreated and treated fibres respectively. The graphs of tensile strength and, tensile modulus against fibre volume fractions (Fig. 2 a and b) show a decrease in these properties as the fibre volume fraction is increased in composites with untreated fibres. The drop in the mechanical properties is likely to have been caused by possible increase in void content with increasing fibre volume fraction. It is also possible that sodium hydroxide textured the fibres to the extent that it affected the mechanical properties of composites[6]. Ramaswamy et al[7] obtained similar effects of sodium hydroxide when used in retting kenaf stalks. However, Reducing the NaOH concentration to less than 1 % is reported to have minimal effect on the loss of the strength of cellulose materials[6].

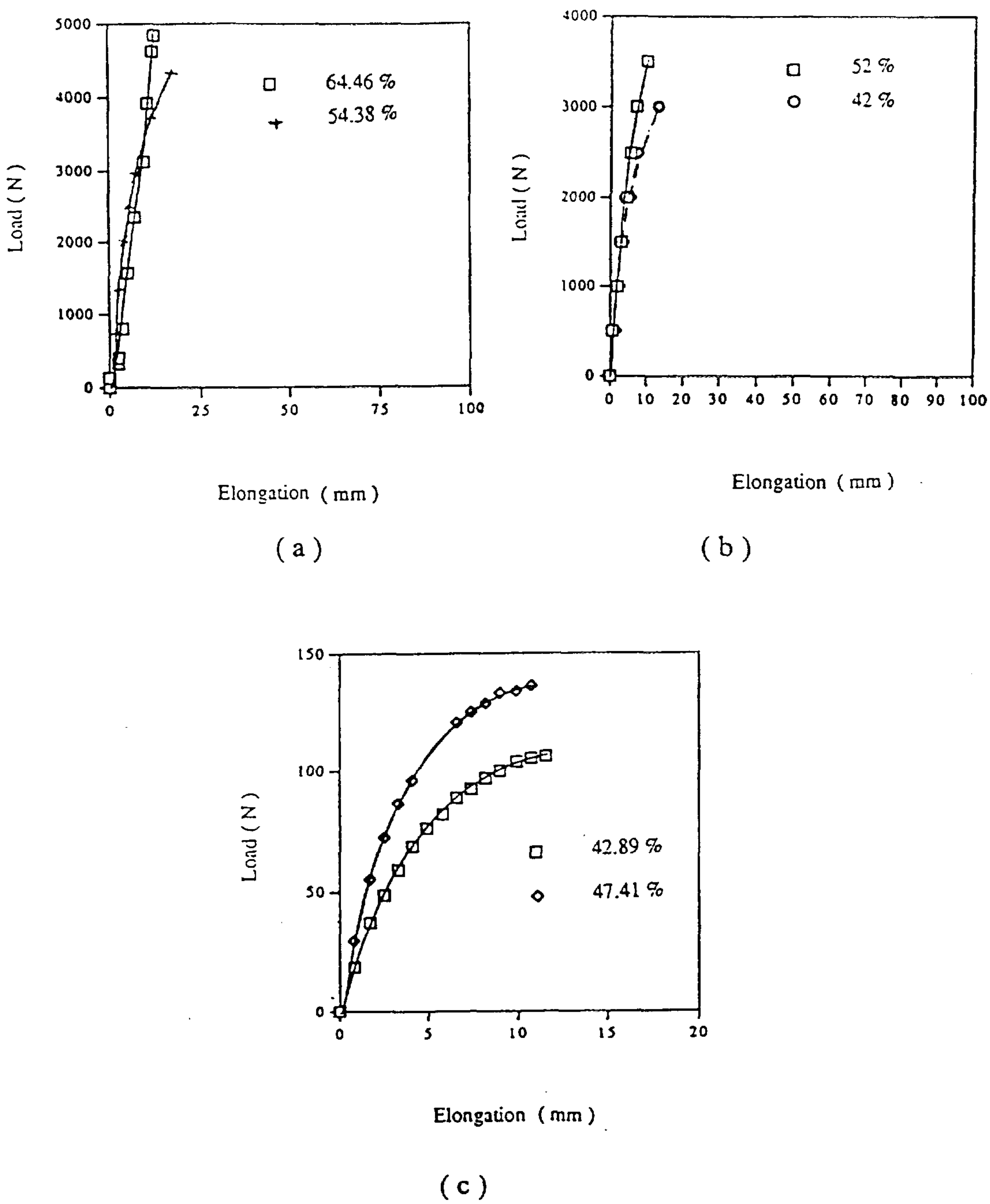


Figure 1: Load - elongation curves of (a) untreated fabric in the cotton - kapok fabric - polyester composite, (b) treated fabric in cotton - kapok fabric - polyester composite (c) three - point bend graphs.

Table 2 : Mechanical properties of untreated cotton - kapok fabric - polyester composite

Fibre volume fraction (%)	Composite density (kg/m^3)	Tensile strength (MPa)	Tensile modulus (MPa)	Impact strength (kJ/m^2)
58	1231	57.49	739.37	103.96
59	1149	57.05	695.17	109.61
60	1171	55.70	884.34	110.53
62	1152	54.71	819.98	85.11
64	1159	54.40	665.08	77.27
65	1143	53.25	769.38	72.79

Table 3 : Mechanical properties of treated cotton - kapok fabric - polyester composites

Fibre volume fraction (%)	Tensile strength (MPa)	Tensile modulus (MPa)	Impact strength (kJ/m^2)
42.89	52.87	1635.24	119.25
44.76	44.76	858.48	-
46.62	41.70	1023.57	-
47.41	40.07	775.75	120.75
47.47	46.34	810.86	107.82
48.80	43.14	801.74	100.48
52.04	40.96	691.22	98.00

Table 4 : Flexural properties of treated cotton - kapok fabric - polyester composites

Fibre volume fraction	Flexural strength (MPa)	Flexural modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)
(%)	No weather treatment	No weather treatment	Accelerated weathering	Accelerated weathering
37.06	-	-	24.91	435.30
42.05	55.34	698.70	34.40	676.10
42.85	-	-	36.07	711.50
44.76	-	-	37.01	542.30
46.62	52.40	708.90	39.55	702.80
47.41	54.96	801.60	-	-
47.47	48.15	715.70	-	-
48.80	-	507.00	45.77	841.50
52.04	44.32	526.60	-	-

Table 5 : Comparison of some natural fibre - polyester composites with glass fibre - polyester composites

Composite	Composite density (kg/m³)	Fibre volume fraction (%)	Tensile strength (MPa)	Tensile modulus (MPa)	Impact strength (kJ/m²)	specific energy (kJ/kg)
Cotton - kapok - polyester	1171	60	55.70	884.34	110.53	47
Straw fibre - polyester	804	50	47.00	5600		58
Glass fibre - polyester	1930	50	750	38000	60	338

Table 5 show that the tensile strength of glass fibre - polyester composite is about 14 times that of cotton - kapok fabric - polyester composites, and that the specific energy is about 7 times higher. However, the price of glass is 15 times that of kapok fibre and 5 times the price of cotton - kapok fabric at a 3 :2 ratio respectively.

The SEM thermograph (Fig.3 a) show highly convoluted cotton fibres. The fibre's cross sections have a bean shape structure with collapsed lumen. Figure 3 (c) show smooth cylindrical surfaces of the longitudinal view of kapok fibres while its cross section (Fig.3 d) reveals a wide open lumen with thin walls of about 2.5 μm. The width of the lumen is 16 μm.

The fracture surface of the matrix shows features of very brittle materials. Figure 4 (a) show a severe surface action of the sodium hydroxide on the cotton fibre. The surfaces of kapok fibre still have a smooth texture not very different from the not treated kapok fibres and show a good interface with the matrix. Delamination at the cotton - kapok fabric - matrix interface is due to the release of water on the surface of the fibres.

The shape of the DMTA thermogram of cotton - kapok fabric - polyester composite shows the presence of absorbed water in the composites and a glass transition temperature (T_g) of the matrix at approximately 84.°C. The DSC analysis on the individual fibres (Fig. 5 a and b) gives similar thermogram characteristics with regard to the presence of water, and the heat of fusion of about 163 J/g and 222 J/g for cotton and kapok fibres respectively. The water present in the composite, originates largely from the fibres and/or fabric, implying that the fabric and the composites were not effectively pre - conditioned before testing or that the time between removing the samples from the conditioning chambers and testing allowed the absorption of water, enough to affect the mechanical properties. However, observations on the thermogram (Fig. 6) indicates that the composite was well cured. The presence of water in the composites tends to develop plasticity on the material thus lowering its mechanical properties. Also high moisture content leads to poor wetting ability with the resin and weak interfacial bonding between the fibres and the relatively hydrophobic polyester matrix[8-9].

The curve of storage modulus (E^{l}) and loss modulus (tan δ) of the treated and not treated composites as a function of temperature is given in Figure 7. From the analysis of the curves it can be deduced that the modulus E^{l} is higher at higher fibre volume fraction which in this case appears to be the composites with the not treated fabric.

In both cases the storage modulus, E^{l} , decreases as samples goes through the matrix - glass transition temperature. However, the glass transition temperature seems not to be affected by the filler material. The slight difference in the T_g values is probably caused by higher fibre volume fractions and good curing and therefore less molecular segmental movements. No dynamic mechanical thermal analysis were performed on the neat matrix.

3.2 Impact strength

Figure 8 show the impact strength of untreated and treated fibre in cotton - kapok - polyester composites. In both cases, the impact strength decreases as the fibre volume fraction is increased. Similar observations have been reported by Berlin et al[10], and Hancox [11] when testing the impact strength of carbon fibre reinforced composites using Izod impact strength tester. The reduction of the amount of matrix as the fibre volume fraction is increased contributes to the decrease in impact strength as the matrix is greatly responsible for the absorption of the impact energy.

3. Flexural strength

There was increase in flexural strength and modulus of the cotton - kapok - polyester composites subjected to accelerated weathering conditions as the fibre volume fraction increased see Figure 2 (c and d) This was possibly due to continued cross-linking of the polyester resin during the accelerated weathering process, However, this conflicts with the DSC results (Fig.6), where the matrix appears to have been well cured suggesting that another fibre - matrix phenomena was responsible for the increase in the flexural properties.

4. Conclusion

Cotton - kapok fabric- polyester composites provides a new class of materials that have demonstrated industrial potential. Increase in flexural strength and modulus as the fibre volume fraction is increased is an indication of a promising composite material in commercial use as design applications frequently involve a bending rather than tensile mode[12].

Moreover, it can be deduced from Table 1 that the comparatively low price of cotton - kapok fabric against glass fibre and the relatively good cotton - kapok fabric - polyester composite tensile and specific strength, and more so flexural properties, implies that the new composite material may be preferred in applications such the low cost grain silos, school buildings, and housing units for the low income and rural settlements.

However, the presence of free water in the cellulose cavities and water bonded by the amorphous regions has adverse effects on the mechanical properties of the composites. It is therefore, important that the absorbed water is completely removed and that the hydroxyl groups on the cell wall are replaced with reactive chemicals thus reducing the hydroscopic characteristic of the lignocellulose materials.

Extreme care must be taken when bleaching and/or mercerising cellulose with sodium hydroxide as when it is used in large quantities it tends to texturise the cellulose structure thus affecting its mechanical properties. Avoiding the use of sodium hydroxide on plant fibres is strongly recommended. The application of fibre volume fractions of less than 30 % should be assessed for their effect on the mechanical properties of cotton - kapok fabric - polyester composites

Accelerated weathering temperatures (~100 ° C) does not seem to have degrading effect on the composite, perhaps longer period of accelerated weathering will facilitate the fabric - matrix degradation. This is expected with polyester, which is known to degrade at temperatures above 200 ° C.

Further research is needed to develop the application of kapok fibre and blends as reinforcement for polymeric resins. Its positive results will revamp the commercial value of the crop with the added advantage on the environment, and improve the rural income where kapok is grown.

Reference

1. Rohatgi, P K ; Satanarayana, K G ; Chand, N (1991) : Natural fibre composites. International Encyclopedia of Composites, Lee, S M (ed.), Vol. 4, VHC Publishers, 8 - 16.
2. Rohatgi, P (1997) : Composites from local raw materials - overview, New and Advanced Materials 1996/3, Emerging Technology Series, UNIDO, 30 - 36.
3. Singh, B ; Gupta, M and Verma, A (1995) : Mechanical behaviour of particulate hybrid composite laminates as potential building materials, Construction and Building Materials, Vol. 9, (1), 39 - 44.
4. Bisanda, E T N and Mwaikambo L Y (1996) : Potential of kapok fibre as a substitute of cotton in textiles, Journal of Agriculture, Science and Technology, Vol. 1 (1), in print.
5. Atkins, E (1979) : Polysaccharides : Biomolecular shape and structure, Applied Fibre Science, vol. 3, Happey, F (ed.), Academic press, Chapter 8.
6. Mukherjee, A ; Ganguly, P K and Sur, D (1993) : Structural mechanics of jute : The effect of hemicellulose or lignin removal, Journal of Materials science, vol. 19, 3925 - 3934.
7. Ramaswamy, G N ; Ruff, C G and Boyd, C R (1994) : Effect of bacterial and chemical retting of kenaff fibre quality, Textile Research Journal, vol. 64 (5), 305 - 308.
8. Rowell, R M (1991) : Natural composites, fibre modification, International Encyclopedia of Composites, Lee, S M (ed.), Vol. 4, VHC Publishers, 1- 16.
9. Varma, I K : Krishna, A : Krishnamoorthy, S (1989) : Composites of glass/modified jute fabric and unsaturated polyester resin, Composites, vol. 20 No. 4, Butterworth and Company, 383 - 388.
10. Berlin, A A ; Volfson, S A ; Enikolopian, N S and Negmatove, S S (1986) : Principles of polymer composites, Springer - Verlag Berlin Heidelberg, Chapter 1.
11. Hancox, N L (1981) : Introduction to fibre composite hybrids, fibre composite hybrid materials, Hancox, N L (ed), Applied Science Publishers, Chapter 1.
12. Shackleford, J F (1988) : Polymers, Introduction to materials science for engineers, 2nd Edition, Macmillan Publishing Company, 403 - 440.

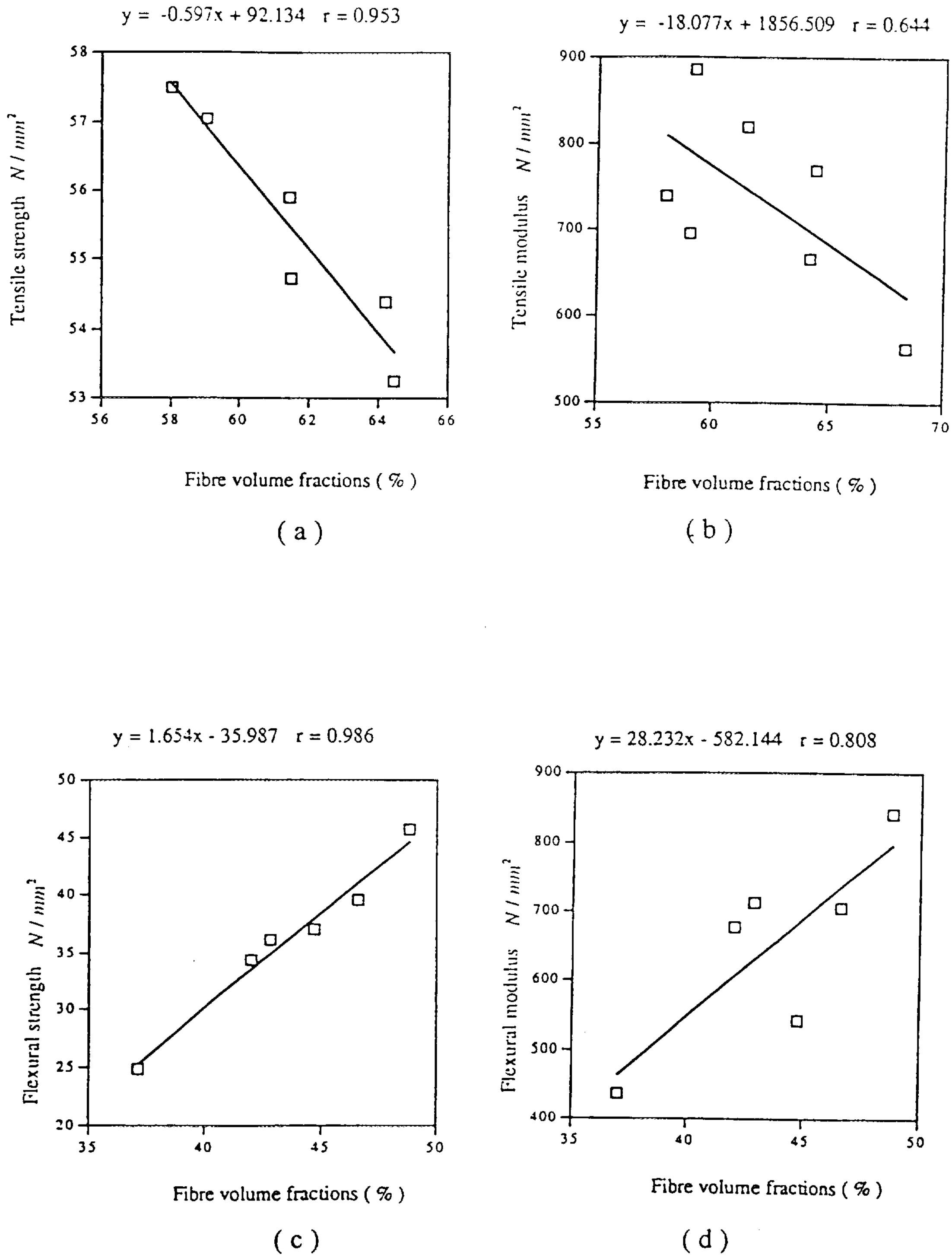
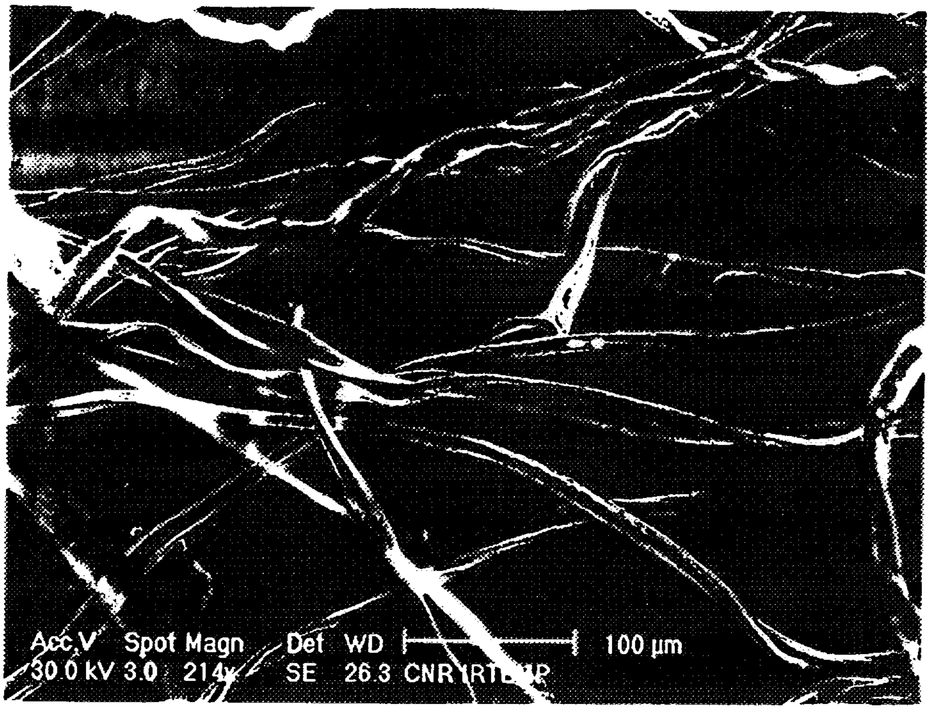


Figure 2 : (a) Tensile strength and (b) Tensile modulus of not treated fabric of cotton - kapok fabric - polyester composites. (c) Flexural strength (d) and Flexural modulus of composites subjected to accelerated weathering conditions.

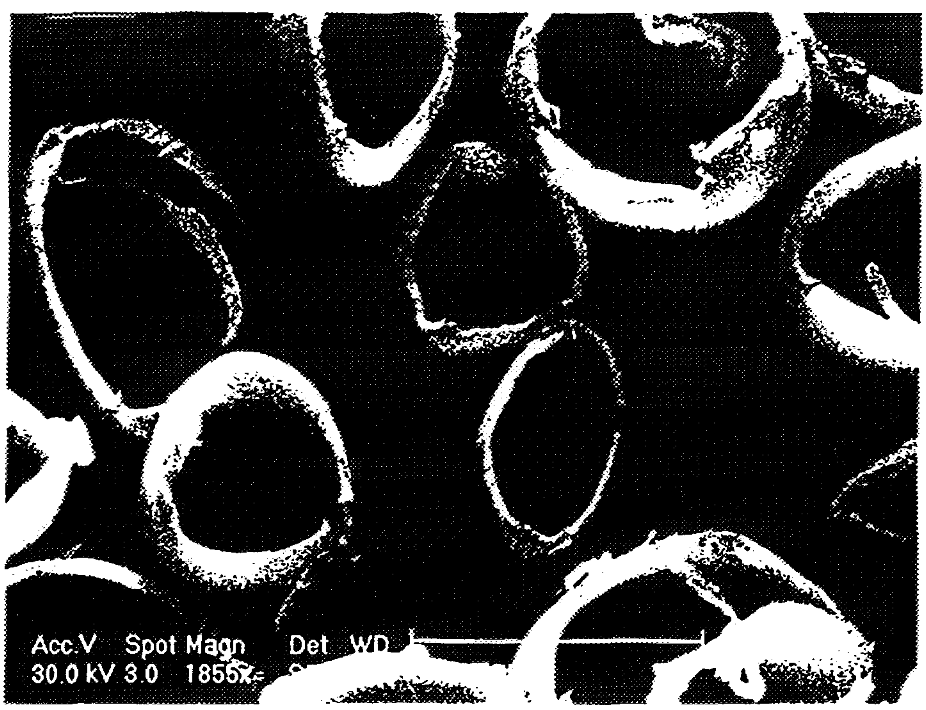


(a)

(b)

Figure 3 : SEM micrographs of (a) Longitudinal view of cotton fibres, (b) Cross sectional view of cotton fibres, (c) Longitudinal view of kapok fibres and (d) Cross sectional view of kapok fibres

(c)



(d)

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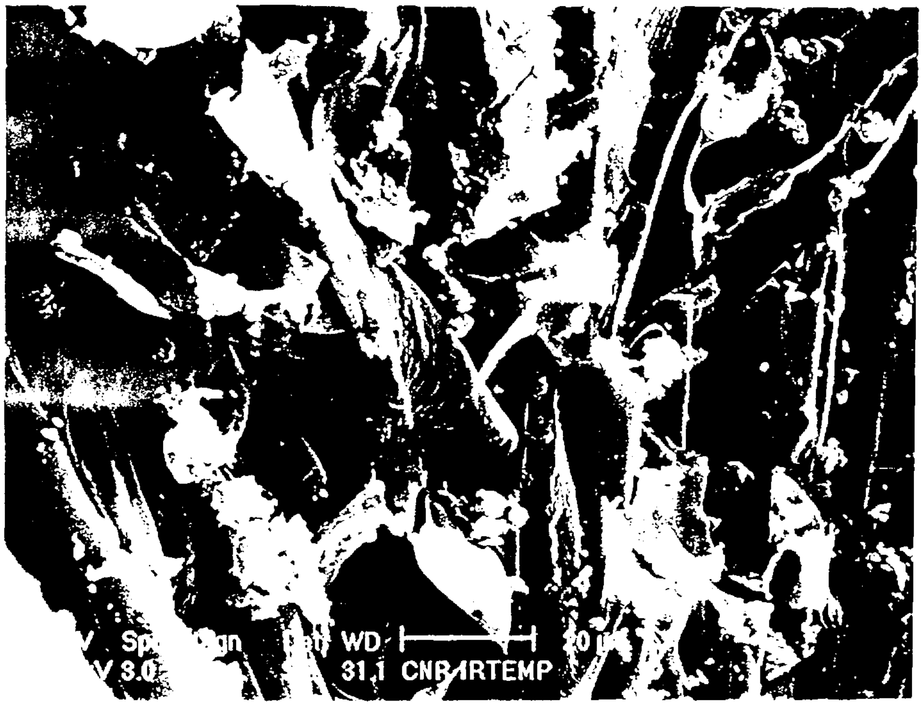
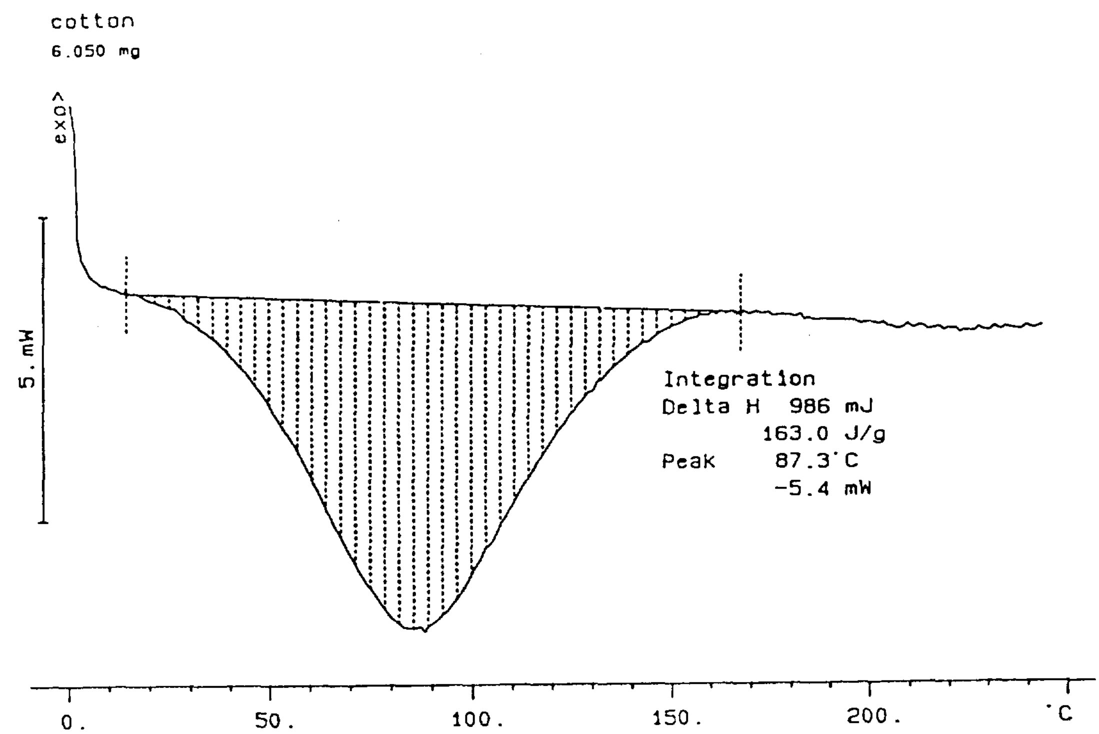


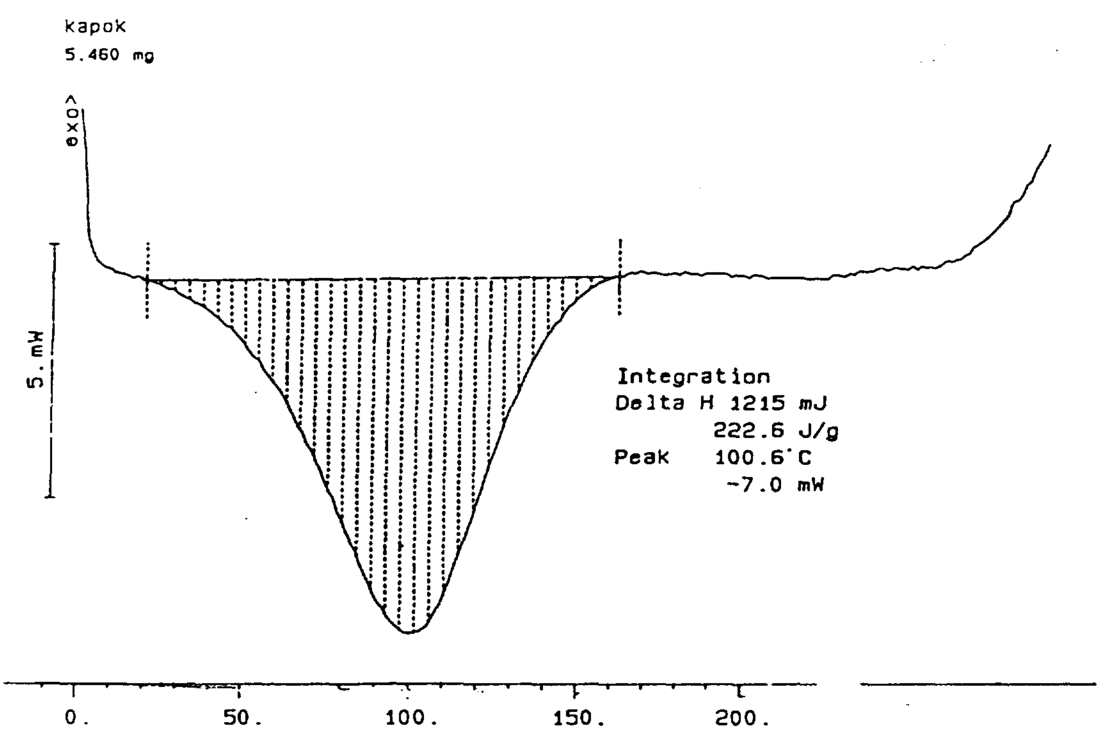
(a)

(b)

Figure 4 (a and b) : SEM micrographs of the tensile fracture surface of polyester - cotton - kapok fabric composite.



(a)



(b)

Figure 5 : D.S.C thermogram of (a) cotton fibre and (b) kapok fibre.

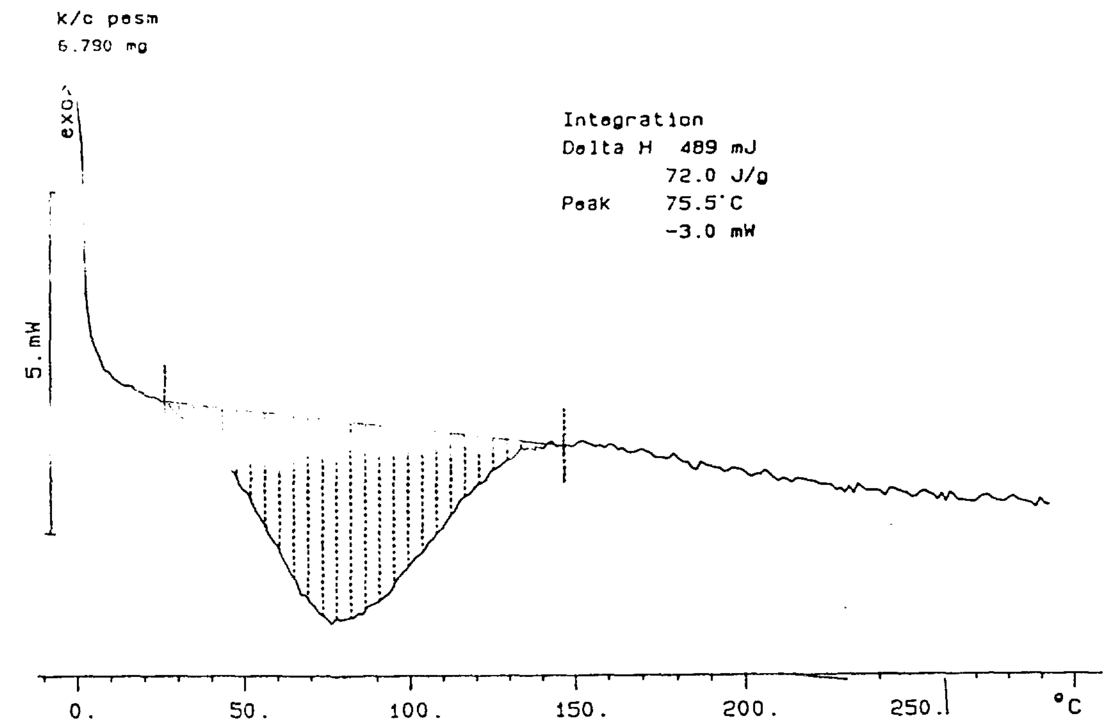


Figure 6 : D.S.C thermogram of cotton - kapok fabric - polyester composite.

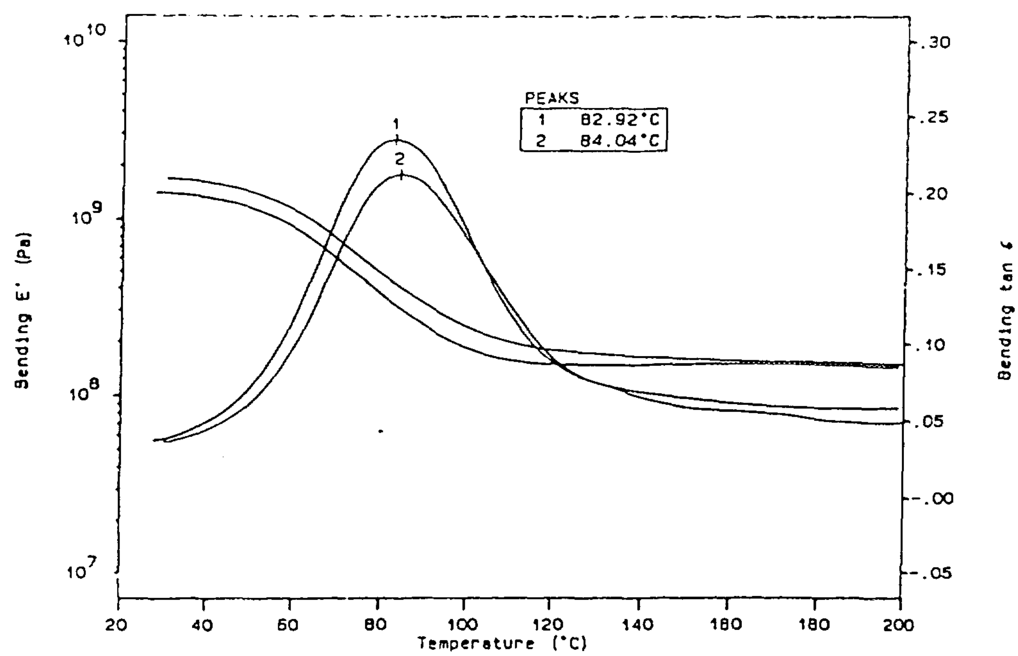


Figure 7 : DMTA thermogram of cotton - kapok fabric polyester composite (1 - 42.05 % and 2 - 61.46 %)

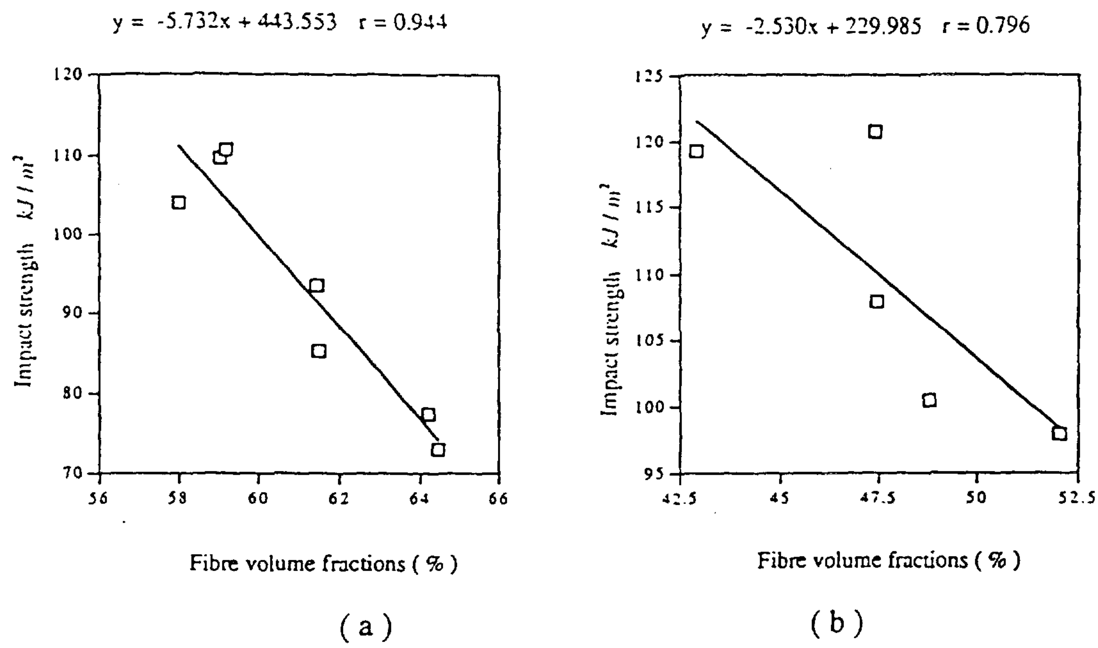


Figure 8 : Impact strength of (a) not treated (b) treated fabric - polyester composites.

INTERFACIAL DEBONDING OF NATURAL FIBRE REINFORCED COMPOSITES

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Abstract

The mechanisms and processes involved in interfacial debonding and fracture of natural fibre reinforced composites (NFRC) have been investigated. The Pull out theory which depends upon factors such as lateral deformation, Poisson's effect and non-uniformity of fibres was used to determine the fracture toughness. The total fracture energy is a contribution from the surface energy, redistribution energy and pull out energy. The surface energy term originates from the creation of three new surface energy terms (fibre, matrix and fibre-matrix interface). The fracture mode is complex as it involves fibre splitting, decohesion, crack formation and propagation.

Using Eshelby's equivalent inclusion method, the transition stresses between the three stages of stress-strain curves were predicted. The first stage of the curve is linear and indicates that bonding of matrix interface is essentially perfect and both phases deform elastically. The second and third stages are non-linear. During the second stage, microcracks are initiated from fibre ends and extend to the matrix. In the third stage, the microcracks become abundant, interlink or coalesce into macrocracks which propagate to fracture. The transition from second to third stage occurs when the crack extends further in the matrix and propagate as a Griffith-type crack.

The propagation of stress corrosion cracks in aligned NFRC were also investigated by using the concept of strain energy release rate as primary parameter to derive values of stress intensity factor for plane strain.

1. Introduction

The manufacture and use of improved natural fibre-reinforced composites have not been conmercialised on a large scale in Ghana, and there is an urgent need to improve upon the physical, chemical and engineering properties of these natural composites so as to facilitate easier fabrication and prolong their service life since there are unique advantages to be gained by developing new and sophisticated uses of the natural fibre composites. The fibres are readily available and renewable, and their extraction and processing into composite materials require simple techniques and minimum energy input. Due to their low density, these fibres can be used to produce composites with high specific strength. In addition, the natural fibres are non-toxic and environmentally degradable.

Unfortunately, the epidermis of the fibre has a thin layer of silica at its outer surface which inhibits good bond formation with polyester resins. Caustic soda or ammonia can remove the silica rich layer to improve surface adhesion. Alternatively, the fibre could be mechanically crushed by rolling to improve the fibre to resin bond, reduce porosity and air content of the parenchyma and lumen, shear the hard epidermis and allowing easy penetration of the resins and other binders to the softer tissues beneath

The binders or matrix materials used can be categorized as polymer based, laterite based, and concrete based (with additive of ash to decrease weight). The common polymer binders are elastomers, wood glues, latex, natural and commercial resins. The most common natural fibre reinforced composites (NFRC) produced in Ghana are polymeric and concrete based.

By incorporating strong, stiff and brittle natural fibres into a softer or more ductile matrix, the NFRC produced would have improved strength, fatigue resistance, stiffness and high strength to weight ratio [1-7]. The matrix material transmits the force to the fibres and provides ductility and toughness, while the fibres carry most of the applied force. The fibre reinforcing materials can be arranged in a variety of orientations, such as, uni-directional, randomly oriented, orthogonal and multiple-ply. In this paper, the complex nature of misoriented short fibre composite interfacial debonding and fracture is discussed since the understanding of such a structure sensitive property is essential for material design and applications.

2. Polymer Natural Fibre Reinforced Composites

The polymeric NFRC produced in Ghana are based on thermosetting phenolic, epoxy and polyester resins as binders; to produce straw-polyester composites, bagasse-phenol formaldehyde composites, coir-polyester composites, plantain/banana-polyester composites, pineapple- and sisal- epoxy composites and jute-epoxy/polyester/phenol formaldehyde composites. The fibres are produced by manual picking and processed with the matrix by either press moulding or hand lay-up. Table 1 shows data on physical properties of various fibre-polyester resin composites, while Table 2 shows data on environmental degradation of fibre reinforced composites [8]. Tables 1 and 2 deserve careful study as they show that mechanical properties of NFRC are lower than glass fibre reinforced composites (GFRC) under normal and adverse conditions. The reason for the discrepancy can be attributed to the poor bonding of natural fibres to the matrix and this phenomenon is the main subject of this paper.

3. Natural Fibre Concrete

Natural fibre-concrete (NFC) is basically made of sand, cement, fibres and water, and is used mainly in the production of corrugated sheets and pantiles for roofing in low cost construction. The plant fibres used are stems (jute, kenaf, hemp), leaves (sisal, pineapple, raffia, palm), fruit hair (coir) and wood fibres (reeds, bagasse, bamboo).

The fibre content (1-2% by weight) is required primarily to hold together the wet mix during manufacture, to inhibit drying shrinkage cracking and to provide early strength until the roof is installed [9]. In normal portland cement matrices, the fibres decay within months or a few years on account of alkali attack. This alkaline attack can be minimized by using high alumina cement or replacing 50% of the cement with pozzolana.

4. Fibre-Matrix Interfacial Debonding

Interface bonding and debonding of NFRC is a structure sensitive property which must be evaluated to determine the compatibility of fibres with matrices. Natural fibres are themselves fibre-reinforced materials and the microfibril angle and cellulose content determine the mechanical behaviour [10].

The effectiveness of the fibre-matrix bond is dependent on the chemical compatibility and the presence of mechanical "keying" between the fibre and matrix. An irregular surface of the fibre is likely to enhance the efficiency of fibre-matrix interfacial bond than smooth ones, due to greater surface area present at the interface. However, natural fibres contain waxes and fatty acid bye-products that are unlikely to form any chemical bonds between the fibre surface and resin, and thereby causing a weaker interfacial bond [1].

Natural fibres fail because as the applied stress increases the weak primary cell wall collapses and decohesion of cells begins following decohesion of cellulosic and non-cellulosic

Table 1. Properies of variuos fibre-polester resin commposites [8]

PROPERTY	POLYESTER RESIN (0 % V_F)	GLASS REINFORCED POLESTER RESIN (UNKNOWN % FIBRE)	BANANA REINFORCED POLYESTER RESIN (11 WT % FIBRE)	COIR REINFORCED POLYESTER RESIN (9 WT % FIBRE)
Density x 10^3 (kgm^{-3})	1.30	1.50 - 1.90	1.22	1.16
Tensile strength (MPa)	41.38	241.4 - 689.6	27 9.6	18 6.1
Flexural strength (MPa)	89.69	344.8 - 862.1	64.00	38.15
Elastic modulus (GPa)	2.06	6.90 - 41.38	3.34	4.05
Impact resistance (kJm^{-2})	7.75	31.16 - 84.76	32.92	39.10
Water absorption (%)*	0.21 - 0.40	0.2 - 1.0	1.36	1.36
Volume resistivity (Ω-m)+	1000	-	400	-

* 24 hour soaking at room temperature + At 100 V(dc)

Table 2. Environmental effect on physical properties of fibre reinforced composites before and after weathering for seven years [8].

PHYSICAL PROPERTY	UNWEATHERED JUTE-FIBRE REINFORCED	WEATHERED JUTE-FIBRE REINFORCED
Bulk density x 10^3 (kgm^{-3})	1.150	1.025
Fibre content (%)	12 - 15	-
Water absorption % (25 °C)		
(a) 24 hours	2.34	3.23
(b) 3 days	2.88	4.16
(c) 7 days	3.87	5.07
Water absorption % (100 °C, 1 hour)	3.08	3.90
Flexural strength (MPa)		
(a) Dry	23.00	11.60
(b) 24 hour soaking	32.10	28.20
(c) 3 days soaking	42.60	19.60
(d) 7 days soaking	34.00	19.10
Tensile strength (MPa)	24.20	14.8

molecules, mainly through cracks and imperfections. The applied stress also causes the uncoiling as well as extension of the crystalline fibrils in the secondary cell walls.

The fracture of NFRC therefore depends on the fibre failure strain and matrix failure strain resulting from viscoelastic behaviour. The failure of the fibres results from uncoiling of microfibril angle accompanied by decohesion and tearing of cell walls. The fracture mechanics of the Pull out theory and Eshelby's equivalent inclusion theory were applied to study the processes involved in fibre-matrix interfacial debonding of NFRC. The work of fibre pullout energy which depends upon factors such as lateral deformation, Poisson's effect and non-uniformity of fibres was used to determine the fracture toughness of the composites. The Eshelby's equivalent inclusion method was used to predict the transition stresses at which interfacial debonding takes place.

Figure 1 shows typical stress strain curves of a natural fibre and NFRC. The low strength characteristics of the NFRC compared with the single fibre can be attributed to lack of compatibility and debonding. By the rule of mixtures (ROM), the strength of NFRC is given by

$$\sigma_c = \sigma_f V_f + \sigma_m (1 - V_f) \qquad (1)$$

where σ_c and σ_f are the composite and ultimate fibre strength respectively; and σ_m is the stress taken up by the matrix at the failure strain of the fibres (ε_f) and is given as $E_m \varepsilon_f$. Similarly, for the tensile modulus,

$$E_c = V_f E_f + (1 - V_f) E_m \quad (2)$$

where E_c, E_f and E_m are the initial tensile moduli of the composite, fibre and matrix, respectively.

5. Pull out theory of fibre-matrix interfacial debonding

The Pull out theory assumes that the fibres break due to presence of flaws that are randomly distributed, and in the absence of this randomness the fibres will break in the crack plane and no pull out will occur [7]. The Pull out theory can be used to determine the fracture toughness in terms of the volume fraction, V_f, fracture critical length, l_c, diameter, d_f, tensile modulus, E_f, failure strength, σ_f, of the fibres; and the interfacial frictional shear strength (τ_f). The fracture mode of NFRC is complex since it involves fibre splitting, decohesion, crack formation and propagation and other energy absorbing mechanisms.

The fracture critical length is calculated by assuming that the average pullout length, $\bar{l}_p$, is half the maximum attainable pullout length and therefore the interfacial frictional shear strength can be obtained from the Kelly-Cottrel equation [11]

$$\tau_f = \frac{\sigma_f d_f}{2 l_c} \quad (3)$$

The fracture toughness can be predicted from contributions of the total work of fracture, W_T, by summing the contributions of all sources of fracture mechanisms involved; i.e., the surface energy term, W_S, the redistribution energy term, W_R, and the pull out energy term, W_p, [12]

$$W_T = W_S + W_R + W_P \quad (4)$$

where [13, 14]

$$W_R = \frac{V_f \sigma_f^3 d_f}{6 E_f \tau_f}, \quad W_P = \frac{V_f \sigma_f^2 d_f}{24 \tau_f} \quad (5)$$

The major contributions to the overall work of fracture of the composite are W_S and W_P. The surface energy term originates from the creation of three new surfaces, namely; the fibre fracture energy, W_F; the matrix fracture energy, W_M; and the fibre-matrix interface energy W_I. The energy absorbed to create these new surfaces is given by [12]

$$W_S = W_M (1 - V_f) + W_F V_f + W_{IF} \quad (6)$$

where W_M is matrix energy term (~ 1.365 kJm^{-2}), $W_F = ½\sigma_f \varepsilon_f l_d$ is the fibre fracture energy term or energy absorbed in creating the fibre fracture surface and l_d is the average debonded length (which is assumed to be of the order of l_c whereby $l_d \approx l_c$). The interface fracture energy term, W_{IF} for mode I debond where the fibre fracture strain is less than matrix strain ($\varepsilon_f < \varepsilon_m$), is given by

$$W_{IF} = V_f \frac{l_c}{d_f} W_I \tag{7}$$

where W_I is the interface energy term or interfacial fracture toughness. It is difficult to determine W_I but can be approximated to be $\approx W_M$ since the matrix adheres to fracture surface.

Usually the debond length l_d is in the range of l_c such that $l_d \approx l_c = 4T_p$. If $l_d > l_c$ the predicted energy of the debonding, W_D (which is implicit in the surface energy term), and the energy to fracture the fibre (W_F) would be affected. The fracture toughness or energy increases linearly with fibre content up to $V_f = 0.24$ [7]. As volume fraction of fibre becomes higher than 0.24, fibre-fibre interactions would increase and cause changes in τ_f and l_c , which would lead to low values of debonding energy and fracture toughness.

The expression deduced for W_T then becomes

$$W_T = W_M (1 - V_f) + W_F V_f + \frac{V_f l_c}{d} W_M + W_R + W_P \tag{8}$$

For resins, $W_M = 1.365$ kJ/m^2, eqn (8) becomes

$$W_T = 1.365 \left[1 + V_f \left(\frac{l_c}{d_f} - 1 \right) \right] + ½\sigma_f \varepsilon_f l_c V_f + \frac{V_f \sigma_f^3 d_f}{6E_f \tau_f} + \frac{V_f \sigma_f^2 d_f}{24\tau_f} \tag{9}$$

The experimental data obtained for the sisal fibre were $l_f = 0.40$ mm, $d_f = 0.02$ mm, $V_f = 0.20$, $\varepsilon_f = 5$ %, $\sigma_f = 400$ MPa, $\tau_f = 0.70$ MPa and $l_c = 0.20$ mm and these were used to calculate contributions of each energy absorbing mechanism as shown in Table 3. For the NFRC, $\varepsilon_f = 2$ %, $\sigma_f = 160$ MPa.

Table 3. Contribution of energy absorbing mechanisms to debonding and fracture

NFRC	W_S (kJm^{-2})			W_P (kJm^{-2})	W_R (kJm^{-2})	W_T (kJm^{-2})	W_{FE} (kJm^{-2})
	W_M (kJm^{-2})	W_F (kJm^{-2})	W_{IF} (kJm^{-2})				
$0.20V_f$	1.365	2.000	2.730	38.100	1.722	44.044	20-35

The total fracture toughness or energy of 44.044 kJm^{-2} obtained by the Pull out theory is very high as compared to typical experimental value of the work of fracture, W_{FE}, = 21.000 kJm^{-2} [7] of the NFRC determined by the Izod Impact test. The difference could be attributed to the mode of specimen preparation and testing conditions.

6. Eshelby's Equivalent Inclusion Method (EEIM)

Typical stress-strain curves of a fibre and a NFRC characterized by an initial linear region and followed by a curvature indicating the increased rate of strains produced with increases in stress are shown in Fig. 1, which confirm the viscoelastic behaviour of the materials as a two element Maxwell model.

The first stage of σ - ε curve is linear and indicates that bonding of matrix interface is essentially perfect and that both phases deform elastically. The second and third stages are non-linear, and the non-linearity is due to the initiation, development and extension of microcracks. During the second stage, microcracks are initiated from fibre ends and extend to the matrix. In the third stage, the microcracks become abundant, interlink or coalesce into macrocracks which grow to a large size, propagate, leading to failure of the composite. The transitions at B' and C' in the stress-strain curves or the transition stress between stage I (AB'), stage II (BC') and stage III (CD') of the σ - ε deformation curve of short fibre reinforced composites can be correlated with the interfacial debonding.

As an analytical method, the EEIM can be used to predict the transition stress, σ_1 , between the first and second stages where it is assumed that while a majority of the fibres are randomly oriented as shown in Fig. 2, a penny-shaped crack can be initiated from the end of a short-fibre which is aligned to the loading direction as illustrated in Fig. 3. In addition, the critical stress, σ_2 , necessary for the crack to propagate into the fibre as penetration type, or into the fibre-matrix interface as debonding type could be predicted.

6.1. Transition Stress, σ_1

The critical applied stress at which a penny-shaped crack arrested by adjacent fibres penetrates the fibres and the cumulative crack density function were determined. Figure 2 shows the configuration of a randomly oriented short fibre reinforced composite showing both the global and local coordinates denoted by X_i and X'_i respectively. The applied stress along X_3 axis, σ_0 , can be decomposed into three components, $\sigma_{3'3} = \sigma_0^2 \cos^2\theta$, $\sigma_{2'2} = \sigma_0^2 \sin^2\theta$, and $\sigma_{23'} = \sigma_0 \sin\theta\cos\theta$, where the prime denotes the local coordinates attached to the fibre, and θ is the orientation angle of a short fibre with respect to the X_3 axis (loading direction). The short fibres shown in Fig. 2 are assumed to be elongated ellipsoids of the same size and oriented randomly such that the composite material possesses transverse isotropy. The probability density function, or the orientation factor, $g(\theta)$, is taken as [15]

$$g(\theta) = 1/\alpha \quad (0 \le \theta \le \alpha); \qquad g(\theta) = 0 \quad (\alpha \le \theta \le \pi/2) \qquad \textbf{(10)}$$

A plot of the orientation factor versus orientation angle is shown in Fig. 4.

The transition stress, σ_1, between the first and second stages was calculated for the condition at which the penny-shaped crack was initiated from the end of a short fibre which is aligned to the loading direction as shown in Fig. 3(a). Toya and Mitra [16] have computed σ_1 for a completely aligned short fibre composite. If the total free energy of the composite before and after the fibre-end crack is initiated are U_1 and U_2 respectively, then to form a small penny-shaped crack at the fibre-end, the following inequality must be satisfied, $U_1 \geq U_2$.

The inequality can be expressed as [13]

$$\frac{8\sigma_0^2(1 - \nu_m^2)(1 + \xi)c_1^3}{3E_m} \geq \pi c_1^2 \gamma_m$$

where c_1 is the radius of the penny-shaped crack, and E_m, ν_m, and γ_m are the Young's modulus, Poisson's's ratio and surface energy of the matrix respectively. The fibre interaction parameter, ξ, is a function of elastic constants of the matrix and fibre, the fibre aspect ratio and volume fraction. It is also assumed that the surface energy term of the matrix-fibre interface, γ_I, is much smaller than that of γ_m. For completely aligned short fibre system,

$$\sigma_0 = \left[\frac{3\pi\ \gamma_m\ E_m}{8(1 - \nu_m^2)(1 + \xi_1)c}\right]^{1/2} \quad (12)$$

To account for the random orientation of the short fibres, and by neglecting the shear and transverse stress components, the effective applied stress for a short fibre at an angle θ with respect to the X_3 axis is $\sigma_0^2\cos^2\theta$. By replacing σ_0^2 with $\sigma_0^2\cos^2\theta$ and considering the contribution of all misaligned fibres, the transition stress becomes

$$\sigma_1 = h_1 \sqrt{\frac{3\pi\ \gamma_m\ E_m}{8(1 - \nu_m^2)(1 + \xi_1)c_1}} \quad (13)$$

where h_1 is the orientation factor defined by [15]

$$h_1 = \int_0^{\alpha} \cos^4\theta \frac{1}{\alpha} d\theta \quad (14)$$

6.2. Transition Stress, σ_2

The end of the stage II corresponds to the position when the crack of radius, c_1 and c_2 is about to propagate as indicated by solid line in Fig. 5. Therefore, the transition from second stage to third stage occurs when the crack extends further into the matrix, and the critical stress σ_2 for the penny-shaped crack of radius c_1 and c_2 to propagate as a Griffith-type crack is [15]

$$\sigma_2 = \sqrt{\frac{\pi \gamma_m E_m}{2(1 - \nu_m^2)(c_1 + c_2)}} \quad (15)$$

The crack propagation may be into the fibre (penetration type) or into the fibre-matrix interface (debonding type), and in either case may occur at a stress level below σ_2, and hence it is feasible for the crack to extend into the matrix at the beginning of the third stage of the σ-ε curve.

6.3. Computation and Data analysis

Consider a 20 % short fibre reinforced resin with the following materials properties. Matrix: $E_m = 2 \times 10^9$ Pa, $\nu_m = 0.42$, $\gamma_m = 1.356$ kJm^{-2} ; Fibre: $E_f = 2 \times 10^{10}$Pa, $\nu_f = 0.20$, $l_f = 0.40$ mm, $d_f = 0.02$ mm; and Composite: Interfacial energy, $\gamma_I = 2.730$ kJm^{-2}, $c_1 = d_f$, and $c_2 = 1.5d_f$ $g_I = E_R / E_A = 0.73$, $\alpha \approx 30°$, and $h_I = 0.8407$ (where E_R and E_A are respectively the values of Young's modulus for composite with fibres arranged in random and aligned to the loading).

The predicted value of $\sigma_1 = 133$ MPa as compared to experimental value of about 100 MPa, while the predicted value of $\sigma_2 = 191$ MPa as compared to experimental value of 160 MPa.

7. Environmental effect and Stress-Corrosion

Under the combined influence of stress and environment, NFRC may fail at much lower stress than in the absence of the environment. Spontaneous cracking of fibres in acids in the absence of an externally applied stress based on ion exchange and leaching of material at crack tip have been reported [17]. Crack growth data can be used to predict component lifetimes and the existence of inherent flaws in the material. The analyses of crack growth in composite materials are based on strain energy release rate, G, as a primary parameter from which values of stress intensity factor for mode I opening, K_I, can be derived using the plane strain equation

$$K_I^2 = \frac{EG}{(1 - \nu^2)} \quad (16)$$

where E and ν are the Young's modulus and Poisson's's ratio parallel to the fibres respectively.

In NFRC the crack growth is irregular as the direction of the crack growth and the shape of the crack front varies considerably from point to point, and these changes are due to local variations in fibre packing and indicate that crack growth through the resin may have a significant effect on the overall crack growth rate [18]. The average crack growth rates in Fig. 6 can be represented by the relationship

$$\frac{da}{dt} = CK_I^n$$

where C and n are constants. For $V_f = 0.6$, $n = 3.6$, while for $V_f = 0.5$, $n = 4.2$.

For direct comparison, it has been reported that da/dt in 0.6 N HCl is higher than in 1 N H_2SO_4 for a given K_I [17]. The changes in appearance of the fracture surface with increasing K_I are consistent with the model for stress corrosion cracking proposed by Hogg and Hull [18]

8. Interfacial Bonding Improvement

The two common methods of improving wettability of fibres in matrix are chemical treatment and mechanical treatment. Caustic ammonia or soda will remove silica while crushing fibres increases surface area for bonding. The cost of chemically removing the silica rich layer at the surface of the epidermis or plasticising the fibre may outweigh any improvement in mechanical properties. To improve interfacial fibre-matrix bonding, wettability of fibre by resins must be studied. Fibres treated with solution of NaOH result in modification of surfaces leading to increased wettability and prevent floatation and segregation of fibres in resins, since strong bonding improves mechanical properties. The chemical treatment causes the removal of cuticle and tyloses from the surface of fibre resulting in rough fibre surface with regular spaced pits. Untreated fibres tended to float in the polyester whereas alkali-treated fibres are uniformly dispersed in matrix.

The effect of alkali treatment on the microstructure, surface topography and tensile strength of fibre have been investigated [19], and Table 4 shows the mechanical properties of alkali treated (NaOH, 3 weight %) and untreated coir polyester composites which illustrates the effect of soaking time on debonding stress. Treatment T1 involves soaking the coir in NaOH for 72 hours, while treatment T2 consists of soaking in 144 hours with NaOH replenishment at every 24 hours.

Table 4. Mechanical properties of coir-polyester composites [19]

V_f	Coir treatment	% Porosity	FS (MPa) *	FM (GPa)+	IS(kJm^{-2}) #
0.00	-	-	48.5	3.08	8.33
0.10	Untreated	3.71	33.5	2.79	-
	T1	0.65	34.0	3.03	-
	T2	0.50	34.5	3.00	-
0.20	Untreated	9.17	33.0	2.50	7.44
	T1	1.60	42.3	3.38	11.33
	T2	0.89	42.0	3.39	-
0.30	Untreated	11.24	29.0	1.72	-
	T1	4.60	41.5	3.33	-
	T2	2.43	40.5	3.38	-

* FS = Flexural strength; + FM = Flexural modulus; # IS = Charpy Impact strength

9. Discussion and Conclusions

The benefits of using natural fibre reinforced composites include but not limited to improved plastic shrinkage, settlement cracking, low permeability, greater impact, abrasion, and shatter resistance of the matrix material. However, it is clear that the problems of durability are associated with compatibility of fibres and matrix material and environment effect on stress corrosion resulting from interfacial debonding.

The analysis of interfacial debonding considered from the analyses of the Pull out theory and Eshelby's equivalent method can provide basic mechanical data required for design of the composite materials without expensive and time consuming experimentation.

References

1. McLaughlin, E.C., *J. Mater. Sci.,* 1980, Vol 15, pp. 886 - 890.
2. Kulkarni, A.G., Satayanarayana, K.G., Sukumaran, K., and Rohatgi, P.K., *J. Mater. Sci.,* 1982, Vol. 16, pp. 905 - 914.
3. Satayanarayana, K.G., Pillai, K.S., Sukumaran, K., Pillai, S.G.K, Rohatgi, P.K., and Vijayan, K., *J. Mater. Sci.,* 1982, Vol. 17, pp. 2453 - 2462.
4. White, N.M., and Ansell, M.P., *J. Mater. Sci.,* 1983, Vol. 18, pp. 1549 - 1556.
5. Kulkarni, A.G., Satayanarayana, K.G., Rhotagi. P.K., and Vijayam, K., *J. Mater. Sci.,* 1983, Vol. 18, pp. 2290 - 2296.
6. Mukherjee, P.S., and Satayanarayana, K.G., *J. Mater. Sci.,* 1984, Vol. 19, pp. 3925 - 3934.
7. Sandi, A.R., Prasad, S.V., and Rohatgi, P.K., *J. Mater. Sci.,* 1986., Vol. 21, pp. 4299 - 4304.
8. Rohatgi, P., **Composite materials from local raw material resources**, University of Wisconsin Publication No. 568E/6365E, 1983.
9. Jamiru, T., *J. Appl. Sci & Tech.*, Vol. 1, Nos. 1 &2, 1996, pp. 127 - 131.
10. Ayensu, A., *J. Appl. Sci & Tech.*, Vol 1, Nos. 1 & 2, pp. 28 - 40, 1996 .
11. Kelly, A., *Proc. Roy. Soc.*, London, A 319, 1970, p. 95.
12. Martson T.U., Atkins, A.G., and Felback, D.K., *J. Mater. Sci.*, Vol. 9, 1974, p. 447
13. Piggott, M.R., *Load Bearing Fibre Composites*, Pergammon, Oxford, 1980, Chpt. 7.
14. Beaumont, Fitz-Randolph, J., Philips, D.C., and Tetelman, A.S., *J. Comp. Mater* 5, 1971 p. 542.
15. Taya, M., and Chou, T.W., *J. Mater. Sci.*, Vol. 17, 1982, pp. 2801 - 2808.
16. Taya, M., and Mura, T., *J. Appl. Mech.*, Vol. 48, 1981, p. 361.
17. Price, J.N., and Hull, D., *J. Mater. Sci.*, Vol. 18, 1983, pp. 2798 - 2810.
18. Hogg, P.J., and Hull, D., **The British Plastic Federation, 13th Reinforced Plastics Congress**, Brighton, 1982, pp. 115, London.

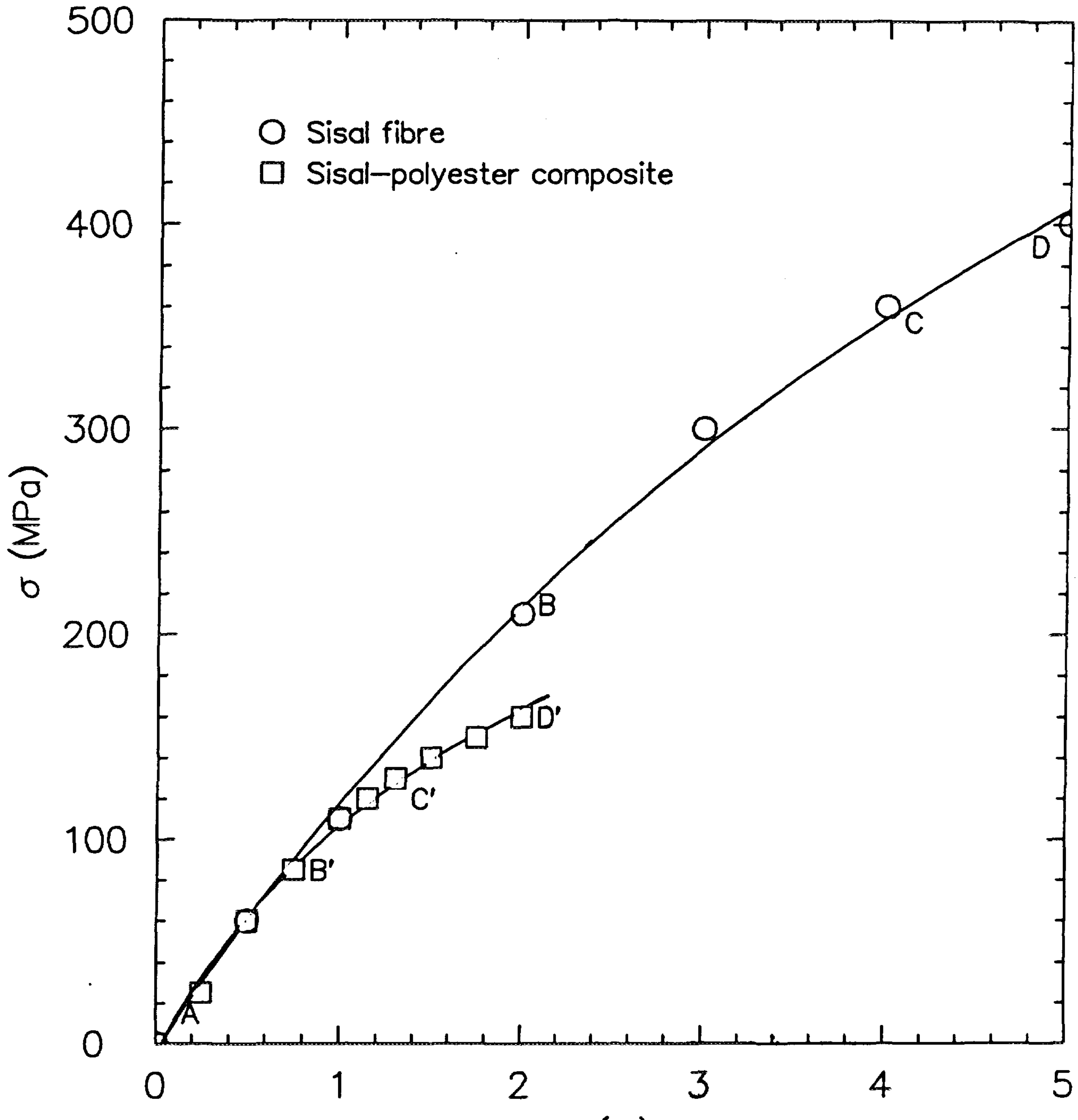

Fig. 1. Typical stress—strain curves of a sisal fibre and NFRC showing transition stage at B, C, B′ and C′ respectively

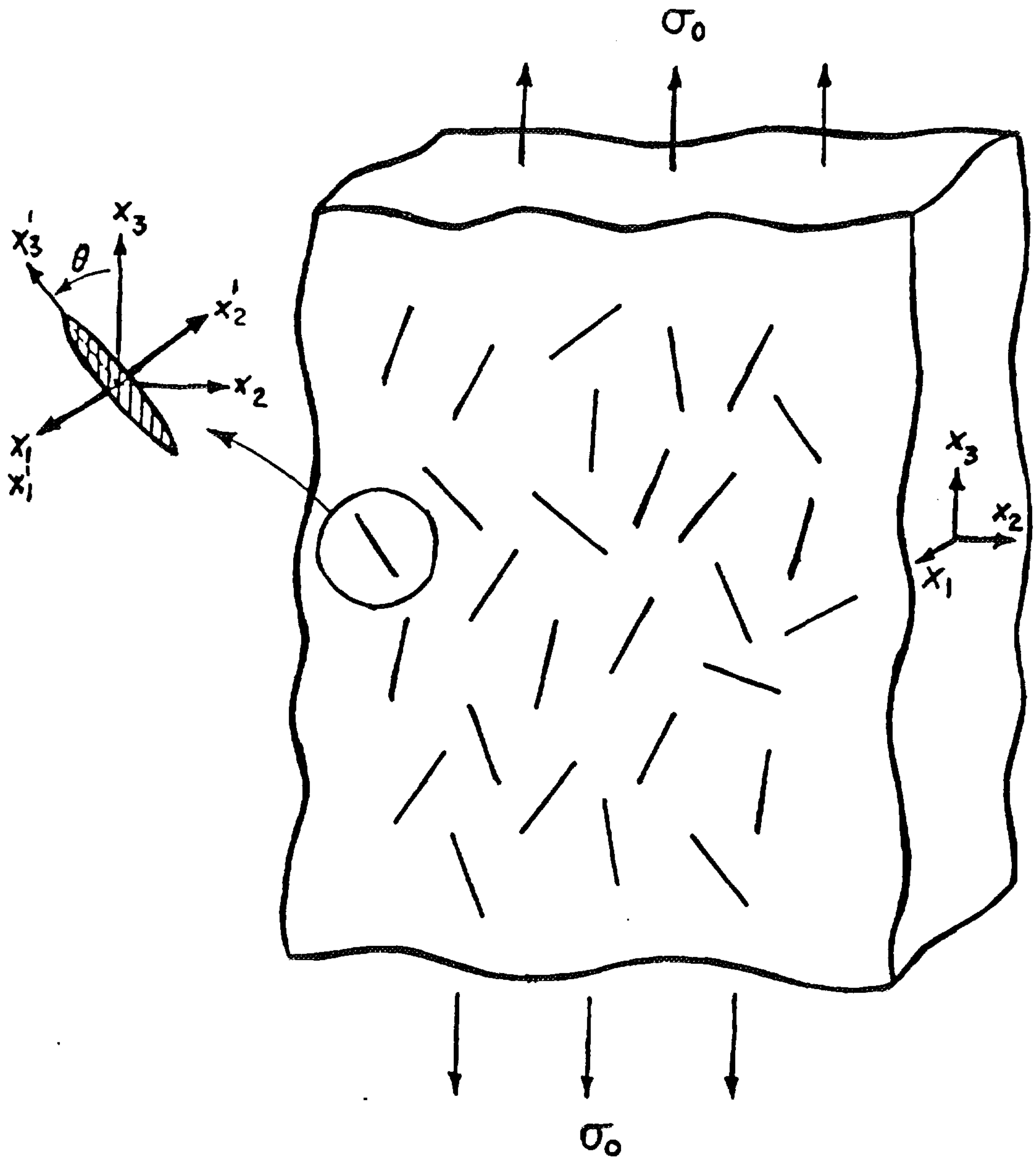

Fig.2 A schematic diagram of a randomly oriented short fibre reinforced composite.

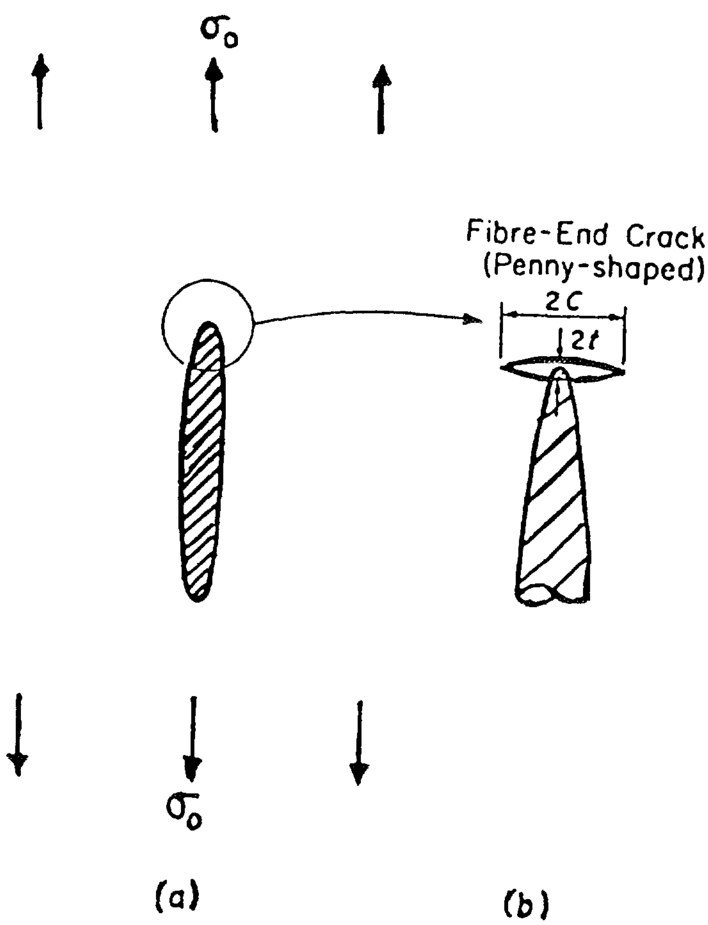

Fig.3 A crack model for calculating the first transition strees .

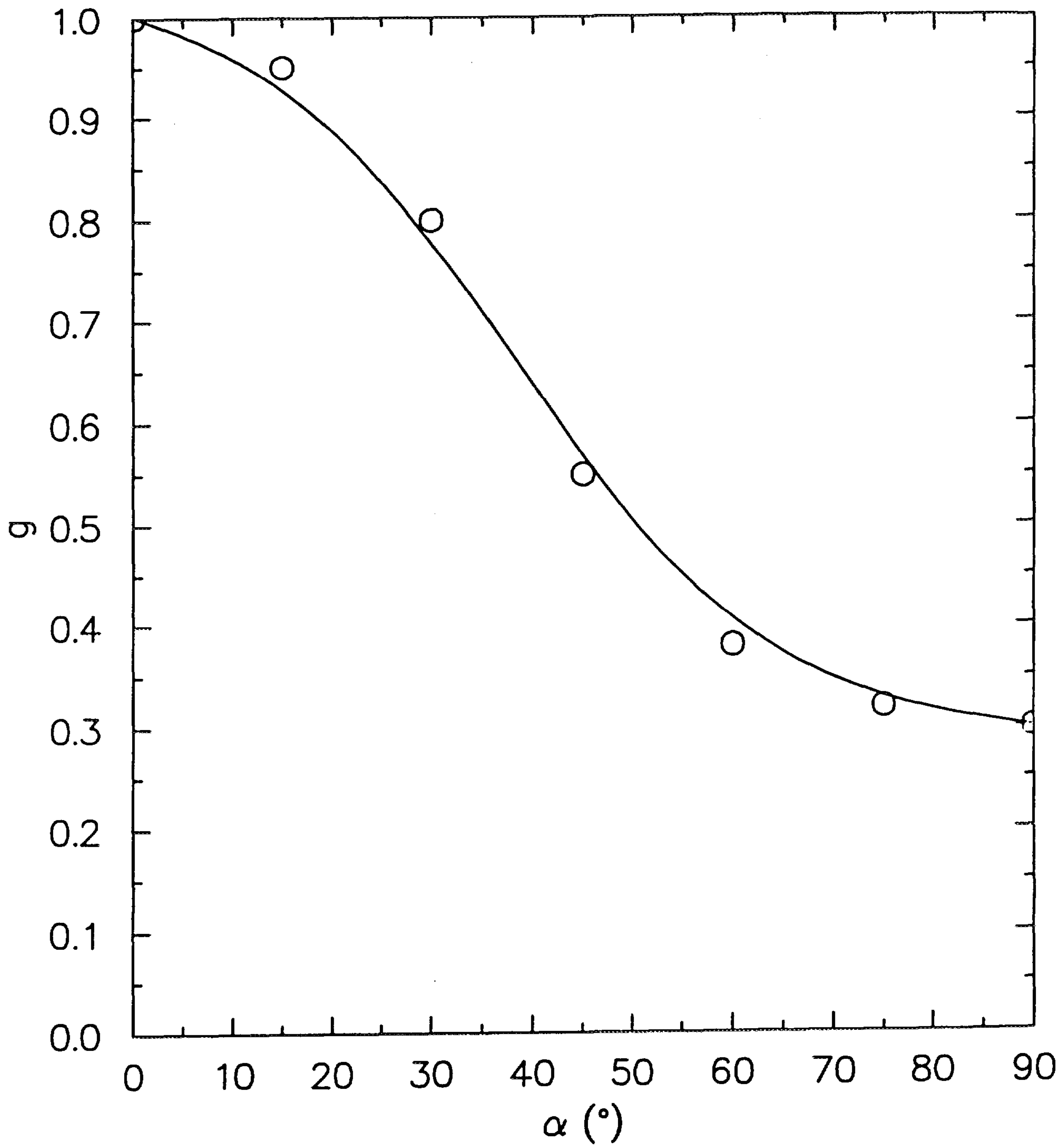

Fig.4. Plot of orientation factor versus orientation angle

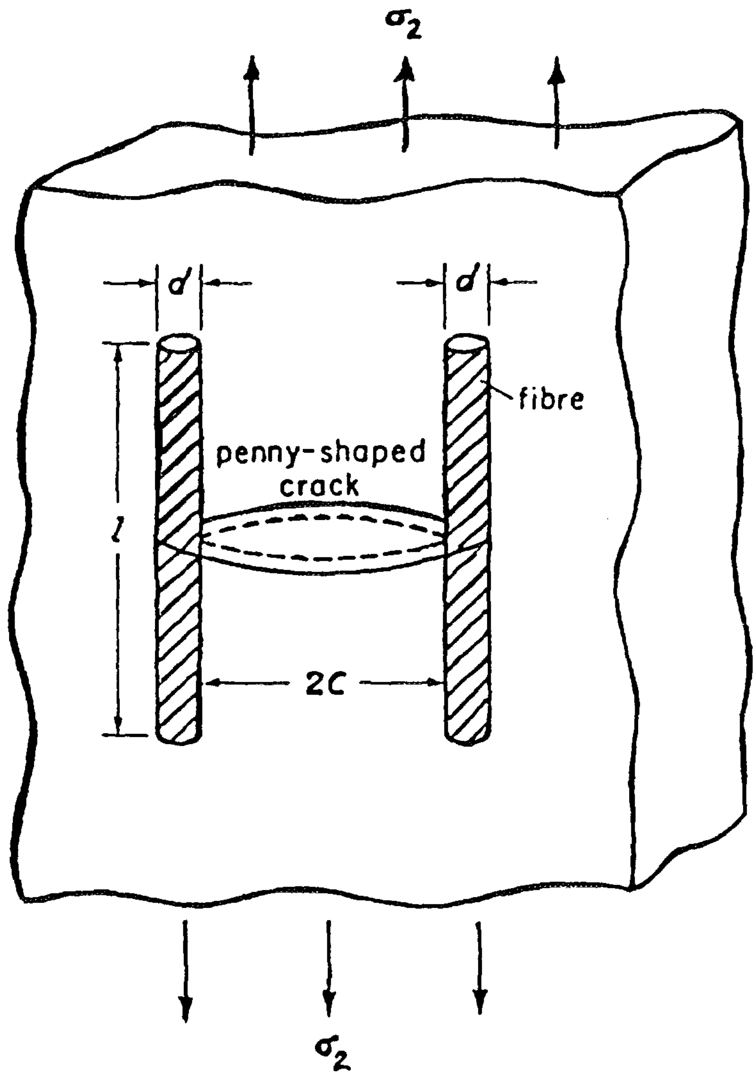

Fig.5 A crack model for calculating the second transition strees.

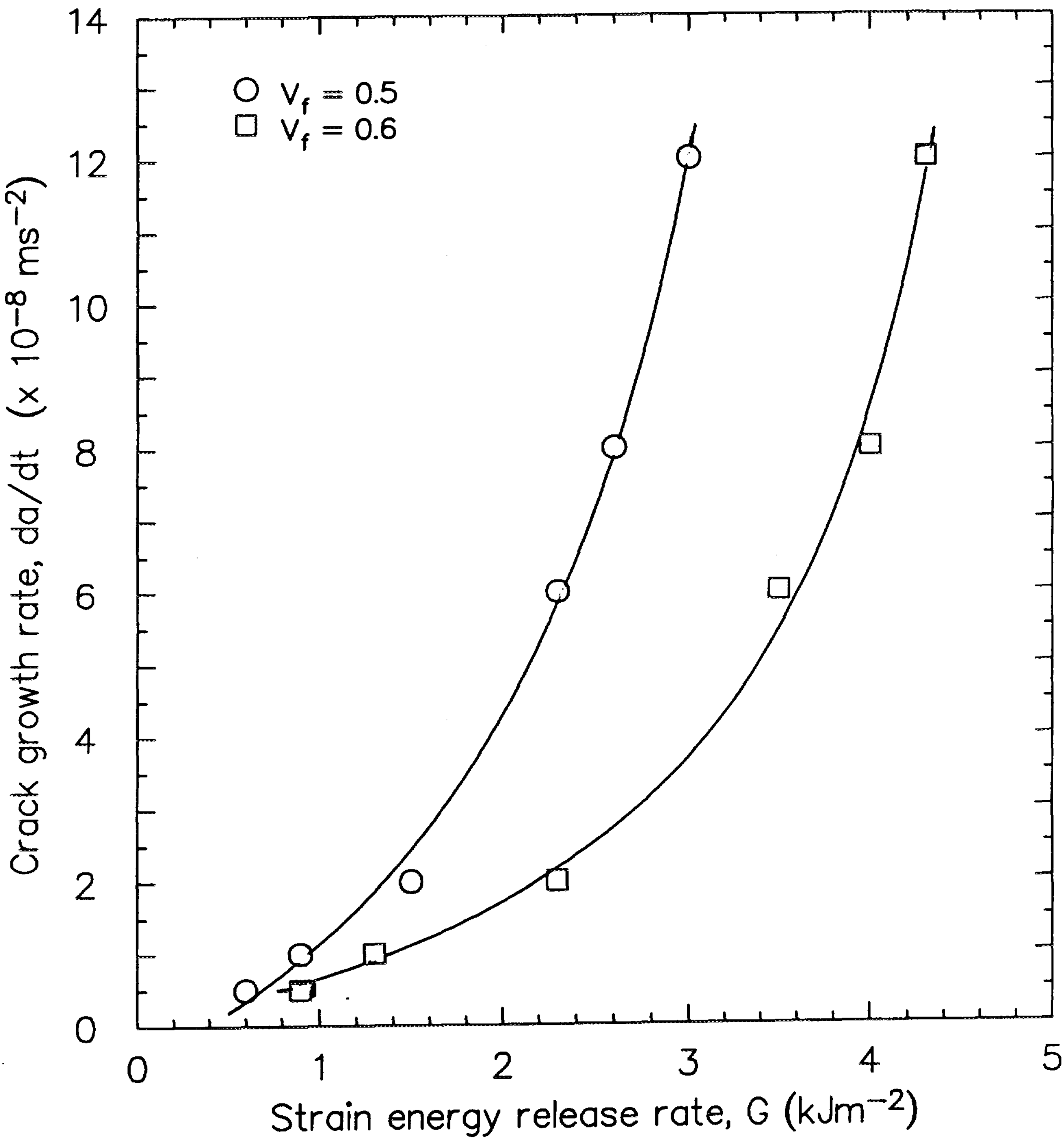

Fig. 6. Effect of G on crack growth rate for two values of V_f

WOOD WASTES AND RESIDUES IN PARTICLE BOARDS: OPPORTUNITIES FOR EFFICIENT AND ECONOMICAL USE OF FOREST RESOURCES IN DEVELOPING COUNTRIES

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Abstract

The rising cost of solid timber, increasing trend towards maximising use of scarce wood resources and the need to produce dimensionally stable products that are cost effective has led to fast growth of the wood panel industry. World production of panel products has increased tremendously from a mere 10 million m^3 in 1950 to more than 140 million m^3 at present. Among the various panel products, particle boards are the fastest growing with an estimated annual production of 57 million m^3 (or 37%).

Particle boards are manufactured from wood chips using binders under heat and pressure. Raw material requirement is less stringent compared to other panel products like plywood. Virtually, any species of wood can be used depending on availability and cost. Additionally, wood wastes and residues are often utilised providing a known composition mix is prepared.

The use of industrial wastes and residues for production of particle boards is one area that is the focus for economical and efficient use of forest resources in developing countries. The level of production of these wastes and residues is quite alarming. In Kenya for example, it is estimated that non-commercial thinnings as wastes contribute about 8% of the forest plantations (cypress and pines), logging wastes account for 24% of harvested wood volume while saw dust is in the order of 15% of the wood. The need for increasing their use in the production of particle boards, among others, ranks high in the country.

This paper presents an overview of the particle board industry in the world with emphasis on the use of wood wastes and residues in the developing countries. It provides a case study of the level of wood wastes and residues production in Kenya and initiatives in their utilisation for particle board production. The quality of locally produced particle boards from these resources and the future scope are examined.

1.0 Background

1.1 Overview

The term particle board refers to a pressed sheet of material made from wood chips or other lignocellulosic material, bonded with synthetic or other organic binders. The term covers a wide range of products available in the market. The following are the main types;

- Chipboards - manufactured from very small wood chips and represent the most common type,

- Cement boards - manufactured from wood chips bonded with cement. It has high dimensional stability, good fire and fungal resistance but comparatively heavy (1000 kg/m^3),
- Waferboards - manufactured from large wood flakes in comparison to chipboards, and
- Strandboards - manufactured from wood chips mid size between those used for chipboards and waferboards.

Commercial production of particle boards started in 1941 following commissioning of the first plant at Bremen in Germany. The board was from spruce chips (sawdust) using phenolic resin as the binder. Several developments were carried out in the mid 1940s involving expounding production parameters and their effect on board properties as well as introduction of urea-formaldehyde resins that were cheaper. The technology spread to Switzerland in 1944 and by mid 1950s it had reached USA and Australia. By the 1970s improved machinery and equipment had been developed to make better quality boards from mill residues placing more emphasis and capital in utilising these cheaper materials. Further initiatives during this decade saw development of new products like waferboards and strandboards. In the 1980s intensive research was undertaken in alternative sources of adhesives (isocyanates, sulphite liquor, kraft lignin etc).

Production of particle boards has expanded rapidly since the mid 1940s. World production increased from around 50,000 m^3 in 1950 to 57 million m^3 in the 1990s and is projected to reach 70 million m^3 by the year 2000. USA is the largest producer (9 million m^3) followed by Germany (7 million m^3) and Russia (6.4 million m^3). The three countries account for about 54% of the total world production. Developing countries contribution to world production is generally insignificant.

In terms of trade, total volume of particle boards on the world market was in the order of 9.32 million m^3 in 1990. Developed countries contributed about 8.89 million m^3 of the total exports. The four leading exporting countries were Belgium/Lux, Canada, Germany and Australia accounting for 58% of the total exports. Developing countries contribution to the export market was only 4.63 % with Indonesia being the major exporter.World imports were in the order of 8.61 million m^3. The four leading importers were USA, Germany, UK and France accounting for 55.08% of the total imports. Imports by developing countries were only 8.24%. China and Singapore were the main importing countries.

The end-uses of particle boards can be classified into two groups; structural and non-structural. A wide range of particle boards are produced with design parameters that permit their use as structural materials. Typical examples are waferboards used in the construction industry. However, the greatest use of particle boards by far is as non-structural panel products. Majority of the particle boards are produced for use in the furniture industry. Wide application is in the production of fixed (eg. cupboards, shelves, wardrobes) and movable furniture (chairs, tables, wall units, TV cabinets) both for home and office use. Additionally, particle boards are used for interior building (eg. wall panels, doors, flooring) or carriage work (trains, coaches, casinos etc). New developments have led to the production of particle boards for exterior panels. Typical example is Novobord, a product from South Africa. It is made using wattle tannin adhesive covered with a phenolic laminate paper finish. It has many exterior uses such as highway signs, exterior cladding and concrete formwork.

1.2 Raw Materials for particle boards

Particle boards are products which came into the market as a result of the search for alternative composite products that are cost effective. Cost is thus one of the major over-riding factors in deciding raw materials for particle board production. Four requirements have been identified as important in deciding raw materials for particle boards (Moslemi, 1974);

- availability in adequate quantities,
- inexpensive,
- incurring relatively low cost in handling and storage, and
- suitable form for board manufacture

Wood is the most widely used lignocellulosic material. Virtually any species of wood (hardwoods and softwoods) can be used providing it conforms to the first three of the above requirements. Nevertheless, it is advisable to use a single species, closely related species or a constant composition mix to avoid variation in density (hence strength variations) and appearance.

Apart from wood, non-wood lignocellulosic materials have also formed application in particle boards. Majority are agricultural residues notably;

- flax shives - woody stem residues after the removal of flax fibres. They were once used in the particle board industries in Europe after World War II for production of low density boards but reliability of supply led to decline in favour of more available sources.
- bagasse - residue after extraction of sugar from sugar cane.
- cotton and maize stalks hold some possibility as sources of lignocellulosic materials.

However, most of these sources have their own limitations. Some of these are with respect to harvesting, transportation, storage and elimination of impurities that make the source of raw material unattractive.

Adhesives (resins) are the next important raw materials in particle boards. The main types used are thermosets. Amongst these are:

- Urea formaldehyde (:UF) - the most widely used resin due to low cost, versatility and ease of application. It is used in particle boards for interior use.
- Phenol formaldehyde (PF) - second most widely used resins and more important where waterproof properties are required due to their resistance to breakdown in both cold and hot water. However, it is generally more expensive than UF.
- Melamine Formaldehyde (MF) - Most durable but expensive resin. Rarely used by itself but occasionally used in conjunction with UF for better moisture and heat resistance.

- Other binders:
  - Tannin Formaldehyde - It is similar to PF and more readily available in some areas eg. South Africa. Cheaper than PF.
  - Sulphite waste liquor - from sulphite pulping process. Has been used in Europe.
  - Isocyanates - been used in Japan, UK and Germany.
  - Cashew nut shell liquid (CNSL) - useful PF type of resin.

The third and final group of raw materials are additives. The latter are compounds added to particle boards in the course of manufacture to obtain desired properties. They include;

. Waxes - added to improve dimensional stability and impact water repellence.

. Fire retardants - to increase resistance to fire eg. borax.

. Fungicides and insecticides - against disease and insect attack.

. Hardeners and buffers - incorporated into the resin system prior to blending to make binders more responsive to the requirements of particle boards manufacture.

2.0 Wood wastes and residues in particle boards

2.1 General

In section 1.2 it was noted that particle boards were developed as alternative cost-effective composite products. Amongst important criteria for raw material requirement is ready availability and low cost. Wood wastes and residues have thus been the natural choice of wood material in particle boards. Infact particle boards were developed as an answer to disposal problems arising from production of wastes and residues in saw milling and plywood manufacturing operations.

Wood wastes and residues are of different types originating from different sources. However, they can be conveniently classified into two categories; forest and factory. Forest wastes and residues comprise silvicultural operations (pruning and non-commercial thinnings), breakages, tops and branches. Factory wastes and residues on the other hand comprise those from sawmills (slabs, edgings, trimmings, and saw dust), plywood mills (cores, trimmings and veneer clippings), and furniture (shavings, shorts, trimmings).

Consumption of wood wastes and residues seems to vary by region depending on their availability. In the USA, factory wastes remain the major source of raw material. This is due to the ready availability of comparatively inexpensive mill residues leading to little economic incentive to use forest wastes. However, the trend is changing gradually as the drive to resource conservation catch up in the USA. Development of mobile chippers has also helped the use of forest wastes/residues to become an economic reality. In the meantime, planner shavings still account for a significant proportion of mill residues consumed. In Europe, logging wastes and residues are the major source. The driving factor has been the the rising production from limited raw material supply. The development of mobile chippers, concept of whole tree utilisation and integrated industries have clearly enhanced the use of forest wastes and residues. In the developing countries, inefficient conversion technologies in sawmilling and plywood industries have led to generation of large volumes of inexpensive mill wastes and residues which form the major source of raw materials. Meanwhile, limited capital and technological know-how have made logging wastes and residues to be consumed in relatively limited quantities.

The quality of wood waste/residue is of prime consideration apart from availability and cost. Foreign matter eg. metal, stone and soil are undesirable as they can affect board quality and damage the equipment. Excessive amount of bark is likely to weaken board strength and affect board appearance. A high proportion of sapwood (prevalent in tops, branches and thinnings) has a high absorption capacity of adhesive resulting in inadequate amount retained on the surface and hence poor bonding. Cases of high moisture content leading to more fuel consumed in chip driers have also been reported though changes in weather conditions seem to be major factors of variation in moisture.

2.2 Production and consumption of wood wastes and residues in the developing world: The case of Kenya.

2.2.1 Production of wood wastes and residues

The forest area in the country stands at 1.4 million hectares (ha) comprising 1.22 million ha of natural forests and 170,000 ha of plantations (KFMP, 1994). Plantation forests are the backbone of the relatively well developed wood based industry for the production of timber and related composite products. The main species are cypress (74,000 ha) and pines (52,000 ha) accounting for 75% of plantation forests. Eucalyptus species cover 15,900 ha (10%) with 22,600 (15%) comprising minor species (both indigenous and exotics).

The amount of forest resources that end up as wastes and residues in the country is quite significant. In this paper forest wastes and residues will be examined in three categories; silvicultural , logging and factory. Silvicultural wastes/residues are those generated during two main operations; thinning and pruning. Of significance are the silvicultural thinnings carried out for proper management of plantations but without a commercial concern. According to the current forest technical orders (Forest Dept. T.O. No. 42, 1969; No. 44, 1969; No. 53, 1981) three thinning regimes are carried out for plantation cypress and pine. For cypress and radiata pine, thinnings are carried out at 12, 17 and 22 years of age while for patula pine it is at 10, 15 and 20 years. In the former species thinnings at age 12 years are non-commercial while for patula pine they include those at ages 10 and 15 years. An analysis was carried out for this category of thinnings to determine the amount of wood produced from such sources for the period 1997-2000. The results are given in Table 1. It is observed that a total of 340,965 m^3 of wood will be generated as non-commercial thinnings. This accounts for 7.8% of the total volume of wood in the forest plantations.

Table 1: Volume of non-commercial thinnings for the year 1997-2000 (in m^3)

Species	1997	1998	1999	2000	Total
Cypress	71,370	66,825	65,025	70,245	273,465
Pines	41,910	17,595	3,450	4,545	67,500
	113,280	84,420	68,475	74,790	340,965

Source: Kenya Forestry Dept., Inventory records, 1997

For logging wastes and residues, an estimate was based on an earlier study undertaken by Nyakiti and Ogweno (1996). The study examined logging wastes generated from three groups of forest industries; a pulp and paper mill (PPM), a plywood factory (Elgeyo) and a medium-scale sawmill (Kaptagat). Table 2 provides the volume of wood assessed for the three factories for the period 1995-1996 while Table 3 gives the amount of logging residues generated over the same period.

Table 2: Total volume and area assessed for Panafrican Paper Mills (PPM), Elgeyo Sawmill and Kaptagat Sawmill for 1995/1996 for cypress and pines

		1995		1996	
INDUSTRY	SPECIES	VOL(m^3)	AREA (Ha)	VOL (m^3)	AREA(Ha)
PPM	Cypress	14,757.73	42.10	48,584.55	133.60
	Pines	137,425.46	269.47	215,801.75	451.80
Elgeyo Sawmill	Cypress	2,098.36	4.6	5,494.94	16.9
	Pines	12,473.47	47.86	5,566.14	25.8
Kaptagat Sawmill	Cypress	4,264.45	17.1	4,018.26	25.8
	Pines	-	-	-	-

Source: Forestry Dept. Inventory records, 1997

Table 3: Average volume of residues produced for these industries

			1995	1996
INDUSTRY	SPECIES	VOLUME/ HECTARE (m^3/Ha)	VOLUME (m^3)	VOLUME (m^3)
PPM	Cypress	89.28	3,758.69	11,927.81
	Pine	96.25	25,936.49	43,485.75
ELGEYO SM	Cypress	81.83	376.42	1,382.93
	Pine	89.06	4,262.41	2,297.75
KAPTAGAT SM	Cypress	55.7	952.47	657.26
	Total	412.12	35,286.48	59,751.50

Source: Nyakiti and Ogweno, 1996

The mean volume of logging wastes generated over a two year period as a percentage of the volume allocated was 20.5% for PPM, 32.5% for Elgeyo factory and 18% for Kaptagat sawmill. Except for Elgeyo factory the values compare well with a mean value of 20% reported by FAO (1977). It must be stated here that the figures given are only for the tops and exclude breakages and branches which, which if included, would raise the figure. The data shows that Elgeyo factory generates a high proportion of logging wastes compared to the other two. The factory specialises in the production of sawn timber, plywood and blockboards and appears to be utilising only high quality timber. The study established that logging operations are highly mechanised for this industry (use of skidders and loaders) resulting in high incidence of breakages which are often left in the forests. A further analysis of the data revealed that logging wastes account for about 24% of the wood volume on the average. This translates to 167,828 m^3 of wood over the same period.

Regarding factory wastes and residues, an estimate was based on those generated from the sawmilling industry. The number of operational sawmills varies from year to year and hence cannot be ascertained for certain. An estimate was thus carried out based on figures compiled by the Forestry Master Plan in 1994. During that time there were a total of 448 operational sawmills comprising 82%,15% and 3% of small, medium and large scale sawmills respectively. The criteria of classifying the mills is the amount of annual log intake where small scale mills have an intake of <1000 m^3, medium scale 1000-5000 m^3 and large scale >5000 m^3 of log volume.

Taking an average log intake of 449,000 m^3, a recovery rate of 41% (184,090 m^3), and the amount of sawdust generated as 15% (67,350) it was found that about 44% (or 197,560 m^3) of wood ended up as factory wastes in the form of slabs and bark. The above recovery rates compare favourably with a recent study carried out in Tanzania where it was found that 44% and 14% are generated as slabs/bark and sawdust respectively by Tanwat Factory in southern Tanzania (Attanas and Ishengoma, 1997).

2.2.2 Consumption of wood wastes and residues

There is limited industrial use of wood wastes and residues in the country at present. Major conventional uses of non-commercial thinnings, tops and offcuts are as wood fuel (fuelwood and charcoal) especially in rural areas with high population or in locations close to urban centres. In areas with horticultural activities like flower farming or growing of passion fruits, thinnings are used as support poles. In other areas offcuts are used as low quality fencing materials. Sawdust is being used to a limited scale as a source of energy in specially designed *jikos* (cooking stoves), as absorbent material in poultry farming and one industry is making organic fertilisers for kitchen gardening. Otherwise most of the materials go to waste or as observed above are inefficiently utilised. Sawdust is the main residue which is underutilised with heaps (mounds) burned by saw mills or merely left in the open resulting in major disposal and environmental problems.

The major industrial use of some wood wastes and residues is in particle board production. There are only two factories in the country producing chipboards (Rai Ply and Ply and Panels). Rai Plywood had an average annual log intake (1995/96) of 47,315 m^3 while Ply and Panels Ltd was 4603 m^3 for 1996/97. With the exception of bark and fine sawdust the other wastes and residues generated are consumed as raw materials in the production of chipboards. These comprises of sawmilling, plywood and furniture wastes and residues largely from pines (80%) and cypress (20%) species. Rai Ply collects some sawdust from sawmills around Eldoret town while Ply and Panels obtains logging wastes (tops and breakages) and saw dust from factories within Nakuru District, the actual contribution of the two industries to wood waste/residue reduction is under study. All that can be said for now is that their contribution is a positive step but the amount being consumed is still low in comparison to that being generated.

2.2.3 Quality of locally produced particle boards

As noted above, chipboards are the only type of particleboards produced in the country though one company (Simbarite Ltd based in Mombasa) is in the process of commercially producing a cement type of board where sawdust and kraft paper provide the reinforcement material. The chipboards produced must conform to the Kenya Bureau of Standards specification (KS 02-447, 1988). Table 4 provides a summary of the specifications required. To establish whether the boards produced in the country conforms to the specification, the Kenya Bureau samples are randomly collected from the industries and occasionally from retail outlets. Table 5 presents data of the tests carried out between 1991-1995.

It is observed from the densities that all the boards tested fall in one of the two categories; general purpose and furniture but not structural. This was confirmed by both industries who produce boards mainly for the two purposes. The moisture content was within acceptable limits i.e. 6-14% and so was to the bending strength where the minimum bending strength allowed is 13.1 Mpa. Nevertheless most boards did not satisfy the requirement for water absorption and thickness swelling. Only 13% and 31% of the boards met the minimum requirements for water absorption and thickness swelling respectively. The reasons for non-conformity are under study. Meanwhile, KEBS normally informs the industries on such limitations but more strict measures of monitoring and quality control are needed.

Table 4: Physical requireme[illegible] [illegible] [illegible]chanical Properties for Chipboards

GRADE NO.	GRADE DESCRIPTION	DENSITY Kg/m³	[illegible] ABSORPTION, PER CENT Max.		SWELLING IN WATER, PER CENT Max.		SWELLING DUE TO WATER ABSORPSION, PER CENT Max.	BENDING STRENGTH N/mm² Min.	TENSILE STRENGTH PERPENDICULAR TO PLANE OF BOARD N/mm² Min.	MODULUS OF ELASTICITY E N/mm²
			[illegible]	24 Hours Immersion	Thick-ness	Length/Width				
1	General	500-900	[illegible]	70	12	0.5	9	13.1	0.34	2 000
2	Furniture	700-900	[illegible]	60	10	0.4	8	13.1	0.5	2 000
3	Structural	900-1 2[illegible]	[illegible]	25	10	0.4	8	16.2	0.5	2 500
4	Moisture resistant	500-900	[illegible]	25	8	0.3	6	18	0.5	2 750
5	Combination of grades 3 and 4	900-1 2[illegible]	[illegible]	25	8	0.3	6	18	0.5	2 750

Table 5: Data of chipboards tested between 1991-1995

Density (Kg/m3)	Water Absorption (%) (1hr immersion)	Swelling (%) (Thickness	Bending Strength (Mpa)	Moisture Content (%)
545	42	8	24	10
545	54	7.5	24	9.5
550	24	17	25	9
730	110	18.5	26	9
500	98	16.5	26	8
550	87	14	29	9
550	82	14	32	9
600	79	21	30	8
550	87	16	26	7.5
620	98	18.5	21	9
550	80	13	30	8
550	79	12	30	8
550	111	12	24	9
800	21	21	52.5	9
800	131	14	27	9
750	45	10	39	8

Source: Kenya Bureau of Standards, 1997

[illegible]

3.0 Opportunities for increased use of wood wastes and residues in particle boards

It has been established that the amount of wood wastes and residues generated in the country is enormous whilst the present level of industrial use is low. It is proposed that introduction of mobile chippers by these industries or another entrepreneur contracted to supply this could enhance the use of logging wastes tremendously. Of course establishing integrated factories would go a long way in reducing the level of forest wastes and residues but that requires high capital investment which is often limiting. One other viable option would be to get entrepreneurs to supply sawdust to particle board factories. Meanwhile initiatives by Simbarite Limited to begin commercial production of a cement tupe of particle board using sawdust is quite timely. It is proposed that further research be carried out that will increase sawdust furnish from the present level of 40%.

The aspect of board quality is of great importance. Whereas boards produced are generally accepted on the local market, it is noted that there are problems with respect to water absorption and thickness swelling. Work should be intensified with the industry to identify and address these problems. This is more so if the regional export market is expected to flourish.

Literature cited

Attanas, M.T. and R.C. Ishengoma (1997). Utilisation of wood residues for production of electricity at Tanganyika wattle company (Tanwat). Njombe Iringa. Sokoine University of Agriculture, (unpublished).

FAO, Rome (1977). Residue utilisation of Agricultural and Agro-Industries. FAO/UNEP Seminar on residues utilisation.

Forestry Dept. Tech. Order No. 42 (1969). Treatment of cypress plantation.

Forestry Dept. Tech. Order No. 44 (1969) Treatment of *Pinus radiata* plantations

Forestry Dept. Tech. Order No. 33 (1981). Treatment of *Pinus patula* plantations.

KFMP (1994). Kenya Forestry Master Plan. Forest Industries Annex V.

KS 02-447 (1988). Kenya Standard Specification for chipboards. UDC 674.815-035.3

Moslemi, A.A. (1974). Particle board. Vol. 1: Materials. Southern Illinois University Press.

Nyakiti, M.O. and D.C. Ogweno (1996). Quality and characteristics of logging residues in three softwood operations in Western Kenya. Moi University (unpublished).

DEVELOPMENT OF WOOD ADHESIVES FOR TANZANIAN PLYWOOD AND PARTICLEBOARDS MILLS USING WATTLE TANNIN AND CASHEW NUT SHELL LIQUID.

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ABSTRACT

Under the sponsorship of the International Development Research Centre (IDRC) of Canada, TIRDO in collaboration with Forintek Canada Corp. managed to develop tannin based wood adhesives for the production of exterior grade plywood and particleboards. The Plywood adhesive was obtained by mixing the tannin solution with small amounts of urea-formaldehyde (UF) and formaldehyde emulsified in sunflower oil or CNSL at room temperature. The adhesive for particleboard requires the hydrolysis of tannin solution before it is mixed with other ingredients as is done in the plywood adhesive. When tested at laboratory and industrial scale, the adhesives proved to be water resistant and emit less formaldehyde compared to the commecial UF adhesives. CNSL as an emulsifier of formaldehyde improved the bond strength and life span (pot life) of tannin based adhesive for particleboards.

INTRODUCTION

Synthetic phenolic resins are among the most expensive components of wood-base panels. This is caused by the high prices of oil. The alternative urea-formaldehyde (UF) resin which is relatively cheap, slowly hydrolyses and emits formaldehyde during the life of the board. This creates adverse publicity for the wood base panel industry[1, 2]. As a result, research is being conducted in many countries to find substitute phenolics of equal quality and performance but based upon cheaper raw materials from natural renewable resources.

An extensive research have been conducted on the utilisation of wattle tannin[3-10] to formulate wood adhesives for production of exterior grade plywood and particleboards. Wattle tannin reacts with formaldehyde to form a polymer through methylene bridge linkages at the reactive positions on the flavanoid molecules, mainly the A-rings[11]. Similarly, cashew nut shell liquid (CNSL)[12-16] is reported to be used in producing wood adhesives for exterior grade plywood and particleboard. Both wattle tannin and CNSL are produced in Tanzania in abundance and exported at US$ 0.50 and 0.40/kg respectively.

Usually, paraformaldehyde is used as a hardener in industrial wattle tannin bonding.

Unfortunately paraformaldehyde is very expensive and is substituted by a cheaper aqueous formaldehyde. However, formaldehyde has one disadvantage that when used as a hardener, it "flushes out" during pressing and releases formaldehyde gas quite readily. Because of this, sufficient cross-linking is not achieved and the released gas creates unfavourable working atmosphere. Efforts to solve this problem has been to reduce the formaldehyde high vapour pressure by emulsifying the aqueous formaldehyde in either the liquid paraffin, sunflower oil, raw fish oil or linseed oil[17].

While Tanzania is exporting suitable raw materials for making exterior grade wood adhesives at cheaper price, it is at the same time importing expensive (US$ 1.20/kg) non-water resistant UF resin for making plywood and particleboards. Although extensive research has been done in formulating wood adhesives using either wattle tannin or CNSL, very little, if any, has been reported at all about the formulation of wood adhesives using wattle tannin combined with CNSL. This paper reports on some findings obtained by TIRDO in collaboration with Forintek Canada Corp., under the sponsorship of The International Development Research Centre(IDRC), when developing wood adhesives for plywood and particleboard using these cheaply exported Tanzanian raw materials i.e. wattle tannin combined with CNSL in presence of small amounts of formaldehyde and urea or UF resin.

Experimental.

UF powder (aerolite FFD) for plywood manufacture was obtained from CIBA-GEIGY in the United Kingdom (CIBA-GEIGY 1976). This UF powder is currently used in Tanzania for production of plywood and particleboard. Spray-dried wattle tannin extract powder was purchased from Tanganyika wattle company Ltd in Njombe, Tanzania. Sunflower oil, coconut shell flour(200 mesh), CNSL, and castor oil were also obtained in Tanzania. Urea, paraformaldehyde, 37% formaldehyde containing 10% methanol, sodium hydroxide, ammonium chloride and acetic acid were GPR chemicals obtained from local suppliers in Canada. UF liquid (BA-245) and phenol-formaldehyde (PF) control resins with catalysts, fillers and extenders were kindly supplied by Canadian resin manufacturers.

Tannin hydrolysis

Tannin hydrolysis was carried out as described by Pizzi[4]. Accordingly, 100g of 45% tannin in a water dispersion, 7.6g of 33% sodium hydroxide and 0.13g of castor oil were stirred for 2.5 hours at 92°C. The solution was then cooled to 70°C at which 4.0g of 99.5% acetic acid was added and further cooled to 25°C.

Adhesive mix

The following adhesive mixes (ingredients listed in order of addition) were prepared. They were adjusted to a pre-determined pH with small amounts of 99.5% acetic acid or 33% sodium hydroxide.

(i) Tannin-UF-paraformaldehyde for plywood

100g of 46.4% tannin in a water dispersion, 8.1g of 60% UF (FFD), 2.7g of paraformaldehyde, 13.3g of coconut shell flour and 0.3g of castor oil.

(ii) Tannin-UF-Formaldehyde-oil for plywood

100g of 46.4% tannin in a water dispersion, 7.8g of 60% UF (FFD), 20.3g of formaldehyde-sunflower oil at 1:1.4 weight solids ratio (Pizzi and Cameron 1981), 8.4g of coconut shell flour and 0.3g of castor oil.

(iii) Tannin-UF-Formaldehyde-oil for particleboard

100g of 46.4% tannin, 8.6g of 60% UF(FFD), 25g of formaldehyde-sunflower oil at 1:2.7 weight solids ratio and 0.2g of castor oil.

(iv) Hydrolysed tannin-UF-Formaldehyde-Oil for particleboard

100g of 46% hydrolysed tannin in a water dispersion, 8.6g of 63% UF(BA-245) and 25g of formaldehyde-sunflower oil at 1:2.7 weight solids ratio.

(v) Hydrolysed tannin-Urea-Formaldehyde-CNSL for particleboard

100g of 46% hydrolysed tannin in a water dispersion, 20g of formaldehyde-CNSL at 1:1 weight solids ratio and 8.9g of urea.

(vi) Hydrolysed tannin-UF-Formaldehyde-CNSL for particleboard

100g of 46% hydrolysed tannin in a water dispersion, 8.6g of 63% UF (BA-245) and 20g of formaldehyde-CNSL at 1:1 weight solids ratio.

PF and UF plywood and particleboard adhesives controls were prepared using ingredients and recipes provided by the CIBA-GEIGY and Canadian manufactures. Ammonium chloride (2.5% on solids) was the catalyst for the UF particleboard adhesives.

Adhesive "pot life"

The "pot life" of the adhesive mixes is defined as the time required to reach 10,000cP for plywood and 1,000cP for particleboard. The viscosity was measured with a Brookfield viscometer at 25°C. The "pot life" for the PF and UF adhesives was as reported by the manufactures.

Plywood preparation and testing

White pine (*Pinus strobus L.*) veneer of 3.2 mm thickness were used for the preparation of three layer plywood panels (300 x 300 x 9.6mm). For the PF and UF adhesives the veneer was conditioned to 4-5% moisture content (MC) and the liquid spread per single glue line was 365g/m^2 for UF and 325g/m^2 for PF. The veneer for Tannin-UF-Paraformaldehyde and Tannin-UF-Formaldehyde adhesives were conditioned to 12% MC and the glue spread per single line was 355g/m^2 and 356g/m^2 respectively. A 10 minute closed assembly time was used prior to pressing 3 to 6 minutes at 120-175°C and 175psi. Three replicate plywoods were prepared for each set of variables evaluated.

Wood failure (WF) after vacuum pressure and boil cycle treatments was evaluated on 25 x75 mm plywood tension shear specimens as specified by the Canadian softwood plywood standard methods and requirements of CSA Standard 0151-M1978[18].

The plywood plant trial was conducted at Sikh Saw Mills(T) Ltd. in Tanga, Tanzania using 1.3mm thickness veneer of pine and the tannin adhesive formulations described. The 1214 x 2429mm panels of 3, 5 and 9 plys were prepared. Resin application and press parameters were those used during the normal plant operation with UF resin. The average MC of the veneer was approximately 10%. Plywood panels were tested at Forintek according to CSA Standard 0151-M1978.

Particleboard preparation and testing

Three layer laboratory particleboards (380 x380 x 11.1mm) were prepared at the targeted density of 730kg/m^3. The wood particles, mainly white spruce (*Picea Glauca [Moench] Voss*) and Jack pine (*Pinus banksiana lamp.*), were supplied by a local particleboard mill.

The particleboards were produced using fine particles which passed through 355μm screen for surface layer and coarse particles which passed through a 3.34mm for core layer (surface to core ratio of 34:66). The particleboards were bonded with 12% adhesive in the surface layer and 10% in the core layer. The final MC of the furnish was adjusted at 6% core and 10% surface for UF. With Tannin adhesives, the MC for the core furnish was 10% while that of the surface furnish was 20%. The mats were pressed at press temperature of 175°C with 500psi press pressure. The dry and wet modulus of rupture (MOR) of the particleboard panels was tested together with the dry modulus of elasticity (MOE) and internal bond strength (IB). These were evaluated according to CSA methods and requirements of CAN3-0188.0-M78, CAN3-0188.1-M78 and CAN3-0188.3-M82[19, 20] standards for interior and exterior mat-formed wood particleboard.

The particleboard plant trials were conducted at Tembo Chipboards Ltd. in Tanga, Tanzania using wood particles from pine. Particleboards of size 12000 x 24000 x 8mm were prepared. Press temperature of 150°C, press pressure of 495psi and a MC of 10% (core) and 17% (surface) was employed. The glue spread was 10% core and 12% surface. The particleboards were tested at Forintek according to CSA standard CAN3-0188-M78 and M82.

Formaldehyde emission test

The particleboards bonded with UF and tannin-based adhesives were cut into 127 x 70 mm specimens. The specimens were then conditioned and evaluated for formaldehyde emission using the two-hours desiccator test as recommended by the formaldehyde council of Canada, Ottawa[21]. This test follows a procedure similar to the U. S. desiccator test except that the edges of the test samples are left uncoated[22].

Results and discussion

Plywood test results

A viscosity of between 1500cP and 10,000cP is preferred by plywood mills. Adhesives with high viscosity are difficult to apply while those with low viscosity soak into the wood resulting into a starved glue joint. The tannin-UF-formaldehyde adhesive's initial viscosity obtained (Table 1) is comparable to that recommended by Pizzi for this type of adhesives[23]. Considerable working "pot life" of tannin-UF adhesives is obtained at a lower pH of 4.5 to 5.0[11, 23, 24]. At high pH close to neutral, the resin is highly reactive leading to a short "pot life". In this study, it was found that at pH 5.0, the "pot life" of tannin-UF resin was 3-4 hours at 30°C. This time is relatively short compared to that of

UF(5-6hours) and PF(12-24hours), but it is sufficient if the adhesive is prepared in small batches and immediately applied. Longer "pot life" can be obtained by adjusting pH, adding alcohol or by the use of hexamethylenetetramine hardener[3]. The results in Table 1 further shows that tannin-UF adhesives produce strong exterior grade bonds at short press cycle and low press temperature compared to the PF adhesive which requires a higher temperature ... strong exterior bond.

The mill trial test results (Table 2) confirmed that commercial exterior grade panels can be produced with the tannin adhesive system. Formulation containing formaldehyde emulsified in sunflower oil is more attractive because the cost ratio of paraformaldehyde to formaldehyde in Tanzania is 8:1. A press temperature of 115 to 130°C and press cycle of 4 minutes was employed during the mill trial. Higher press temperatures or longer press cycle may be required for the adhesive containing formaldehyde emulsified in sunflower oil so as to improve bond strength.

Particleboard test results

Adhesives for particleboards need to have low viscosity(up to 1,000cP) to avoid application problems. A tannin-UF-formaldehyde adhesive with initial viscosity of 850cP and "pot life" of 1/2-1 hour was obtained. Such a short "pot life" was not suitable for application in particleboard mill because the adhesive expires before it is all used. But viscosity of tannin-based adhesive can be reduced significantly by heating the tannin solution with sodium hydroxide[4, 9]. The viscosity decreases through hydrolysis of the co-extracted hemicelluloses and hydrocolloid gums present in the wattle tannin extract to sugars, reduction of the intermolecular hydrogen-bonding and the cleavage of the high molecular weight tannins to less condensed polyflavanoids[3, 4, 11, 25]. The hydrolysis of tannin solution reduced the adhesives' initial viscosity from 850 to 400cP, 850 to 260cP and 850 to 180cP for the hydrolysed tannin adhesive with formaldehyde emulsified in sunflower oil, with formaldehyde emulsified in CNSL and for the hydrolysed tannin-urea-formaldehyde-CNSL adhesive mix respectively(Table 3). Of all the tannin adhesive mixes studied, tannin-urea-formaldehyde-CNSL adhesive mix is of interest because it avoids the use of expensive, non-water resistant and imported UF resin. The adhesive has an improved "pot life" and bond strength (MOR, MOE and IB) at a slightly increased glue spread in the chips (Table 3). It is reported that improved cross-linking, strength and water resistance of tannin based wood adhesive is obtained by copolymerising tannin extract with small amount of commercial UF or simple phenol/resorcinol/ formaldehyde resin and cured with formaldehyde[11]. When catalysed by either acid or alkali, CNSL reacts with formaldehyde to form phenolic resin[12, 14]. It is anticipated that during CNSL-formaldehyde emulsification and hot pressing some of the formaldehyde reacts with CNSL to form the resin which copolymerises with tannin and the copolymer is cured by the excess formaldehyde. The in-situ formed CNSL-formaldehyde resin is responsible for the improved strength and water resistance.

Formaldehyde emission

Table 4 indicates the test results obtained after testing the formaldehyde emitted from particleboards prepared at the mill using UF and hydrolysed tannin-UF-formaldehyde-oil adhesives. The use of hydrolysed tannin-UF-formaldehyde-oil adhesive resulted into a decreased desiccator value from 1.08μg/ml of UF adhesive to 0.33 or 0.43μg/ml of tannin adhesive. The tannin bonded boards meets the German E-1 requirement of 0.38μg/ml formaldehyde emission[1].

Conclusion

PF adhesives are extremely expensive such that the plywood and particleboard mills in Tanzania cannot afford. The alternative UF adhesives are non-water resistant and these pollute the environment, hence being unpopular world wide. The tannin-based adhesives have produced exterior grade wood panels and emit less formaldehyde compared to UF adhesives. The use of CNSL as emulsifier in the tannin-based adhesives has further improved the bond strength and the adhesives'" pot life". Given all these advantages and the fact that tannin and CNSL are available in abundance, Tanzania and the neighbouring countries stand a better chance of producing exterior grade wood panels at a lower cost if the formulation is optimised and promoted to a commercial scale.

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References

1. Calve', L. R. and Brunette, G. G., Reducing formaldehyde emission from particleboard with urea-salt or sulphite liquor, *Adhesive age*, 27(9), (1984) 39-43

2. Pizzi, A. and Scharfetter, H. O., The chemistry and development of tannin-based adhesives for exterior plywood, Journal of applied polymer science, 22, (1978) 1745-1761
3. Pizzi, A., Tannin-based adhesives, *J. Macromol. Sci., Rev. Macromol. Chem.*, 18(2) (1980a) 247-315
4. Pizzi, A., Effect and mechanism of hot caustic soda treatment on wattle tannins, *Int. J. Adhesion and Adhesives*, 1(2), (1980b) 107-108
5. Pizzi, A., Research vs industrial practice with tannin-based adhesives, In: *Adhesives from renewable resources*,: Eds. R. W. Hemingway, A. H. Conner and S. J. branham,ACS Symposium Series 385, American Chem. Soc., Washington, D. C. (1989) 254-265
6. Pizzi, A., An assessment of the future industrial prospects for panel adhesives from renewable natural materials, *Holzforsch. und Holzverwert*, 43(4), (1991) 83-86
7. Barnes, J. L., martin, C. A. and Lentz, M. T., Tannin adhesives for waferboard, *Proc. of the 20th WSU International Particleboard/Composite Material Symposium*, Ed. T. M. Maloney, Washington State University, pullman, Washington, (1986) 83-104

8. Kreibich, R., Chemistry significance of condensed tannins, Procedings of the First North American Tannin Conference, Eds. R. W. Hemingway and J. J. Karchesy, Plenum Press, New York, N. Y. (1989) 457-479
9. Saayman, H. M. and Oatley, J. A., Wood adhesives from wattle bark extract. *For. Prod. J., 26(12)*, (1976) 27-33
10. Plomley, K. F. The formulation and industrial application of naturally occurring polyphenol (tannin) adhesives in the wood based panel industry, Presented at the *Workshop on Adhesives Used in the Wood processing Industries of the United Nations Industrial Development Organization held in Veinna*, Austria, Doc. No. ID/WG. 248/6 (1977) 1-45
11. Pizzi, A., Wattle-based adhesives for exterior grade particleboards, *For. Prod. J.*, 28(12), (1978b) 42-47

12. Dhamaney, C. P., Acid polymerised cashew nut shell liquid (CNSL) for plywood adhesives, *Paintindia*, 19(12), (1969) 23-27

13. Dhamaney, C. P., Development of plywood adhesives based on cashew nut shell liquid and urea, *Paintindia*, 20(6), 91970) 21-22

13. Dhamaney, C. P., Development of plywood adhesives based on cashew nut shell liquid and urea, *Paintindia*, 20(6), 91970) 21-22

14. Dhamaney, C. P., Plywood adhesive based on cashew nut shell liquid, Paintindia, 21(11), (1971) 33-39

15. Dhamaney, C. P. and Sigh, K. R., Cashew nut shell liquid for Indian particleboards, *Paintindia*, 29(6), (1979) 40

16. Narayanamurti, D., Narayana, P. T. R. and Rangaraju, T. S, Cold-setting wood adhesive based on cashew nut shell liquid phenol-formaldehyde resins, *Res. Ind.*, 13(3), (1968) 134-6

17. Pizzi, A. and Cameron, F. A., A new hardener for tannin adhesives for exterior particleboard, *Holz als Roh-und Werkstoff*, 39, (1981a) 255-259

18. Canadian Standards Association 1978a, Canadian softwood plywood, *CSA Standard 0151-M1978*. National Standard of Canada, Rexdale, Ontario

19. Canadian Standards Association 1978b. Interior mat-formed wood particleboard, *CAN3-0188.0-M78 and CAN3-0188.1-M78*, National Standard of Canada, Rexdale, Ontario

20. Canadian Standards Association 1982, exterior mat-formed wood particleboard, *CAN3-0188.3-M82*, National Standard of Canada, Rexdale, Ontario

21. Formaldehyde Council of Canada 1982, Canadian tentative test method for emission of formaldehyde from wood products, Two hour desccator test, *The Canadian Chemical Producers Association*, Suite 805, 305 Sparks street Ottawa, Ontario, KIR 758

22. National Particleboard Association 1983, Small scale test method for determining formaldehyde emission from wood products, Two hour desiccator test 2306 Perlins Place, Silver Spring, Md. 20910

23. Pizzi, A., Hot-setting tannin-urea-formaldehyde exterior wood adhesives, *Adhesive age*, 20(12) (1977) 27-29

24. Pizzi, A., Utilising wattle-based adhesive in making particleboard, *Adhesive age*, 21(9), (1978a) 32-33

25. Laks, P. E. and Hemingway, R. W., Condensed tannins, Base catalysed reactions of polymeric procyanidins with toluene-alpha-thiol, Lability of the interflavanoid bond and pyran ring, *J. Chem. Soc. Perkin Trans I*, (1987) 465-469

Table 1 Comparison betwwen tannin-UF-, UF and PF adhesives for plywood applications: Laboratory test results.

Main ingedient	pH	Solids (%)	Viscosity (cP)	Pot life (hours)	Temp. (°C)	Cycle (min.)	Vacuum pressure (WF) (%)	Boil (WF) (%)
UF	5.8	58	480	5-6	150	3 4	50 85	0 0
PF	10.0	46	2040	12-24	150 175	4 4	66 87	72 97
Tannin-UF-paraformaldehyde	5.0	52	2200	3-4	150	3 4	87 95	65 84
Tannin-UF-formaldehyde-oil	5.0	53	2040	3-4	150 120	4 6	91 88	81 80
CSA standard 0151-M1978	-	-	-	-	-	-	80	80

Table2 Plywood mill test results

Main ingredient	pH	Temp. (°C)	Cycle (Min)	Vacuum pressure (WF) (%))	Boil (WF) (%)
UF	5.7	130	4	91	0
Tannin-UF-paraformeldehyde	5.0	130	4	98	93
Tannin-UF-formaldehyde-oil	5.2	130	4	81	78
CSA Standard 0151-M1978	-	-	-	80	80

Table 3 Comparison between UF, tannin-UF, Hydrolysed tannin-UF, Hydrolysed tannin-UF-CNSL, and Hydrolysed tannin-Urea-CNSL adhesives for particleboards applications: Laboratory test results.

Main ingredient	pH	Solids (%)	Viscosity (cP)	Adhesive spread-core/surface (%)	Pot life (hours)	Density (kg/m^3)	Dry MOR (MPa)	Wet MOR (MPa)	MOE (GPa)	IB (kPa
UF(BA-245)	5.3	63	180	10/12	5-6	716 718	18.8 17.4	0 0	2.9 3.0	837 822
Tannin-UF-formaldehyde-oil	5.1	51	850	10/12	1/2-1	753	14.4	4.6	2.5	621
Hydrolysed tannin-UF-formaldehyde-oil	5.36	50	400	10/12	3-4	724	16.4 16.8	5.3 5.0	2.5 2.6	656 725
Hydrolysed tannin-UF-formaldehyde-CNSL	5.48	49	260	10/12	4-5	749 735	17.4 15.9	5.6 5.7	3.1 3.1	938 881
Hydrolysed tannin-Urea-formaldehyde-CNSL	5.48	51	180	10/12 12/14	4-5 "	724 727 725 730	15.0 14.3 21.4 20.1	2.2 2.2 6.3 5.7	2.7 2.8 2.9 2.8	631 532 780 794
CAN3-0188.3-M82 Grade Y	-	-	-	-	-	-	14.0	5.6	2.5	500
CAN3-0188.1-M78 Grade R	-	-	-	-	-	-	14.0	-	2.0	450

Table 4 Formaldehyde Emission

Trial	Main ingredient	MOR (MPa)	MOE (GPa)	IB (kPa)	Formalin Desiccator level (µg/ml)
1st	Hydrolysed tannin-UF-formaldehyde	29.3	1.7	673	0.33
2nd	-do-	32.2	2.9	737	0.43
-	UF	27.7	2.4	638	1.08

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COST 508 WOOD MECHANICS STATE OF THE ART REPORT

WOOD-BASED BOARD MATERIALS

PW Bonfield and JS Mundy

EXECUTIVE SUMMARY

This paper provides a state of the art review of work associated with the performance of wood-based board materials for use in construction applications. The review is intended for publication in the final report of the European Commission COST 508 Wood Mechanics Action.

This comprehensive review considers recent research on the major performance parameters (short-term properties, long-term performance, fatigue and fracture) which govern the use of wood-based board materials in structural and semi-structural applications. The level of activity within each of these areas varied considerably. Although much has been carried out to examine and quantify the factors controlling the short-term properties of wood-based composites, only a limited amount of work has dealt with knowledge on the source of their influence and on modelling performance. However laminated plate theory and rule of mixtures modelling approaches have been attempted with some degree of success. A large number of publications were concerned with long-term performance and these showed that considerable amounts of data have been accumulated for many material types under a wide range of test environments. This review describes how these affect performance and also reviews the different methods (mathematical, rheological, chemical kinetic, constitutive and duration of load) for modelling and predicting long-term performance. There has been relatively little activity in the areas of fatigue and fracture. Work to evaluate fatigue performance has shown that fatigue life is dependant on applied stress level, material, load type and environmental conditions. Fatigue damage (measured by stress-strain hysteresis loop area) accumulates non-linearly and may be used to calculate the material's fatigue limit (level below which fatigue damage does not occur). Fracture tests have demonstrated that fracture energy is dependant on moisture content and that the design of test specimens and test methodology used influence both the values and variability of fracture data.

This paper is intended for publication in the Final Report of the COST 508 Action on Wood Mechanics.

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COST 508 WOOD MECHANICS STATE OF THE ART REPORT

WOOD-BASED BOARD MATERIALS

PW Bonfield and JS Mundy

1. INTRODUCTION

This state of the art report reviews recent work carried out in Europe to improve the knowledge and understanding of the performance of wood-based panel products. The use of these materials in the construction industry is widespread, with a European consumption of 44 million m^3 in 1990 (FAO, 1990). Consumption is likely to increase as the cost of solid wood increases and as manufacturing technology advances to produce better quality products with improved, tailored performance. Efficient utilisation of these materials is reliant on having a thorough knowledge and understanding of performance so that realistic design values for the critical performance parameters are available. For construction applications these parameters include:

-short-term properties
-long-term performance under load (creep),
-fatigue
-fracture

The level of activity within each of these areas varies considerably. The propensity of these materials to undergo time-dependant deformation (creep) is of major consequence when using these materials in structural and semi-structural applications. This is reflected in the relatively large number of publications associated with the characterisation, evaluation and modelling of creep. In contrast, the fatigue and fracture properties are often less critical and there has been considerably less activity in these areas. Short-term performance is of major significance when using wood-based panels in-service, but these properties are easier to take account of in design compared with long-term performance.

This report reviews the current state of the art in each of the areas of activity highlighted above and also gives a brief overview of the major types of wood-based panel product.

2. WOOD-BASED PANEL PRODUCTS

The main characteristic that differentiates board types is particle size. Further distinction may be made relating to the resin type, wood species, density and manufacturing processes employed and it is these parameters that control the nature, grade and quality of the resultant board material.

2.1. Chipboard (or particleboard)

Chipboard is constructed from small wood chips (usually softwood) that are bonded together with generally less than 10% resin (of the dry weight of chips). The surface layers are usually made up of smaller, more densely packed chips whilst the core material is of lower density. The resin system has a direct effect on the properties of the board with usual systems being urea formaldehyde (UF), a blend of urea melamine formaldehyde (MUF) and phenol formaldehyde (PF) or isocyanates (IC). Chipboard has widespread application in flooring, roofing, sheathing, shelving, ceilings and furniture.

2.2. Medium-density fibreboard (MDF)

Medium-density fibreboard (MDF) is constructed from softwood or hardwood that has been defibrated into bundles of wood fibres, which are then dried and coated with resin. These are then laid in a mat and consolidated using heat and pressure. The resin type, quantity used and board density (which is over 600 kg/m^3), control the performance characteristics of these products. The smooth surface finish of MDF makes it ideal for use in skirting boards, architraves and mouldings. This material is primarily used in furniture construction, but also for doors. Other fibre boards (FB) may be manufactured without resin where the wood fibres are mixed with water to produce a pulp, additives such as fire retardants and other chemicals are included and this mixture consolidated under heat and pressure. The integrity of these boards results from the thermoplastic properties of the lignin.

2.3. Oriented strand board (OSB)

Oriented strand board (OSB) is manufactured using large, thin flakes of wood where the width is characteristically half the length, bonded together with resin (usually PF). The board is generally laid as three layers, where the flakes in the outer layer are often aligned along the length of the board. The use of the large flakes imparts good mechanical performance as well as reducing the amount of resin needed (about 2.5% of the dry weight) to consolidate the board. Mechanical properties are usually superior to chipboard but less than plywood. OSB is finding increased use in many applications previously occupied by chipboard and plywood, *ie* sheathing, flooring, roofing, shuttering and packaging. Other types of non-oriented waferboards also find widespread use in construction, but they too are tending to be superseded by OSB. The particles used in waferboard tend to be larger than for OSB and they are aligned randomly in the plane of the board. They generally have inferior strength properties to OSB.

2.4. Cement-bonded particleboard

Cement-bonded particleboard is made by mixing 60% cement, 20% wood chips and 20% water, spreading this mix onto forming plates which are then pressed followed by heating at approximately 80 C for 6 to 8 hours until the cement has hardened. Principal applications are in cladding, internal wall lining and flooring where the high fire resistance and sound insulation properties may be exploited.

2.5. Plywood

Plywood is formed by laminating sheets or veneers of wood together using an adhesive. The type, thickness and quality of the veneers used and the adhesive system may be varied to give a wide range of products with significantly different performance attributes and end-use applications. Consecutive veneers are usually orientated so that the grain directions are at right angles to each other. These products are used in a wide range of applications including floor and roof decking, sheathing and shuttering.

3. SHORT-TERM PROPERTIES

The safe use of wood-based composites requires knowledge of short-term performance.

Much work has been carried out on the acquisition of data and the development of test methods for the reliable determination of properties such as the strength and stiffness (under different forms of loading) and the dimensional stability of these materials. However, there has only been a relatively low level of activity concerning modelling and predicting performance.

3.1. Factors influencing short-term properties

The performance of a wood-based boards is strongly linked to the type of constituent materials used, their relative quantities and their shape and packing.

3.1.1. Species

The influence of wood species and whether a single species or a mix is used, appears to vary according to the property under investigation. Bending strength, shear strength and modulus have been shown to be affected by the species used (Suematsu *et al*, 1993) whereas thickness swell has been found to be species independent (Kawai *et al*, 1993). Where a mixture of species was used, the mechanical performance was affected by the relative amounts of each species used in the composite (Pirkmaier *et al*, 1996, Poblete, 1992).

3.1.2. Particles

The size, geometry, distribution and alignment of particles have a major influence on board properties. Many boards contain layers and the influence of these on performance varies. McNatt *et al*. (1992) reported that the modulus of rupture (MOR) and modulus of elasticity (MOE) of flakeboards were improved by aligning the surface flakes in the direction of the applied stress but the internal bond strength or thickness swell properties remained unaffected. Suematsu *et al* (1991) found good correlation between the interlaminar shear and internal bond strength of particleboard of the surface layers and the core, with values for the surface layers being greater than those for the core. The levels of retention in these properties following accelerated ageing tests was unaffected by the differences between the layers (Suematsu *et al*, 1991). Chip thickness in particleboard has an influence on modulus of elasticity (MOE) and modulus of rupture (MOR) (Niemz *et al*, 1991) but there appeared to be a critical chip length (80 mm, Hata *et al*. 1993) above which varying chip thickness had no affect. Hata *et al*. (1993) also determined that thickness swell increased as chip length increased.

3.1.3. Resin

The type and amount of resin used to manufacture a board material may influence its properties. Increasing the amount of isocyanate resin in particleboard can improve mechanical properties and enhance its dimensional stability (Kawai *et al*, 1993). Increasing the amount of resin used can also improve decay resistance (Fukada, 1994, Kajita *et al*, 1992). Different resin types have varying affects on strength properties. For example, increasing the level of isocyanate resin created a higher increase in strength than when using PF resins (Suematsu and Okuma 1993, 1992). However, shear modulus was unaffected by adhesive type (Suematsu *et al*, 1993). Adhesive type also influences the level of MOR retention (Suematsu *et al*, 1992) but does not influence either interlaminar shear or internal bond (Suematsu *et al*, 1991).

3.1.4 Density

The density of a board is dependent on factors such as the species used, particle size, resin level and processing method. The bulk density of particleboard has been shown to have considerable influence on the strength and stiffness of particleboard (Niemz *et al*, 1991) with linear relationships between specific density and MOR (Suematsu *et al*, 1993, 1992), shear strength (Suematsu *et al*, 1993), and MOE (Suematsu *et al*, 1992). It has also been determined that for particleboards a linear relationship exists between the ratio of board density to raw material density ("compaction ratio") and mechanical performance (Kawai *et al*, 1993). These findings suggest that failure should occur in the lowest density (core) regions of the materials. However, this does not appear to be the case, with the majority of failures occurring in the higher density surface layers (Schulte *et al*, 1996, Schulte 1996). The influence of a density profile is complex but is affected by the laying-up process. Overlapping between particles is thought to reduce thickness swell (Suchsland *et al*, 1991).

3.1.5 Processing

Although the method used to produce the board has an impact on performance, recently less attention appears to have been given to this aspect. One area which has received some attention is that of pressing. It has been determined that the use of steam injection tends to produce flakeboards of lower strength than obtained using conventional pressing but the level of reduction appears to be adhesive dependent with polyisocyanates performing better than either PF or MUF resins (Hse *et al*. 1991). An investigation into pressing times and schedule showed that using a 2-stage regime, the length of the first stage and the gap between the 2 stages affected both MOR and internal bond strength (Suematsu *et al*, 1994).

3.1.6 Chemical modification

Boron vapour can be used to impart a degree of decay resistance to wood-based panels. Hashim *et al*. (1994) found that boron vapour treatment on MDF and OSB did not affect the strength, stiffness or internal bond strength but reduced impact resistance.

Treatment of particleboard with monoammonium phosphate, boric acid and borax for fire retardant purposes has been shown the reduce both tensile strength and bending strength but not affect hygroscopicity (Rashid *et al*, 1990). However, the treatment of isocyanate-bonded waferboard with borax or zinc borate improved strength and thickness stability (Laks *et al*, 1991).

Acetylation of wood particles has been widely studied and has been found to improve the dimensional stability, but reduce the mechanical performance of both hardboard (Chow *et al*. 1996) and particleboard (Fuwape, 1995). The cold water soak performance of MDF has been shown to be improved by subjecting it to a formaldehyde treatment at around 70°C without altering MOR or hygroscopic behaviour (Minato *et al*, 1995).

3.2 Modelling

Understanding the behaviour of composites is a prerequisite for ensuring their safe and efficient use along with their continued development. An essential part of this process is the development of models able to describe and predict the behaviour of these materials. Some work has been done in this field and it has mainly come from the adoption of techniques developed in the parallel field of synthetic fibre-reinforced composites, eg carbon or glass fibre-reinforced plastics. The methods used generally fall into two main categories: those using laminated plate theory and those adopting the rule of mixtures approach. Other techniques employing a probabilistic technique have been adopted for materials.

3.2.1 Laminated plate theory
This approach investigates the properties of individual plates / layers in a material and how they interact to give the properties of the composite. The bending strength of plywood has been modelled using elasto-plastic theory applied to the individual plies and treating the whole as a multi-layer beam (Booth, 1990). This method achieved reasonable success when predicting the strength of a 5-layer plywood but the degree of success depended on the failure criterion selected in the model (Booth *et al*, 1990). Koponen *et al*, (1995) incorporated shear deformation theory into the plate theory approach to predict the shear and bending performance of plywood. The adoption of an approach based on the presence of distinct layers is appropriate to plywood but layers are also present in other board materials and the approach has been applied to chipboard to predict MOE, MOR (Suo *et al*, 1995, Suematsu *et al*, 1992) and internal bond strength (Suo *et al*, 1995).

3.2.2 Rule of mixtures
This method calculates performance by summing the contribution of the individual constituents of the composite weighted according to the amount of each present. This approach has been used to predict the strength and stiffness of chipboard with reasonable success (Mundy *et al*, 1996, Poblete, 1992) and a single layer OSB (Hoover *et al*, 1992).

4. LONG-TERM PERFORMANCE (CREEP)

One of the main factors governing the use of wood-based board materials in structural applications is their propensity to deform under sustained load. The material type (particle size, resin type) and in-service conditions (moisture, temperature, loading type, mode and frequency) affect the creep response of wood-based board materials and can interact to accelerate deformation.

This behaviour may be modelled using different approaches: mathematical, rheological, chemical kinetic, constitutive and duration of load. Each method has advantages and disadvantages, although a rheological and a mathematical model have been specified in ENV 1156 for the calculation of creep factors used for design. Chemical kinetic modelling has considerable potential for use in design in the future.

Dinwoodie *et al* (1995) provides a useful review of the rheological behaviour of wood-based panels.

4.1. Particle size.
The size of the wood particle component is a primary factor that distinguishes the board types. The particle size has a marked effect on creep performance with the general rule that as the particle size increases the resistance to creep also improves. This is illustrated by Table 1 (Dinwoodie *et al*, 1992) which gives the ranking order in relative creep (where relative creep = (total deflection - initial elastic deflection) / initial elastic deflection) for nine materials, based on the mean values of relative creep averaged over a range of environmental conditions and stress levels after 43,200 minutes (30 days) under load. Five of the nine materials tested were different types of chipboard and a wide range of creep responses were measured. The fibreboard (high density medium board) fell within this range which illustrates that overlap may occur between the upper and lower grades of different board types.

Table 1. Ranking order of relative creep of nine materials after 43,200 minutes

Rank	Material	Relative creep	Ratio
1	Timber	1,278	1.00
2	Plywood	1,756	1.37
3	Waferboard	1.943	1.52
4	MUF Chipboard	2.404	1.88
5	MUF Chipboard (a)	2.514	1.96
6	UF Chipboard	2.809	2.20
7	Fibreboard	4.108	3.21
8	UF Chipboard (a)	5.776	4.51
9	PF Chipboard	6.488	5.08

4.2. Moisture

Moisture content may have a marked affect on the creep performance of boards, especially for the lower grade materials, and careful consideration of the in-service environment must be made to ensure that the integrity of the board is maintained in use. Dinwoodie *et al* (1991) found that large changes in relative creep occurred (increasing by up to four times) as the relative humidity (RH) was increased from 65% to 90%. This change was non-linear and that the variations in relative creep measured for each board type were lower when the relative humidity was increased from 30% to 65%. Comparison of the board types tested showed that the five chipboards were more sensitive to the higher humidity than the timber, fibreboard (high density medium board), waferboard and plywood.

Changing the humidity above 65% has a significant affect on creep deformation; however an even greater affect is found if the humidity is cycled between two levels. Dinwoodie *et al* (1992) showed that for an MUF chipboard, (type C4 BS 5669:1989) increasing the humidity from 30% to 90% caused an increase in deflection of 4 times but that cycling the humidity between these levels, caused a larger increase of over ten times after 200,000 minutes (20 weeks). A negligible mechano-sorptive effect (where deflection increases with decreasing humidity level on each cycle) was observed for chipboard. Test were also carried out to measure the creep response under a protected external environment where samples were protected from sun, rain and wind, but were subjected to the natural fluctuations of humidity and temperature. The level of creep measured was considerably greater than at 30% RH and slightly less than at 90% RH. Boehme (1995) evaluated the performance of several plywoods manufactured using low formaldehyde emitting resin systems and found that increasing humidity levels caused significant increase in creep deformation.

4.3. Load type and level.

(i) Stress level; An approximately linear increase between applied stress level (of between 30% and 75% of the short-term strength) and relative creep has been demonstrated (Dinwoodie *et al*, 1991) following testing of fibreboard, plywood, waferboard and 5 chipboards. These data represent the mean values accumulated at a range of humidities and temperatures. Some non-linearity did occur at high humidities. Gressel (1982) and Schober (1987) suggested that there is an acceleration in creep above a limiting stress value, Schober (1987) proposed that this was at 30% stress level. A second series of creep tests was therefore carried out (Dinwoodie *et al*, 1992a) at low stress levels between 15% and 45% of the short-term strength for 9 different materials and again a linear relationship was

found. However other work (Dinwoodie, 1991a) has shown that non-linearity occurs at approximately 40% stress level for OSB and cement-bonded particle board

(ii) Loading mode; There has been relatively little work carried out on the effect of loading mode on the creep response of board materials, although BRE is currently carrying out creep tests in both planar and panel shear. The current design codes use the same design factors for shear, compression and tension which have been derived from four-point bending tests even though the performance under each of the loading modes may be different. Work has been carried out on plywood by Ranta-Maunas (1976) and on particleboard by Kuhne *et al* (1981) which suggested that creep increased under shear loading. However, more recently Kliger (1991 and 1995) found that less creep occurred in chipboard samples loaded in shear and in compression than in bending.

4.4. Temperature

Increasing the temperature causes an increase in relative creep. Dinwoodie *et al* (1984 and 1991) tested nine board materials at 10, 20 and 30 C. The increase was non-linear with larger changes between 20 C and 30 C than 10 C and 20 C. Dinwoodie *et al* (1992a) also investigated the effect of cycling the temperature on the performance of nine materials and found that an increase in creep deflection occurred, although the effect was much lower than that caused by cyclic humidity.

4.5. Resin type.

Dinwoodie *et al* (1992) tested nine different chipboard materials and found that least creep was recorded for melamine formaldehyde (MUF) bonded type, followed by urea formaldehyde (UF), high alkaline cured phenol formaldehyde (PF). Similar results were found by Clad *et al* (1981) who ranked a PF/isocyanate (IC) board between UF and high alkaline cured PF. The combined effect of resin type and other variables, particularly moisture content, will affect the relative creep of boards, with the high alkaline PF most susceptible to changes in moisture content due to a lower degree of cross-linking than the other resins.

4.6. Interaction between factors

The results described above demonstrate that individually, each of the specific factors can have a marked effect on creep deformation of board materials. However, the combined effect of one or more of these variables can change the expected pattern of creep deformation much more than on their own (Dinwoodie *et al*, 1991 and 1995).

4.7. Modelling creep behaviour.

4.7.1. Mathematical modelling

The mathematical approach is one that applies curve fitting principles to creep curves to attain the best possible fit. By using power functions Gressel (1984) and Kliger (1991) found that reasonable prediction of creep deflections could be made. However, although this approach is relatively straightforward and useful for predictive work, development may be limited as it is not based on applying an understanding of the deformation processes in operation. Kliger *et al* (1995) evaluated the performance of two empirical models, one without exponential terms and one with both exponential and power terms, to predict the deformation of chipboard used in stress skin panels. The power function with exponential terms proved to be superior at extrapolating short-term results to long-term predictions.

4.7.2. Rheological modelling

Rheological modelling is based on the assumption that the deformation of board products (and timber) is composed of three major components; elastic (instantly recoverable), visco-elastic (time-dependant, recoverable) and viscous (time-dependant, permanent). Pierce *et al* (1979 and 1985), proposed rheologically based models that summed these three components in a manner that was considered to most accurately reflect the deformation processes occurring. The models were described using a series of spring and dashpot element analogues (Maxwell element in series with a Voight element) to represent the deformation components. Models using 3- and 4-elements were initially proposed (Pierce *et al*, 1979) but latterly a model comprised of 4-elements but with a fifth parameter (power function) was developed (Pierce *et al*, 1985). The models were tested against experimental data accumulated over 7 to 10 years and reasonable predictions were obtained (Dinwoodie et al, 1990), with the 4-element, 5-parameter model accurate to within 50% for all samples. However, predictions of deflection at 7 or 10 years from data achieved 6 months data (for over half the samples tested) were accurate to within 25%. However Mundy *et al* (1995) showed that the mathematics of curve fitting using exponential functions were difficult and that caution must be exercised to avoid large over- or under-predictions of long-term creep deformation. Kliger (1995) showed that weighting a few data points at the end of a creep curve improved the predictive qualities of the 4-element, 5-parameter model.

Kliger (1991) carried out a comparison of deflections predicted by the 4-element, 5-parameter rheological model and those from 7 other models, including power models, and found that the optimum prediction was obtained from the 4-element, 5-parameter model.

4.7.3. Chemical kinetic modelling

Recently attention has been focused (Bonfield *et al* 1994, Van der Put 1989) on the use of chemical kinetic modelling to describe creep. This approach examines the deformation of the material at a molecular level and applies the theory of chemical rate kinetics to the energy required to break and reform bonds within the material. Both elastic and time-dependant deformation may be considered to produce a model that reflects the deformation characteristics of the material. The approach has been applied with reasonable success to solid wood (Bonfield *et al*, 1994, Van der Put, 1989) but further developments were required for good long-term prediction. Bonfield *et al* (1996), have taken the work further, identifying two deformation processes occurring during creep tests on thin wood samples. This considerably enhances the potential of using the technique for long-term modelling.

4.7.4. Constitutive modelling

Although considerable effort has been devoted to developing models for describing the combined effects of different parameters (particularly mechanosorption under variable humidity) for solid wood, there has been relatively little attention to panel products. Two of the few examples of constitutive modelling for wood based panels are those by Ranta-Maunus (1975, 1976) for plywood and Martensson (1988) for tempered hardboard. While the former worker developed two models for constitutive relations depending on whether the variations in moisture content had a cumulative effect or not, the latter worker developed a model of total strain rate as given by the sum of the linear elastic strain rate, the creep strain rate, and the stress dependent moisture induced strain.

Urbanik (1995) used 6 parameters, including terms for hygroexpansion and mechanosorption for modelling the creep of fibreboards in variable climates. Mundy *et al*

(1994) presented a constitutive approach to modelling creep performance of chipboard based on combining the creep response of the wood and resin constituents. The work showed that the resin dominated the deformation process, despite its low volume fraction.

4.7.5. Duration of load

Another approach to modelling creep is to consider the applied stress level versus log(time to failure) or 'duration of load'. Data plotted in this way will usually fall on a straight line, the linear regression of which may be used to extrapolate for long-term life prediction.

5. FATIGUE.

Work on chipboard at both high frequencies (1 to 10Hz Bonfield *et al*, 1993) and at low frequencies (7 or 17 day cycles Dinwoodie *et al*, 1993) showed that lower creep deflections occurred under fatigue loading than under constant loading except at very high stress levels (80%) where the deflections of the fatigue samples became greater. The principle of superposition was applied to both the low and high frequency test work to assess whether the damage accumulation mechanisms of creep and fatigue were similar. It was found not to apply. Analysis of the affect of stress level on creep showed a linear increase between 30, 45 and 60% stress levels.

Bonfield *et al* (1993), Thompson *et al* (1995) and Thompson (1996) reported that stress-strain hysteresis loop capture during fatigue testing could be used to quantify the accumulation of fatigue damage. The loop area gives a measure of energy dissipated per cycle and the mean gradient gives the dynamic modulus (stiffness) for each hysteresis loop captured. Fatigue tests carried out on chipboard, OSB and MDF showed that there was no apparent fatigue limit at stress levels down to 30% of the short-term strength for up to 10^7 fatigue cycles. Measurement of dynamic modulus for each of these materials showed that the stiffness remained almost constant until the few cycles before failure where a rapid decrease occurred. The hysteresis loop area was shown to increase non-linearly through the fatigue tests. Further analysis of the loop areas showed that comparison of the initial and final loops captured during a test could be used to calculate the stress level beneath which damage did not occur (fatigue limit). The stress level at which difference between the initial and final loop areas captured is zero could be defined as the fatigue limit. For chipboard this occurred at approximately 20% of the short-term strength.

Thompson *et al* (1995) also reported on the effects of frequency on fatigue life and found that increasing the frequency from low to medium to high levels caused significant increases in the number of cycles to failure.

Pritchard *et al* (1996) compared the results from fatigue tests on chipboard, OSB and MDF on an actual stress level basis, rather than on a percentage of the short-term strength. Using this approach, MDF gave longer fatigue lives than OSB and chipboard. However tests were carried out at a constant 65% rh. The relative performance of the three materials examined may be expected to change at higher or under cyclic humidity.

6. FRACTURE

Only a small number of papers associated with the fracture of wood based panel products have been published in scientific literature, although there are a considerable number associated with sawn wood and newer products such as laminated veneer lumber (LVL).

Morris *et al* (1995) carried out mode 1 (opening) fracture tests to determine the energy release rate (G) for chipboard, MDF and OSB at different relative humidities (30%, 60% and 90%) and three test speeds (10, 1 and 0.5 mm/min). Acoustic emissions were also monitored. It was found that increasing the moisture content caused the fracture energy to rise for MDF at all tests speeds, for OSB at 10 mm/min and chipboard at 1 mm/min. However at the lower test speeds, the fracture energy peaked at 60% rh for OSB and chipboard.

Measurements of acoustic emissions during fracture tests showed that as the relative humidity increased, the acoustic emission counts and events decreased. There was no apparent trends for the different test speeds evaluated. Niemz *et al* (1992) also monitored acoustic emissions in tests on panel products and found that the events measured were strongly influenced by the load and the material type. The results varied considerably and did not allow correlation with conventional strength properties.

Ehart *et al* (1996), carried out a series of fracture tests on chipboard both parallel and perpendicular to the plane of the board and used finite element analysis to develop an optimum test technique and sample geometry. It was found that the ligament length and aspect ratio (width to height ratio) strongly influenced the stress distribution in the ligament and affected the stability of crack propagation. The work showed that specimen geometry needs careful consideration when designing fracture tests and analysing the results.

7. CONCLUSIONS

7.1. Short-term properties

Although much has been carried out to examine and quantify the factors controlling the short-term properties of wood-based composites, only a limited amount of work has dealt with knowledge on the source of their influence and on modelling performance. However laminated plate theory and rule of mixtures modelling approaches have been attempted with some degree of success.

7.2. Long-term performance (creep)

A substantial amount of data related to the creep performance of board materials has been accumulated under a variety of loading and environmental conditions for a range of material types. Subsequent analysis of these data has lead to the development of rheologically-based models that sum elastic, visco-elastic and viscous components to allow good creep deflection prediction, with the optimum predictions based on a 4-element, 5-parameter model. The research information generated and models developed have been used by the board manufacturers to improve their products and also to exert a major influence over the use of board materials via incorporation into design standards. The draft European standard for the determination of creep in board materials uses two parameters to describe rheological behaviour; the duration of load factor is used to calculate life to failure and the creep factors used to predict creep deflections. In both cases models developed following creep tests are used in these calculations.

7.3. Fatigue

A limited amount of work has been carried out to assess the performance of panel products

Dinwoodie, J.M.; Robson, D.J.; Paxton, B.H. and Higgins, J.S. 1991. Creep in Chipboard. Part 8: The effect of steady-state moisture content, temperature and level of stressing on the relative creep behaviour and creep modulus of a range of boards. Wood Sci. Technol. 26: 225-238.

Dinwoodie, J.M. 1991a. Determination of the rate of creep and time to failure of OSB, MDF and cement-bonded particleboard. Report to DG XII of the CEC. (to be published)

Dinwoodie, J.M.; Paxton, B.H.; Higgins, J. and Robson, D.J. 1992. Creep in Chipboard. Part 10: The effect of variable climate on the creep behaviour of a range of chipboards and one waferboard. Wood Sci. Technol. 26:39-51.

Dinwoodie, J.M.; Higgins, J.S.; Paxton, B.H. and Robson, D.J. 1992a. Creep in Chipboard. Part 11: The effect of cyclic changes in moisture content and temperature on the creep behaviour of a range of boards at different levels of stressing. Wood Sci. Technol. 26: 429-448.

Dinwoodie, J.M.; Paxton, B.H.; Bonfield, P.W. and Mundy, J.S. 1993. Fatigue in chipboard Part 2. The influence of slow cyclic fatigue on the creep behaviour of chipboard at a range of stress levels and moisture contents. Paper accepted for publication in Wood Science and Technology.

Dinwoodie JM and Bonfield PW. 1995. Recent European research on the rheological behaviour of wood-based panels. Proceedings COST 508 workshop on mechanical properties of panel products, March 1995

Ehart R, Tschegg, SS and Tschegg, E. 1996. Fracture properties of particleboard. Influence of specimen geometry. Proceedings International COST 508 Wood Mechanics Conference, May 1996.

Food and Agriculture Organisation (FAO), Timber Bulletin, XLIV No 9, 1990

Fukuda, K. 1994. Deterioration of particleboard by mould fungi and its preventive method. Bulletin of the Experiment Forests, March , 32, 67-71.

Fuwape, J A. 1995. Strength and dimensional stability of acetylated Gmelina and Sitka spruce particleboard. Journal of the Timber Development Association of India, 41(2), 32-37.

Gressel, P. 1982. Kriechverhalten von Holz und Holzwerkstoffen-Auswirkungen auf den Formanderungsnachweis. Ingenierholzbau in Forschung und Praxis Bruderverlag, Karlsruhre.

Gressel, P. 1984. Zur Vorhersage des langfistigen Formanderungsverhaltens aus Kurz-Kriechversuchen. Holz Roh-Werstoff 42: 293-301.

Hashim, R; Murphy, R J; Dickinson, D J and Dinwoodie, J M. 1994. The mechanical properties of boards treated with vapor boron. Forest Products Journal, 44(10), 73-79.

Hata, T; Kawai, S; Ebihara, T, *et al.* 1993. Production of particleboards with a steam-injection press 6. Effects of particle geometry on board properties. Journal of the Japan Wood Research Society, 39(2), 169-173.

Hoover, W L; Hunt, M O; Lattanzi, R C, *et al.* 1992. Modeling mechanical properties of single-layer, aligned, mixed-hardwood strand panels. Forest Products Journal, 42(5), 12-18.

Hse, C -Y; Geimer R L; Hsu W E, *et al.* 1991. Effect of resin variables on properties of steam-press cured flakeboards. Forest Products Society Proceedings of the Adhesives and Bonded Wood Products Symposium held in Seattle, Washington, November 19-21, 30-44.

Kawai, S and Sasaki, H. 1993. Low-density particleboard. Recent Research on Wood and Wood-Based Materials, Current Japanese Materials Research, 11, 33-41.
Kajita,H and Imamura,Y. 1992. Improvement of physical and biological properties of particleboards by impregnation with phenolic resin. Wood Science and Technology, 26(1), 63-70.

Kliger, R. 1991. Creep and duration of load behaviour of board materials. Report to DG XII of the CEC. (To be published)

Kliger, IR. 1995. Creep in chipboards under bending, compression and shear loads. Proceeding COST 508 Workshop on mechanical properties of panel products, March 1995

Kilger IR and Pellicane, PJ. 1995. Prediction of creep properties of chipboard used in stress skin panels. Journal of testing and evaluation, v23, no 6, p408-414.

Koponen S and Saavalainen. 1995. Effect of moisture on short-term properties, creep and long-term strength of plywood slabs. Proceedings COST 508 workshop on the mechanical properties of panel products, March 1995

Kuhne, G; Niemz P. 1981. Untersuchungen zum Einfluss der Plattenschichten auf das Kriechverhalten von spansplatten. Holztechnologie 22(4): 214-221.

Laks, P E; Quan, X and Palardy, R D. 1991. Effects of sodium octaborate tetrahydrate and zinc borate on the properties of isocyanate-bonded waferboard. Forest Products Society Proceedings of the Adhesives and Bonded Wood Products Symposium held in Seattle, Washington, November 19-21, 144-157.

Martensson, A. 1988. Tensile behaviour of hardboard under combined mechanical and moisture loading. Wood sci and technol, 22, p129-142.

McNatt, J D; Bach, L and Wellwood, R W. 1992. Contribution of flake alignment to performance of strandboard. Forest Products Journal, 42(3), 45-50.

Minato, K and Seto, Y. 1995. Formaldehyde treatment of medium-density fiberboard in the low temperature range 2. Physical and mechanical properties. Journal of the Japan Wood Research Society, 41(3), 324-329.

Morris, V, Adams, J and Hunt, D. 1995. Fracture mechanics in wood and wood-based panel products at different testing speeds and relative humidities. Proceedings of COST 508 wood mechanics workshop on the mechanical properties of panel products, March 1995.

Mundy JS. 1994. Contribution of the components of chipboard to its total creep. Submitted to Wood science and technology.

Mundy, JS and Bonfield, PW. 1996. The applicability of composite theory to the short-term properties of chipboard. In proceedings of International COST508 Wood Mechanics Conference, Stuttgart, Germany, May 1996, 297-310.

Mundy JS, Bonfield PW, Dinwoodie, JM and Paxton B.H. Modelling the creep behaviour of chipboard: The rheological approach. Submitted for publication in Wood Sci Technol, 1995.

Niemz, P and Bauer, S. 1991. Relations between structure and properties of particleboards, part 2. Holzforschung und Holzverwertung, 43(3), 68-70 .

Niemz P and Luhmann A. 1992. Application of acoustic emission analysis to evaluate the fracture behaviour of wood and derived wood products. Holz al Roh-und Werkstoff, v50, no.5, p191-194

Pierce, C.B.; Dinwoodie, J.M. and Paxton, B.H. 1979. Creep of Chipboard. Part 2: The use of fitted response curves for comparative and predictive purposes. Wood Sci. Technol. 13: 265-282.

Pierce, C.B.; Dinwoodie, J.M. and Paxton, B.H. 1985. Creep of Chipboard. Part 5: An improved model for creep prediction. Wood Sci. Technol. 19: 83-91.

Pirkmaier, S and Medved, S. 1996. Impact of the used tree species and changes in wood particle structure on mechanical and physical properties of particleboards. In proceedings of International COST508 Wood Mechanics Conference, Stuttgart, Germany, May 1996, 327-344.

Poblete, H. 1992. Influence of Chilean wood species and mixtures on mechanical properties of particle boards. Holz als Roh- und Werkstoff, 50(10), 392-394.

Pritchard, J. Thompson, RJH, Bonfield, PW, Ansell, MP. 1996. A comparison of the fatigue and creep performance of commercial grade chipboard, OSB and MDF based on equivalent applied stress levels. Proceeding of the International COST 508 wood mechanics conference, May 1996.

Ranta-Maunus, A. 1975. The viscoelasticity of wood at varying moisture content. Wood Sci Technol 9, p 189-205.

Ranta-Maunus, A. 1976 A study of creep in plywood. Report No. 5. Structural Mechanics Laboratory, Technical Research Centre of Finland, pp 92.

Rashid, A M and Chew, L T. 1990. Fire retardant treated chipboards. Malaysian Forestry and Forest Products Research, Proceedings of the Conference, October 3-4, 130-140.

Schober, B. 1987. Untersuchungen zum Einfluss der Belastung auf das Kriechverhalten von Vollholz und Holzpartikelwerkstoffen. Holztechnologie 28: 13-16.

Schulte, M. 1996. Density profile and shear properties opf medium density fibreboard (MDF) and particleboard and their relation to internal bond. In proceedings of International COST508 Wood Mechanics Conference, Stuttgart, Germany, May 1996, 311-326.

Schulte, M and Fruhwald, A. 1996. Shear modulus, internal bond and density profile of medium density fibre board (MDF). Holz als Roh- und Werkstoff, 54(1), 49-55.

Suchsland, O and Xu, H. 1991. Model investigations of the particle bonding process. Forest Products Society Proceedings of the Adhesives and Bonded Wood Products Symposium held in Seattle, Washington, November 19-21, 94-120.

Suematsu, A and Okuma, M. 1991. Mechanism of low-density particleboard formation 3. Internal-bond strength and interlaminar-shear strength of low-density particleboard. Journal of the Japan Wood Research Society, 37(9), 795-801.

Suematsu, A and Okuma, M. 1992. Mechanism of low-density particleboard formation 4. Bending strength of low-density particleboard. Journal of the Japan Wood Research Society, 38(9), 847-853.

Suematsu, A and Okuma, M. 1993. Mechanical properties of low-density particleboard. Modulus of rigidity and lateral nail-resistance. Journal of the Japan Wood Research Society, 39(3), 293-300.

Suematsu, A and Okuma, M. 1994. Mechanism of low-density particleboard formation 5. Effect of the hot-pressing method on the properties of board. Journal of the Japan Wood Research Society, 40(12), 1335-1340 .

Suo, S and Bowyer, J L. 1995. Modeling of strength properties of structural particleboard. Wood and Fiber Science, 27(1), 84-94.

Thompson, RJH, Bonfield, PW, Dinwoodie, JMand Ansell MP. 1995. The effects of frequency on the fatigue response of structural grade chipboard. Proceedings of COST 508 workshop on mechanical properties of panel products, March 1995

Thompson, RJH. 1996. Fatigue and creep in wood-based panel products. PhD Thesis, University of Bath, UK.

Urbanik, TJ. 1995. Hygroexpansion-creep model for corrugated fibreboard. Wood Science Technol, v27, no 2, p134-140.

Van der Put, T.A.C.M. "Deformation and damage processes in wood." PhD thesis, Delft University Press, 1989.Booth, L G. 1990. Predicting the bending strength of structural plywood. Part 1: A theoretical model. Journal of the Institute of Wood Science, 12(1), 14-47.

ECONOMICAL SOLUTION TO THE DURABILITY OF PORTLAND CEMENT MORTARS REINFORCED WITH VEGETABLE FIBRES.

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1.0 INTRODUCTION

Composites of Portland cement Mortars Reinforced with Vegetable fibres are known to be suitable for alleviating the problem of high-cost housing; yet the same composites are faced with the problem of durability originating from the mineralization of such fibres due to some inherent factors as well as the influence from their surroundings.

The mentioned problem has been investigated by several researchers without a real viable solution due to the limitation that the solution be economical by using locally available materials and appropriate technological application because they are aimed at solving the housing problem in developing countries for the Low Income Group.

Recently, Doctorate Laboratory studies completed by one of the authors from BRU at the Department of Civil Engineering Construction of the Polytechnical University of Madrid in the "Escuela Tecnica Superior de Ingenieros de Caminos, Canales Puertos - Madrid - Spain" have shown existence of economical Methods of solving the problem of mineralization of the fibres, through fibre impregnation, mortar pore sealing, cement alkaline reduction, etc. (1). The methods are based on the use of natural organic compounds from timber which can be obtained naturally, without special skills or even as a by-product of small-scale Industries.

Moreover once this product is in use it will attract other areas of application as will be expounded along the paper.

2.0 THEORETICAL APPROACH TO THE PROBLEM

2.1. GENERAL

Theoretical and experimental studies carried so far have shown that the use of Portland-cement mortar reinforced with natural fibres is adequate if there is no great fluctuations of temperature and humidity, particularly in the interior of the houses especially when it is not possible to use adequate methods to eliminate or reduce the degradation of the fibres (1).

These composites have good initial physical Mechanical properties which allow their use in various construction works. All this is due to the fact that the fibres control composite crack propagation including the internal microfissures of the matrix. Moreover its Modulus of Elasticity permit great resistance to flex-traction of the composite. On top of all these there are other characteristics which are improved by the fibres.

2.2 DURABILITY OF PORTLAND-CEMENT MORTAR REINFORCED WITH NATURAL FIBRES

Durability of the mentioned composite is a function of specific characteristics which each component contributes as well as the internal union which is produced between them during the process of fabrication and hardening. Thus, its durability will depend on several factors such as heterogenity of the composite, mechanical properties of the constituent materials, adherence between them, condition of exposure, etc. (1).

Durability of such composites is considered as a direct function of their chemical composition and their structure which can be expressed in measurable characteristics such as porosity.

It is infact the porosity of the matrix which is responsible for allowing the penetration of liquids and other aggressive ions into the interior. The liquids and some metal ions are responsible factors producing a more and intensive harm to the natural fibres in the said composites.

Thus ageing of the composite is due to the internal changes in their structure as well as the action of external agents such as water, dissolving of aggressive mineral salts, solar radiation, contaminating gases, microorganisms etc. which are encountered during their service in the site (1).

Solution to this problem was approached through the matrix fibres as expounded below:-

2.2.1 PORTLAND-CEMENT MORTAR (Matrix)

Sensitivity of the matrix before aggressive agents depend, among other factors, on the quantity of CaO present in the cement because during hydration and hardening of cement crystals of $Ca(OH)_2$ are formed known as portlandite. The quantity of $Ca(OH)_2$ varies between 20% and 25% of the weight of cement on the time of curing, some authors say it reduces to up to 10% after 28 days of curing in water. These crystals cause microcracks due to the following:

- Its resistance to tension is only $1N/mm^2$, that is to say the lowest in the cement paste whose value lies in the region of $5N/mm^2$.

- Its interface with the gel is weak, thus the cracks passing through the matrix produce this way a deviation around the areas where they are situated.

- Their swelling can induce tensional states in the matrix which surround them or vice vesa.

- Its solution is transported through the pores, leaves the matrix with empty spaces in its interior.

- It is a strong base which has the property of forming fragile and expansive components with many liquid substances which can provoke the destruction of mortar through the chemical reaction or provoke forces of expansion.

Excess of this material can be reduced through the use of hydraulically active additives which can produce modification in the rheology of the cement paste, variation in the hydration synetic, modification of the composition of the products, effect of the microstructure resistance and durability. All this will depend on the type of additives and the grade of interaction with the cement components. Unfortunately the $Ca(OH)_2$ is also responsible for the natural fibre mineralization in the matrix and must be eliminated or limited (1, 2, 3).

2.2.2 IMPROVEMENT OF THE CEMENT MORTAR DURABILITY

To improve by eliminating or limiting $Ca(OH)_2$ in the matrix either seal the matrix pores from external liquids or use compounds which react with it. Intensive bibliographical revision on this recommend phosphoric acids, carbonated waters, fatty acids and oils, esterates, waxes, natural resins etc. which have a tendency of reacting with $Ca(0H)_2$ to form insoluble compounds (1, 2, 3, 4).

Use of organic additives in cement mortar act as air entraining agents, water reducing agents, retarders, plastisizers, increase adherence and

- Acids, alkalis and water produce hydrolysis fragmentation, salvation dissolution, decomposition, pealing and swelling which can increase their pores to proportions higher than 50% of the total volume of the fibres.

- The mentioned agents of degradation of the fibres dissolve transport the fibre polymers and their cellulose, finally leaving them without adherence to the matrix while themselves without their glueing materials.

2.3.2 FIBRE PROTECTION

From above it is observed that fibre mineralization in matrix is complex; as such protection measures which can give satisfactory solution to this problem are:-

- Use of impregnants which form a protective layer and don't allow water through.

- Seal the matrix pores to reduce the permeability thus reducing alkalinity formation.

- Combine both of the above.

In this study all methods produced satisfactory results, the combined method as best (1, 3).

2.3.3 SELECTION OF IMPREGNANTS

In the selection of the impregnants it is important to bear in mind that the fibres are formed of very sieve like fibrils. This means only certain substances can pass through i.e. lipid-soluble ones, very small molecules; which need intervention of certain molecules, through special mechanisms inorder to penetrate into the fibres. Thus in the selection one ought to consider the structure, form and size of the crystals because penetration is proportional to their solubility respectively to the lipidic substances of the fibres.

Revision on timber preservation shows that the best results are obtained by using organic compounds because they are insoluble in water, are good water repellents with powerful attachment to the cells and allow contact with surface impregnated fibre. Thus the impregnating material to be used ought to have a lubricating action, wetting, fungicides and power to reinforce the weak bonds between the hydrophobic agents in the interfibrilares spaces of the surfaces of the bonds in the fibres.

Natural fibres are not so much different from timber. A brief literature review of the extracts of wood shows the following (4):-

Table 1 : Classification of the extracts of wood with examples according to analysis groups (4)

EXTRACTION AGENT	MAIN GROUPS	SUB-GROUPS	INDIVIDUAL SUBSTANCES
STEAM DISTILLATION	TERPENES Phenols, Hydrocarbons, Lignin	MONOTERPENES Sesquiterpenes, Diterpenes, Triterpenes, Tetralerpenes, Polyterpenes,	Camphenes, Carene, Limonone, Pinene, Borneol,
ETHER	FATTY ACIDS Fats, oils, waxes Resins, Resin acids, sterols	Unsaturated fatty acids, Saturated fatty acid,	Oleic Acid, Linoleic Acid
ALCOHOL	COLOURING MATTERS Phlobaphenes, Tanning, Stilbenes	FLAVONOIDS ANTHOLYANINS	Taxifolin Quercetin
WATER	CARBOHYDRATES Proteins, Alkaloids, Inorganic Materials	MONOSACHARIDES Starch , Pectic Material, Cations, Anions	Arabinose, galactose, Raffinose, Ca, K, Mg, Na, Fe, carbonates, Phosphates, Silicates, Sulphates, etc.

3.0 EXPERIMENTS

3.1 Effects of some admixtures in Portland Cement Mortar

The Portland cement mortars tested were composed of the following components:-

- CEMENT:

  Portland cement type II - Z/35 which complies with Spanish Norm UNE 80301

- SAND :

  Siliceous sand from river of maximum size 3mm, washed.

- WATER :

  Portable water

- ADMIXTURE:

  Hand ground colophony (incorporated during the mixing of cement and sand)

  - Vegetable tanning in powder form, soluble in water.

Mortar mix proportion of cement : sand used were 1:1.5 and 1:2 by weight. In such mixes different proportion of the above admixtures were added varying the water/cement ratio.

In each mortar mix various series of prismatic cube of 40 x 40 x 160mm were casted for mechanical strength determination and cubes of 3 x 40 x 40mm for water absorption and porosity.

Half of the specimen fabricated in each mortar were subjected to heat treatment at the curing age of 14 days in water 24 hours drying at laboratory temperature followed by heating 3 hours at 40°C and then 3 hours at 80°C, then lowering temperature down to 40°C and maintaining it for 3 hours and lastly lowering to laboratory temperature. The rest were tested after 28 days in water.

For determination of water absorption and relative porosity the cubes were submerged in water for 24 hours. Later taken from the water and dried at 80°C for 24 hours followed by cooling them at ambient temperature.

Results are shown on the following tables.

Table 2 : Summary results of Mortar 1:1.5 (by weight)

DENTIFIC-IATION[a]	Type of Admixture	Admixture %	W/C	Mechanical strength Flexion [N/mm²]	Compression [N/mm²]	Relative Porosity (%)[b]	Water absorption (%)[b]
M-I-S	Control	-	0.45	4.6	56.1	24	13
M-I-T	Control	-	0.45	8.4	52.2	23	11
M-III-S	Tannin	0.2	0.36	4.8	41.3	19	11
M-III-T	Tannin	0.2	0.36	8.2	31.5	18	10
M-IV-S	Colophony	0.5	0.37	5.2	57.1	12	6
M-IV-T	Colophony	0.5	0.37	4.2	43.3	10	5

a s = Thermally untreated, T = Thermally treated
b = The relative porosity and water absorption (by weight) are average of 3 specimen.

Table 3: Summary results for mortar 1:2 (by weight)

DENTIFIC-IATION[a]	Type of Admixture	Admixture %	W/C	Mechanical strength Flexion [N/mm²]	Compression [N/mm²]	Relative Porosity (%)[b]	Water absorption (%)[b]
M-I-S	Control		0.45	4.6	48.2	28	12
M-I-T	Control		0.45	5.6	49.7	23	11
M-III-S	Tannin	0.4	0.37	5.3	62.4	7	3
M-III-T	Tannin	0.4	0.37	5.8	68.9	7	4
M-IV-5	Colophony	0.4	0.37	3.7	39.4	9	4
M-IV-T	Colophony	0.4	0.37	4.0	33.0	9	5

3.1.1 Observation :

- There is strength increase of about 4 - 13% in relation to control in mortar mix 1:1.5 for all specimens which are thermally untreated (flexural test).
- Compressive strength results are variable depending on whether the mortar is thermally treated or not and on the admixture used.
- In relation to pore sealing and water absorption the reduction is high, reaching above 70% in relation to control particularly for mortars 1:2.
- There was no substantial improvement on the mechanical strength observed when colophony was mixed with wax neither when used in sodium hydroxide solution.

Thus it can be said that such admixtures improve a bit of mechanical strength and seal the pores of the mortar. Also these admixtures have no negative effects on the Portland cement mortar. A study on the optimum % of colophony to be added on the mortar was studied and results are presented below in reference to collophony. (Fig. 1).

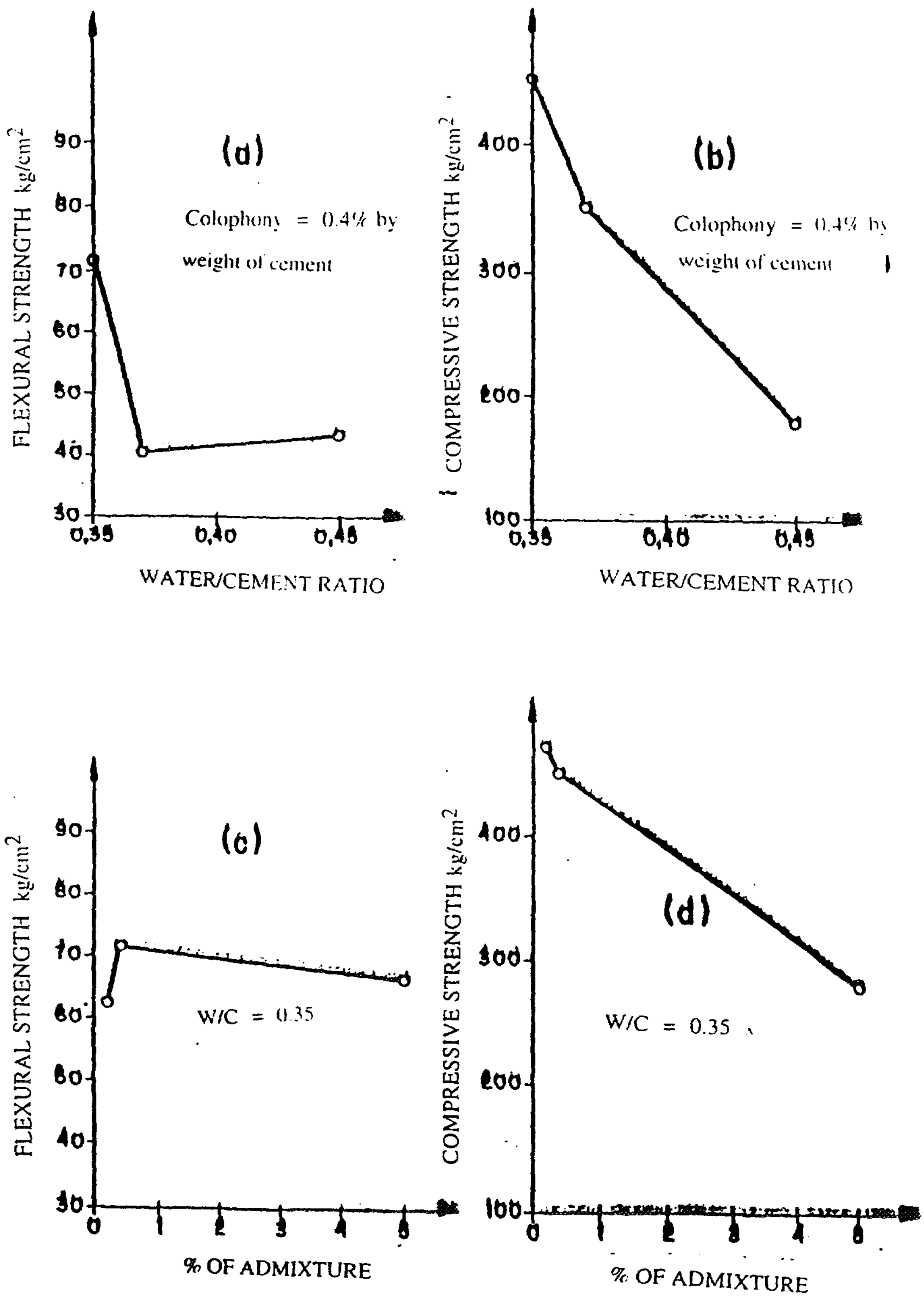

Fig.1. Behaviour of Portland cement with colophony as admixture in relation to variation of water/cement ratio (curves a and b) and in relation variation of the % of colophony added (curves c and d) [1].

3.2 Fibre Impregnation

Natural fibres impregnated were sisal fibre grade 1 from Tanzania and the impregnants used were various, dissolved in organic solvents.

Method of impregnation is double diffusion (hot 100°C and cold - room temperature) - Several repeatation; compounds used were various but the best results were obtained in the following compounds.

Table 4: Results of Studies in Impregnated Sisal fibres (5)

Type of Impregnant	Proportion by weight	Monoxial tensile strength N/mm^2	% absorption of water
Control	-	570.0	70
Collophony + Turpentine	1.6	487.0	33
Clove oil+Xylene+Alcohol+Turpentine	13:3:1:30	530.0	14 - 20
Tannin + Alcohol + Xylene	1:30:1	407.5	39

3.2.1 Observations:

Use of these compounds shows an improvement in the reduction of water absorpiton which coincides with changes in the internal structure of the fibres as indicated in the results of the X-ray diffraction of some samples in tables 5 & 6. The reduction in the tensile strength is probably due to the way of evaluating it where the fibre density was deemed to be constant and the fibre diameter calculated on the basis of the weight of a bundle of 10 fibres of the same length.

Table 5: Number of pics observed in X-ray diffractogram

Impregnants used	Number of pics	Type of Alpha pics
Clove oil	28	28
Acetone	18	15
Control	11	9

Table 6: Characteristic of principle pics

Impregnants Used	Angle of diffraction (grade)	Height of pic (cm)	Width of pic (degree)
Clove oil	22.4775	2809	0.40
Acetone	22.8425	882	0.32
control	22.5525	942	0.80

3.3 Composite Strength:

Mortars of mix 1:1.5 and 1:2 and water/cement ratio of 0.45 with or without addition of colophony admixtures, reinforced with sisal fibres impregnated or unimpregnated were exposed to different conditions and flexural strength determined. Accelerated ageing consisted of 3.5 hours of oven heating at 95°C followed by submersion in water at room temperature for 0.5 hours. Thus a total of 4 hours was considered as one cycle of ageing. Results are presented in the following figures 2, 3, 4, 5, 6 and 7 (1).

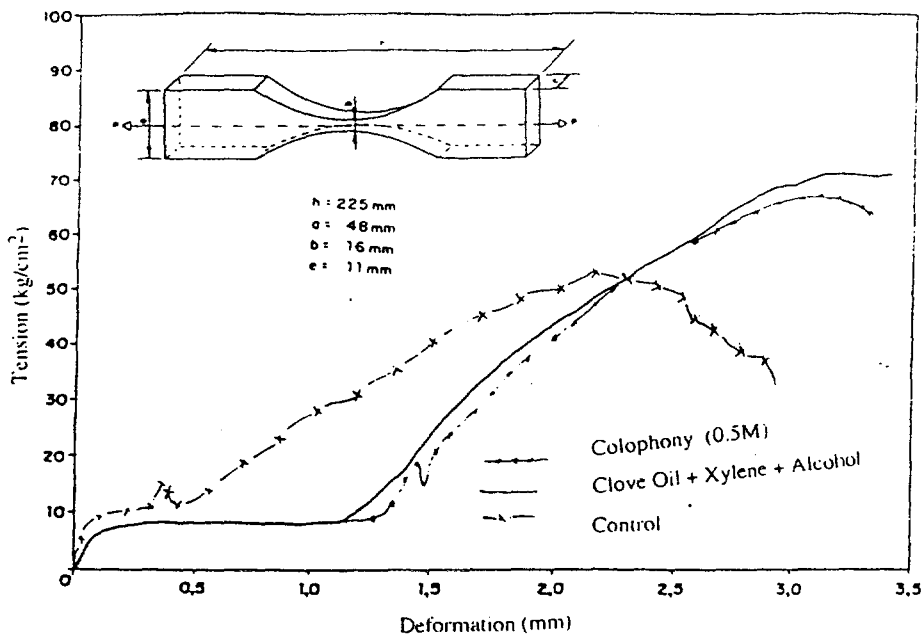

Fig. 2 : Curves of Portland Cement Mortars without admixture reinforced with impregnated sisal fibres subjected to direct tension (1)

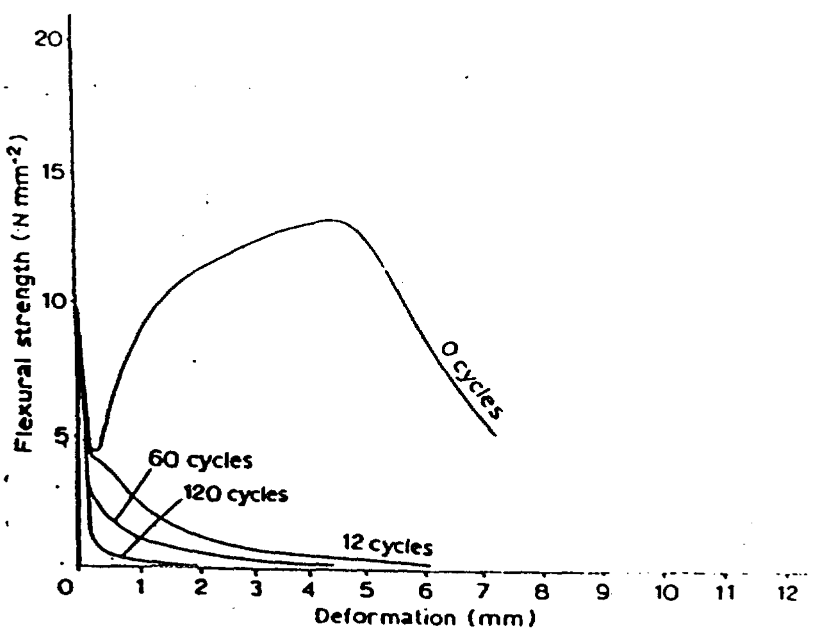

Fig. 3 : Strength - deformation curves of Portland Cement Mortars without admixture, reinforced with unimpregnated sisal fibres subjected to accelerated ageing (1).

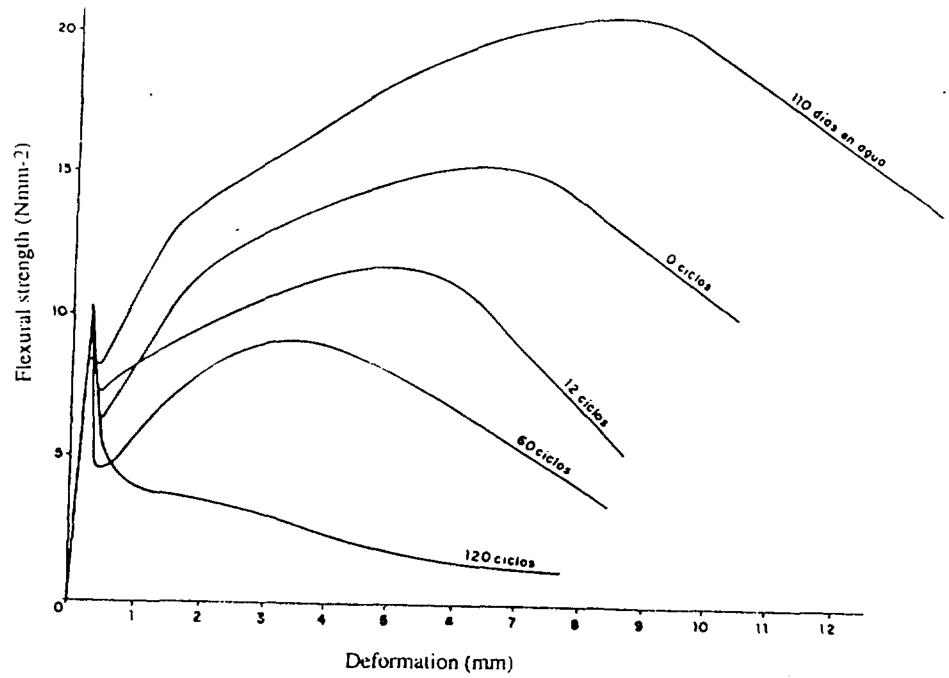

Fig. 4: Strength - deformation curves of Portland Cement Mortars without admixture, reinforced with sisal fibres impregnated with colophony and subjected to accelerated ageing (1,5).

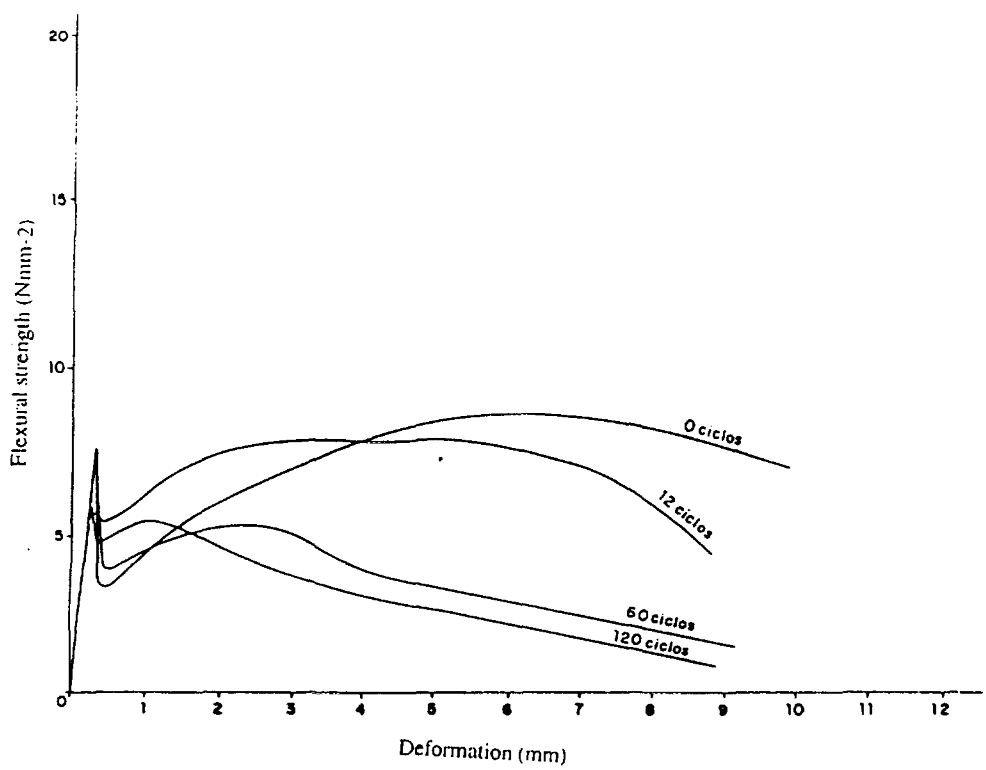

Fig. 5 : Strength - deformation curves of Portland Cement Mortars with admixture of colophony, reinforced with unimpregnated sisal fibres and subjected to ageing (1,5).

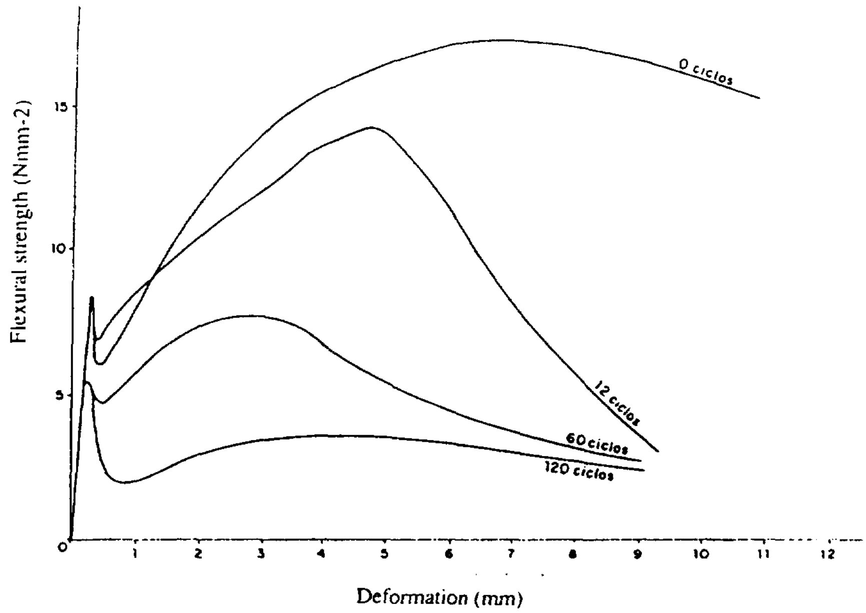

Fig. 6 Strength - deformation curves of Portland-Cement Mortars with admixture of colophony, reinforced with impregnated sisal fibres and subjected to ageing. (1,5).

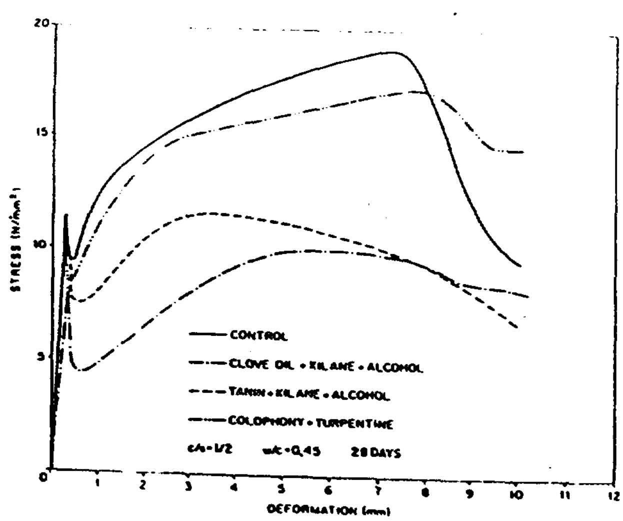

Fig. 7: Strength - deformation curves of Portland cement mortar without admixture reinforced with impregnated sisal fibres as indicated (3).

3.3.1 Observations:

- During ageing the impregnants were flowing through the cut sides of the specimen.
- All the results indicates an improvement of durability behaviour in mortars reinforced by impregnated fibres against those unimpregnated ones.
- In normal ageing colophony is more effective in reducing the mineralization of the fibres in both conditions of exposure.
- In case of accelerated ageing mortars with colophony as admixture with impregnated or unimpregnated fibres shows great improvement in relation with control.

4.0 Conclusions:

- Compounds used show a good efficacy in alkaline reduction, pore sealing and reduction of water absorption in both mortars and fibres.
- Tannin and colophony form insoluble compounds with the majority of metallic salts, chemically stable and impermeable. This background presupposes good results in the solution of durability of mud and pole or mud blocks houses including the problem of plastering in such houses.
- Colophony dissolved in toluene has been used successfully in the extraction of heavy metallic cations from industrial affluence in other countries e.g. Spain, (1, 6), this case can also be of use in Tanzania.
- Colophony is a non volatile fraction of pine resins which is a by-product of the turpentine industry, in Tanzania there are such trees it is time to widen its use.
- It is necessary to optimize the study.

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REFERENCES

1. Kawiche, G.M. "Estudio de morteros reforzados con fibras de sisal" Tesis Doctoral Univ. Politecnica de Madrid, E.T.S. Ingenieros de Carminos, Canales Y Puertos. Auo 1991.
2. Canoras, M.F., Selva, N.H. and Kawiche, G.M. "Influence on the physical-mechanical properties of Portland Cement Mortars of admixtures of Colophony and Tannin". Material de Construccion (Instituto Eduardo Torroja, Madrid) 1989.
3. Canovas, M.F, Kawiche, G.M. and Selva, N.H. "Possible Ways of preventing deterioration of vegetable fibres in Cement Morters". Proc. of 2nd Inter. RILEM symposium (Chapman & Hall, London 1990) pp 120 - 129.
4. Wegner, F.D. "Wood Chemistry Ultrastructure Reactions (Walter de Gruyter, Berlin 1984).
5. Canovas, M.F., Selva, N.H. and Kawiche, G.M. "Neco economical solutions for Improvement of durability of Portland cement Mortars reinforced with sisal fibres" Materials and structures (RILEM) 1992, 25 pp 417 - 422.
6. Selva, N.H. "Extraccion de Ag(1) y Cd(II) con Acidos Resinicos" Tesis Doctoral, Univ. Complutense de Madrid, Facultad de Ciencias Quimicas (1987).

ALTERNATIVE CEMENTS BASED ON LIME POZZOLANAS\

A PAPER TO BE PRESENTED AT THE FIRST INTERNATIONAL WORKSHOP ON COMPOSITE MATERIALS BASED ON NATURAL RESOURCES:
CHALLENGES AND OPPORTUNITIES FOR BUSINESS

EASTERN AND SOUTHERN AFRICAN MINERAL RESOURCES DEVELOPMENT CENTRE, DAR ES SALAAM, TANZANIA

4TH - 8TH AUGUST 1997

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ABSTRACT

The potential use of Kisoro volcanic ash, Bunyaruguru tuffs and Kajansi burnt clay in production of lime-pozzolan and other blended cements were investigated in the laboratory. Field trials of the various cements mixes were carried out to assess their performances.

Various samples picked from the project area proved positive to the pozzolanicity test. Grindability tests carried out in 3 x 3 ft ball mill at 33 r.p.m, 45% ball charge and feed of 400 kg gave the power requirements for production of pozzolan cement at 125 KW h per ton.

The blended cements exhibited mortar strengths between 13.2 and 29 Mpa.

Field trials of the cements indicated that Lime Pozzolan Cements served as good binders for masonry units and blended cements showed good performance in general concrete work.

The economic evaluation of lime-pozzolan and blended cements was assessed based on 675 ton/annum production capacity mill installed at Geological Survey and Mines Department. Savings of up to 45% in the partial replacement of Ordinary Portland Cement for low cost housing were achieved. This augers well for construction industry since cement costs would be reduced as more people would have access to alternative cements.

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background:

Uganda which occupies an area of 241,000 km^2 and is situated between elevations of 1000 and 1500 m above sea level, and enjoys mild equatorial climate.

In 1991 the population was provisionally put at 16.5 million with a growth rate of 2.5% per annum between 1980 and 1991 and an average household of 5.7%. The same results give an occupance density of 1.05 and hence gives an estimated housing stock of 2,690,900 units and a backlog of 235,904 units in the country.

More than 90% of the population live in rural areas and the moderately good to fertile soil, combined with generally adequate rainfall, ensures that throughout most of the country it is possible to sustain successful crop production. (Ref. A National Shelter strategy for Uganda Volumes 1 and 2 - prepared by the Department of Housing, Ministry of Housing and Urban Development, Kampala, Uganda, 1992).

1.2 Housing Stock Conditions and Characteristics:

1.2.1 Housing Conditions

There has been no significant housing development in Uganda for the last two decades. Instead the period saw a decline in existing housing stock due to lack of maintenance and obsolescence. Along with high population growth rate during the 1980's, this has led to a steady deterioration of housing situation. Since 1986, there has been some improvement, but given the situation the impact has not yet been felt particularly in the lower income levels who are the majority.

The housing situation in Uganda leaves a lot to be desired both in terms of quality and quantity. The quality of housing mostly in rural areas and to some extent in the high density areas of urban centres (slums) is very poor because of lack of adequate infrastructure, use of non-durable building materials and the poor technology used. It is worth noting that rural population have the houses but are of poor quality while urban area housing has both problems of quality and quantity (quantity as indicated by overcrowding, conversion of outer houses e.g stores and garages into dwelling units). This overcrowdness has affected the quality of the even would-be good houses because of the high pressure and demand exerted on the services that were otherwise designed for fewer people.

1.3 Cements:

Portland cement has a clearly defined role as binder in fulfilling requirements for high strength application. Under the Uganda case and many other third world countries, Portland cement is being used in low strength applications; foundation concrete, plasters, mortars and soil stabilization.

This wrong application of Portland cement is not only unnecessarily costly but technically defective. Portland cement mortars are at times too harsh and lack plasticity, and do not spread easily resulting in partially filled joints. This leads to lack of intimate contact between mortar and masonry unit.

The degree to which Portland cement is wrongly used has reached alarming proportions and its estimated that only 20% of the worldwide use of cement requires the strengths of Portland cement. Building technologists have established that a 0.55 MPa mortar can support a four storey building. Lack of alternative binder to Portland cement has been partly responsible for this state of affairs.

1.3.1 Pozzolan Cements

Pozzolans are materials containing reactive silica and alumina or one of them which on their own have little or no binding properties. However, when mixed with lime in the presence of water at ordinary temperature and pressure, they set and harden like cement. They provide an important base in the production of alternative cements.

Under the Pozzolan Housing Project the main objective was to come up with acceptable and affordable cements for low cost housing construction since the cost of building materials especially cement were very high. At present a 50 kg bag of Ordinary Portland Cement costs $12 (Shs 13,000/= in Uganda compared to $3 in South Africa, $4.5 in Kenya.

The provision of shelter is one of the basic needs for human beings and from time immemorial, man's effort has always been addressed to improvement of quality and expansion of shelter available to him.

With constant increase in human population without correspondent resources, housing has become a critical sector of the economy. The situation is even worse in developing countries like Uganda where high population growth (over 2.5%) and acute resources constraint have located a section of the population to live below the poverty limits implying that the only shelters that can be built by the poor both in towns and rural areas are just "shacks", hence sprawling urban slums. This situation is not only a source of socio-economic disparity and tension, but can also contribute towards political problems.

The search for long lasting building materials has led to increased production of Portland cements with raw materials - limestone, clay, gypsum extracted from natural sources. However, the production of Portland cement involves significant investment in heavy machinery which in turn leads to the high cost of finished product. The end result is that the rural population cannot afford the high cost. This has resulted in unimproved shelters, with mud and wattle constituting the only economic materials available to it.

Recent research into appropriate low-cost building has come out with improved binders as a result of identification of alternative and cheap raw materials. These raw materials are found in natural abundance and which can be processed with simple technologies. Pozzolana cement is one of these binders which could complement the use of Portland cement for binding purposes and production of blocks in rural areas at a lower cost.

Pozzolana cement has the basic raw materials as lime from limestone and volcanic ash which occur in abundance in some parts of the country. Pilot experiments in its use have been carried out and the next stage is commercial production of the product so that it could benefit the larger section of the population.

Pozzolan cements are made as described above from pozzolanas and lime. A pozzolana can be described as a material which is not cementitious by itself but when activated/mixed with lime at normal temperature and with the aid of moisture becomes cementitious i.e. it acquires properties akin to those of Ordinary Portland Cement.

1.4 Building Materials:

Building materials constitute the single largest input to construction, accounting for 50 - 80% total value (UNCHS). It has been found out that in Uganda, to construct a dwelling of any standard, 60% of the materials are imported. In many developing countries a large proportion of building materials are imported. For instance, it is estimated that building materials alone annually account for 5 to 8% of total value of imports in Africa, representing an expenditure of about US $ 2.5 billion. In Uganda, statistics indicate that building materials constitute the largest proportion of productive imports for the period 1986 - 1990. Imported building materials although they constitute a large proportion of the country's import bill, are used on high income housing which is largely urban. Among the imported products are cement, sanitary ware (sinks, wash basins, bathroom tubs, glazed tiles etc.), plumbing pipes and associated fixtures and fittings, glass, iron mongery (locks, door handles, hinges, etc) and electrical items.

Some of the above items such as cement, clay tiles and iron sheets are produced locally and in most cases production is below the designed capacity. For example, Hima Factory after over 20 years of rehabilitation the production capacity is not more than 70% of designed 300,000 tons per year and the utilization capacity for most of the local manufacturing plants is less than 50% of designed 150,000 tons per year installed capacity.

It is possible for Uganda to overcome the problems caused by the high cost and scarcity of imported building materials by replacing them with traditional building materials but in most cases these materials (e.g clay products, lime, building stone and soil blocks) are not produced in sufficient quantities and their quality and cost are not competitive with the imported materials. The limited output and range of indigenous materials is largely attributed to the low level (inappropriate) technologies being used for their production. For example, in rural areas stones are crushed manually on small scale basis in Tororo and Kasese districts using hand tools and occasionally pneumatic drills. The same simple technology is used for timber, pozzolana and clays. Preparation of clay products involves stamping the raw clay and then draining out into moulds. Drying is direct by the sun and then firing in kilns.

In Uganda, a number of building materials are locally available for construction purposes and these include among others:-

Stone (e.g. sand, stones shales) which is mainly used for foundation, walls (as in Bunyaruguru county - Bushenyi district) and fencing. Stones are scattered all over Uganda.

Lime is used by itself in road construction as a stabilizer in brick production and other construction activities.

Pozzolanas, mainly derived from volcanic ash and activated with lime, have weak cementing properties.

In order to alleviate this situation, the Research and Development of alternative cements based on lime-pozzolanas was carried out. Various tests both laboratory and field confirmed the potential for partial replacement of Ordinary Portland Cement using pozzolanic materials from Kisoro, Rubanda and Bunyaruguru.

2.0 RAW MATERIALS BASE

Alternative affordable and appropriate cements can be manufactured through use of pozzolanic materials blended with lime, portland cement or a combination of the three.

Large quantities of pozzolans exist in Uganda as idle resources. Further more they occur as nuisance in terms of disposal in several instances whereas they could be gainfully utilized.

2.1 Pozzolans

Pozzolans are generally categorized into two groups; those of natural and artificial origin. The types available in Uganda are outlined below;

2.1.1Natural Pozzolans

This grouping include; volcanic ash, scoria, pumice and tuffs occurring extensively in Kisoro - Kabale areas and to a lesser extent in Bunyaruguru and Fort Portal area. Millions of tons of material are known to exist. (see map).

Shales and diatomaceous earth occur extensively in various areas;

- Toro - Ankole area as light grey sediments mainly ashy shales and mudstones.The reserves have not been estimated.

- Mt. Elgon area, they exist as sandstones and fine grained black/dark grey ashy shales and mudstones.

- In Pakwach area the reserves of diatomaceous earths are estimated at 100,000 tons.

2.1.2 Artificial Pozzolans

These comprise of pozzolans of agro-waste ashes and industrial wastes. The former include coffee husk ash, ground nuts shells ash, bagasse ash and others. Its estimated that the amount of ash output are:-

Coffee husk - 650,000 tons
Bagasse husk - 850,000 tons (UNIDO ESTIMATES).
Saw dust - 20,000 m^3

The group include soft fired clays and clay reject products and fly ash.

2.1.3 Chemical Analysis of Pozzolans

Chemical analysis was done for Kisoro volcanic ash, Bunyaruguru tuffs and Kajjansi clay reject bricks. Typical results are shown below. A pozzolan to be used in cement production should have the combined percentage weight of silica and alumina greater or equal to sixty - [$SiO_2 + Al_2O_3$ % ≥ 60%]. Samples meeting the above criterion yielded the best results, but physical characteristics were the final determinant of a usable pozzolana as a cementitious material.

Note: Sample No.1 - 12 are from Kisoro, Kabale
No.13 - 25 Bunyaruguru tuffs
No. 26 - Kajansi burnt clay.

2.2 Lime:

Lime to be used in lime pozzolana cements is produced at Hima and Tororo near the cement factories. These factories also use the same limestone resources for cement production. The reserves were indicated at 23 million and 6 million tons of limestone for Hima and Tororo respectively (1969). Other important locations are Dura and Muhokya in Kasese District where a number of small scale works are reported. The Dura deposits are secondary limestone derived from lime leached from calcareous volcanic tuffs and carbonate springs. The limestone reserves are estimated at 1.2 - 1.5 million tons. The reserves at Muhokya have never been adequately assessed but a deposit of at least 3/4 million tons of limestone have been reported.

Another limestone deposit occurs on Kaku river, 16 km from Kisoro town, there the reserves are estimated at 2.5 million tons.

There is hence sufficient limestone to be exploited for the production of lime for use in pozzolan cenmets.

2.2.1 Available Lime Index

The lime to be used should be of acceptable quality. Most Ugandan small scale lime burners produce low grade lime due to poor kiln designs. To ascertain their suitability, tests on various hydrate lime samples using the rapid sucrose test were carried out. The results are summarised in table 2.2.1.

Table 2.2.1 Available Lime Index

Sample No.	Origin	Available $Ca(OH)_2$ %
1	Kenya Lime	92.0
2	Equator lime Kasese	81.2
3	Equator Lime Kasese	76.6
4	NEC Lime	64.7
5	Kisoro District Adm. Lime works	38.3
6	Muhokya lime	38.0

Lime No. 5 and No. 6 contained a lot of unburnt limestone hence very low amount of free lime available for pozzolanic cement reaction. Available lime represents the total free lime CaO content in a quicklime or hydrate, and it is the active constituent of a lime. It provides a means of evaluating the concentration of lime.

2.3 Pozzolanicity Test

This test is intended to determine the reactivity of a pozzolan with lime in a solution. The test consists of storing 15 g of a pozzolan and 5 g of lime in 100 ml of distilled water in a sealed bottle at 41°C for 8 days. The contact solution is analysed to determine the total alkalinity (OH^-) and the calcium ion concentration. Since the concentration of the alkalies strongly affects the calcium ion concentration, the total alkalinity is necessary to determine whether the solution is saturated or not with respect to calcium hydroxide. A lime saturation curve is used for this purpose. If the representative point falls below the curve, the pozzolanicity test result is positive, if the point is above the curve the result is negative. If the result is in doubt the test is repeated and continued to 15 days.

The result obtained for Kisoro volcanic ash, Bunyaruguru tuff and Kajansi burnt clay are shown in table 2.3.1

Table 2.3.1 Pozzolanicity

Pozzolan	Sample No.	Hydroxyl ion Conc. m moles/litre	CaO Conc m moles/ litre	Test resu- lt
Kisoro Volcanic ash	1	3.96	8.05	+ve
	2	32.67	10.06	+ve
	3	1.57	8.68	+ve
	4	3.96	7.47	+ve
Bunyaruguru tuff	5	4.90	26.51	+ve
	6	5.24	28.42	+ve
	7	10.25	35.40	+ve
	8	3.60	32.71	+ve
Kajansi burnt clay	9	6.04	26.73	+ve

Table 2.3.2 **Pozzolanicity**

Sample No.	Cement mix (%) OPC	Lime	Pozz	Pozzolan	Concentration (moles/l) OH^-	CaO	Test Results
1	80	-	20	Burnt clay	17.67	6.57	Positive
2	80	-	20	Volcanic	24.30	11.85	Positive
3	60	-	40	Burnt clay	21.93	15.66	Positive
4	60	-	40	Volcanic	26.83	19.15	Positive
5	30	17.5	52.5	Burnt clay			
6	30	17.5	52.5	Volcanic	23.98	8.99	Positive
7	80 (Bamburi)	-	20	Volcanic	27.77	19.82	Positive

Table 2.3.3 **Ranking of blended cements in Pozzolanicity**

Cement Mix (%) OPC Lime POZZ	Pozzolan	CaO Concentration in contact solution moles/litre	Rank
80 - 20	Burnt clay	6.37	1
80 - 20	Volcanic ash	11.85	2
60 - 40	Burnt clay	15.66	3
60 - 40	Volcanic ash	19.15	4
80 - 20 (Bamburi)	Volcanic ash	19.88	5

Ranking 1 - 5 is in decreasing order of pozzolanicity.

Note: Pozzolanicity decreases with increasing CaO concentration.

2.4 Grindability and Power Consumption during grinding

Grindability tests for various samples were carried out using a 3" x 3 ball mill with 45% ball charge and a feed of 400 kg operating at 33 rpm. The sample tested were ground for 6 hours. A hourly intervals 12 kg samples were taken and the specific surface area measured using a Blaine permeability apparatus. At the same time power consumed was read off an electric meter. Results are shown in table 2.4.1

Table 2.4.1 Grindability Tests.

Time of Grind (hrs)	Energy consumed per ton (KW hr/ton)	Fineness Blaine of Pozzolan cm^2/g A	B	C	D
1	25.0	1520	2200	4100	3900
2	150.0	1990	3000	4800	4600
3	175.0	2390	3550	5600	5800
4	100.0	3050	4800	6400	6600
5	125.5	3310	5650	7300	7400
6	150.0	4030	6400	8500	8200

Sample - A Kisoro
Samples B and C - Bunyaruguru
Sample No. D- reject burnt clay products Kajansi.

From the results materials No. A from Kisoro was the hardest to grind whereas C and D proved to be the softest. The pozzolan to be used in cement production were ground for 4 hours consuming 100 KW hours/tonne.

3. POZZOLAN CEMENTS

The pozzolans were ground for 4 hours then interground for 1 hour with lime, portland cement or both in varying proportions. This gave rise to various mixes of cements. These were characterised for fineness, initial and final set times and mortar compressive strengths.

The fineness test was carried out using the Blaine permeability apparatus in accordance to ASTM C 204 - 83. The initial and final set times were determined by the Vicat frame test ASTM C 187 - 86, whereas the compressive strength were done using ASTM C91 - and 109. The results are shown in table 3.1.1.

3.1 Blended Cement- Application

The various cements produced were tested in the laboratory as well as in the field and observed for periods ranging from 6 months to 2 years. The ensuing discussion is based on the laboratory and field observations.

3.1.1 Lime-Pozzolan Cements

These cements bear a composition of 25% lime and 75% ground pozzolans. They exhibited low mortar compressive strengths ranging from 0.48 - 2.70 MPa. Lime-pozzolan cements showed excellent workability when used to bond masonry units, this applied to both burnt clay bricks and stabilized soil blocks. Slightly longer setting times did not adversely affect the progress of construction work. (observed from model house construction).

3.1.2 Lime-Pozzolan-Portland Cements

Addition of Portland cement to lime-pozzolan cements in percentage 10 - 30% enhanced the strength of these cements. This effect is illustrated in table 3.1.2

Table 3.1.2 Lime-Pozzolan-Portland Mortar strength

Pozzolan Type	Lime-pozzolan cement	Lime-pozzolan + 10% OPC	Lime-pozzolan + 30% OPC
	Compressive Strength MPa (28 days)		
Kisoro volcanic ash	0.93	7.03	15.35
Kajansi burnt clay	0.48	7.78	15.57
Bunyaruguru volcanic tuffs	2.70	-	22.23

The lime-pozzolan cements with 30% OPC have been used in slabs to simulate foundation concretes. Strengths of 5.9 - 11.0 MPa have been registered in 1:3:4 concrete mixes (cement:sand:aggregate), water cement ratios (W/C) of 0.65. Plasters done using this mix provided excellent workability and nice finishes in the field tests.

3.1.3 Portland-Pozzolan Cements

Portland cement replacement by a Pozzolan were done up to 50%. The mortar strengths for 28 days varied from 38.4 for Portland cement to 13.5 and 20.94 for Kisoro and Bunyaruguru tuffs respectively at 50% portland replacement by pozzolan.

The strengths attained for Blended Ordinary Portland Cement (OPC) to Pozzolan (OPC/POZZ) 80/20 and 70/30 were found to be acceptable for general concrete works. (Designation ASTM C: 595-86).

The blend OPC/POZZ 60/40 can be classified for general concrete construction where high strength at early ages are not required.

Blend OPC/POZZ. 50/50 can be classified as a type of masonry cement for use in binding and rendering works and other simple construction chores involving low load bearing members.

4. ECONOMICS OF POZZOLAN CEMENTS

The cost of production of lime-pozzolan and blended cements were estimated based on the 675 ton/annum production capacity using the ball mill installed at Geological Survey and Mines Department, Entebbe laboratories. Kisoro being the furthest source of raw material was selected to serve as an indicator to the cost of production.

4.1 Operating parameters

- 300 days working/year was assumed
- Plant capacity - 2.25 tons of cement per 8 hour working shift;
- Daily volcanic ash requirements are 1.7 tons, hence annual total would be 510 tons;
- Annual lime requirements - 168 tons;
- Cost of volcanic ash - 4000 sh/ton (Kisoro)
- Cost of lime - 160,000 sh/ton
- Transportation of volcanic ash by 10 ton trucks hired at 350,000 sh/trip, 51 trips are required. (Kisoro - Entebbe)

4.1 Cost-Strength Benefit Analysis of Blended Cements

The replacement of Ordinary Portland Cement with Pozzolan or lime-pozzolan brings about a reduction in cost ranging up to 45%. There is a general loss in strength as Ordinary Portland Cement is replaced. One important feature to be noted is that these cements are targeted for application where low strengths are required. An added advantage attached to these cements is their better workability in mortars and renders.

The capital cost per unit of production of lime-pozzolan cement smaller than in conventional cement plants. These cements can be used a base material for production of triple component Blended Cements (Lime-Pozzolan-Portland). This is of crucial importance in a country like Uganda suffering from chronic shortage of capital investment. Lower capital cost would encourage investors hence higher availability of these low-cost binders leading to better and increased housing stock.

The production of blended cements within the existing cement factories in Uganda would certainly make the price of these cements go lower than the estimated laboratory figures due to economies of scale and higher efficiency.

5. CONCLUSION

The following conclusions can be drawn from the field and laboratory experimental work performed on Ugandan pozzolans for production of blended cements.

5.1 The volcanic ash and tuffs sampled in Kisoro, Kabale and Bunyaruguru proved to be reactive when combined with high quality lime. Similar results were exhibited by reject burnt clay products from Uganda Clays Ltd. at Kajansi near Kampala. Thus these pozzolans can be used in the production of lime-pozzolan cement or as admixtures to ordinary portland cements.

5.2 Lime-Pozzolan Cements

Lime-Pozzolan cement produced using Kisoro volcanic ash, Bunyaruguru tuffs and reject burnt clay products provided excellent workability as binders for masonry units. Mortar compressive strengths 0.48 - 2.70 Mpa were achieved by these cements. Addition of 10 - 30% Portland cement to lime-pozzolan enhanced their strength development.

5.3 Portland-Pozzolan Cements

Blended cements produced through utilisation of the local pozzolans with portland cement achieved sufficient strengths to be utilised in general concrete construction in the low and middle cost housing schemes.

5.4 The power consumption for production of Pozzolan cement was estimated at 125 KW hr/ton of cement using a laboratory mill.

5.5 Savings of 30-50% in cost of cement are achieved when blended cements and lime-pozzolan cements for low-cost housing are produced compared to Portland cement.

5.6 From the investigation done on the pozzolanic cement building materials (mortar and concrete), and tests carried out on the model beams, the conclusions below are drawn.

5.7 Concrete made with pozzolanic cement has low strength at early age, but attains long term strength almost equivalent and in some cases greater than that of Ordinary Portland cement. Though blended cement concrete has low workability it is less prone to bleeding and segregation, thus giving better utilisation of material strength. Also the slow setting of pozzolanic cement does not affect the speed of concreting, but improves on the long term strength.

5.8 The economic analysis showed that when pozzolanic cements are used, savings in concrete costs of 10 - 20% per cubic metre can be achieved corresponding to a saving of 15-40% in cement costs. This is very beneficial especially where the concrete work is big.

5.9 Economically, burnt clay is a better pozzolan. Its blends have lower setting time and achieve higher strengths than those of volcanic ash, yet it costs less. However its viability is limited by the rate at which rejects can be produced, whereas volcanic ash exists abundantly as a natural resource.

5.10 Except at early age the Portland-pozzolan cements with 80% Portland and 20% pozzolan are stronger than Bamburi blended Portland, already on the market. If produced in large quantities, these blends can easily out compete Bamburi, which is going at prices equivalent to those of Ordinary Portland Cement.

6. RECOMMENDATIONS

6.1 It is recommended that production of quality lime be given serious attention. Most kilns used in burning techniques are poor. These result into incomplete burning of limestone rendering the products inferior in grade.

6.2 Pilot plant production to be set up in Kisoro and Bunyaruguru to continue the assessment of lime-pozzolan cement production economy outside laboratory conditions.

This should provide more data, leading to laying down codes of practice and specifications for Uganda lime-pozzolan cement and related products.

6.3 Lime-pozzolana cement be used as binder for the masonry units. In case of foundation and plastering 30% portland cement should be added to enhance strength development.

REFERENCES

1. Chemistry and Technology of Lime and Limestone — Chemistry Publishing Co. Inc. NEW YORK

2. The Chemistry of Cement and Concrete (3rd Edition) — Wiley InterScience Publications — S. Boynton

3. Annual Book of Standards Section 4 Volume 04.02 Concrete and Aggregate

4. Alternative cements in India — Intermediate Technology Development Group — R. Spence

   Paper - Building Research Establishment Rice Husks Ash cement. — Nov. 1992 — R.G. Smith

GLOSSARY

Available lime	-	This is the amount of free lime available for chemical reaction.
Pozzolanicity	-	Measure of reactivity of a pozzolan with lime.
OPC	-	Ordinary Portland Cement
Pozz	-	Pozzolan
OPC/POZZ	-	Cement mix involving Portland cement and a Pozzolan.
ASTM	-	American Standards and test Methods.
LPC	-	Lime Pozzolan Cement
UNBS	-	Uganda National Bureau of Standards
IDRC	-	International Development Research Centre of Canada

APPENDIX 1 : SOURCES OF POZZOLAN SAMPLES IN THE POZZOLAN HOUSING PROJECT

Sample No.	Location
1. -	Hakadege, Kisoro - Bunagana Rd; Ash consist of yellowish brown layered formation.
2. -	Karambi - 4 km on Kisoro-Kyanika Rd; Darker and uniform grained.
3. -	Gatarara - 1 km from Kyanika of Kyanika-Kisoro Rd; Ash and tuffs are finer and lighter coloured.
4. -	Nyakabande - Kilembe: Greyish black ash with isolated boulders.
5. -	Nyakabande - Catholic: Same as 4.
6. -	Kamageza: Finer grain weathered to yellowish at top.
7. -	Kaseregenyi: Large boulders brownish grey - Pumice lava.
8. -	Katozo - Kalengire: Yellow brown lava
9. -	Katozo II (lateritic Conglomeratic): Conglomerate with lava.
10 -	Muko-Kasenyi junction: Dark fine ash.
11 -	Muko Parish: Same as 10
12 -	Muko III: Same as 10
13 -	Kyanyonza Hill - Bunyaruguru
14 -	Kyanyonza Hill - Bunyaruguru
15 -	Kyanyonza Hill - Bunyaruguru
16 -	Kyanyonza Hill - Bunyaruguru
17 -	Kyangabo Crater - Bunyaruguru
18 -	Kyangabi Crater - Bunyaruguru
19 -	Kyangabi Crater - Bunyaruguru

20 - Katinda-Murambi area

21 - Katinda-Murambi area

22 - Chabafu Crater

23 - Chabafu Crater

24 - Chabafu Crater

25 - Chabafu Crater

26 - Kajansi clays rejects.

THE POTENTIAL OF COCONUT SHELLS FOR ACTIVATED CARBON PRODUCTION IN TANZANIA

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Abstract

Coconut is the most important oil crop in the entire coastal best of Tanzania. The coconut shell is a valuable raw material for a number of industries and is considered as a valuable which is suited for manufacture of superior quality activated carbon. Activated carbon is a material very much sought after in the world market for water treatment, decolorisation, solvent recovery, air treatment, precious metal recovery and for military and nuclear purposes. At present all activated carbon requirements in Tanzania and the Southern Africa Sub-region are met by imports. Activated carbon is traded internationally in several categories and contracted prices are confidential. Critical to competition are quality, price and delivery terms. The activated carbon customer have a choice to buy from a variety of sources, hence command a strong bargaining power. While coconut shell based activated carbon is preferable in many applications, the problem encountered with its processing is that it has to compete with coal and other carbonaceous materials which are comparatively cheaper. With the support of appropriate technology shell based activated carbon may be in a position to compete price-wise and quality wise in the domestic and export market for

selective application in pollution control devices and in chemical, food and mining industries.

Though a valuable commodity, in Tanzania the shells available at homesteads do not serve any purpose because they are not concentrated at any point. The shells wherever they are available are burned as domestic fuel or even wasted. Further processing of shells is not carried out in the country. Coconut shell based activated carbon is mainly preferred in the mining industry for recovery gold due to its resistance to abrasion. With potential development in the mining industry in Tanzania activated carbon has great potential. There is also export potential for coconut shell based activated carbon in the Southern African Sub-region. Production of shell charcoal may be initiated in Zanzibar by the Waste Heat Process in order to determine the suitability of the charcoal for production of activated carbon. In order to move forward a study should be carried out to quantify the markets and raw materials supplies.

1.0 INTRODUCTION

Coconut is the most important oil crop in the entire coastal belt of Tanzania. While in some parts of the world, the coconut is grown in extensive plantations it is principally a small holder crop in Tanzania. More than 95% of all coconut palms are grown by peasants. The estimated area under coconuts is 240,000 hectares with a production of 536.6 million units of which 33% is consumed by farmers for domestic purposes. The remaining 67% is marketed for copra production and domestic consumptions in urban and inland area where coconut is not the main crop.

The major products and by-products of the coconut palm are under utilised in the country resulting in slow progress in the traditional coconut growing belts. Even the traditional activities of copra making have not been well developed.

The coconut shell, the endocarp which embodies the coconut kernel is a valuable raw material for a number of industries. It is considered as a valuable by-product which has not been fully exploited yet. It is very much suited for the manufacture of superior quality activated carbon, a material very much sought after in the world market for water treatment, decolorisation, solvent recovery, air treatment, precious metal recovery and for military and nuclear purposes.

The conversion of shell into shell charcoal is not a popular activity in the important coconut growing areas in Tanzania for the simple reason that the shell charcoal does not find major applications now. Shell charcoal is the raw material for production of activated carbon. Currently, the shell is mainly used as fuel in the household, for copra drying and in very minor quantities in the manufacture of shell power. Roughly, about 7,500 to 8,000 shells weight one metric ton and can produce about 25 to 30% by weight shell charcoal.

Conventional methods for production of shell charcoal although still in use produce low quality products and results into emissions which pollute the environment. Modern methods such as the Waste Heat Unit process are now in use where in the same process coconut shells are converted into shell charcoal while the heat generated can be used to dry copra. This latest technology developed by the natural Resources Institute of London has advantages over conventional methods.

Production of shell charcoal, the raw material for activated carbon manufacturing can commence in places where coconut shells are available in large quantities such as government Factory Enterprise, Zanzibar where

850-1,000 metric tons are accumulated annually which may produce about 336 metric tons shell charcoal at 28% yield. Once shell carbonisation units are established in other areas such as Mafia, Bagamoyo and Tanga, the shell charcoal produced can be conveniently used as raw material for production of activated carbon.

At present all activated carbon requirements in Tanzania and the Southern African regions are met by imports. The main world suppliers are the United States of America, the Netherlands, German, the United Kingdom, France, Japan, Belgium, Sri Lanka, Philippines and India.

The main consumers of shell based activated carbon in the Southern African region are gold mining companies whose annual demand including South Africa is estimated at 5,300 metric tons. However, a properly organised market survey would reveal requirements in other areas where activated carbon enjoy preference over other sources.

Activated carbon is traded internationally in several categories and contracted prices are confidential. Critical to competition are quality, price and delivery terms.

Although the general trend for activated carbon usage around the world is increasing, the effect of the current world recession has temporarily reduced the size of the market. At this time the world market is saturated with activated carbon with a consequent reduction in selling price.

Installation of a new plant is costly exercise and in the present economic climate returns would be low. A complete factory capable of producing approximately 1000 metric tons per annum of activated carbon would cost in the order of £1 million.

2.0 FINDINGS AND OBSERVATIONS

2.1 Supply situation f coconuts and by-products

2.1.1 Production of coconuts in Tanzania

(a) Coconut cultivation in Tanzania

Among African countries Tanzania has the largest area under coconuts but in production it is rated the third (as indicated in table 3). In Tanzania coconut cultivation is concentrated in the coastal region commencing from Tanzania in the North to Mtwara in the South including the Islands of Pemba, Zanzibar and Mafia. Cultivation of coconut is done also in interior areas such as Tabora and Morogoro. The coconut variety grown is East African tall. The crop is grown in a mixed crop pattern with cashew, citrus, cocoa and cloves, in homesteads. 95% of the area is cultivated by small holders and 5% of the area is owned by large plantations. The palms commence bearing from the 6^{th} to the 7^{th} year and stabilises by the 10^{th} year.

Good plantations remain productive up to the age of 60 to 70 years. The National Coconut Development Programme of Tanzania launched in 1979, to revive the coconut cultivation estimated the area under coconut in the country as 239.361 hectares with an estimated production of 532.7 million nuts per year. The area under coconuts with yield per palm and estimated production of nuts are given in Table 1 and Table 2.

2.2 Coconut utilisation

It is estimated that about 32.5% of the nuts produced are consumed by the producers for domestic purposes, 0.5% is utilised as seed nuts for new plantings and the remaining 67% is the marketed surplus. This 67% of the production is consumed for domestic purposes by the non-growing population and for copra production which is the major industry in Tanzania relating to coconuts. The surplus production is obtained from the main producing areas of the Zanzibar and Mafia Islands. Out of the surplus nuts it is estimated that 75% is utilised as fresh nuts for domestic consumption and the remaining nuts are converted to copra which is ultimately used to produce coconut oil and cake. Copra production and oil extraction are concentrated in the main coconut producing areas of Zanzibar and Mafia.

Absence of exports of copra or oil indicates that whatever increase in production is achieved is being nullified by the increase in domestic consumption of fresh nuts. It was also observed that utilisation of tender nut for drinking purposes is gaining popularity and the practice of tapping inflorescence for production of toddy is a common practice in all of the coconut growing areas in the country. The yield reduction caused by tapping is yet to be assessed.

2.3 By-product utilisation

Each and every part of the coconut tree is useful to mankind and the tree is rightly called as the "Tree of Life". The hard part of the stem can be used for furniture, building material and fuel. The leaves are used for thatching and broom making. The fruit is used from the inflorescence stage, to tap sweet juice, the unripe nut provides a refreshing drink and the mature nut provides fibre, valuable shell and kernel which has numerous uses in several fields.

In Tanzania, industrial use of coconuts is still confined to copra production and oil milling of the surplus nuts left over after domestic consumption.

2.3.1 Copra production

At present copra production is mainly concentrated in the surplus producing area of Zanzibar and Mafia. In the mainland overripe and undersized nuts which are not preferred for domestic use are sorted out and converted to copra which is subsequently milled for oil production. Commercial copra production is done by dehusking the nut, splitting, drying on kilns, scooping the cup and further drying to required moisture content.

At present the copra produced in the country is milled to produce oil and cake. Due to shortage in copra only major oil mills in Zanzibar and Mafia alone are engaged in milling. The oil is extracted by expeller mills and the average recovery of oil varies from 58 to 60%. The oil produced in the mills is sold to mainland and used locally for domestic consumption. Few small scale mills operating in mainland sell out the oil to local soap manufacturers since the quality of oil is not fit for human consumption. The case is sold out in retail and whole sale as cattle feed.

2.3.2 Coconut husks

Husk is the fibrous material surrounding the nut. The thickness of the husk ranges from 2.5 to 4.5 cm. The husk becomes fibrous and spongy when coconut is about eleven months old. The husk content of a mature coconut varies between 35 to 45% of its weight and is separated from the nut during the dehusking process just before utilisation. In Tanzania dehusking occurs when the nuts are ready for transport to the market for sale or in the Copra yard just before splitting open. This leads to the accumulation of husks at processing or marketing centres spread throughout the coconut growing areas. Generally, husk accumulating at the marketing centres and small scale copra processing centres are wasted by burning as fuel.

Coconut husk contain 30% fibre and 70% pith. The fibre and fibre products such a coir, rope, mat, mattress, carpets, etc. are very valuable commodity in the world market. The demand for coir and coir products in the world market is met by India (60%) and Sri Lanka (30%). Processing of husk into fibre is practised on a commercial scale only in two locations in Zanzibar and Mafia. All the remaining husk is wasted.

In Zanzibar the Government Factory Enterprises has a fibre processing centre. The factory process dry husk into brown fibre and consumes only 10% of the husk produced in its Copra processing centre. The remaining 90% of husk is sold out for fuel. The fibre recovery is about 27% of the husks. Part of the fibre is utilised at the factory for production of coir, mats and carpets, part of the production is sold locally and other part is exported.

The pith separated from fibre at the processing centres are accumulated and this results into a big disposal problem.

2.3.3 Coconut shell

The endocarp of coconut which encloses the most useful kernel commonly called coconut shell is a very useful raw material for a number of industries. The availability of coconut shells are concentrated at Copra processing centres and widely distributed in human inhabitations where coconuts are consumed for domestic purpose. In homesteads the shell is discarded and used as domestic fuel. In conventional Copra "kilns" usually 50% of the shells are utilised for energising the kilns. The remaining 50% are not gainfully utilised.

The coconut shell is a valuable raw material for production of shell charcoal, activated carbon and shell flour. Other uses are for marketing handicrafts, as a fuel in factories and bakeries and for later collection is rubber growing areas. Due to its biodegradability, recently it is being used as a dish for serving ice-cream, salad, puddings, etc. composition of shell is given below:

Composition of coconut shell

Moisture	6.76%
Ether extract	0.17
Alcohol benzene extract	1.98%
Ash	1.32%
Hot water extract	1.76%
Pentosans	30.01%
Lignine	32.22%
Cellulose	50.99%

Source: Handbook on coconut palm by P.K. Thompson 1981

Though a valuable commodity, in Tanzania the shells available at homesteads do not serve any purpose since they are not concentrated at any point. The shells wherever they are available are burned as domestic fuel or even wasted. The shells left after extraction of copra at the processing centres are currently available for further processing.

It is estimated that the Government Factory Enterprises in Zanzibar could collect 850 to 1000 metric tons shells from its various processing sites annually. At present the same shells are chipped and sold to some processors in Dar es Salaam for further processing.

Availability of shells from Mafia Coconut Limited is estimated at 340 tons shells annually of which 140 tons are consumed for production of shell flour in its own factory. The balance is available for further processing. The shell flour produced is marketed in Tanzania at a cost of T.sh. 120,000 per metric tons. Copra processing is also done by private processors in Zanzibar and some locations in the mainland. The shells produced by them can also be collected for further processing.

2.3.5. Coconut shell flour

Coconut shell flour is extensively used in industrial applications as a compound filler for synthetic resin glues and as a filler and extender for phenolic moulding powers. Shell flour gives a smooth and lustrous finish to moulded articles and also improves their resistance to moisture and heat. Shell flour is used for manufacture of mosquito coils and as a carrier in insecticide dusts.

The Mafia Coconuts at its site at Mgombeni have installed a shell flour machine. The shells of fully matured nuts are first cleared off the adhering pithy matter and broken down to small pieces. These pieces are then subjected to repeated grinding in grinding mills till they are finally powered to the desired particle size. The installed capacity of the plant is to produce 500 kg. Flour per hour shift. The shell flour manufactured is marketed in Dar es Salaam. The production is not sufficient to meet internal demand and export.

2.4 Technical Aspects of Producing Activated Carbon from Coconut Shells

2.4.1 Product description

The bulk of active carbon produced today is made from either coconut shells or coal based materials, activated by selective oxidation at elevated temperatures with steam or chemicals. This produces a product with the ability to effectively absorb even trace quantities of either unwanted or valuable liquids and gases. This is its main field of application where it plays a very important part in solvent recovery processes, water and effluent treatment and treatment of flue gases before discharge to the atmosphere. These are all applications which are likely to expand in the future due to stricter anti-pollution legislations.

Coconut shell charcoal is primarily used as the raw material in the manufacture of activated carbon. World-wide production of activated carbon from coconut shell is in the order of 40,000 metric tons annually, of which the Philippines and Japan account for 50% most of the remainder being produced by France, the United States, India, Sri Lanka and the United Kingdom in that order. International Trade in coconut shell charcoal is normally 70,000-80,000 metric tons annually. The principal importers are Japan, France, the United States and the United Kingdom. The main origins are the Philippines and Sri Lanka.

Total world production capacity of activated carbon is in the region of 275,000-300,000 tons per annum available as granular, extruded or powdered product.

Quality of an activated carbon is described by reference to its surface area and the ability of that surface to absorb a particular molecule. The highest quality material produced has a surface area of up to 11300 m^2/g, the lower qualities start around 700 m^2/g. Table 8 shows a range of activated carbon with their relevant specifications.

2.4.2 Manufacturing

2.4.2.1 Raw materials

The presence of significant quantities of coconut shells has been established as discussed earlier. It has also been demonstrated that coconut shells can be processed to yield readily saleable activated carbon. Coconut shell contains about 75% volatile matter and moisture which is removed largely at the source. The cellulosic structure of shell determines the end product which, at normal yields of 30-40% on the carbonised basis is a material with a very high internal surface.

Good coconut shell charcoal is uniformly dark and snaps with a clean shining fracture and produces a metallic sound when dropped on hard ground. Under burnt shells do not give a metallic sound and a clean fracture, while the over brunt ones are fragile and the surface of the fracture sounds dull when dropped and easily crumbles. Coconut shell charcoal contains the highest percentage of fixed carbon of all the ligneous charcoals. The average composition of good charcoal is moisture 6.24%, volatiles 5.46%, ash 0.54% and fixed carbon 87.76% (Source: handbook on Coconut Palm by P.K. Thampan - 1981).

Shell charcoal is used a culinary fuel in smithies, bakeries and laundries. It has a high adsorption capacity for gases and colouring matter and can, therefore, be used as a refining agent both as a deodoriser and a decolouriser. The major use of shell charcoal in modern world is as a raw material for production of activated carbon since activated carbon produced from shell charcoal is of superior quality and it is required for specific applications. The demand for shell charcoal in the international markets is met by the Philippines, Sri Lanka and Indonesia.

All the industrially advanced countries are importing shell charcoal to produce activated carbon.

2.4.2.2 Manufacturing processes

(a) Carbonisation

- Shell from mature nuts are normally used for production of shell charcoal. Heavy shells produce high quality shell charcoal. On average, about 7,500 - 8,000 shells weight up to one metric ton and will produce about 25 - 30% charcoal.

- In the production of shell charcoal, the coconut shells are burned in the absence of air or limited supply of air so that the shells are not burned to ashes but merely carbonised. By conventional process this can be easily carried out in pits in the ground, however, there are improved methods of using brickwork or steel kilns.

- To initiate production of shell charcoal in Tanzania tow sites at the Government Factory Enterprises Zanzibar where 850 to 1,000 tons of shells are collected annually from its copra processing sites and Mafia Coconuts Ltd., where 200 tons of shells would be available annually are recommended.

- For carbonisation of shells the United Nations Industrial Development Organisation and Asian Pacific Coconut Community, designed kiln which is 6t in diameter and 8 ft deep may be adopted. The walls of the pit slope to avoid collapse and are lined with ordinary brick and mud. The walls of the pit diverge upwards and the slope depends on the compactness of the soil. Few galvanised iron sheets are used as cover.

  The pit can be loaded with 40,000 whole shells which yield metric tons of charcoal after every three days. Charging of the pit is done from the base followed by igniting the initial charge. The pit is gradually filled as the shell burns. Once the pit is full the pit is covered with a perforated galvanised iron sheet and the sides sealed to favour slow burning.

- The burning is completed slowly and the shells cooled gradually, fire eruption is prevented by sprinkling water when necessary. Once the fire is fully extinguished the charcoal is spread in the shade for two weeks for cooling and then bagged. Conventional pit and drum methods are associated with smoke emissions and consequent environmental hazards. It is also reported that shell charcoal may have a mixture of sand or earth particles.

- To overcome the above defects and to prevent loss of 50% of the shells for energising copra kilns, the Natural Resources Institute (NRI), the scientific arm of the United Kingdom's Overseas Development Administration, have designed a Waste Heat Unit which would enable production of shell charcoal and drying of copra simultaneously with the hot gases produced at the time of carbonising shells. The advantages claimed are restricted emissions, higher yield of clean shell charcoal up to 33% and saving in shells otherwise used for energising the copra kilns. The gas and smoke emitted during carbonisation in the Waste Heat Unit are burned in a furnace producing heat, which may be used for copra drying or elsewhere. The shells therefore may replace either the imported oil or locally felled wood currently used as fuels. Where shells are used as a substitute for wood, deforestation and associated environmental problems are reduced.

- The Waste Heat Unit was commissioned in Sri Lanka by the Coconut Development Authority and NRI by installing a 1.0 metric tons shell capacity waste heat unit. It is proposed to make an on-the-spot evaluation of the waste heat unit and to study its merits in comparison with the cost of installation and to ascertain its suitability for Tanzania in comparison with the conventional pit and copra production methods. If the project is viable then a formal design and cost estimation for a specific location in Tanzania may be arranged with NRI. If the financial estimation and output of shell charcoal production is viable the project may be recommended to the Government.

(b) Activation

- Activation of shell charcoal involves the use of steam or chemical process at selected temperatures to induce selective oxidation of charcoal material resulting in the production of particles with pores. About three tons of coconut shell charcoal produce one ton of activated carbon.

- The activation process clears the exterior surface of the carbon which was otherwise wasted with extraneous material such as tar and other materials, clears the pores which would otherwise remain clogged and widen the existing pores in the charcoal particle.

Due to activation, the effective adsorption area of carbon particles are tremendously increased in comparison to the external area of the particles and the total available area become more active or receptive to gases and dissolved solutes for absorption. Numerous methods of activation suitable for different raw materials are described in literature. Chemically porosity is achieved by dehydration of the structure while in steam activation porosity is obtained by the removal volatiles and oxidation of the carbon atoms.

(i) Steam activation

- A variety of methods have been developed and they all share the same principle which is carbonisation at 500-600°C and subsequent activation with steam at 800-1,000°C. The overall reaction involving conversion of carbon to carbon dioxide is exothermic, however, the action of steam on carbon is endothermic.

$C + H_2O$	$CO + H_2$	- 31 Kcal
$C + {}^{1}/_{2}O_2$	CO_2	+ 67 Kcal
$H_2 + {}^{1}/_{2}O_2$	H_2O (steam)	+ 58 Kcal
$C + O_2$	CO_2	+ 94 Kcal

- A number of different types of kilns and furnaces are used for carbonisation/activation and include rotary (fired directly or indirectly). Vertical multi-earth furnaces, fluidised bed reactors and vertical single retorts, with manufacturer having their own preferences. In all cases the quality of the product depends ultimately upon the residence time of the material in the 'activation zone'.

- The raw material (saw dust, woodshavings or peat) and reagent are mixed into a paste dried and carbonised in a rotary furnace at 600°C. When phosphoric acid is the activating agent the carbonised product is further heated at 100-1,000°C during which state the carbon is oxidised by the acid. The activated product is washed with water and dried.

- Activating can be controlled by altering the proportion of raw material to reagent between the limits of 1:05 to 1:4 by increasing the concentration of the reagent, the activity increases although control of furnace temperature and residence time can achieve the same objectives.

- Carbons produced in this manner however, have one inherent failure, their lack of mechanical strength and are not suited for vapour phase operation or to liquid phase operation in granular form.

The technology developed in Japan and currently used in the Philippines is considered to be the most effective of all known technologies. World production of activated carbon is around 454,000 metric tons from different sources. The estimated annual increase in production is 7 to 10%. Out of the total production coconut shell activated carbon would be of the order of 10% i.e. around 45,000 tons. Due to its superior quality and necessity for specific applications the world demand for activated carbon produced from shell charcoal is expected to increase annually.

2.4.3 Industry analysis

Currently the requirement for activated carbon in Tanzania is met by imports. Tanzania's requirements will definitely increase in future due to expansion of industries. Considering the current availability of coconut shell in Tanzania there is potential for production of shell charcoal at the rate of 336 metric tons annually. Shell charcoal production within the country may be initiated first. Once the production of shell charcoal is stabilised a project for production of activated carbon from coconut shell charcoal may be studied up and finalised. The activated carbon produced in the country can meet internal demand and excess production can be exported in the world market. Initiation of the industry within the country will help technological advancement, save foreign exchange and promote value of coconut by elevating demand for the by-product-coconut added shell. The value addition to coconut shell by processing it to shell charcoal and activated carbon is illustrated below:

Value addition to coconut shell

Commodity & Quantity	Coconut Shell 100kg →	Shell Charcoal 30kg →	Activated Carbon 9kg
Value in US$ (1990 price)	1.6	6.0	10.78

Major activated carbon producers in the world are Norit Group from ICI, America produces activated carbon by the brand name "Darco" and the Calgon Corporation. In Germany Bayers and in the United Kingdom Sutcliffe Speakman and National Coal Board. In France Caca and Peca. Japan, China and the Republic of Korea also produces activated carbon. In the Philippines there are six plants producing activated carbon. Sri Lanka produces it in two sites.

The activated carbon produced in EEC countries, the United States of America, Japan and China are fully utilised domestically and the balance requirements is met by imports from Sri Lanka and the Philippines. A project for production of activated carbon if implemented in Tanzania will be in direct competition with the above mentioned suppliers. Critical to competition will be quality, price and delivery terms.

The activated carbon customers have a choice to buy from a variety of sources, hence command a strong bargaining power. To date, resin carbon is the known substitute to coconut shell based activated carbon. However, the absorption resistance properties and lower prices of the later render it to be a preferable product.

2.4.4. Market analysis

2.4.4.1 Current world markets

Although the general trend for activated carbon usage around the world is increasing, the effect of the world recession has temporarily reduced the size of the market. In addition the proliferation of producers for both coconut shell and coal based activated carbon in the Far East (China, Indonesia, the Philippines and Sri Lanka) has exceeded the growth of the business generally. At this time the world market is saturated with activated carbon with a consequent reduction in selling price, making economic production extremely difficult.

2.4.4.2. Tanzania market (domestic market)

The current demand for activated carbon which is mainly imported from the Netherlands is estimated at 50 tons per annum. It is mainly consumed by beverage manufacturers. This indicates an insignificant current market for activated carbon in Tanzania. However, the objective is to concentrate on capturing all the current and potential local market bearing in mind expected increase in demand by the developing domestic mineral industry, as well as the potential export market that exists within the Southern Africa Region.

2.4.4.3. Southern Africa market (export market)

There are many industries in the Southern Africa region utilising activated carbon. The big mining houses in Zimbabwe and South Africa are the main consumers of coconut shell based activated carbon. There also exists a number of smaller companies who utilise activated carbon for other uses. The mining industries in Zimbabwe and South Africa imports about 5,250 tons of activated carbon per annum. This indicates the ready market of the product which should be targeted.

3.0 CONCLUSIONS

Coconut is a major crop in the entire coastal belt of Tanzania mainland and Zanzibar. The stability of the coconut based economy of these regions depends on the development of a vibrant post harvest processing and marketing sector which would facilitate diversified uses of major coconut product and commercial utilisation of the valuable by-products. With the fuller utilisation of the products and by-products of coconuts the value of coconut will be enhanced and additional rural and urban employment generated. There are immense possibilities for the promotion of many non-traditional industries based on coconut such as activated carbon.

Coconut shell a valuable by-product of copra processing is under-utilised. Currently, only about 10% of the shells are collected at two copra processing centres and are used for production of shell flour. For commercial production of activated carbon collection, shells need to be looked into.

Further processing of shells to shell charcoal and activated carbon is not carried out in the country. There is potential for export of these coconut by-products in the world market.

The pace of modernisation in the coconut post harvest processing sector has been slow in our country mainly due to inadequate R and D. By applying technology innovations already developed in the country and abroad in the field of product diversification and by-product utilisation, it is possible to promote modern activities based on coconut.

While modernisation of processing activities is important, their success would depend on marketing support that would be extended to the new enterprises. One of the basic requirements for the promotion of non-traditional processing activities is the creation of consumer demand for the products. This is a field where organised support from the government is required.

The government is fully aware of the importance of coconut industry. However, importance has to be given to processing and marketing activities. Establishment of profitable processing units and organised markets would greatly encourage horticultural production.

While coconut shell based activated carbon is preferable in many applications, the problem encountered with its processing is that it has to compete with coal and other carboneous materials which are comparatively cheaper. However, with proper technology shell based activated carbon has a future. A properly organised market survey would reveal the areas where shell based activated carbon may enjoy preference over other sources or selective uses.

With the support of appropriate technology shell based activated carbon may be in a position to compete price-wise and quality wise in the domestic and export market for selective application in pollution control devices and in chemical, food and mining industries.

With potential development in the mining industry in Tanzania activated carbon has great potential.

Coconut shell based activated carbon is mainly preferred in the mining industry for gold recovery due to its resistance to abrasion. There is export potential for activated carbon especially in the Southern Africa region.

There is considerable amount of development work being carried out to improve activated carbon performance in existing operations and to use its remarkable properties in solving new problems especially in environmental pollution.

Consumers of activated carbon have choice of suppliers hence command a bargaining power. An activated carbon project if implemented in Tanzania will be indirect competition with major suppliers.

The installation of a new plant is a costly exercise and in the present economic climate, even with the anticipated captive home market, returns may be slow. However, the projected net profit before tax of TSh 44.6 million is a positive indicator for further investigations.

A new producer entering the world market has to operate close to capacity in order to cover the cost of finance for the purchase of the production plant since the current world market is saturated with activated carbon.

Table 1
Area under coconuts in the United States of Tanzania

LOCATION		AREA UNDER PALMS	PALM POPULATION	PALM DENSITY
REGION	DISTRICT			
TANGA	Tanga	5,299	345,143	65
	Muheza	38,946	2,554,242	66
	Pangani	12,234	1,067,589	87
	Korogwe	273	19,251	71
Sub-total		**56,752**	**3,986,225**	**70**
COAST	Bagamoyo	11,536	1,000,304	87
	Kisarawe	45,216	4,857,000	107
	Rufiji	11,906	1,388,353	117
	Mafia	16,441	1,669,495	102
Sub-Total		**85,099**	**8,915,152**	**105**
DAR ES SALAAM	Ilala	2,827	221,063	78
	Kinondoni	2,499	168,363	67
	Temeke	12,204	1,343,157	110
Sub-total		**17,530**	**1,732,583**	**99**
LINDI	Kilwa	10,284	1,314,564	128
	Lindi	5,511	605,740	110
Sub-total		**15,795**	**1,920,304**	**122**
MTWARA	Mtwara	2,879	290,989	101
TOTAL MAINLAND		**178,055**	**16,845,253**	**95**
ZANZIBAR	Unguja	44,036	4,684,921	106
	Pemba	17,270	1,090,705	63
Sub-total		**61,306**	**5,775,626**	**94**
TOTAL TANZANIA		**239,361**	**22,620,879**	**95**

Source: NCDP Marketing Study Phase II

Table 2
Production of coconuts in
United Republic of Tanzania

LOCATION		PALM POPULATION	YIELD PER PALM/YEAR	NUT PRODUCTION
REGION	DISTRICT			
TANGA	Tanga	345,143	22.0	7,593,146
	Muheza	2,554,242	22.0	56,193,324
	Pangani	1,067,589	22.0	23,486,958
	Korogwe	19,251	22.0	423,522
Sub-total		**3,986,225**	**22.0**	**87,696,950**
COAST	Bagamoyo	1,000,304	21.5	21,506,536
	Kisarawe	4,857,000	21.5	104,425,500
	Rufiji	1,388,353	21.5	29,849,590
	Mafia	1,669,495	21.5	35,894,143
Sub-Total		**8,915,495**	**21.5**	**35,894,143**
DAR ES SALAAM	Ilala	221,063	20.2	4,465,473
	Kinondoni	168,363	20.2	3,400,933
	Temeke	1,343,157	20.2	27,131,771
Sub-total		**1,732,583**	**20.2**	**34,998,177**
LINDI				
	Kilwa	1,314,564	25.4	33,389,926
	Lindi	605,740	25.4	15,385,796
Sub-total		**1,920,304**	**25.4**	**48,775,722**
MTWARA	Mtwara	290,898	27.3	7,944,000
TOTAL MAINLAND		**16,845,253**	**22.0**	**371,090,615.90**
ZANZIBAR	Unguja	4,684,921	27.7	129,772,312
	Pemba	1,090,705	29.2	31,848,586
Sub-total		**5,775,626**	**28.0**	**161,620,898**
TOTAL TANZANIA		**22,620,879**	**23.5**	**532,711,514**

Source: NCDP Marketing Study Phase II

Table 3

Production of coconuts in Africa (main producing countries)

Country	Production of coconuts in nut equivalent of 1,000mt for 1990
Ivory Coast	587,500
Mozambique	525,000
United Republic of Tanzania	456,250
Ghana	250,000
Nigeria	131,250
Madagascar	105,000

Source: Coconut statistical year book 1990

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A Presentation
on
Use of Coir Fibres in the Development of Building Components

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USE OF COIR FIBRES IN THE DEVELOPMENT OF BUILDING COMPONENTS

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INTRODUCTION

Coir fibre us abundantly available in India in the coastal belt as agricultural by-product. A part of its availability is used for making coir mats, ropes and cushions etc. and rest of it is dumped heither and theither to rot and pollute the atmosphere. Work at Central Building Research Institute, Rookee, India on composite materials have shown potential use of this fibre for making building components in cement matrix.

PRODUCTION PROCESS

Ordinary portland cement, coir fibres and chemical admixtures have been used for making fibre reinforced building panels and blocks. These panels and blocks can be suitably used for several applications in the buildings. For production of coir cement composite materials, the coir fibre is soaked in water for 1-2 hours and then thoroughly mixed with pre-determined quantities of portland cement and the chemical admixtures dissolved in water. The cement coated fibre thus obtained are then uniformly spread in a steel mould. Steel plunger is put onto the mould and the mix is pressed hydraulically to the required thickness. The whole assembly of the mould and plunger is kept in processing position for about 6-8 hours till the mix attains sufficient handling strength. The pressed panel is then taken out of mould and is moist cured for 10 days. On curing, the panel gets hardened and develops adequate strength. It is then dried under natural conditions for 4 to 6 days and trimmed to the required size for use.

Coir fibre cement bonded panels in the density of 1300-1400 kg/m^3 have been found suitable to be used as penelling material in the door shutters, windows and several other applications. Various production parameters like fibre length, fibre volume, casting pressure and casting time governing the production of panels have been optimised and used for production of panels.

A semi-mechanised plant has been developed by the CBRI for production of coir cement composite panels. The plant, as shown in Fig 1, is equipped with a hydraulic press of 3000KN pressing capacity, moulds for casting panels, roller tracks for movement of moulds and gantry crane system for handling moulds and other godgets with this plant 100 panels of 1000mmx1000mm size can be produced daily in a single shift of eight hours using 70 moulds. The press has the capacity of pressing 40 panels per hour. The production can be increased with 80 panels per day by adding more number of moulds an supporting structure.

RESULTS AND DISCUSSION

The produced panels were tested for the various physical and mechanical properties such as density moisture content, water absorption, swelling thickness, being strength, modulus of elasticity, according to the procedures given in ISO:8335-1987. Fire behaviour of the panels was studied by carrying out ignitability, fire propagation index and surface spread of flame tests as per BS:467 Part (5 to 7) - 1983. The results obtained for various physical and mechanical properties are given in Table 1. The results show that the coir fibre reinforced panels conform to the requirements laid in ISO:8335-1987, for wood-based cement bonded-panels comply with the requirements described in BS:476 (Part 6 &7) - fire propagation and surface spread flame tests and therefore, could be rated of class 'O'. The coir cement panels also conform to all the requirements laid down in BS:5669 (Part 4) - 1989 and thus the fire behaviour of the panel is similar to that of wood cement bonded particle board. Moreover, the fibre behaviour of the developed panels is superior to that of plywood, wood particle and fibre boards (Table 2).

APPLICATION

Durability studies on fibre reinforced cement boards showed that these boards are more resistant to various alternate drying and wetting cycles and hence would be more durable than resin bonded particle boards and plywood in service. The developed boards can, therefore, be recommended for both internal and external applications in buildings as an alternate to wood and reconstituted wood products.

The developed coir fibre cement boards can be used for various applications in buildings such as panelling and window shutters, partitioning, false ceiling, cladding etc. These boards can be sawn and drilled using normal wood working tools and can be painted like wood based products. The use of boards as penelling material for door shutters is shown in Fig. 2. These door shutters were installed in the Institute in 1992 to study their performance. The performance of the door shutter is satisfactory after about 5 years of their use, i.e. there are no signs of cracking or delamination in the coir-cement panels and the doors are in good shape. The weight of the door shutter, made by using sheesham wood for frames and coir fibre cement boards as panels, is bout 19-20kg/m2. These shutters are 15-25% cheaper in comparison to sheesham/deodar wood shutters.

R & D IN PROGRESS

Work on development of light weight fibre reinforced roofing and walling components for buildings systems is in progress. Coir cement panels of sizes 750mmx500mm and thickness varying from 25mm to 100mm and densities of 400 kg/m^3 to 800 kg/m^3 have been cast. Behaviour of such panels with changing weather conditions and finally for adoption as walling and roofing components is under investigation.

Panel of size 600mm x 600mm x 15mm thick in the densities of 400-600 kg/m^3 made from coir-cement have shown potential for several field applications. These panels have low thermal conductivity and very good fire resistance, and may find use as false ceiling elements and also as consumable shutterings in construction of multistoreyed house.

BUILDING BLOCKS

Fig. 3 shows a walling block of size 400x300x150mm, these blocks were cast in the densities of 400 to 1000 kg/m^3. Light density boards of 400 to 800kg/m^3 may be used for non non-load bearing walls and those above 800 kg/m^3 for supporting light weight roofs of single storied houses.

A typical property of these blocks was observed during compression testing. These blocks do not fracture under compression at any load but get compressed and deshaped. As shown in Fig.4. Blocks may be used for construction of houses in disaster prone areas. Being light in weight, even at their utter failure in severe disastrous conditions like earthquake etc. chances of fatal injuries are minimal. Blocks and panels can be plastered, painted and white washed and may find various applications like partition walls, divider cabinets in offices and hospitals and thermal insulation boards for buildings. Moreover, basic material being agricultural waste and cement, the coir cement products will be cheaper than timber, plywood and particle boards.

DEVELOPMENT OF PURLINS

Purlines are used for supporting light weight roofs like AC/GI corrugated sheets, tiles and thatch etc. In rural parts of India usually timber purlines are used for supporting roofs which consumes lot of timber. The forest cover in India has already gone down from 33% to almost 12% causing serious concern to ecological balance. Use of timber in Government constructions has been banned and now statuary requirements restrict cutting of trees. This has resulted into steep rise of timber. To conserve timber CBRI is working on the development of coir fibre structural members are strengthened by further cement bonded structural members to be used as purlins. Coir cement with coir ropes, coir mats, bamboo and steel bars. Encouraging results have been obtained and the work is in progress for testings and evaluation of the members.

CONCLUSIONS

(i) Coir fibres can be used for making Coir Cement Composite panels conforming to ISO:8335-1981 - Cement bonded particle boards.

(ii) The developed composite panels possess better fire resistance and exterior durability as compared to commercial wood based products.

(iii) Coir fibre cement bonded products have low cost, low density and are non-toxic and less polluting.

(iv) The composite material has potential for development of light weight walling and roofing components and also for diversified applications as structural members.

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REFERENCES

1. Kalra, M.S., Aggannal, L.K., and Kaushish, J.P., Building Products from Coir Fibres, Proceedings International Conferences on Non Conventional Building materials, Bhubneshwar, India, (June 17-19, 1997)
2. IS:269-1976, Ordinary and low heat portland cement, Bureau of Indian Standards, New Delhi, India, (1976).
3. Aggarwal, L.K., Studies on cement bonded coir fibre boards, Cement & Concrete Compo-sites, 17(1975), 107-112.
4. ISO:8335-1987, Cement bonded particle boards - Boards of porland or equivalent cement reinforced with fibrous wood particles, International Organization for Standardization, Geneva, Switzerland, (1987).
5. BS:476 (Part 5-7) - 1983, Fire tests for building materials and structures, British Standards Institution, London, UK, (1989).
6. Aggarwal, L.K. Durability studies on coir fibre reinforced cement boards, Proceedings IV Rilem International Symposium on Fibre Reinforced Cement and Concrete, Shefield, (July 1992), 1120-1127.
7. Kuashish J.P., Aggarwal L.K. Bhagwan Dass, M.S. Kalra and Narender Kumar, Conserving timber in panelled door shutter; J. Indian Architect & Builder, Bombay (December, 1991) 31-34.

Table 1 - Properties of coir fibre reinforced cement panels

Property	Coir-Cement Panel	ISO:8335-1987
Density, kg/m³	1300-1400	1000 min
Moisture content, %	6-7	6-12
Water absorption, %	14-16	-
Swelling thickness, %	0.8-1.2	2, max
Bending strength, N/mm²	9.0-11.0	9,min
Modulus of elasticity, N/mm²	2500-2800	3000
Tensile strength, N/mm²	3.2-3.5	-
Impact strength, weight - 2 kg, height - 100 cm	No indentation or cracking	

* Tested as per IS:2380-1977

Table 2 - Fire behaviour of coir-fibre reinforced cement panels

Product	Test: Ignitability	Fire propagation Index: i	Fire propagation Index: I	Surface spread of flame, class
Coir Cement Panel	P	2.94	4.98	1
Wood Cement Panel	P	<6.00	<12.00	1
Particle Board				
Sample I	P	14.21	36.52	3
Sample II	P	13.29	32.62	2
Fibre Board				
Sample I	P	33.10	56.82	4
Plywood				
Sample I	P	18.56	36.52	4
Sample II	P	7.47	25.42	3

P = Not easily ignitable
i = Initial propagation indices
I = Total fire propagation Index

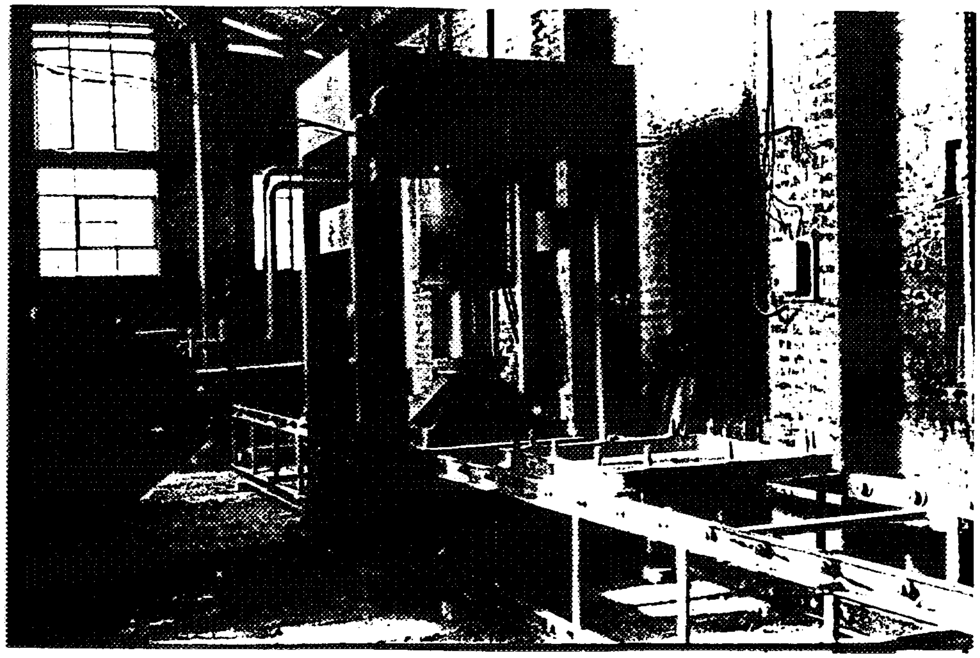

Fig.1. Plant for Production of Coir Cement Panels

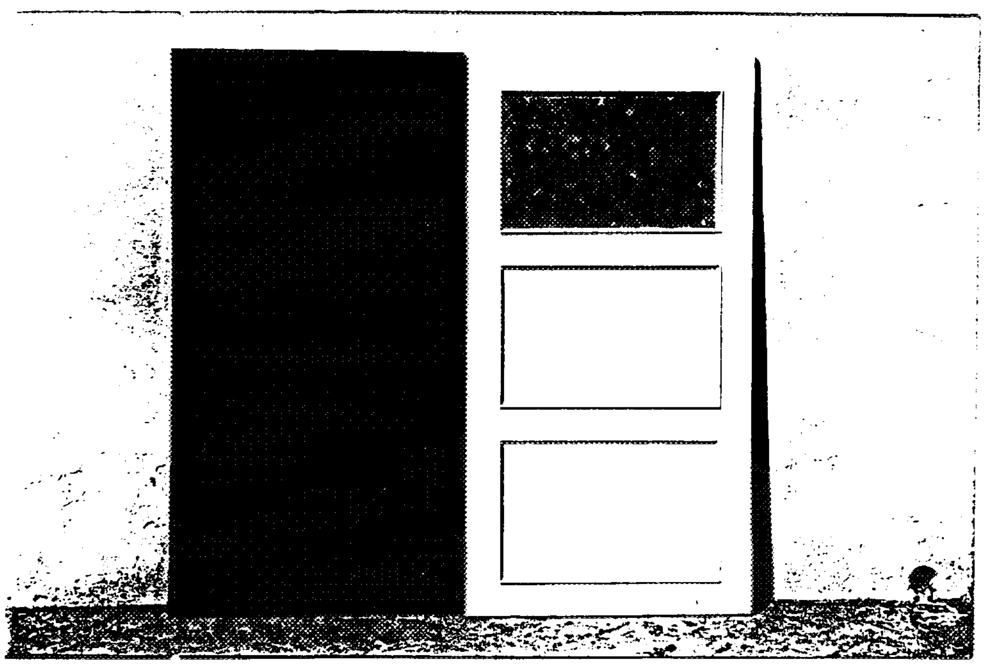

Fig. 2. Panelled Door Shutter using Coir Cement Panels

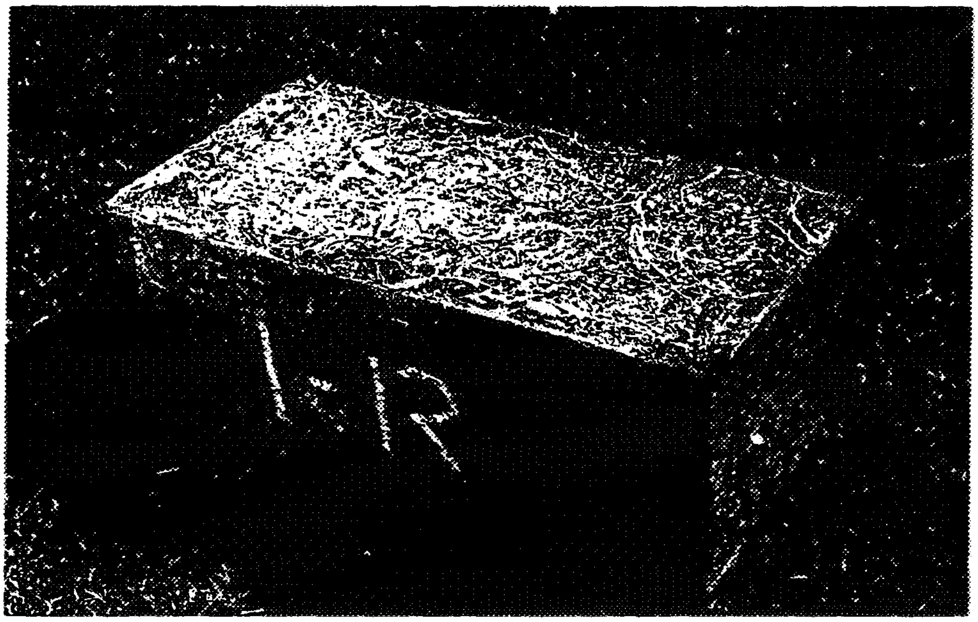

Fig.3. Coir cement Building Block

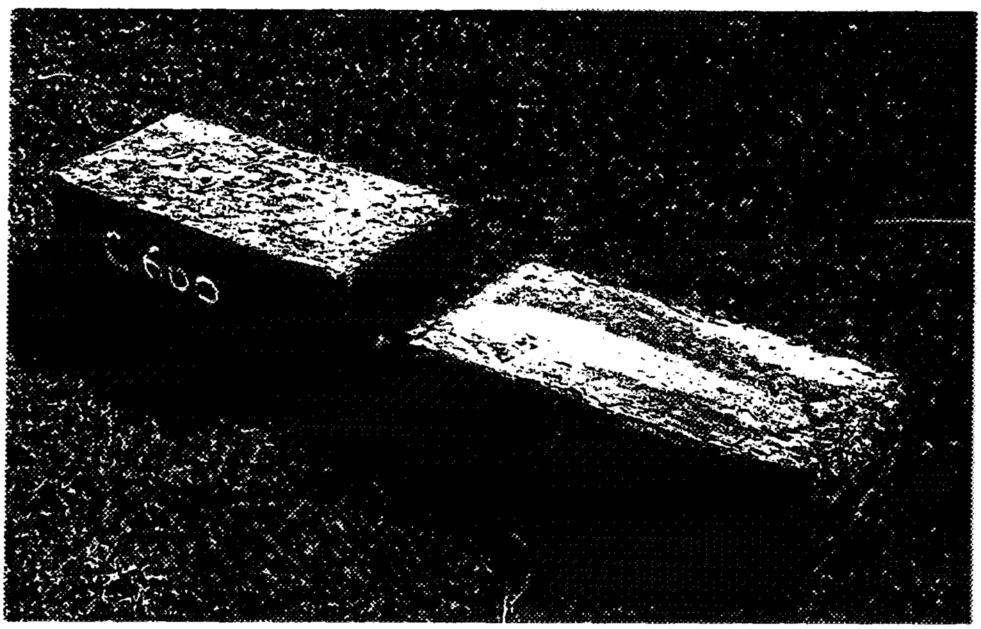

Fig.4. Coir cement Building Block do nor facture under any load

ICS

INTERNATIONAL CENTRE FOR SCIENCE AND HIGH TECHNOLOGY

International Workshop on Composite Materials and Waste Minimization: Fibre reinforced materials based on local resources

Dar es Salaam, Tanzania
4^{th} - 8^{th} August, 1997

A Presentation
on
Utilisation of Industrial Waste "Red Mud"
in Experimental Housing at
RRL, Bhopal

By

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(UNIDO)

UTILISATION OF INDUSTRIAL WASTE "REDMUD" IN EXPERIMENTAL HOUSING AT RRL, BHOPAL

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ABSTRACT

Industries are generating waste materials during manufacturing of primary product. This waste material enhance the problem of storage, disposal, environmental pollution and use of working areas. In industries, the final products can produce without any waste will give much advantages not only towards cost benificiations but also pollution point of view. In India about 2 million tonnes of redmud is being generated anually by producing alumina based alloys. As stated above this waste redmud creates problem of storage, occupying useful lands and leading environmental pollution. To overcome these problems, R&D work is being carried out for its fruitful utilisation in many areas particularly in development of alternate building materials. RRL Bhopal has taken up a challange to utilise this industrial waste redmud in developing alternate building materials such as Redmud cementitious binder, Redmud polymer composite door shutter / panel / flooring tiles / roof ceiling / wall panelling / corrugated roofing sheet etc.

Tremendous work has been carriedout towards the testing of full size Redmud door shutter to pass all the tests related to door shutter and it has passed all the tests. RRL Bhopal is not only developing new alternate building materials by using industrial waste but also it strongly recommends and implementing these new materials by constructing 16 prototype houses for its real acceptance to the user agencies.

Development of new materials is difficult in nature but its implementation is much difficult towards the benificiers. Therefore, it is necessary to implement these materials at relevant places so that it can be picked up easily in actual directions. At RRL Bhopal about 10 tonnes of redmud cementitious binder was used in Prototype houses construction for base concrete, foundation and plinth masonary works etc. This redmud cementitious binder replaces 30 - 40 % of OPC in the above items and saving about 25 % of OPC cost. About 120 number of Redemud polymer door shoutters were made using about 5.00 tonnes of redmud for this construction.

INTRODUCTION

Shelter is one of the most important need to the human being. To provide shelter to every family, government brings number of schemes which encourage construction industries. By the end of this century about 100 crores of housing will be required to meet the demand from the people. Yet it is dream because enormous cost involved in the construction of houses. To fulfil the demand in economical way, there is a need of developing suitable technologies that minimise the cost of the construction.

Keeping in view the above, RRL Bhopal has developed some of the cost effective building materials using industrial waste like redmud, flyash etc. The above studies were carried out in laboratory scale level. Still, there is unawarness among the people to utilise these materials totally. Therefore, further studies were carried out to implement these cost effective alternate building materials in actual construction at RRL Bhopal. By constructing the experimental houses, the fruitfulness of the technologies will be innovated between the people and also the real construction will become familiar. The experimental housing will also be one of the model houses for the visitors. This way, it can be possible to encourage large scale aceptance of the benificiers.

MATERIALS AND METHOD

Using industrial waste redmud at RRL Bhopal some of the building materials are developed such as Redmud cementitious binder, Redmud polymer composite door shutter / panel / flooring tiles / roof ceiling / wall panelling / corrugated roofing sheet etc. The redmud cementitious binder was used in base concrete and in plinth masonry work where as the redmud polymer composite door shutters were fixed in Experimental prototype houses at RRL, Bhopal.

A) REDMUD CEMENTITIOUS BINDER

Cement is the most important building material and is very expensive. To bring the cost of the construction lower, redmud cementitious binder developed by RRL Bhopal was used. The process of manufacturing of this binder is very simple. Without using any sophisticated machinery this can be produced. The mixture of redmud, rice husk and local clay in appropriate amount were moistured with water and shaped into spherical balls manually. These balls were sundried for 30 hours and fired in a kiln at 700 °C. The resultant fired product thus obtained is ground with hydarted lime in 2:1 ratio in a ball mill. This ground material after passing through 150 micron seive were tested for its engineering properties as per IS : 4098 - 1983 and is reported in Table - I.

Table - I : Properties of Redmud cementitious binder

1. Fineness (% retained on 150 micron seive)	- 15
2. Setting time (in hours)	
a) Initial	- 2.0 - 3.0
b) Final	- 10.0 - 12.0
3. Compressive strength (kg/cm^2)	
a) At 7 days	- 20.0 - 40.0
b) At 28 days	- 40.0 - 50.0
4. Soundness (in mm)	- 1.0

B)REDMUD POLYMER DOOR SHUTTER

Government of India has banned the use of wood in its all construction work in April 1993 because of increasing environmental hazardous by cutting trees in forest areas. Therefore, it is necessary to find out an alternate material to replace wood without changing its major proerties etc. Besides this, there is tremendous industrial waste materials like redmud are being generated by the industries. The disposal problem of this redmud can be solved by utilising it in manufacturing wood based materials.

A peocess has been developed by RRL Bhopal using redmud as filler, sisal fibre(natural fibre) as reinforcement in polymer matrix.

This process of making redmud polymer composite is also simple. The redmud and polymer mixed thoroughly in mixer. Hardner & accelerator mixed in 1-3% by weight of polymer depending upon the atmospheric condition and time required in complete processing. After thorough mixing of these materials, it has been spread over jute fibre mats and kept under pressure to remove voids and to maintain uniform thickness for a period of 30 minutes.

The material thus obtained were removed from the hydraulic press is the final product. Out of this final product any shape may be given as per requirement like door shutter, panel, flooring tile, wall panelling, ceiling material etc. The type tests of door shutter were evaluated at RRL as per the specifications issued by CPWD TAD cell, New Delhi.

RESULTS AND DISCUSSION

The redmud cementitious binder and redmud polymer door shutters used in prototype houses has made the entire construction cost effective. This can be evidenced by the Table - II

Table -II : Comparative rate analysis between conventional and experimental items.

S.NO	ITEM	CONVENTIONAL RATE / M^3	EXPERIMENTAL RATE / M^3	%SAVING
1.	Base concrete	783.40	635.35	+ 18.90
2.	C.R.Masonry in foundation plinth	793.85	743.45	+ 06.00
3.	Clay flyash bricks	580.45	668.30	- 13.10
4.	Precast RCC slab	3000.00	2500.00	+ 16.50
5.	Redmud door shutters	4000.00	3000.00	+ 25.00

The use of redmud cementitious binder gives marginal saving in cost by replacing ordinary portland cement by 40 %. By implementing these technologies in prototype houses can acts as demonstration for construction agencies & public which will bring awarness amogst them.

ACKNOWLEDGEMENT

The authors are greatly acknowledge National Building Organisation, New Delhi who have sponsored the project on Experimental proptotype house construction using new building materials developed by RRL, Bhopal. They also thanks to Prof.(Dr) T.C.Rao, Director RRL, Bhopal for his valuable suggestions and guidence.

REFERENCES

1. Technology profile " R-Wood Composite " RRL Bhopal, 1994.
2. "Utilisation of redmud " L.K.Panda, National Aluminium Company, Bhubaneshwar.
3. Procedings of " national Seminar on Building Materials, Science & Technology, Vol.-2, April 1982, New Delhi.
4. Project proposal on " Protoype houses construction using new alternate building materials " .
5. Final report on " Redmud cementitious binder".

Appendix 4

List of Workshop Participants

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Appendix 5

Terms of Reference

24 April 1997
604/3.2.C. LF/jl

(TOR/C.97/122)

Terms of Reference for the

ICS-UNIDO Training Activity on
"Composite Materials Based on Natural Resources".

Tanzania, 4 - 8 August 1997

Budget Line 21:

a) *General background information*

The fact that the construction industry today is required to link its production of building materials to sustainable and environment-friendly development means that the building materials industry is under pressure and struggles to cope with the new demands from different industrial sub-sectors. Moreover, the costs of building materials are usually high and many of the poorer countries are unable to afford them. Such costs are not only caused by the expensive technological processes required in their production but also from the costs of the raw materials to be used.

This has led to a growing concern for developing and promoting alternative building materials. One of the strong options is to promote development and utilization of composite materials based on local renewable resources such as natural fibres and plant materials. Research and development undertaken on alternative building materials and waste exploitation has not only shown but also effectively demonstrated that the use of some of these wastes and of local renewable resources can reduce the use of expensive materials such as cement, bricks, steel and wood. Furthermore, it has been shown that expensive synthetic fibres can be replaced by natural plant fibres to produce reinforced composites with the desired mechanical strength and durability.

Aggregate composites, based on inorganic industrial wastes, and natural fibre-reinforced composites are materials for cost-reduction in housing and a possible answer to meeting the requirements of building materials for millions of shelters to be constructed in all developing countries.

Taking the above into account, the International Centre for Science and High Technology (ICS) within the framework of UNIDO, has proposed an international programme on development, manufacturing and application of composite materials based on local resources and recyclable by-products.

The outline of this programme was discussed during a Scientific Planning and Coordinating Meeting (SPCM) that took place from 13 to 15 November 1996 in Trieste, Italy and was attended by scientific experts in the field from Tanzania, India and China. Among the activities for 1997, a Workshop to be held in Tanzania aiming at conveying information on the state-of-the-art and advances in the area of building materials based on natural resources was planned.

The Workshop will be entitled *First International Workshop on Composite Materials Based on Natural Resources* and will be held in Tanzania from 4 - 8 August 1997.

b) *Aim of the Workshop*

The Workshop is addressed to scientists working in the field of New Materials and aims to:

1. bridge the gap between the materials science and technology of composites based on natural materials;
2. exchange knowledge and experience on aspects of design, production, testing and application of these materials;
3. enhance the industrial use of environmentally friendly natural materials and create new opportunities for business;
4. facilitate the transfer of technology in both advanced and new materials to developing countries while also promoting South-South co-operation.

c) *Structure of the Workshop*

Lectures will be given by approximately 15 experts both from local and international universities/research centres and by some Tanzanian policy makers. Case studies will be presented and site visits,or exhibitions organized in the afternoon.

Invited participants whose travel and accommodation expenses are to be covered by the organization will be experts from developing regions of the world, namely Angola, Ethiopia, Mozambique, Uganda, Kenya, India, Tanzania and South Africa from industries, R&D projects, and/or scientists working in academic and industrial laboratories in developing countries. About 25 participants are expected to attend.

The Workshop will be conducted in English.

The selection of participants and lecturers will be made by the Local Scientific Organizer in close consultation with ICS;

d) *The Scope of the Contracting Services*

The activities to be fulfilled and the tasks of the subcontractor are as follows:

1) Local organization of the Workshop

The subcontractor will contact participants and selected lecturers, send them official invitations with preliminary detailed information and arrange their round trip air tickets, when required, as well as their hotel accommodation. The subcontractor will be responsible for logistic and hospitality services for the lecturers and participants in the Workshop (i.e. travel arrangements, payment of invited participants and lecturers with the fixed per diem for their accommodation and living expenses, etc., see tentative budget).
The subcontractor will also organize bus transportation from the accomodating hotel to the Workshop venue.

2) Conduction of the Workshop

The scientific conducting is to be carried out by the University of Dar es Salaam by the Local Scientific Organizer, in close consultation with ICS-UNIDO while organizational conducting will be taken care of by the subcontractor, including:

- providing essential facilities for the duration of the workshop, i.e. the meeting room, photocopy machine, telephone, fax, computer facilities;
- secretarial assistance.

3) Reporting:

A final report will be prepared in English by the contractor and 5 copies forwarded to UNIDO shortly after the termination of the activity. A copy will be forwarded to ICS.

e) General Time Schedule

1) All basic documents, (i.e. programme and aide-memoire), will be sent to UNIDO one month before the Workshop.
2) The contractor's personnel is already located in the area where the Workshop will be held.
3) The works will be terminated on Friday 8 August 1997.
4) The final report will be forwarded to UNIDO at the end of the activity.
5) Lecture Notes of the Workshop will be prepared and sent to participants at the end of the activity.

f) Personnel in the field

The management and handling of the Workshop foresee the presence at the hosting institute in Tanzania of:

- the management, operational and administrative staff of the hosting institution for receiving the lecturers and participants, administering their reimbursements and coordinating the programme of activities for the duration of the Workshop.
- the ICS Scientific Coordinator as well as the Associate Professional Officer for New Materials for the duration of the Workshop to illustrate the ICS programme of activities to the participants.
- the Local Scientific Organizer for the scientific conducting of the Workshop, in close consultation with ICS officers.

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