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APPROPRIATE TECHNOLOGY FOR THE PRODUCTION OF CEMENT AND BUILDING MATERIALS

SISAL FIBRE/CONCRETE FOR ROOFING SHEETS AND OTHER PURPOSES.

Background Paper

id. 78-5814

SISAL FIBRE CONCRETE FOR ROOFING SHEETS AND OTHER PURPOSES

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CONTENTS

SUMMARY AND CONCLUSIONS

When building in rural areas in developing countries, roofing normally is the major difficulty. Palm leaves and straw materials are commonly used for roofing but corrugated iron and asbestos cement sheets are nowadays used at an increasing scale. These latter materials have, however, to be imported, either as raw materials or as finished products, and only few locally made new products for roofing can be found.

Concrete reinforced with sisal fibres has been shown to have properties suitable for the production of thin sheets e.g. for roofing. Concrete technology is rather well known all over the world, the constituent materials in concrete are almost everywhere readily available and sisal fibres can be found in many developing countries. The production of sisal fibre concrete can be carried out manually by local craftsmen but can also be mechanized in different steps in order to increase the production rate and the quality.

The sisal fibres can be used either chopped to short lengths or continous. The fibre reinforcement gives the concrete higher tensile strength, higher deformation capacity and an improved crack distribution. If properly done, sisal fibre concrete has also all potentially good qualities of normal concrete, e.g. fire resistance, water tightness, durability, ease of production, low price. Sisal fibre concrete is also a low-energy consuming material.

Sisal fibre concrete products can be produced, transported and erected with a great flexibility allowing the production and building process to be adjusted to local conditions. The products can be used in traditional as well as in more advanced building techniques.

Suitable products for sisal fibre concrete can be roofing sheets ranging in sizes from "tiles" to free spans of 5 meters or more, wall plastering, sun screens, window gratings, hollow blocks, wall sheets, storage bins etc. Other vegetable fibres than sisal can also be used.

1 INTRODUCTION

In the developing countries there are great demands in the different sectors of the society. Lack of capital puts a limit of what can be imported. Under-employment is very common. It is necessary to find ways to encourage creation of local production, where locally found material and local manpower is used in a great extent. Different ways of assisting the developing countries to have access to appropriate technology should be supported. The quicker this technology could be transferred the quicker the developing countries reaches independence and welfare.

In most developing countries straw, leaves etc, are used for roofing in the rural areas. This type of roof is, however, attacked by fungus and insects and the lifelength is often short. There is also a risk for fire. The use of corrugated iron sheets is nowadays also common especially in areas near the cities. These sheets usually have to be imported, the climate below the roof can be very hot and there is a noise when it is raining. Other types of roofs, often heavier and more expensive, exists parallel to these described above.

Roofing is generally said to be the most important and difficult problem in housing. It is important to find a cheap roofing material with long life length, which is fire-resistant and which has good sound insulating and thermal qualities.

Often there is a need for a wood substitute e.g. for window frames, sun screens, smaller beams. There is also a need for making cheap durable walls. The solution can be locally made sisal fibre concrete products.

FIG 1. Roofing is the major problem in housing in developing countries.

Concrete technology is well known all over the world today. ement, proper aggregates and water can be found in most regions. Unreinforced concrete can not very well withstand tensile forces. The conventional way of overcoming this problems is to reinforce the concrete with steel bars in the concrete structure where tensile stresses are calculated to occur.

In the last ten years there has been a development of fibre concrete. Added thin fibres of steel, glass, carbon, plastics etc have shown to give the concrete not only better possibility to withstand tensile forces but they have also resulted in smaller crack widths, increased deformability, higher impact strength, simplified production technique etc.

Sisal fibres have a rather low modulus of elasticity but a good resistance to tension and have shown to give a concrete material some interesting properties. Of the high-grade vegetable fibres, sisal is the one most extensively cultivated in the world and its price is reasonable. Sisal is fairly easy to grow in all kind of tropical environments. Many other vegetable fibres could, however, possibly be used.

Sisal fibre is produced in a number of countries and the total production in the world is today (1978) about 600 000 tons.

2 ONGOING PROJECT

The background material for the descriptions given in this paper has to a great extent been obtained in a study concerning "roofing sheets of sisal fibre concrete produced in developing countries". The study is carried out by the Swedish Cement and Concrete Research Institute and the Division of Building Construction, Royal Institute of Technology, Stockholm, Sweden, in close cooperation with the Building Research Unit under the Ministry of Lands, Housing and Urban Development, Dar es Salaam, Tanzania.The swedish part of the project is sponsored by the Swedish Agency for Research Cooperation with developing countries (SAREC).

The project started in April 1977 with a joint project planning by the Swedish and Tanzanian counterparts. It was then decided that the first stage of the project should end with a prototype production of some 10-20 m^2 of roofing sheets to be placed on a roof in Tanzania for long time testing. It was also decided that the first stage should comprise studies on fibre properties, mix design, properties of the fibre concrete composite, product design and production technique. The first stage of the project will be finished at the end of 1978 when a prototype production in laboratory scale will take place in Dar es Salaam.

The production process, as it has been developed in the project, lends itself to different levels of mechanization, ranging from a labour-intensive process requiring no electricity, no machinery and almost no equipment up to a fully mechanized process with a low need of personnel but more extensive capital investments.

At the beginning, the work will be focused on production in small scale industries, and the first stage of the project will be followed by an implementation phase, where the work will be carried out in close cooperation with the Small Industry Development Organization in Tanzania. This phase will start at the beginning of 1979 and the aim with that phase will be to develop methods, equipments, etc, and to make transport studies, market surveys, etc, for small scale production of roofing sheets. The knowledge concerning factory layout, production process and product design gained in this phase will then be spread and directly used in establishing production units in different places.

In July 1978 a project similar to the one described above but using coir fibres instead of sisal fibres has started. The same Swedish counterparts and financing unit as above are participating together with the Building Research Institute and Coconut Marketing Board, Colombo, Sri Lanka.

3 SISAL FIBRES

Sisal (Agave Sisalana) is classified as a vegetable fibre, subgroup leaf fibres. The name "sisal" comes from a harbour town in Yucatan, Maya, Mexico. It means cold water. Agave plants were grown by the Maya indians before the arrival of the Europeans. They prepared the fibres by hand and used it for ropes, carpets and clothing. From this origin it was spread over the world in the 19th and the beginning of the 20th century. Sisal was not produced commercially before 1888, when a cultivation commenced on the Bahamas on a major scale. East Africa soon became the largest producer of sisal fibres. In FIG 3.1 a sisal plantation is shown.

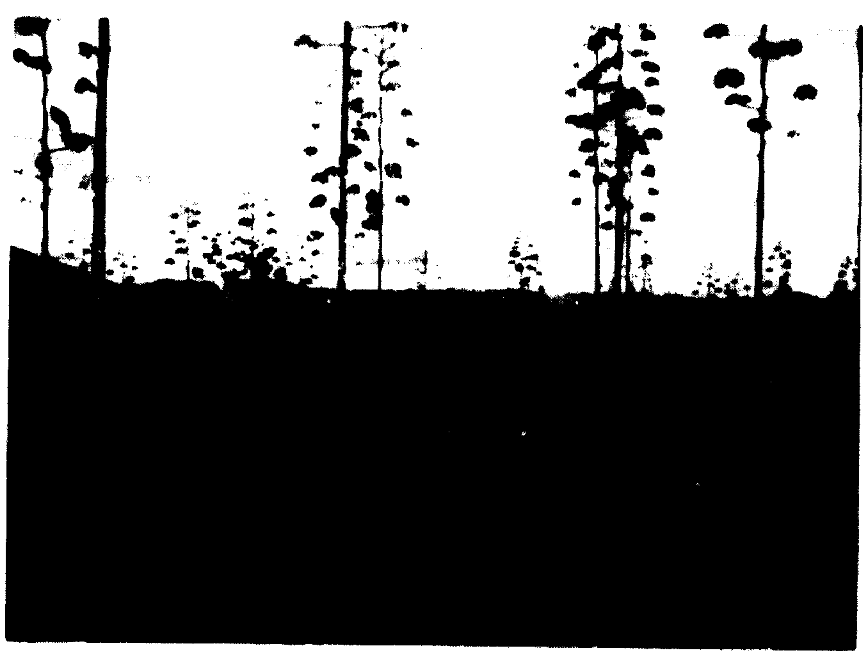

FIG 3.1. A sisal plantation in Tanzania.

The table 3.1 below shows the growth in production in the most important sisal fibre producing countries since 1936.

Tab. 3.1. Production of sisal fibres in 1000 tons.

	1936	1948	1951	1958	1977
United Republic of Tanzania	99	135	163	197	120
Kenya and Uganda	34	41	47	46	
Mozambique and Angola	30	38	47	81	
Brazil	0	29	64	100	
Indonesia	67	4	10	27	
Haiti	7	33	35	38	
Others	13	17	24	36	
Totals	250	297	390	515	

The main product is sisal twines used in agriculture for automatic binding sheaves.

FIG 3.2. Sisal plant where three layers of leaves have been cut.

There is competition from synthetic fibres. The energy crisis will, however, effect this situation. The sisal fibres need very litte energy for their production as the agave plant takes its energy from the sun and sisal processing does not need much energy.

The price situation today, 1978, of about US $ 550 for one ton of sisal fibres is, however, not favorable for the producers. The sisal growers' associations have stated that it is important to find new ways of using sisal fibres.

Composition of sisal plant

	percent
Fibre	4
Sisal pulpy waste	11
Water	85
	100

Composition of sisal fibre

	percent
Cellulose	78
Lignin	8
Waxes	2
Carbohydrates, pectines	10
Ash	1
Analytical loss	1

FIG 3.3 below shows a cross section on a leaf. Each leaf has about 770 longitudinal fibres. The average width of a sisal leaf in the base is 6-12 cm.

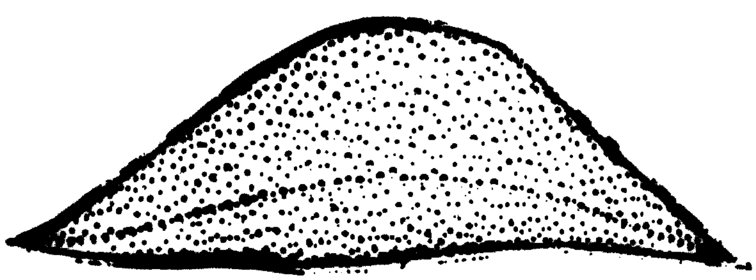

FIG 3.3. Transverse section of a leaf.

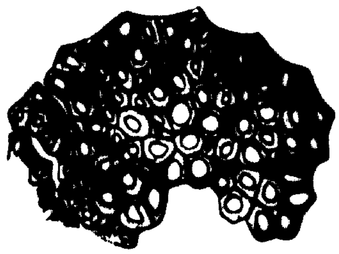

FIG 3.4. A cross section of a mechnical fibre.

FIG 3.5. Scanning electron microscope picture of a sisal fibre with 200 times magnification. The picture shows the rough surface of the fibre.

The lifespan of sisal fibres depends on the frequency and degree of attacks from fungi and bacteria. The moisture content should be more than 25% and the temperature between 3-40°C if the fungus will grow. Most of the fungus types can grow without light and oxygene. Neither fungi nor bacteria are supposed to survive in an environment in which pH is more than 8.5. Concrete has pH between 12-13.

In the literature, the breaking strength for sisal fibres is noted 600-800 MN/m^2. The modulus of elasticity is noted 26.6 GN/m^2. Available results indicate that the fibres are ideal elastic and that creep in a fibre with stress can be neglected. The elongation when breaking is between 2-4%.

Dry sisal fibres swells when water is absorbed. Wet sisal fibres have 87% of the breaking strength of dry sisal fibres. These properties do not seem to be a big problem according to available results (see chapter 4).

In the literature it is mentioned that hempfibre, which is a vegetable fibre dried while in tension, had its modulus of elasticity raised.

The cultivation of sisal plants has proved to be a means of stopping desertification.

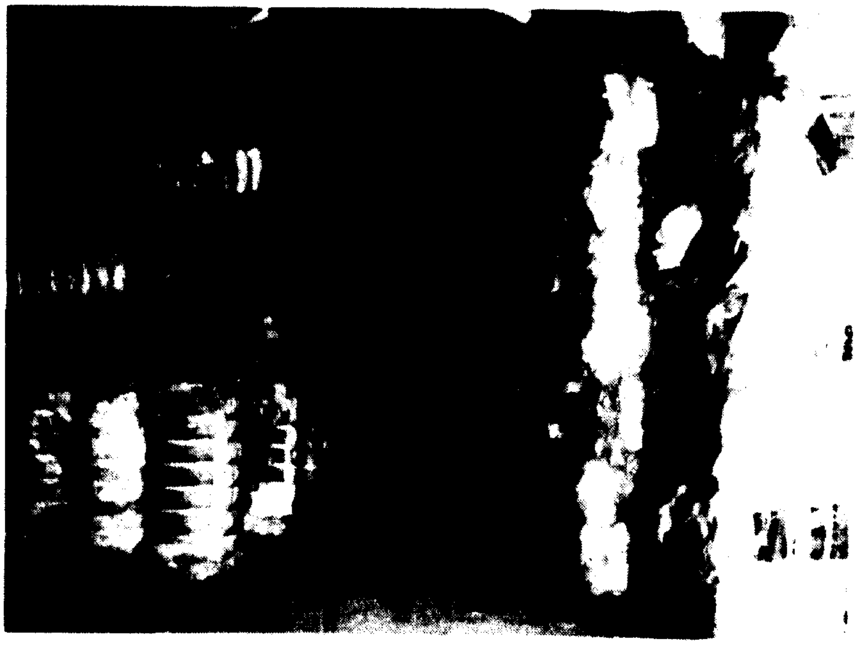

FIG 3.6. Bales of sisal fibres ready for delivery.

4 SISAL FIBRE CONCRETE

4.1 General

Unreinforced cement-based materials can be characterized by a potentially high compressive strength, approaching 100 MPa, a low tensile strength, less than 10 MPa, and a very low deformability in tension, approximately 0.2‰ . The low deformability, together with the low tensile strength, gives unreinforced concrete a very brittle behaviour which makes it difficult to use the material in products where tensile stresses will arise, as for example in thin sheets. The brittleness also tends to cause a large breakage in transport of unreinforced concrete products.

The use of reinforcing steel bars, which by bonding to the concrete matrix carry tensile loads, is the common way overpassing the problem of concretes weakness in tension. Another approach is to premix or place thin reinforcing elements, fibres, into the concrete matrix, and the fibres then work partly as loadbearing elements in cooperation with the matrix and partly as crack distributors. This mechanism gives the matrix a possibility of carrying tensile loads even when microcracking has occurred, and the result is a more energy-absorbing fracture process, i.e. a tougher material. These material properties make it possible to produce and handle sisal fibre concrete in thin walled products, e.g. thin sheets for roofing.

The idea of reinforcing brittle materials with fibres is very old with early examples of mud and clay reinforced with hair and straw. These types of composite materials are also used today in many parts of the world. More recent examples of fibre reinforcement are asbestos cement, where a cement based matrix is reinforced with asbestos fibres and ferrocement, where steel fibre nets are used.

During the last decade there has been a rapid increase in work associated with fibre reinforcement of concrete and many new products have emerged. Alkali-resistant glass fibres have been developed and glass fibre concrete is now used on an increasing scale, mainly in thin sheet applications. Steel fibre concrete has been used in pavements, for rock strengthening and in a variety of precast products. Softer fibres, such as polypropylene, have also been used in concrete, mainly for increasing the impact resistance.

The use of sisal or other vegetable fibres in concrete has not been extensively studied, although a few examples can be found in the literature. Some studies of sisal reinforced gypsum have also been carried out.

Below in this chapter a limited description is given of the matrix and the fibres used, as well as a more detailed review of the properties of the composite material.

4.2 Matrix

In sisal fibre concrete, as in other types of fibre concretes, the matrix should preferably be of a rather high quality and have a small maximum aggregate size. With a high strength and tightness of the matrix, the fibre material will be better utilized by better bond, and the matrix will give a more efficient protection to the fibres. Ordinary portland cement can be used and the sand can be of the same type as used for ordinary mortar. The cement and the sand are mixed with water to a rather wet, but not fluid, mix and no additives have to be used.

A reinforcing effect from fibres can also be obtained in leaner mixes, but these have some disadvantages, e.g. lower strength, less tightness, less durability, less ease of production.

4.3 Fibres

The sisal fibres can be used either chopped in short lengths (15-50 mm) or continuous (up to 1400 mm) in individual form or in nets. The fibres should not be pretwisted to twines but to as great extent as possible be used individually, so that every fibre will be surrounded by matrix.

Constituents in the fibre material or on the fibre surfaces can cause retardation of the cement hydration. This can be avoided by properly cleaning the fibres, but in most cases the normal fibre processing will give satisfactory clean material. Before using a new stock of fibres, the risk for effects from the fibres on the cement hydration can be checked by carrying out a simple test. This test can be made by comparing the stiffening of a plain matrix made of cement and normal water, with the stiffening of a matrix made of cement and water where fibres have been stored for a couple of hours.

4.4 Properties of sisal fibre concrete

4.4.1 Properties in the fresh state

When adding short chopped fibres into a concrete matrix a certain stiffening of the fresh mix takes place and the fibres might tend to interlock and form balls. The stiffening causes a need for additional water in order to keep the workability constant, and the tendency to balling maximizes the possible amount of fibres added. For a matrix with a cement to sand ratio of 1 to 3 and a maximum aggregate size of 2 mm, addition of chopped sisal fibres of different lengths has shown to cause a requirement of extra water as shown in FIG 4.1. The maximum amount of fibres added before balling occurs is also shown in FIG 4.1.

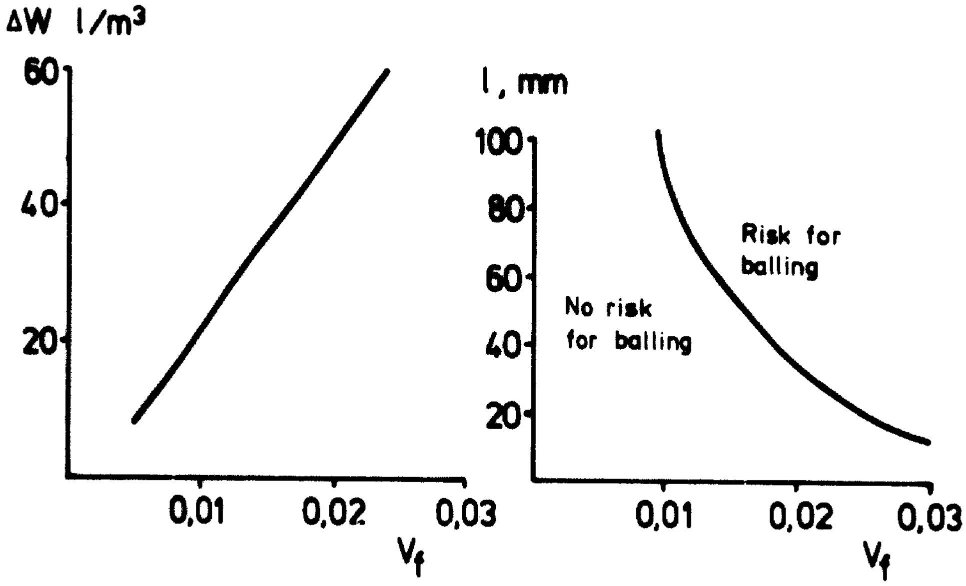

FIG 4.1. Extra water added (Δw) to keep a constant workability and tendency to balling as visually examined.

As can be seen in FIG 4.1 the requirement of extra water to keep the workability constant is only sensitive to the fibre volume fraction (V_f) while the tendency to balling is depending both on fibre length (ℓ) and on fibre volume. Both the requirement for extra water and the tendency to balling are of course also affected by the type of mixer used, and so the diagrams given in FIG 4.1 should only be regarded as a guidance.

When continuous fibres are used, the matrix is premixed and spread on a mould in one layer on which continuous fibre are laid and subsequently pressed into the matrix layer, see FIG 4.2. The process is repeated until the desired thickness of the laminate has been obtained. Here the quality of the matrix, which mainly depends on cement content and aggregate grading, has a pronounced influence on the maximum volume fraction of fibres that can be embedded. When using a sand with a maximum aggregate size of 2 mm the limit of fibre volume embedded is given in FIG 4.3, as a function of the sand/cement ratio.

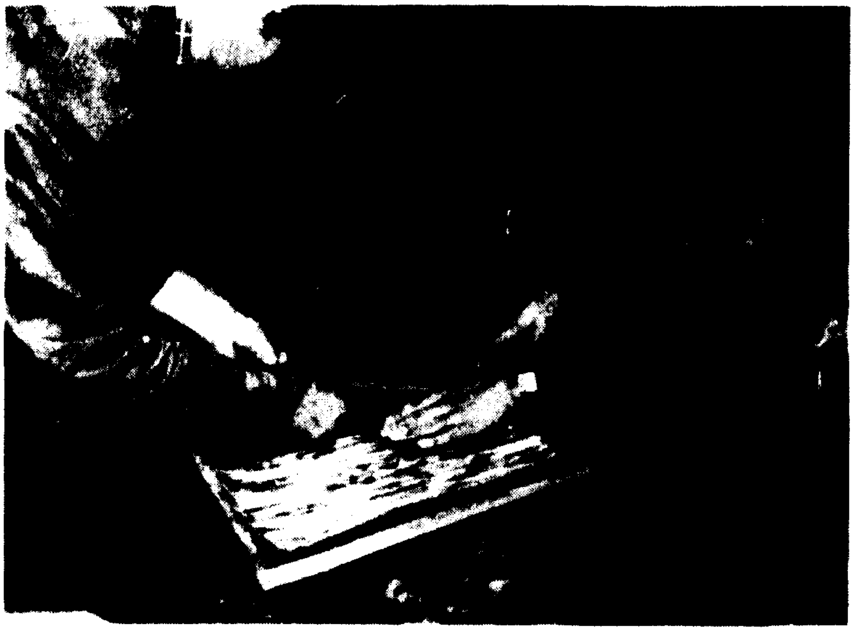

FIG 4.2. Placing of fibres on a matrix layer.

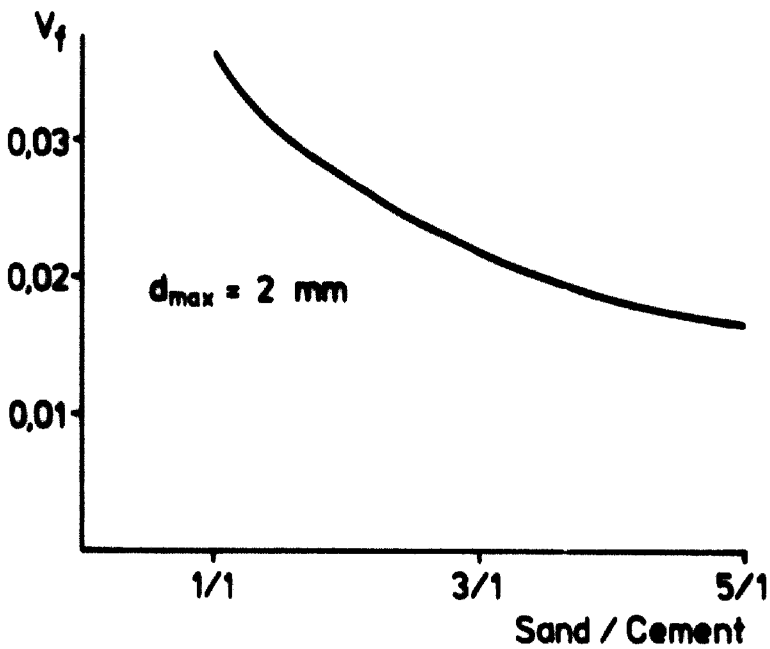

FIG 4.3. Maximum volume of continuous sisal fibres embedded as a function of the sand/cement ratio.

The volume fraction of fibres embedded can be raised over that in FIG 4.3 by the use of finer graded sand. The use of nets instead of single fibres would probably also increase the maximum fibre volume fractions.

With all types of sisal fibre concretes, as with other types of concretes, it is essential to keep the material wet the first days after production.

4.4.2 Flexural properties

When a concrete matrix is reinforced with chopped sisal fibres the stress-strain behaviour changes as indicated in FIG 4.4. Both unreinforced concrete and sisal fibre concrete have a similar degree of elasticity and approximately the same stiffness up to the point where the material cracks (limit of proportionality). The stress at the first cracking (σ_p) may be somewhat lower for sisal fibre concrete than for the unreinforced matrix, if there is any negative effect from the fibres on the cement hydration.

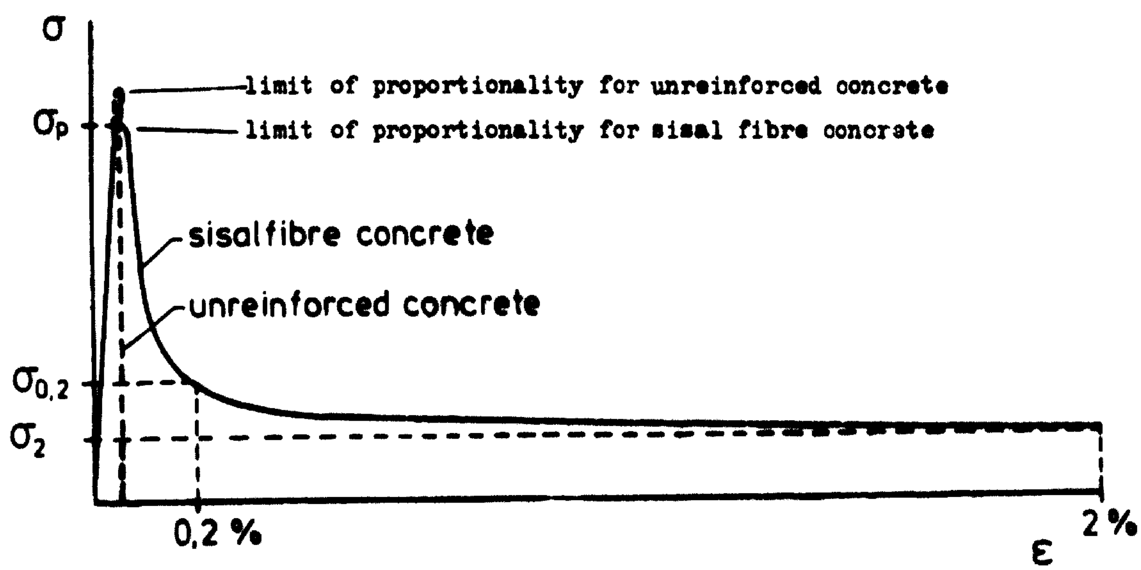

FIG 4.4. Stress-strain behaviour for unreinforced and chopped sisal fibre reinforced concrete.

After the limit of proportionality the stress in unreinforced concrete drops drastically, i.e. the material collapses. In sisal fibre concrete, on the other hand, the stress drops to a lower level where it remains until a big strain before the final fracture.

With 2 vol-% 30 mm sisal fibres and a matrix with the cement/sand ratio 1/3, which gives a flexural stress at the limit of proportionality of approximately 5 MPa, the stress at a strain on the tensile side of 0,2% (see FIG 4.4) can be approximately 3 MPa and at a strain of 2% approximately 2.5 MPa.

When continuous fibres are used a more pronounced strenghtening effect is obtained. A typical stress-strain curve in flexure for continuous sisal fibre concrete is shown in FIG 4.5.

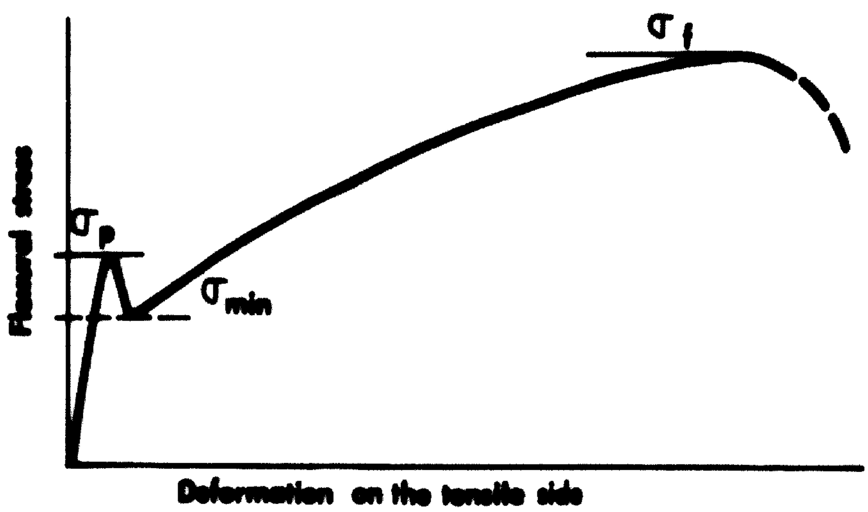

FIG 4.5. Stress-strain behaviour in flexure for concrete reinforced with continuous sisal fibres.

Here a drop in load-bearing capacity is observed immediately after the limit of proportionality, but after that drop the stress increases and surpasses the stress at the first crack before maximum load is reached.

In tests with a cement/sand ratio of 1/2 and 3 vol-% continuous sisal fibres, flexural strengths of approximately 12 MPa, almost double the stress at the first crack, have been obtained.

When changing the quality or the matrix, but keeping the volume fraction of fibres constant, the behaviour according to FIG 4.6 will be obtained.

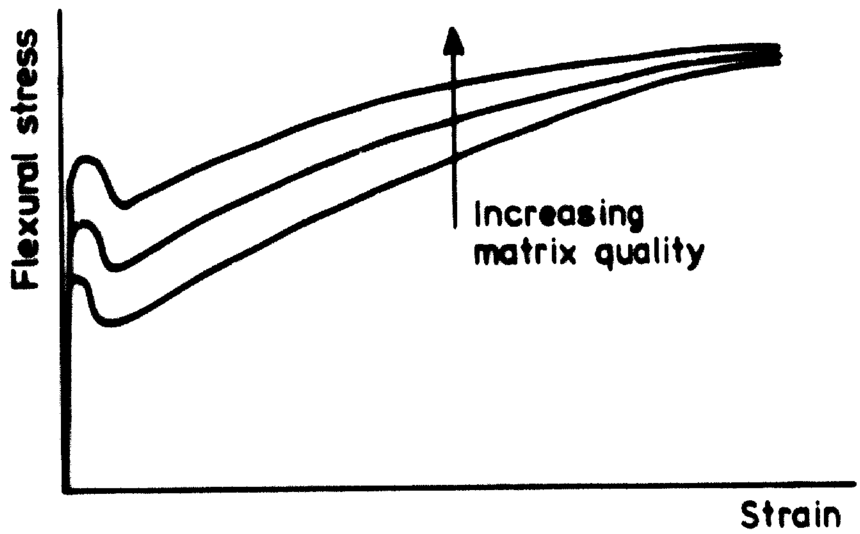

FIG 4.6. Effect on the stress-strain behaviour for continuous sisal fibre concrete when the matrix quality is changed.

When changing the volume fraction of fibres, but keeping the quality of the matrix constant, the behaviour according to FIG 4.7 will be obtained.

From FIG 4.6 and 4.7 can be seen that an increase in matrix strength gives an increase in the stress at the first crack, while an increasing volume fraction of fibres decreases the drop after the first cracking and increases the load-bearing capacity.

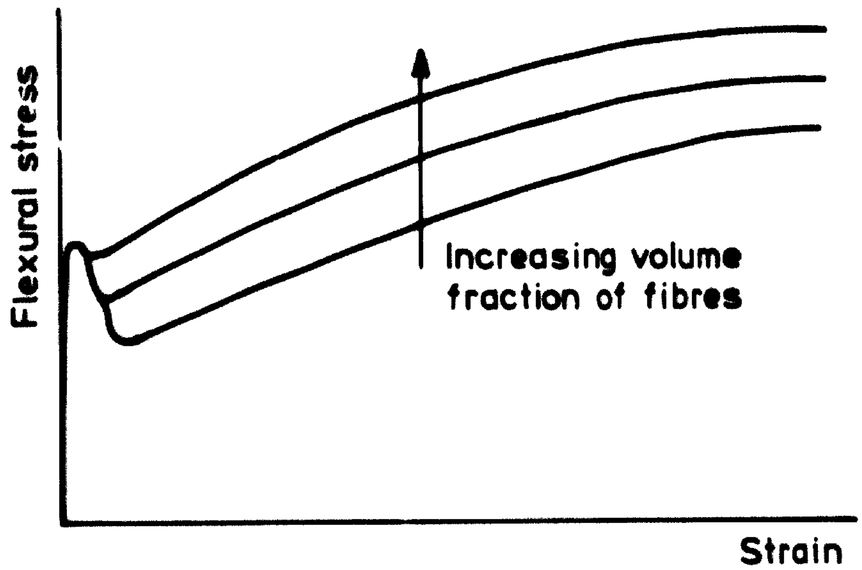

FIG 4.7. Effect on the stress-strain behaviour for continuous sisal fibre concrete when the volume fraction of fibres is changed.

4.4.3 Toughness

The energy-absorbing characteristics of a material, i.e. the toughness, can be estimated as the surface under the stress-strain curve and is thus bigger for sisal fibre concrete than for unreinforced concrete. The toughness is a vital property in many situations, as well in handling and transport as in the working stage. When a limited overstressing of unreinforced concrete takes place, a total collapse and breakage is the result, while in sisal fibre concrete the overstressing only gives a limited cracking.

4.4.4 Water tightness

When using concrete in thin sheets for roofing, the material must withstand penetration from rain-water.

As most of the volume in sisal fibre concrete consists of the matrix, the permeability of the matrix itself has the greatest influence on the permeability of the composite material. From the traditional concrete technology it is well established that there is a close and very strong relation between the quality of the matrix and the permeability. With increasing cement content and a better chosen gradation of the sand the permeability can be drastically reduced. This fact calls for a good quality matrix to be used when thin concrete sheets resisting water penetration are to be produced.

4.4.5 Age. Durability.

The testings forming the basis for the description given in this chapter is mainly made on specimens stored in water for 28 days. Some testings have also been made after 91 days in wet, alternating wet and dry and in dry storage, without any significant change in behaviour for the different storages. Testings with the different storages will also be made after longer periods.

The durability of the fibres is expected to be rather long, since the alkaline environment will protect the fibres from attacks from bacteria and fungus. Long-time use of cement-impregnated wood-wool sheets have shown an excellent performance over very long periods, which shows the protective effect from cement materal on biological fibres. Sisal fibre material has also in itself a good durability which can be seen on the twines used in old mud and pole houses, where the fibres, often not even covered with mud, are unaffected. The long-time behaviour of sisal fibre concrete will of course be further studied, and outdoor test specimens have already been placed.

5 PRODUCT DESIGN

5.1 General

Fresh sisal fibre concrete can be cast in forms of different kinds and shapes as ordinary concrete. Sisal fibre concrete can be produced in thin flat sheets. After compaction and perhaps other treatments, like suction, the thin flat sheet still in the fresh state can be placed on a curved form in order to create a corrugated or folded sheet. Below in this chapter will follow a more detailed description of design criteria such as loads, stresses, safety factors, crackwidths etc. Three types of roofing sheets is considered

1. Designed as ordinary burnt clay tile
2. Designed as corrugated iron or asbestos sheets, length about 1,0-2,0 m
3. Longspanning sheet, length can be more than 3,5 meter.

Plastering walls of soil is described. It is also shown how sisal fibre concrete can be used as wood substitute, for small beams, hollow blocks (type "Lego") and partition walls.

Summing up: sisal fibre concrete can be designed to carry loads and there is a freedom to create different shapes and applications. Full scale tests to ensure design stresses and life-lengths is recommended.

5.2 Design criteria

5.2.1 Loads

Design loads usually described in Building Regulations must be accomplished. When designing a roof it can although be considered if the roof should be able to carry the load of a man or not. Many roofs in the rural areas in the tropics made in a traditional way cannot take the load of a man. In the project, however, this type of load is considered.

5.2.2 Stresses

The stress-deformation curves described in chapter 4 show the results from tests. The stresses are calculated according to the theory of elasticity, even in the cracked zone, where there is a plastic behaviour. This way corresponds to the normal way of designing and calculating other fibre concretes.

5.2.3 Choice of safety factors

Two types of stress-strain curves for sisal fibre concrete exist, one for continuous fibres and one for chopped fibres, see FIG 5.1.

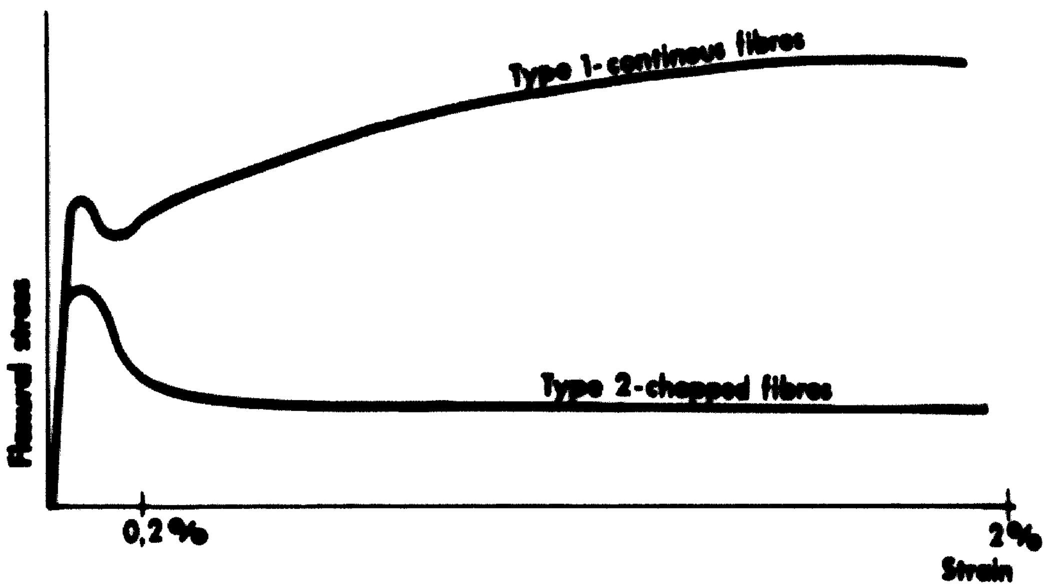

FIG 5.1. Typical stress-strain curves for concrete with different types of sisal fibre reinforcement.

The safety factor can be related to the limit of proportionality when using continuous fibres. When using chopped fibres, where the stress level after cracking can be lower than the limit of proportionality, the safety factor should be related to the stress of 0.2% deformation. Load bearing constructions should often be designed with safety factors 2.0-3.0 according to regulations.

When designing a small tile of sisal fibre concrete, you should make this as strong that you can stand on one tile without it breaking. Although the safety factor is proposed to be smaller than that for an ordinary load-bearing construction or just a little more than 1.0. The philosophy behind this is that the secondary construction system will prevent a person from falling down from the roof if a tile will break. The secondary construction system must then carry the design-load with a proper safety factor.

5.2.4 Crack width

If a crack is above a certain limit there is a chance that PH around the exposed fibres becomes neutral and that rotting starts. This is probably a limit for sisal fibre concrete. The value of the maximum crack width that can be allowed is still not tested and evaluated.

5.2.5 Other criteria

Depending on the product, other design criteria as water tightness, impact resistance, fire resistance etc may be important.

5.3 Products

5.3.1 Roofing sheets

In the project, described in chapter 2, three types of roofing sheets has been considered.

5.3.1.1 **Type 1**

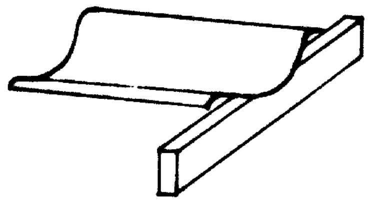

FIG 5.2. Roof tile, estimated measures 400x250x6. Design as ordinary burnt clay tiles. Weight of one tile approximately 2 kg.

5.3.1.2 **Type 2**

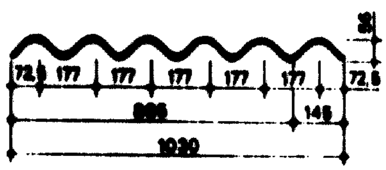

FIG 5.3 Corrugated sheet.
Span= ℓ=1200
Thickness d=10
Weight of one sheet ∿35 kg

This type can be seen as a substitute for asbestos cement sheets or corrugated iron sheets. The span is about 1.0-1.2 meter and one man can stand on it with an approximate safety factor = 2.0.

5.3.1.3 Type 3

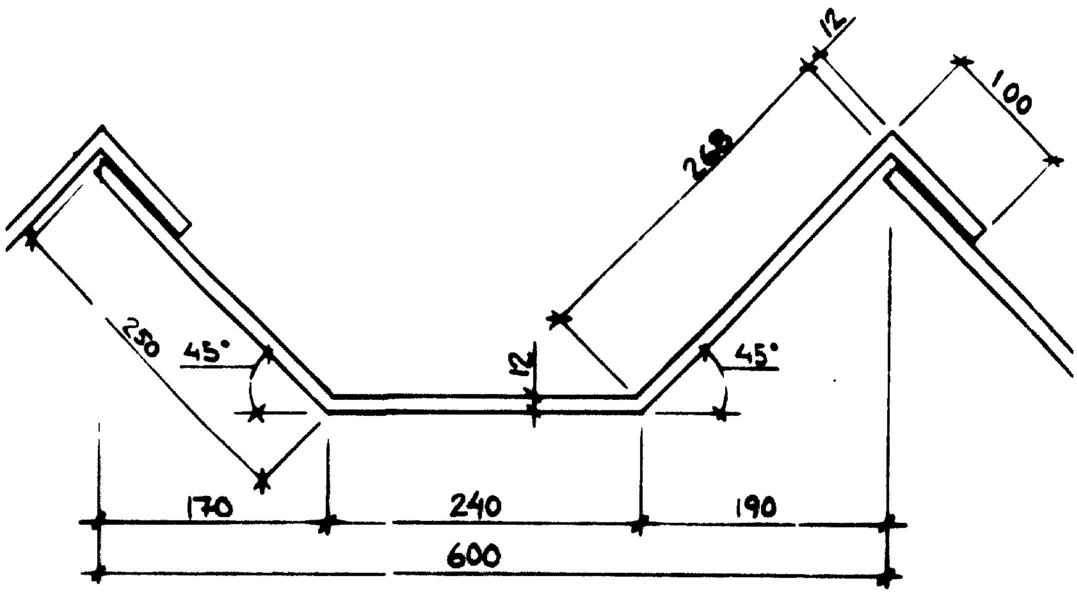

FIG 5.4. Folded sheet.

This type can have a span of about 2.0-7.0 m. The sheet can be supported by two walls and in this case the secondary construction system could be excluded. Weight of one slab with the length =4.5 m is approximately 110 kg.

This type has been tested in full scale, with point-loads and a span = 3.3 m. Continuous sisal fibres in six layers were used. The result showed that it is possible to walk on such roofing sheet with a safety factor bigger than 2.0. When failure occurred the deformation was very great, see FIG 5.5. You could easily notice the cracks and even hear when they occurred.

FIG 5.5. Deformation near final failure.

5.3.1.4 Stress calculation of folded plate

A folded plate with a wider bottom part than the plate described in FIG 5.4 has been stress calculated.

The dimensions are given in FIG 5.6 and the following loads were considered.

P_1 = 0.8 kN Weight of one man on the cantilever.
P_2 = 0.8 kN " " " " " " middle.
P_3 = 1 KN/m^2 Distributed load all over the sheet.
P_4 = 1 kN/m^2 Windload upwards on the cantilever.

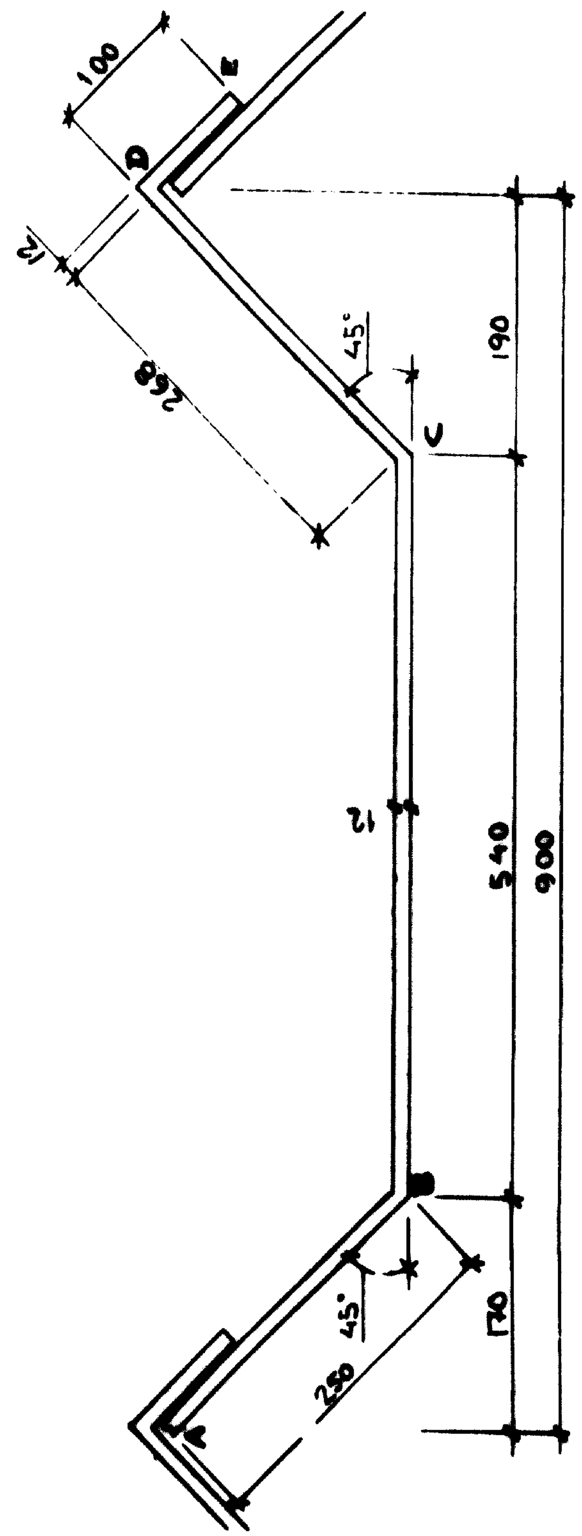

FIG 5.6. Folded sheet, calculated with finite element analysis.

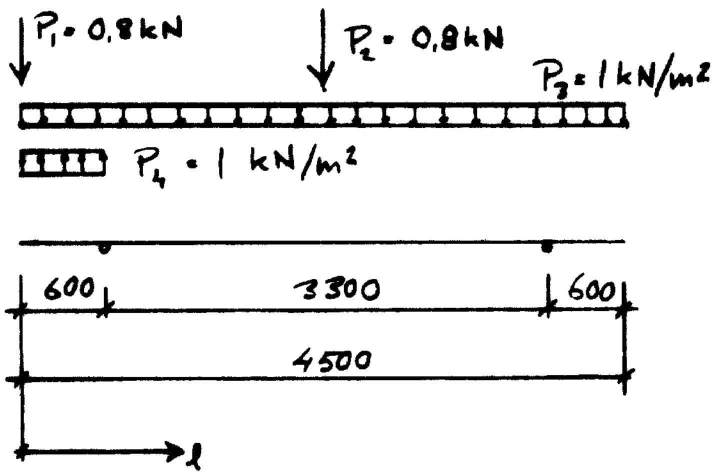

FIG 5.7. Loads and dimensions of the folded sheet.

Calculation is made with help of computer with a program following "Finite element analysis".

From this calculation design stresses according to 5.8.-5.13 are evaluated.

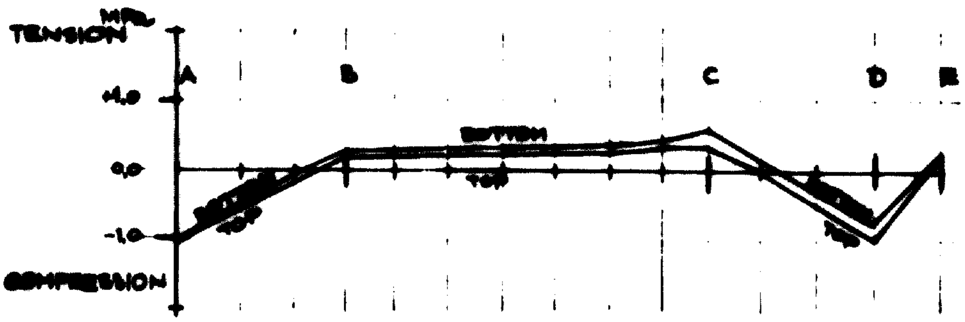

FIG 5.8. Stresses in the cross-section from the weight of the element, l= 2250.

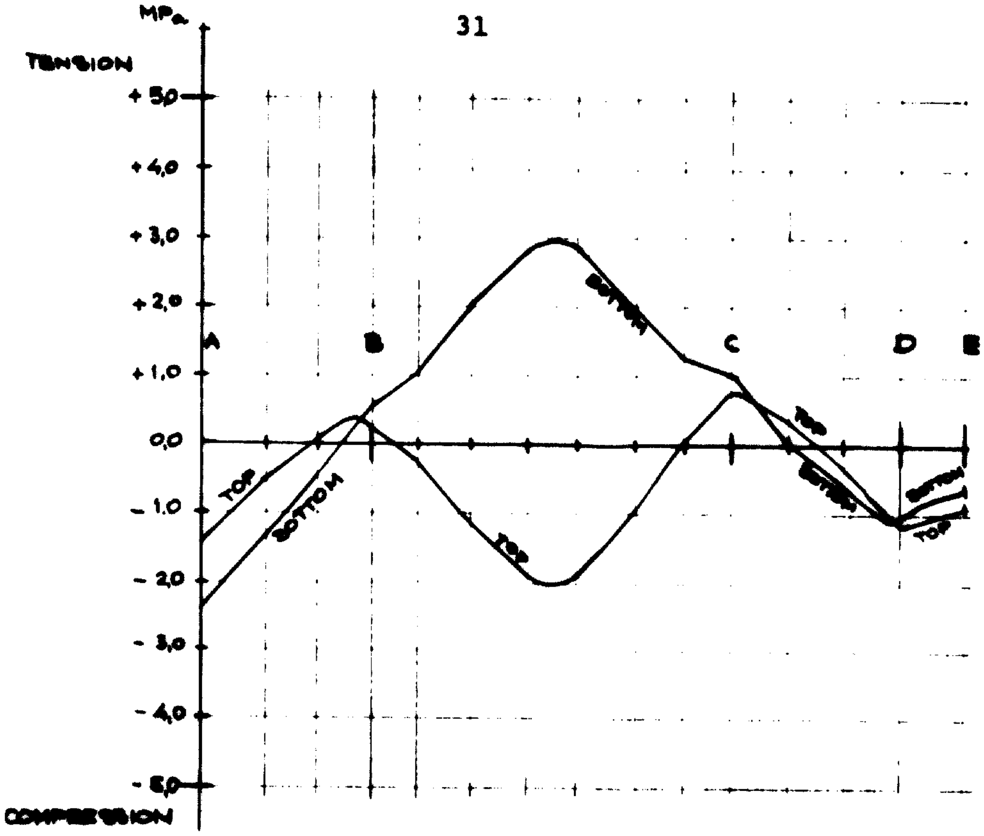

FIG 5.9. Stresses in the cross-section from P_2. ℓ=2250.

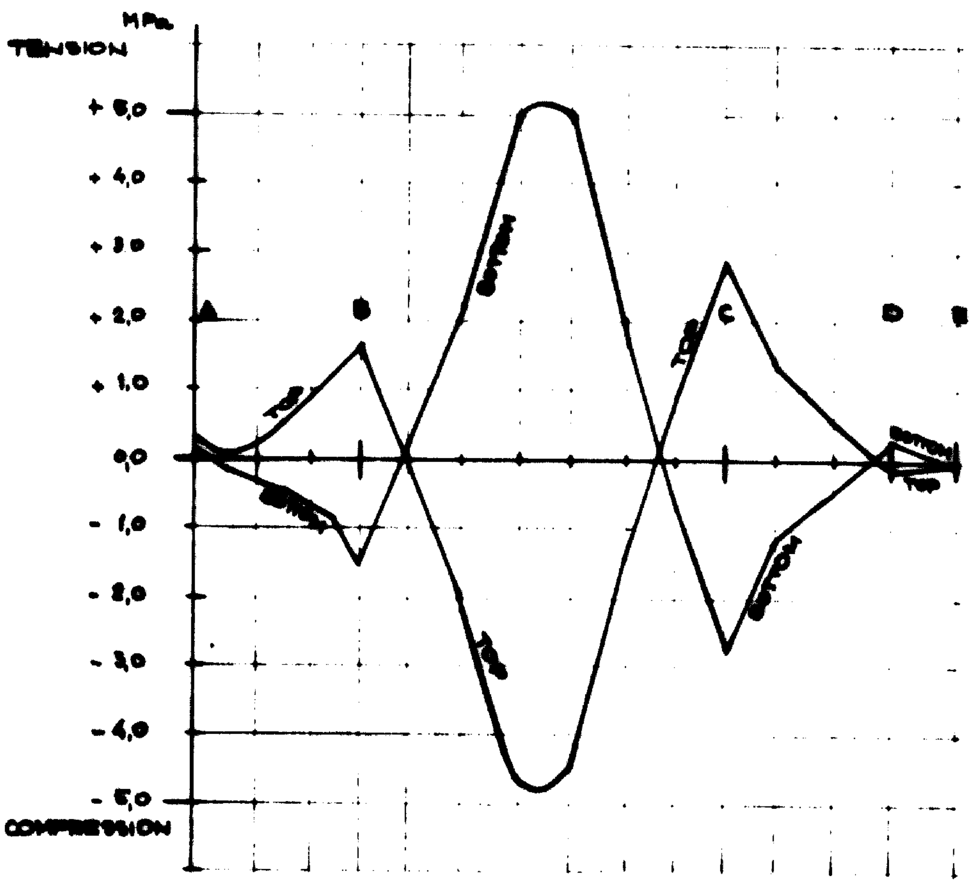

FIG 5.10. Stresses transverse the cross-section from P_2
ℓ=2250

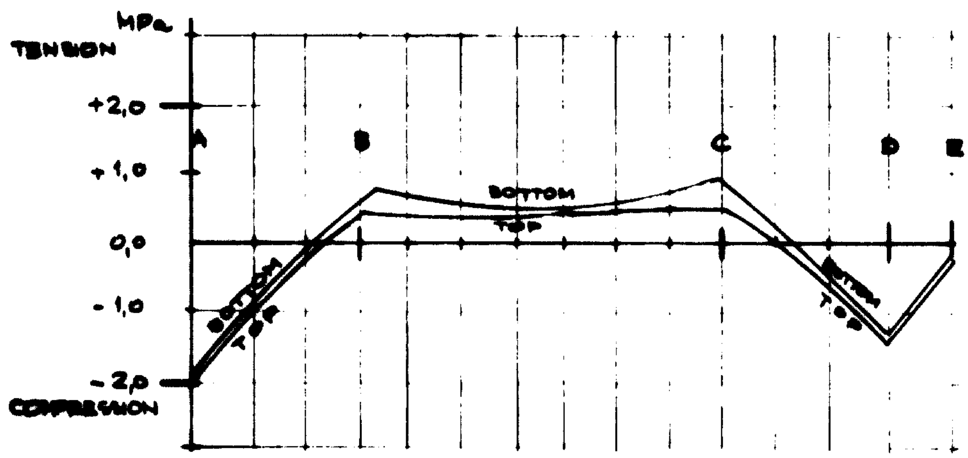

FIG 5.11. Stresses in the cross-section from P_3. ℓ=2250.

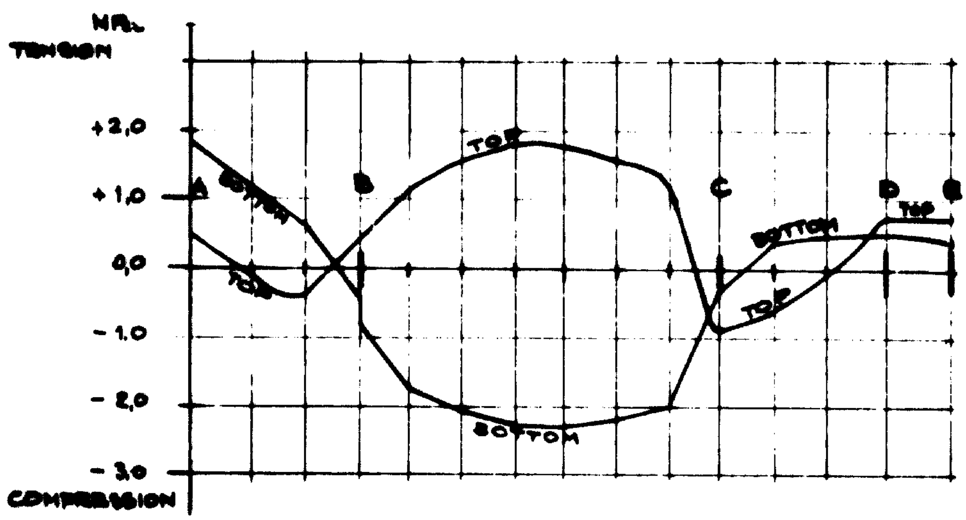

FIG 5.12. Stresses in the cross-section from P_1. ℓ=600.

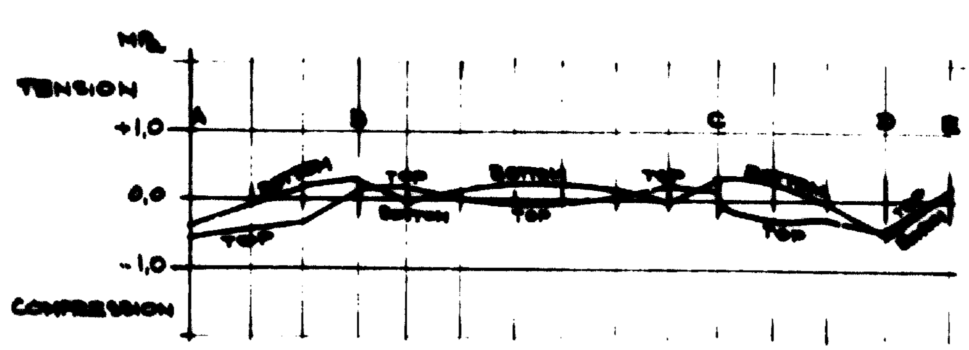

FIG 5.13. Stresses in the cross-section from P_4. ℓ=600.

Stresses in different parts of the slab from single or combinations of design loads could be shown. They are however in this case of less interest.

The design stress is reached by the point load 0.8 kN (with the size 100x250 mm^2). Stress in tension σ_t from this load case is about 5.0 MPa.

Efforts to minimize these stresses should be made. One way is shown in FIG 5.4, where the bottom slab is made smaller.

A similar calculation on this type shows that the stresses from the same point load have been halved i.e. σ_t less than 2.5 MPa.

Other ways of making the stresses from the point load small can be to make corrugations of the bottom slab transverse the load bearing direction.

5.3.2 Plastering

Walls made of mud and pole often have a short lifespan. In Tanzania, BRU, has estimated the average lifelength to 7 years. The main reason of the destruction is the affection from the rain, especially the driving rain.

A sisal fibre concrete surface on the outside of the walls can protect the construction from the rain. The fixation of this coating can be made with sisal fibres knotted to the wall and cast into the coating. This is not yet tested in full scale, but the idea seems sound and should give more durable walls and houses with lower costs per year.

5.3.3 Substitute for wood

Sisal fibre concrete can be manufactured in various shapes and dimensions. Window gratings, sun screens and many different items can be produced. Trusses, even with rather big spans,are possible to make. It can perhaps be suitable to substitute parts in tension with steel bars if the tension forces are great.

5.3.4 Small beams

The probable limit of a maximum crack width for sisal fibre concrete seems to indicate that large beams of this material should not yet be designed, without full scale tests. Small beams and trusses, however, where the crack widths can be kept on a low level, seem to be possible. The products can be beams over openings, as doors and windows, in brickwalls or a tieing beam around the house at the top of a brick-wall. The latter beam gives a rigidity to the whole construction, as for instance for the roof trusses, and stability against forces from earthquakes.

5.3.5 Blocks

With help of sisal fibre concrete made with chopped fibres it should be possible to cast thinwalled hollow blocks, type "Lego", se FIG 5.14.

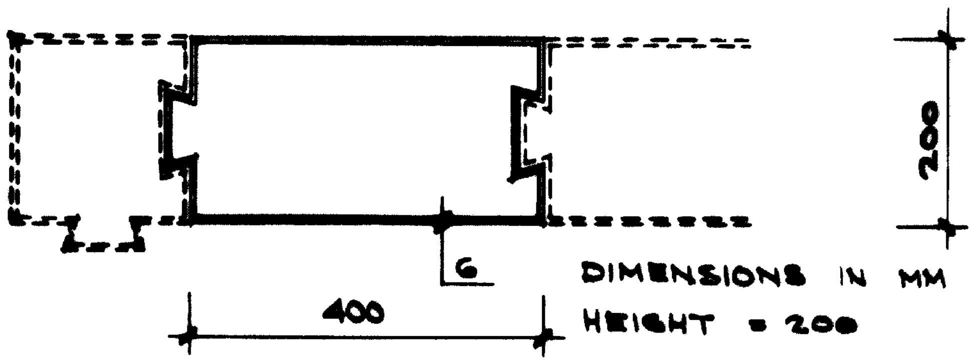

FIG 5.14. Example of a hollow block without top or bottom with the wall thickness 6 mm.

Cement stabilized soil blocks are nowadays used commonly in many developing countries. They need less cement than blocks of concrete.

The hollow block of sisal fibre concrete described above needs less than half of the quantity of cement used in cement-stabilized soil blocks.

One block described in FIG 5.14 needs about 1.0 kg cement and the weight will be approximately 4.0 kg. One square-meter wall requires approximately 12 kg cement.

They can be blocked up dry-laid without mortar. The interlocking details makes the walls stable. After the erection of the brickwalls the innerspace in the blocks can be filled with earth or sand. The surface, both in- and outside, is already finished.

If you want to build a twostorey building it is possible to mount reinforcement and cast concrete column inside the hollows of the blocks.

5.3.6 Wall system, sheets and beams

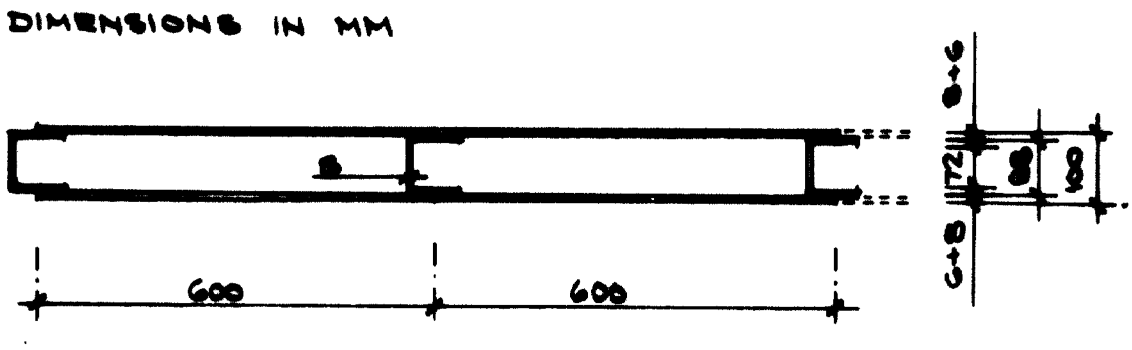

FIG 5.15. Example of a wall system using prefabricated beams and sheets of sisal fibre concrete.

The wall system described in FIG 5.15 weight approximately 35 kg/m^2 and consumes approximately 9 kg cement per m^2 wall.

6 PRODUCTION PROCESS

6.1 General

The production of sisal fibre concrete sheets and other sisal fibre concrete products consists in principle of the following operations:

- Preparing of the constituent materials
- Mixing
- Casting
- Curing
- Storing

Depending on whether chopped or continuous fibres are used the material flow can be described as in FIG 6.1 and 6.2, respectively.

FIG 6.1. Material flow using chopped fibres.

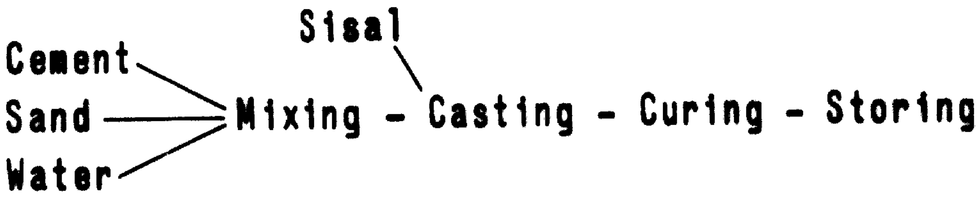

FIG 6.2. Material flow when using continuous fibres.

With both types of reinforcement all steps in the production of the sisal fibre concrete can be made manually, i.e. no electricity, no heat, no over-pressure and no vacuum have to be used, and no extra chemicals have to be incorporated. The production of sisal fibre concrete can thus lend itself to production by local craftsmen in villages but can also be mechanized in different steps to save labour, to increase the quality and to increase the production rate.

Below in this chapter will be given a more detailed description of the different phases in the production process as well as a description on productions on three different levels, namely

- village
- small scale industry
- mechanized industry

No production studies have yet been carried out in the ongoing project (described in chapter 2) and so the descriptions of production processes will have the form of scenarios.

6.2 Preparation of the constituent materials

Cement is in most places a readily-available material delivered in bags, and normally no treatments of or additions to the cement are needed before adding it to the mix.

The sand should have a rather fine grading and the maximum aggregate size should be approximately 2 mm. The sand should not contain any organic substances that can be harmful to the cement hydration.

The water can be of a rather varying quality, but it should not contain contaminations which make it unsuitable for use in cement-based materials. Whether the water is acceptable or not can be easily tested.

The sisal used will be either chopped to different lengths (15-50 mm) or used continuously as individual fibres or in nets. A possible effect on the cement hydration from contaminations on the fibre surfaces should be examined before a new stock of fibres is used.

6.3 Mixing

Chopped fibres are mixed together with cement, sand and water to a mix, and when continuous fibres are used, the matrix (cement, sand and water) is mixed separately. The mixing can be made by hand with shovels or with forks, or mechanically in pan or drum mixers. The workability of the mix has of course to be chosen to the method of production for the product to be made, but the mix should normally be rather wet but not too fluid. A very wet mix leads to separation and poor quality.

6.4 Casting

Chopped sisal fibre concrete is cast by simply pouring the mix to the desired thickness in a mould. Only slight stamping or hammering on the mould is required to get a sufficient compaction, although a vibration table or similar will give a more effective compaction and thus a denser matrix.

FIG 6.3. Casting of chopped sisal fibre concrete.

When continuous fibres are used, a thin layer of concrete matrix is cast on the bottom of the mould. Fibres are then laid on the matrix layer and pressed into that with the help of hand-rollers, see FIG 6.4.

A new matrix layer followed by a fibre layer is placed and compacted, and this is repeated until the desired number of fibre layers is obtained. On top of the laminate a thin matrix layer is placed, and the upper surface can be made even and smooth with the help of simple hand tools.

FIG 6.4. Rolling continuous fibres into a matrix layer.

The sisal fibres give the concrete matrix a very good plasticity in the fresh state, i.e. normally during the first hours after the cement has been mixed with water. This property gives the possibility of forming the material to different shapes after it has been cast. It is, for example, possible to cast a flat sheet of sisal fibre concrete on a plastic foil and then transfer the flat sheet to a corrugated by placing the foil with the material on another, already corrugated product. This postforming technique is shown in FIGs 6.5 and 6.6 .

The plasticity of fresh sisal fibre concrete also gives the possibility of forming different shapes by putting the concrete on a product with the desired shape, thus making a replica of the "mould". This method can be used for making buckets, bins, etc.

The moulds can be made rather simple in wood, but if a postforming technique is used, if high quality surfaces are desired or if a high production rate is aimed at, materials other than wood should be considered for the moulds.

FIG 6.5. Production of a flat sheet 4500x1300x13 mm.

FIG 6.6. The sheet in FIG 6.4 after folding up the sides in the fresh state.

6.5 Curing

All cement-based materials need to be cured after casting in order to hinder the water, needed for the hydration of the cement, to evaporate. The consequences of improper curing are cracking and reduced strength gain. The curing can be made under wet rags or similar, by covering the products with plastic foil or by keeping the products in a water basin. The time required for proper curing depends mainly on the type of cement used and the climate and should be evaluated for every production situation. In most cases three to four days will be sufficient. Demoulding can usually be done, if carefully carried out, after 1 day.

6.6 Storing

The strength of concrete increases with time at a decreasing rate. If standard cement is used, a major part of the final strength will be obtained after 4 weeks. The products are thus not ready for delivery directly after curing but have to be kept in storage for some weeks. When moving the products to curing and from curing to storing, they have to be handled with care.

6.7 Production on the village level

When producing sisal fibre concrete on what can be called a village level the following points should be taken into consideration.

- minimum of transport work for constituent materials
- labour intensive production acceptable
- simple equipment
- no electricity
- no machinery
- limited knowledge needed

The production procedure can be described with the following operations, see also FIG 6.7.

1. Preparing sand by hand-sieving.
2. Chopping sisal fibres to advised lengths or preparing individual fibres or nets.
3. Mixing by shovel cement, sand, water and fibres using a simple mix design.
4. Pouring the concrete in a mould. If continuous fibres are used, layers of fibres are laid in between layers of concrete. Compaction by stamping and surface treating with a trowel made of wood.
5. Curing the products under wet rags or similar.

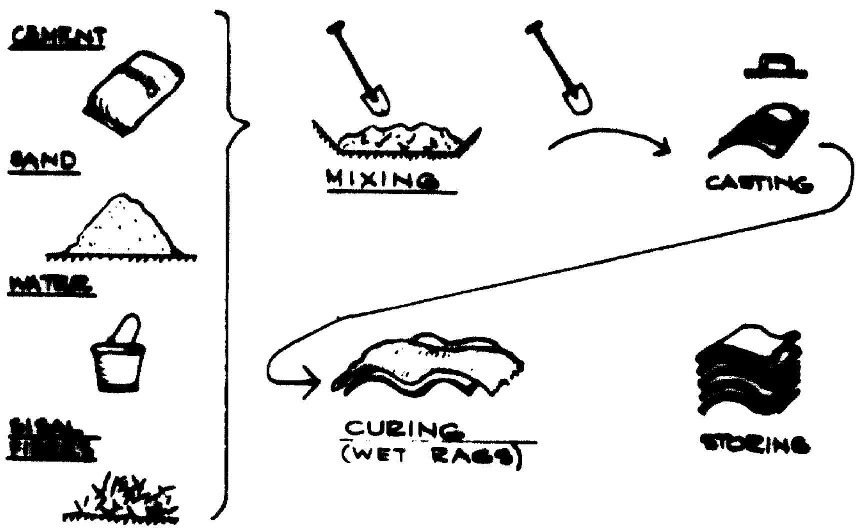

FIG 6.7. Idea of production on the village level when chopped fibres are used.

The equipment needed for this level of production comprises a shovel, a bucket, a wooden mould, a wooden trowel, rags or similar, something to cut the fibres with (not always) and a sieve (not always).

The knowledge needed could possibly be taught to a local craftsman by a visiting instructor and should comprise:

- How to prepare the sand. This will depend on the local resources.

- How to prepare the fibres. Either chopped or continuous.
- The mix design.
- How to mix, pour and compact. Information on thicknesses, etc.
- How to cure the finished products and how to store them.

6.8 Production in small scale industries

In order to increase the production rate, to increase the quality, to get a larger variety of products and more advanced products without too complicated transports or heavy capital investments, production in small scale industry is interesting. For this level of production the following considerations should be taken:

- sand can be taken from local resources or transported over limited distances
- labour-intensive production acceptable
- electricity obtainable
- simple machinery
- limited specialist knowledge needed.

The production procedure can be described with the following operations, see also FIG 6.8:

1. Control of sand and sand preparation by hand-sieving
2. Chopping fibres to different lengths or preparing individual fibres or nets. A machine for cutting fibres will be advisable and nets instead of individual fibres will be preferred. Control of fibre quality.
3. Mixing concrete in a mixer using simple mix designs.
4. Pouring the concrete in moulds which will be of sufficient quality for recycling. Compacting on vibration table and surface treatment with rollers and/or trowels.
5. Curing the products under wet rags or in water basins. Quality control and storage.

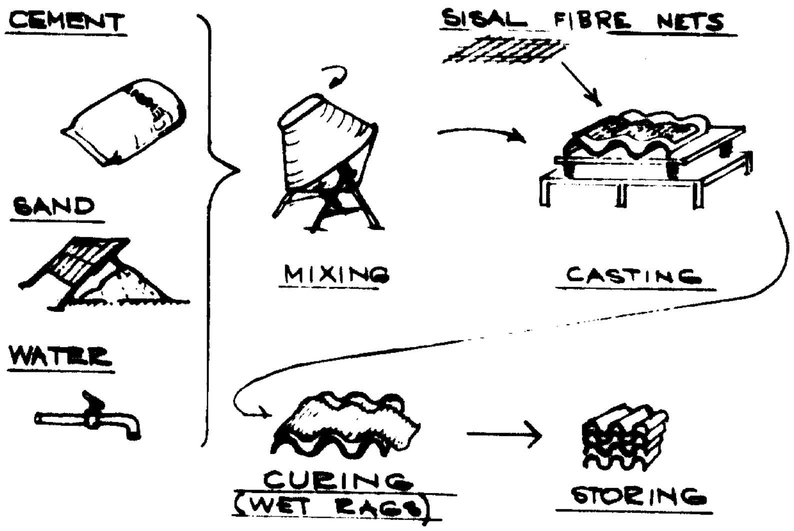

FIG 6.8 . Idea of production in small scale industries. using fibre nets.

Apart from sieves and ordinary hand tools, machinery for fibre preparation, concrete mixing and compaction will be required. For the curing, a water basin can be used but rags or similar will also be sufficient.

The knowledge needed to maintain a small scale industry production comprises limited knowledge of concrete technology, requirements for different products, control procedures and machinery maintenance. Some knowledge of administration, planning and economy will also be needed.

6.9 Production in mechanized industries

Sisal fibre concrete can be made in rather highly mechanized processes similar to the production of asbestos cement. Mechanized production can give further increase in production rate, further increase in quality and a reduction in labour requirement compared with a production in small scale industry but will require high capital investments. The following criteria can be considered for mechanized production:

- transport facilities for sand and finished products over long distances
- low labour requirement
- advanced machinery
- advanced knowledge

The production procedure can be described with the following operations, see also FIG 6.9.

1. Preparing of sand in automatic sieving machines. Careful quality control of the sand. Cement and sand from silos.
2. Chopping of fibres in cutting machines or using continuous fibres in nets. Quality control.
3. Mixing concrete in batch mixers or in continuous screw mixers.
4. Discharging the mix on a continuous mould through pumping. Nets are continuously fed into the mould. Vibration, overpressure and vacuum are used to increase the compaction and to simplify the handling of the products.
5. Curing the products in humidity chambers. Careful quality control and storage.

The machinery needed for this type of production will be extensive and is hard to review in detail at the present stage. Apart from machinery also vehicles for handling and transporting will be needed.

Advanced knowledge will be required concerning for instance administration, economy, production planning, concrete technology, machinery maintenance, marketing, sales and transport planning.

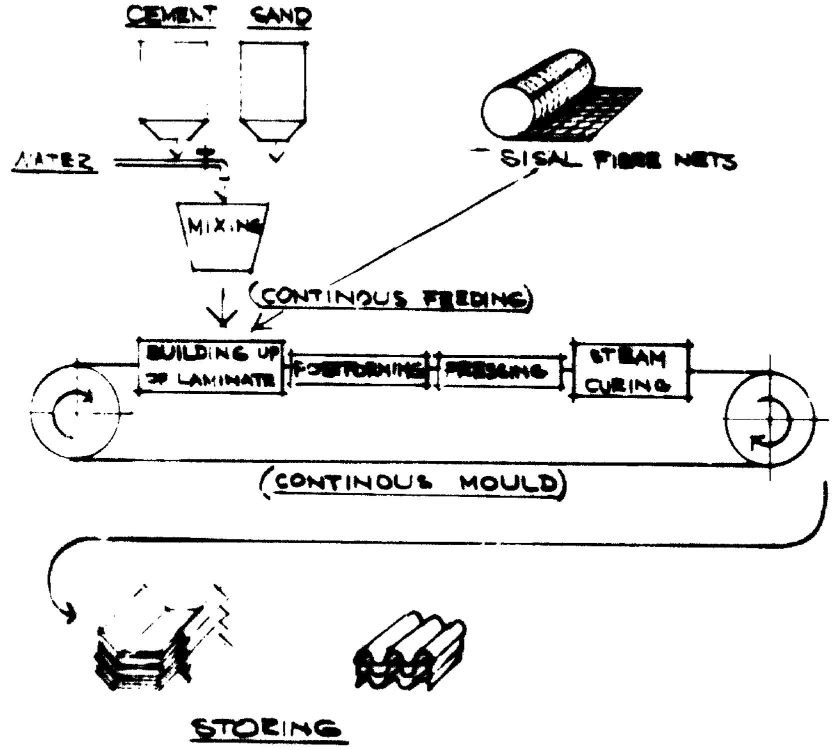

FIG 6.9. Idea of production in mechanized industries.

7 TRANSPORTS

7.1 General

In developing countries there is as a rule a lack of transport facilities. Roads and railways exist to a much lesser extent than in the industrialized countries and the standard is often low. Much transport work is done by people and/or with the help of animals. Concrete work is carried out in many places, which is why transport or raw material for and products of sisal fibre concrete should not be a new problem.

7.2 Cement

Cement is generally produced in rather big factories often concentrated to a few big cities. Transport of cement is therefore done over long distances. Concrete work is, however, wellknown and is carried out practically everywhere all over the world. It should be remembered that cement transportation often already is developed.

Cement must be kept dry to secure that hardening does not start in advance. Papersacks containing 50 kg or steelbarrels are often used.

7.3 Aggregates

Sand, gravel and stone for aggregate can be found in most places. It is, however, essential to use aggregates without organic impurities and with correct sieve analysis. Hard aggregates can in some places be difficult to find and is sometimes collected along streams or is produced by crushing stones or rocks. As mentioned there often exist a local concrete production. It should, however, be noted that if sisal fibre concrete sheet is to be produced, aggregates with smaller particle sizes than for ordinary concrete should be used.

7.4 Water

Water for production should not be a problem. Rain-water can be used.

7.5 Sisal fibres

Transport of sisal fibres in sisal-fibre producing countries is already established. Even if transport has to be carried out long distances it should be noted that sisal fibre volume of total concrete volume usually is below 4% and that sisal fibres have a weight about 20% of steel per volume. Sisal fibres could also be produced locally in villages.

7.6 Products

Weight of the products can determine if the production will be carried out locally or in big factories depending on the transport situation.

Small products like the roof tiles (5.3.1.1) or the blocks (5.3.5) can easily be carried by people. The corrugated roofing sheet (5.3.1.2), the window grating, in other words products with weights between 30-60 kg, can also be transported by people, but with more difficulty. The transport situation in this case may indicate a small-scale industry production.

Heavy products like the folded sheet spanning from one wall to another (5.3.1.3) either need transport with lorries, which may be the case for a industry roof, or can be made locally so it just have to be lifted on the structure after curing. A roof for an ordinary house with the size of 50 m^2 has the weight of approximately 1500 kg. This indicates that sheets for one up to three roofs can be loaded on ordinary lorries with the capacity of 1.5-5.0 tons. Sisal fibre concrete has a great toughness as described in 4.3.3. Damages when transporting the products should be easy to keep on a low level. A minor crack could either be accepted or is rather easy to mend for instance with cement slurry.

8 BUILDING TECHNIQUE

8.1 General

Sisal fibre concrete has a fibre volume less than 5% of the total concrete volume.

When designing constructions or components of buildings, sisal fibre concrete should therefore be thought of as ordinary concrete. The big difference between conventionally reinforced concrete with steel bars and sisal fibre concrete is the possibility of making the latter in very thin sections.

Sisal fibre concrete can be combined with both traditional housing and more industrialized ways of building.

Sisal fibre concrete is fire resistant, has a good thermal capacity as ordinary concrete. Indications show that its lifespan should be long. Full-scale tests are, however, not yet carried out. Need of skilled workers is not big. If cracking occurs the cracks can be mended with cement slurry or with plaster made of chopped sisal fibre concrete.

8.2 Roofing

The small roofing tile (5.3.1.1) should be used in the same way as for ordinary clay tiles. Overlaps from one tile to another should be made in a way that no water can come through. Some of the tiles should be fixed to the secondary construction system. This can be done with nails or with sisal twines cast into the tiles and knotted around parts of the roofing construction. The corrugated sheets (5.3.1.2) and the bigger sheets (5.3.1.3) can also be fixed to the structure with cast in sisal twines. The sisal twines can be protected after the knotting by plastering with chopped sisal fibre concrete.

Another way is of course to use nails or better screws with rubber packings to ensure water tightness. This way is traditionally used for corrugated iron sheets and asbestos concrete sheets. Holes for the fixations in the roofing sheets can easily be done in the fresh state.

If a leakage occurs it should be possible to prevent it by using clay. It is also possible to stop a leakage through a crack by using cement slurry. Bigger repairs can be done with chopped sisal fibre concrete or by replacing sheets.

Loads from the roofing sheets of sisal fibre concrete on the structure are bigger than from corrugated iron sheets. The bigger loads on the walls should not be a problem, as ordinary walls with practically no exception can withstand very big vertical loads. The weight from the roof on the secondary construction system can be compared with the weight from a clay tile roof. When using small sizes of roofing sheets, the parts of the secondary construction system may have slightly bigger dimensions compared with a roof of corrugated iron sheets. The differences are marginal.

Some times when using the corrugated sheet of sisal fibre concrete on a secondary construction it is necessary to adjust the levels of the supports for instance by using small pieces of wood.

8.3 Beams

Beams over openings in a block wall can either be casted on site or be prefabricated. A ring beam at the top of the block walls should be casted on site in order to create a proper interaction.

8.4 Window gratings, sun screens etc

Window gratings, sun screens etc. is preferably prefabricated. They can either be mounted afterwards in holes in block walls and other types of walls or they can be installed at the same time as the erection of the wall.

9 COSTS

9.1 General

Sisal fibre concrete consists of cement, sand, water and sisal fibres.

Production can be carried out mainly on three different levels:

1. Village
2. Small scale industry
3. Mechanized industry

The costs for the raw materials can usually be estimated rather well. The costs for investments like tools, equipment, machinery and buildings are depending on the type of production and are of course related to the cost for labour. Below in this chapter is given some figures showing the cost situations for raw materials, investments and labour on village level and in small-scale industry.

The costs for mechanized industry depends on the rate of automatic production. A cost analysis has in this case to be carried out on more detailed factory plans, which not yet have been studied in the ongoing project.

At last some figures is given showing costs for transport of raw materials and products.

The costs are related to the ongoing study in Tanzania (1978), but gives the levels probably useful for other countries with their respective alterations depending on actual conditions.

9.2 Raw materials

The raw materials for a roofing sheet 1 m^2 and 10 mm thick is analyzed. Weight ratio cement/sand = = 1/3.

9.2.1 Cement

One bag of cement, 50 kg, costs about 2.5 US $ in Dar-es-Salaam, the capital of Tanzania. Due to transportation and in some extent shortage of cement the cost in the urban areas can be 5 $ for one bag or 0.10 $/kg. 6 kg cement per m^2 roofing sheet gives the cost for cement in the urban areas, 0.60 $/$m^2$.

9.2.2 Sand

Sand, useful for this type of production, often has to be crushed from bigger sizes, sieved and transported, or it may be necessary to transport sand from different places in order to mix a sand material with correct sieve analysis. Cost for sand is estimated 4 $/ton, 18 kg sand per m^2 roofing sheet gives the cost for sand 0.07 US $/$m^2$.

9.2.3 Sisal fibres

The need of sisal fibres is usually below 3% in volume of the sheet. In the calculation 2.5% is used which gives approximately 0.4 kg sisal fibres/m^2. 550 $/ton is the export price for sisal fibres cif. Dar-es-Salaam. In urban areas the cost for sisal fibres is lower.

The cost for sisal fibres 0.55x0.4=0.22 $/m^2.

9.2.4 Water

Rain water could be used. There might, however, be a cost for transport etc. The cost for water is estimated =0.01 $/m^2.

The total cost for raw materials will be 0.90 $/m^2.

9.3 Investments and labour

In principle, the villagers can grow their own sisal, pick their own sand and work with selfmanufactured tools and equipment, and the cost for the sheet will just be the cost for the cement. This may, however, not be the common situation. Cost for investments and labour is of course difficult to estimate without experiences from an actual production but a rough guess can be 0.60 $/m^2 based on small scale production.

The total cost will then be 1.50 $/m^2 for a corrugated sheet of sisal fibre concrete on which you can walk. As a comparison a roofing sheet of corrugated iron will cost more than double this sum and these sheets are not possible to walk on without breakage.

9.4 Transport

Transport and its costs is a very important matter. In village level people probably can carry both the raw materials and the products. In this case the costs for transport can be included in the cost for labour.

The more industrialized ways of manufacturing gives costs for the transports.

A roof for an ordinary house, 50 m^2, has the weight of $\sim$1.5 ton and it can be transported by ordinary lorries. This can give the guideline for maximum length of transport if you know the cost per km and ton and a comparison is possible to make with competative roofing materials in the area.

10 ASPECTS FOR THE FUTURE

Within the project described in chapter 2 roofing sheets made of sisal fibre concrete will be made in Tanzania this year (1978). From these sheets, experiences can be obtained concerning for instance water tightness, lifespan, etc. This can also be the start of a small-scale production of roofing sheets in Tanzania.

Other products like blocks, plastering, substitutes for wood, will probably be studied during the next few years. Latrines are one important field where sisal fibre concrete can find applications. Other applications for the material are also probable. Increased knowledge and experience will lead to improvements concerning design, production, transport and building technique.

During 1979 there will be results from a project, "Coir fibre concrete for roofing sheets". This project will be carried out in cooperation with Building Research Institute, Colombo, Sri Lanka. In the future it seems possible that other natural fibres can be used for fibre concrete applications.

The cost situation for sisal fibre concrete seems favourable today. Steel, plastic, glass etc. needs energy for its production. Vegetable fibres do not need much energy for its production as they grow using sun energy in the photosynthetic process. In the long run the price situation therefore seems to be even more favourable.

Sisal fibre concrete

- is made of easily obtained raw materials using already established concrete technology
- does not need skilled labour or heavy machinery
- is preferably produced in thin sheets and with possibility of post forming to different shapes
- can be used in a variety of applications
- is a cheap material compared with other materials
- is low energy consuming.

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