ADVANTAGES IN COMPOSITE TECHNOLOGY

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1. Preface

Technological progress, conbined with the inducement to conserve energy and strategic material, are driving forces behind the development of new high performance materials for structural application.

In the last two decades there is a extensive use of advanced composite evident.

Traditional materials such as metals and concrete, etc. will continue to represent the bulk of structural materials consumption, but they may progressively be substituted by composites in an increasing number of applications.

This way is determined by comparison of performance/cost ratios, where the costs include those of the material itself, the manufacturing costs and the operation and maintenance costs of the final product.

The major objectives and conditions for inplantation of this technology are

- the identification of markets and application
- the evaluation of the timing of implantation
- the necessary technical and econimic conditions for the application
- quantification of the markets
- the needs for further activities (e.g. R & D)
- impact on existing material markets.

The advantages are influenced by

- analysis of high technology industries
- future material performance
- future fabrication techniques
- changing performance demand
- impact on industry
- the economic environment.

2. Materials

For composite materials the developments underway are in the direction of improved cost-effectiveness and quality through:

- fabrication developments
- low cost fibers
- more efficient designs through a better understanding of mechanical behavior and life-time prediction (i.e. lower safety factors, higher stresses, etc.)
- more rapid curing and high temperature resistant resins
- designs involving new reinforcement materials and hybrid structures
- joining systems with improved efficiency
- better detection and understanding of the effect of structual defects
- understanding and resolution of environmental sensitivity, i.e. composites are not absolutely "corrosion resistant", and this problem will become more acute, as the materials are used to ever higher stresses and in corrosive environments.

Starting the fabrication of end using products on the composite materials sector will surely require, that the discussion of design, fabrication and properties will be limited to technical and economic relevant basic materials as matrix-resins and fiber materials presented in the following:

Fibers \ Matrices	Epoxi	Polyimid	Polyest.	Phenolic
Glass	X		X	X
Carbon	X	X		
Aramid	X	X	X	X

Fig. 1 Fiber-Matrix combinations

Manufacturers, being already firm with the basic technologies concerning composites may reflect on further developments.

This means to regard, beside the so-called thermosetting resins presented in Fig. 1, also other polymeric, metalic and inorganic matrices and advanced reinforcement materials presented in Fig. 2, 3 and 4.

Fig. 2

~~TABLE 1~~ POLYMER MATRIX COMPOSITES

Reinforcement \ Resin	Thermosetting				Thermoplastic							Elastomer	
	PE'R	E	PU	PH	PE	PU	PA	PS	ABS	PMM	PC	PU	SBR
Glass fiber	O	O	O	O	O	O	O		O			D	D
Carbon fiber	O	O	X	D									
Organic fiber (ex: aramids)	O	O										X	O
Inorganic (silica, talc, ...)					O	O							
Steel fibers	X	X		D									
Steel ribbons	X	X	X	D								X	
Flakes	X				X	X						X	

Present status: O Industrial
X Tests at industrial level
D R & D stage

PE'R	Polyester
E	Epoxy
PU	Polyurethane
PH	Phenolics
PE	Polyethylene
PA	Polyamide
PS	Polystyrene
ABS	Acrylonitrile Butadiene Styrene
PMM	Polymethyl methacrylate
PC	Polycarbonate
SBR	Styrene Butadiene Rubber

(Fig. 2, 3, 4)

Fig. 3

~~TABLE 2~~ - METAL MATRIX COMPOSITES

Reinforcement \ Matrix	Al	Ti	Mg	Ni/Co	Cu	Pb	Sn
Carbon	O		D	D	D	D	X
Boron, SiC, Borsic	O	X	D	D	D		
Al_2O_3	D		D	D		D	
Steel fibers	X	D			D	D	
Steel sheets	D						
Beryllium	D	D					
Whiskers	D	D	D				
Silica	D						
Metglas®	D		D				
Tungsten, Molybdenum				D	D		
Eutectics					O		

Present status: O Industrial
X Tests at industrial level
D R & D stage

Fig 4

~~TABLE 3~~ - INORGANIC MATRIX COMPOSITES

Reinforcement \ Matrix	Glass	Ceramics	Cement
Ultra-high modulus polyolefins		D	X
Polyamides	D	D	X
Nylon		D	X
Carbon, Graphite	D	D	O
Glass		D	O
Boron, Borate		D	D
SiC		D	D
Al_2O_3		D	D
Whiskers		D	D
Silica		D	D
Asbestos			O
Steel (carbon)	O	X	O
Steel (stainless)	O	D	O
Metglass®	D	D	D
Tungsten, Molybdenum		D	D
Eutectics		D	D

Present status: O Industrial
X Test at pilot plant scale
D R & D stage

3. Fabrication Techniques

Fabrication techniques represent the key element in determining the final properties and costs of the finished product.

New and advanced fabrication techniques, which include all operational sequences leading to the production of the finished part

- raw material production
- forming and curing
- construction or assembly of finished parts
- treatment of products

will be discussed in the presentation of examples of advanced developments (Chapter 4).

The different manufacturing processes employed for composite materials are:

- Hand lay-up moulding and spray-up. Here, the key elements where improvements in quality and costs can be made, and are expected, are in low tooling and finishing costs, but mostly in the replacement of hand lay-up by automatic cutting, ply, layers, pressing (Fig. 5) etc. New polymer resins to simplify and speed-up the curing process are being researched.

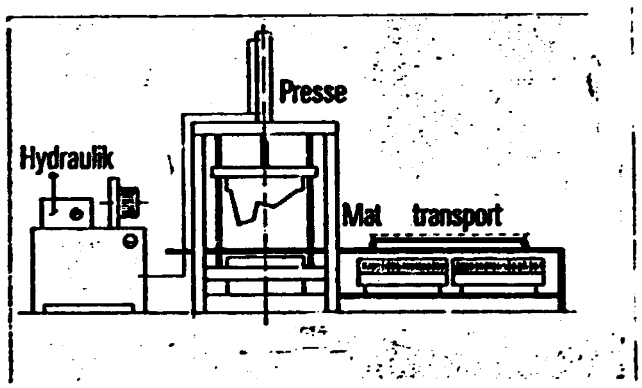


Fig. 5: Automatic pressing

- Filament winding (Fig. 6) of tubular products is already to a certain degree an automated process but much manually assisted equipment is still in operation. Effective automatic control systems are required to increase the pressure and external load capabilities of the tubes thereby expanding their market oportunities.

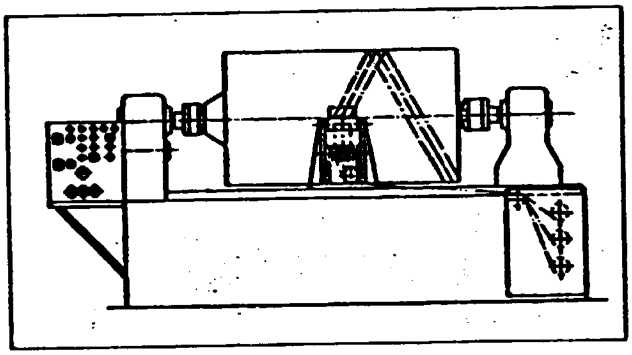


Fig. 6: Filament winding machine

Pipe fittings by filament winding would represent a significant breakthrough from the cost and quality point of view. Computer-controlled systes are developed and their progress will be followed.

- Pultrusion (Fig. 7) is an extremely interesting and effective procedure for the production of continuous composite profiles: bars, profiles, tubes. Progress extensions of this manufacturing technology, e.g. pulforming, will be critically examined. The combination of pultrusion and filament winding represents an interesting potenial production route for certain structural elements.

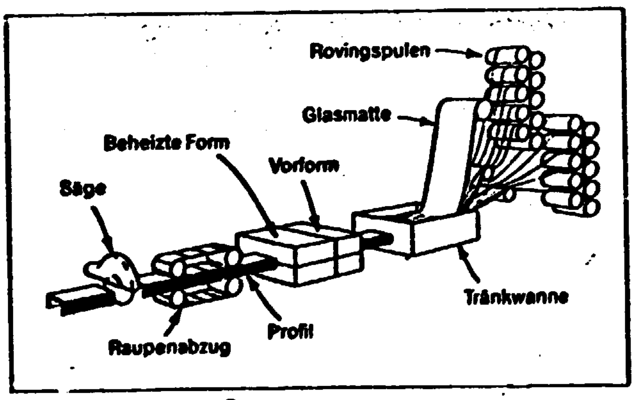


Fig. 7: Pultrusion machine

- Automatic lay-up of prepreg-tapes is an important procedure for the higher cost materials and fastidious applications.
- Compression moulding (Fig. 8) of sheet-moulding compounds (SMC) in assemly lines for big numbers of pieces.
- injection moulding of fiber reinforced plastics. (Fig. 9).

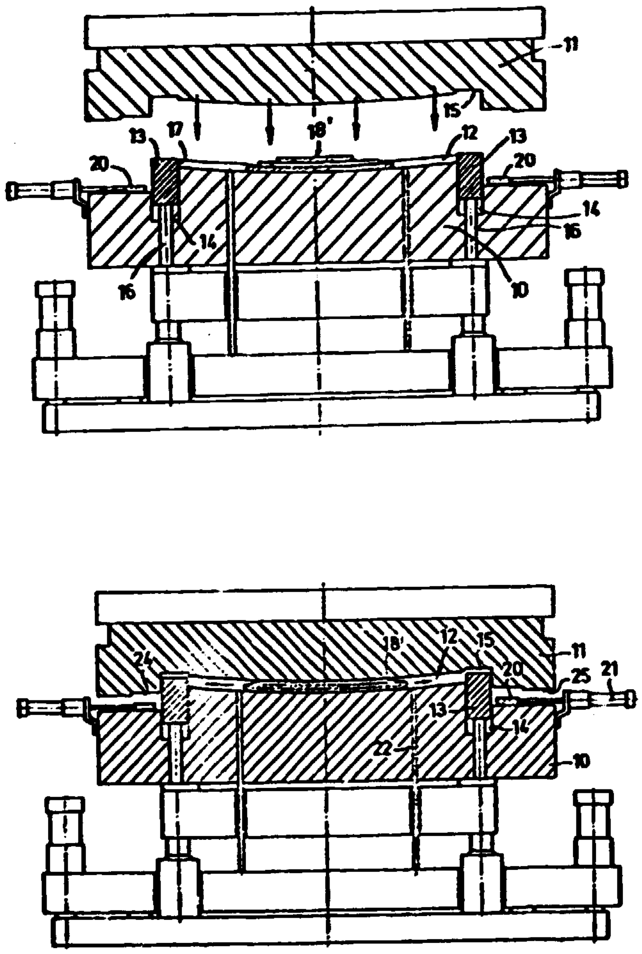


Fig. 8: Compression moulding (SMC)

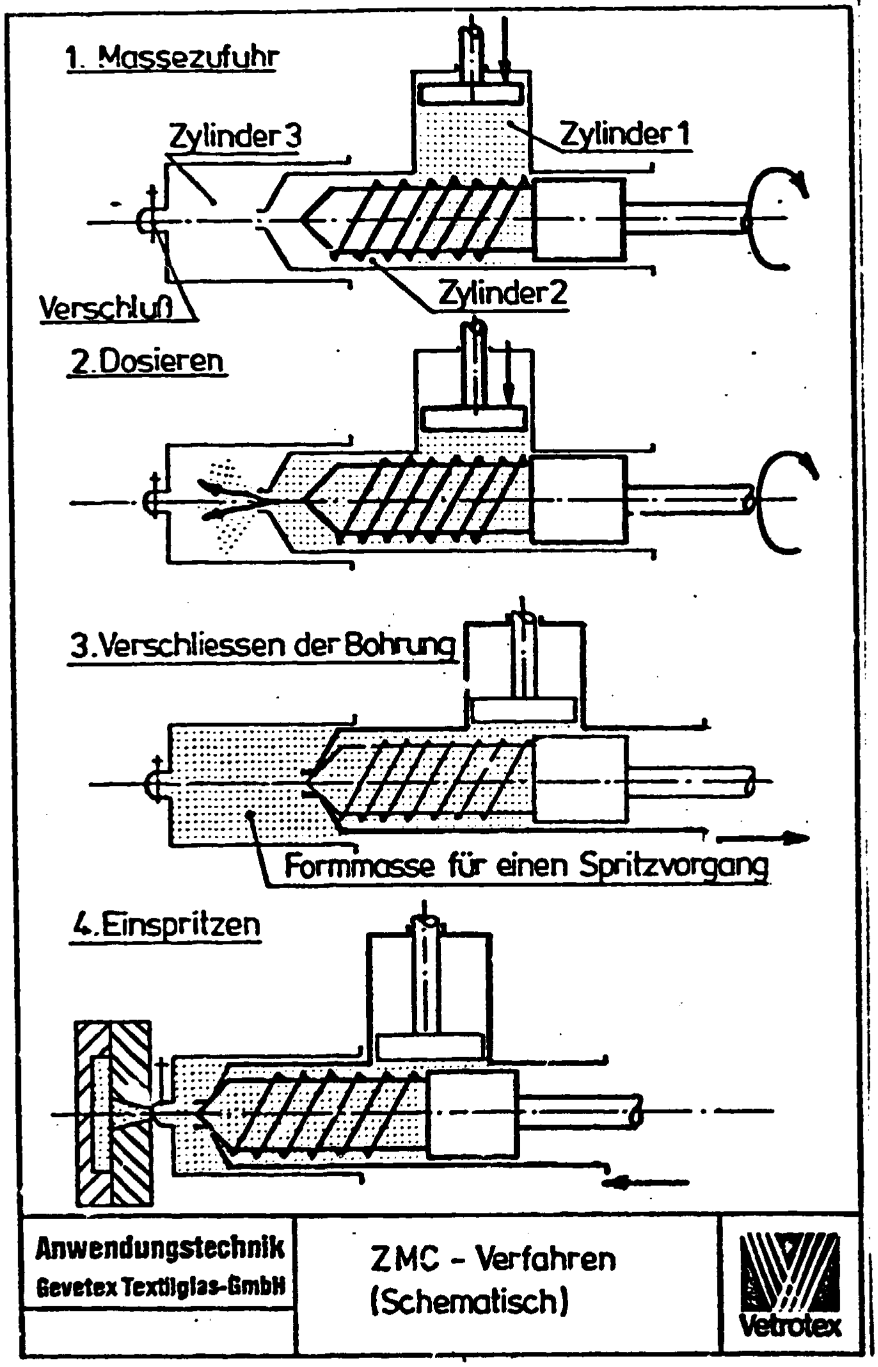


Fig. 9: Injection moulding (ZMC)

4. Applications

Future usages of composites are induced by

- basic production factors (energy, connmodities, costs)
- special demands (growthrate, technological changes, hierarchy of social value of goods),
- industrial and govermental regulations (product safety, environmental protection).

Sectors, where composite materials find very wide utilisation, are

- Aerospace (commerical and millitary)
- Automobiles
- mechanical engineering and industrial equipment
- transportation industry (rail-road)
- ships and boats
- oil/gas industry
- construction
- sports equipment

4.1 Large Panels / Claddings Including Thermal Insulation

Raw material: Sandwich panels will consist of GRP-skins and rigid polyurethan-foam (PUR) as core material.

Design: Design depends on technical demands like thermal stability, chemical resistance, size. Procedures are well established.

Manufacturing/Manpower: There exists some simple techniques for manufacturing the GRP-skins (hand lay-up, continuous laminating). The core material may be used as rigid foam block and bonded with the skin laminates. An other possible method is foam-filling by expansion.
Manpower requirements will be in a rather semi-skilled category.

Energy/Infrastructure: Most composite manufacturing techniques are low energy consuming and do not require large factories to be profitable.

Application: These sandwich-panels could be used in construction industry as well as in mechanical engineering.

4.2. GRP Leaf-Springs

Raw material: According to working loads there must be used unidirectional reinforced fibers, regarding the costs exclusively E-glass-fibers. Polymeric matrices will be epoxy-based.

Design: It is well-established in industrialised countries and easy transferable.

Manufacturing/Manpower: The manufacturing process is a modification of pultrusion. For this production a few skilled and some semi-skilled labourers are required.

Energy/Infrastructure: Requirements are relatively low (electric power, water, pressure air).

Application: Almost every motor-car manufacturer investigates the potential substitution of metal leaf-springs by light-weight composite springs.

4.3. Mass Production of Hoods, Flaps, Lids by Injection Moulding

Raw material: Plastic component is of thermosetting type, specially favoured unsaturated polyester (UP). Reinforcement material is short-fiber material (glass, aramid, carbon).

Manufacturing: Background is the mass production technology of injection moulding of thermoplastics, further developments has been started the last decade to process fiber-reinforced thermosetting materials.

Application: This manufacturing technique allows to realise the entrance of composites in mass production industries (e.g. motor-car industry).
Typical examples are presented in Fig. 10, 11, 12.

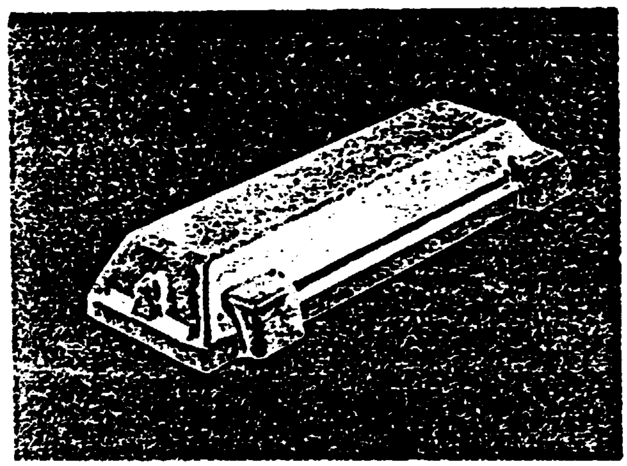
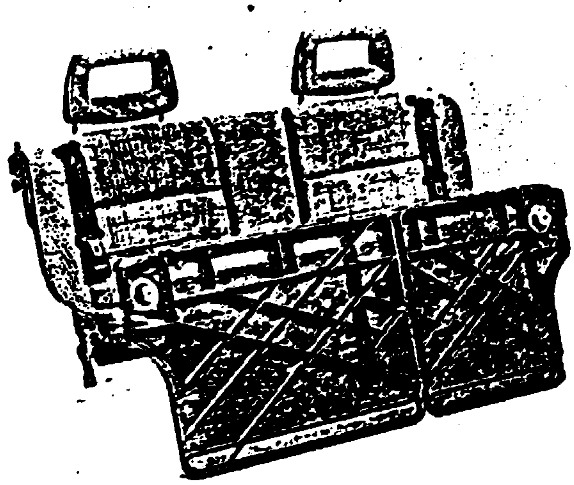
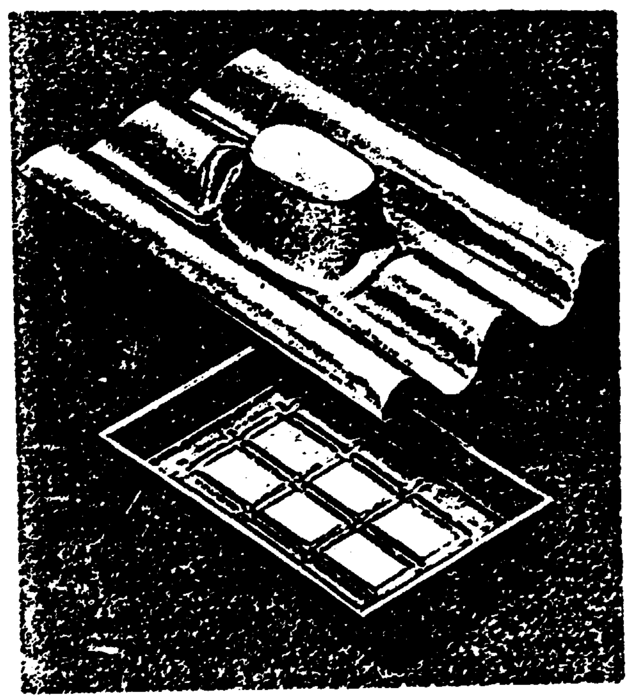


Fig. 10, 11, 12: Examples





4.4. Mass Production of Hoods, Flaps, Lids by Compression Moulding of Glass-fiber Reinforced Thermoplastics (GMT)

Raw material: GMT-semi-finished products are panels or sheets of polypropylen or polyamid reinforced with long glass-fibers and also continuous filaments.

Manufacturing: The schematic process is presented in Fig. 13. He includes applying the precut blanks, heating the material while passing an oven and moulding the article in a following press.

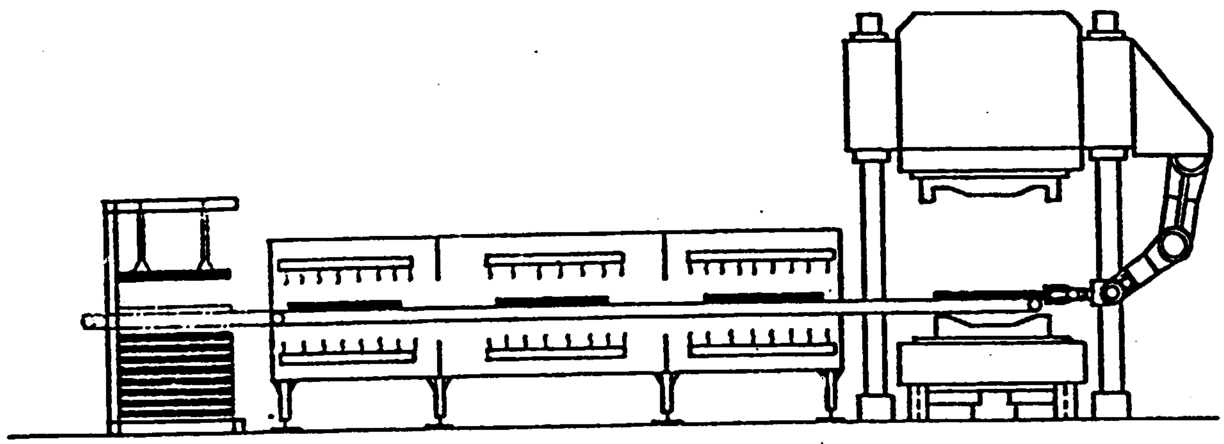


Fig. 13

Application: With this technique finished articles with good properties concerning strength, stiffness, weight, corrosion resistance can be produced to a price competitive to cenventional metallic structures for automotive industry, mechanical engineering, etc.

4.5. Large-Size Flat-Shaped Structures Manufactured of Radiation Curing (UV)

Raw material: Semi-finished product is a prepreg of unsaturated polyester with random oriented short fibers.
It is covered on both sides with an transparent polyethylen-film, which works as a release film.

Design: The rules are exact the same as for vakuum deep drawing of thermoplastics (Fig. 14)

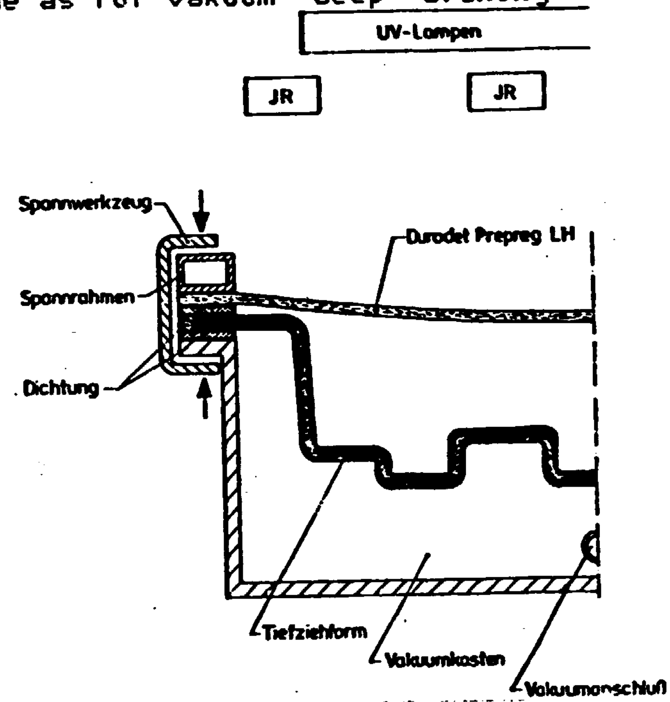


Fig. 14

Manufacturing/Manpower: The deep drawing process of thermoplastics is relatively simple and should be readily introduced in developing countries.
Radiation curing with UV using thermosetting material is an additional technological step.
Manpower requirements will be in the semi-skilled category.

Energy: Energy costs are negligible compared with materials costs and costs of manpower.

Utilisation: Finished products should be maintenance-free, and will find, according to their physical properties, utilisation in a wide variety of industries.

5. Position of Developing Countries

All in the previous chapter presented technologies are state-of-the-art in industrialised countries.

It will be of interest for developing countries considering their cost-effectively solving basic needs and the duty, to redyce the technological lead of industrialised countries.

The following industries could be engaged with this advanced material and manufacturing technologies:

- potential raw material producers (chemical industry)
- metal industry
- building industry
- equipment manufactures
- petrochemical industry
- users and processing industries
- transportation industries (road, rail, air, water).

Use of composite materials must be justified on an economic basis. This means, the use of composites should lead to more easily manufactured and cheaper end-products or reduce life-cycle costs or should result in higher technical performance for some critical components.

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POTENTIAL APPLICATIONS OF COMPOSITE MATERIALS AND ASSOCIATED TECHNOLOGY IN DEVELOPING COUNTRYS

for

UNIDO

Background Paper

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I n h a l t s v e r z e i c h n i s

PREFACE

Composites are modern materials, which consists at least of two components, a reinforcement material and a matrix-system. The selection of materials from a wide variety of basic elements, the design and calculation as well as the fabrication techniques give as a result a product with specific properties.
For potential application in developing countries there are the following reasons:

- energy savings by suitable choice of materials and fabrication technique
- many composite structure fabrication processes are labour intensive
- the componentes of composites are rather simple basic materials, which can be produced in developing countries (fibers, resins, mineralic fillers)
- the manufacturing technology and design procedures are state of the art
- by improvement of properties (optimisation of materials and structures) also with reference to durability higher manufacturing cost are acceptable
- in many cases products made of composites can be fabricated on-site thereby removing reliance on imports and eliminating transport costs.

A) COMPOSITES MATERIAL TECHNOLOGY

1. Composite Materials

The entirety of raw materials can be classified in three groups:
- metals
- organic, macromolecular or polymeric materials (thermoplastics,thermoset plastics and elastomers)
- inorganic materials (glass, ceramic and refractoric materials).

Each of these groups has their own specific properties
- metals are tough, strength, commonly insufficient stiff, heavy
- macromolecular bulk plastics are light-weight, easy of processing, but not strong and not stable to heat
- inorganic materials are hard, stiff, but also brittle.

By combination of uniform substances, a matrix on the one side and the reinforcement material on the other side, which will belong to different of above-mentioned groups, composites will be formed.
These can be ligth-weight as well as stiff and strong.
Typical composites are
- fiber reinforced plastics
- fiber reinforced inorganic materials
- fiber reinforced metals
- prestressed concrete
- coated metals and plastics.

For technical use including economic aspects mainly fiber reinforced plastics (FRP) are important.
Using specific manufacturing techniques the fiber orientations can be adapted to loads and stresses.
For developing countries composites are interesting from the points of view of their
- fabrication potential
- application potential
- production potential from indigenous raw materials
- profiting to the maximum of progress made in high technology sectors.

The (physical) properties of composites depend on physical properties of the single components and the volume fractions of the fiber and matrix in the composite structure.
Normally the properties of the reinforcement material (modulus, strength, coefficient of thermal expansion, long term strength) are much more better than those of matrix material.
However the properties of the composite depend on the interface between fiber and matrix.
In order to be applied in real stressed situations, the composite material must be produced with properties either isotropic or engineered to satisfy the imposed stress conditions. The solutions available are (Fig. 1):
- multilayer laminates made of a stack of unidirectional laminates or fabrics bonded together and correctly orientated to provide isotropic properties
- randomly oriented fibers in the matrix.

In both cases the caracteristics of the material are lower than those of a pure unidirectional laminate but may nevertheless be tailored to satisfy a multitude of stress situations. An example is shown in Fig. 2.

Fig. 1

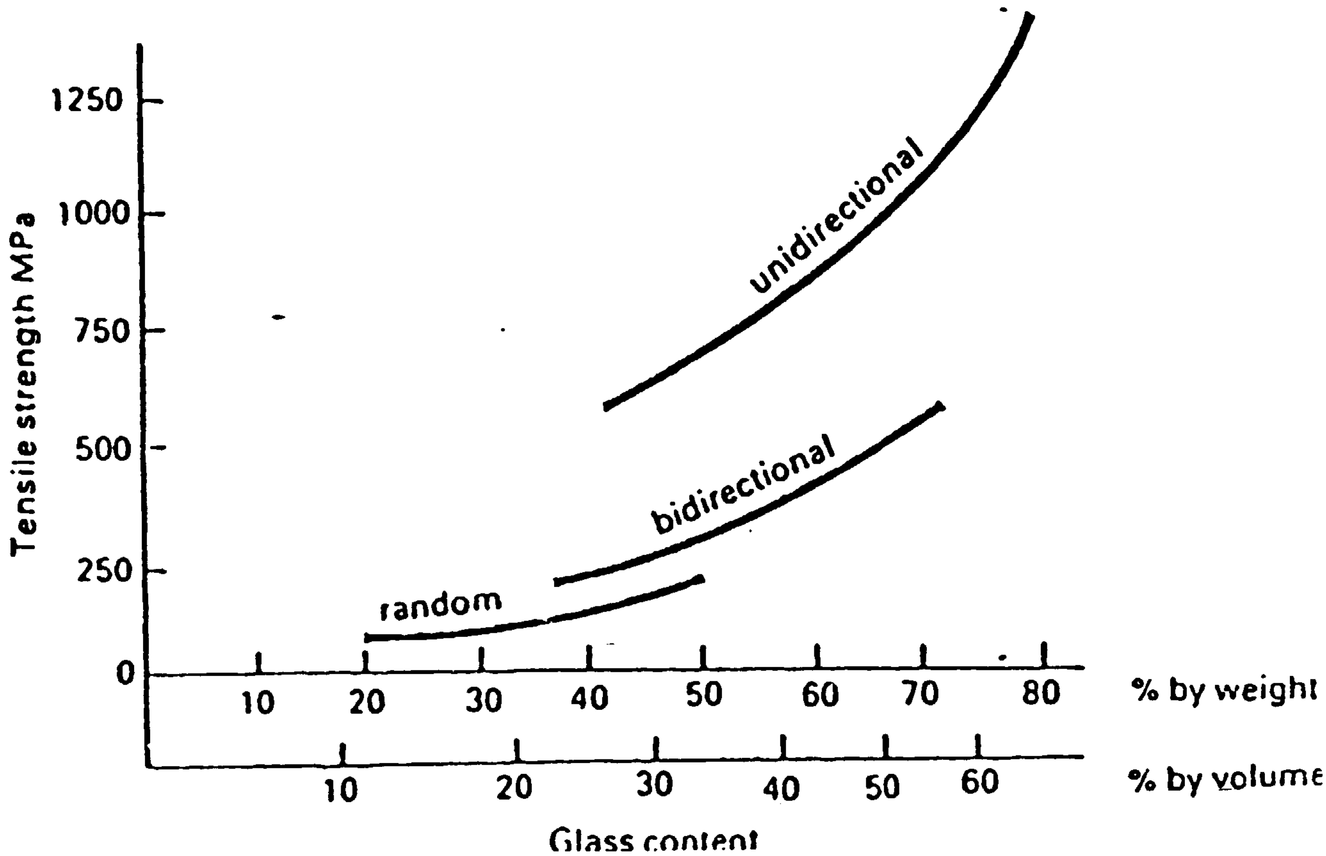

Fig. 1 Effect of glass content and orientation on the tensile strength of GRP laminates

Fig. 2

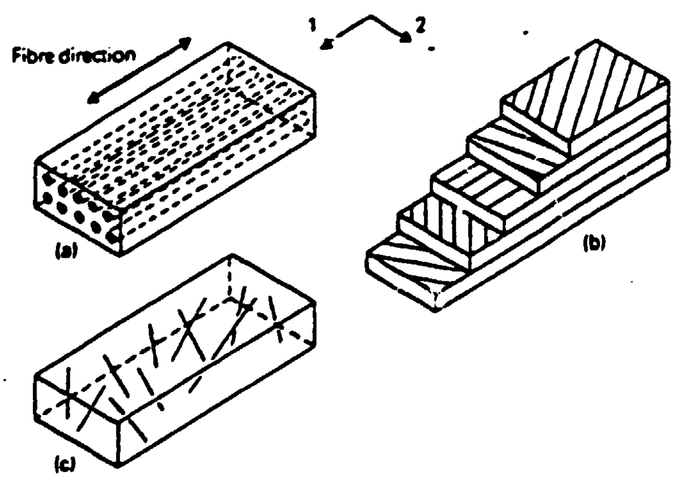

Fig. 2 Schematic representation of

a) unidirectional laminate
b) multilayer laminate
c) randomly criented short-fiber material

In the present paper the general discussion of design, fabrication and properties will be limited to technical and economic relevant matrix-systems and fiber materials which are presented in the following (Fig. 3):

Fibers \ Matrices	Epoxi	Polyimid	Polyest.	Thermopl.	Alu
Glass	X		X	X	
Carbon	X	X		X	X
Aramid	X	X	X	X	

Fig. 3 Fiber-Matrix combinations

Inorganic matrix composites will be specifically dealt with in the presentation of examples in Part B (Potential Applications in Developing Countries).

2. Current Technology

2.1. Classes of Fiber Reinforced Materials

The definition of reinforcement given in Chapter 1 applies to a wide variety of combinations of materials.
Laminates provide the highest strengths and stiffnesses and are fabricated from high strength, continuous filaments in polymeric matrices.
Typical properties of fibers are given in Fig. 4.

Fiber	Diameter μm	Tensile Strength GPA	Tensile Modulus GPA	Density g/cm^3	Price 1985 $/kg
Carbon high strength	7	2.9	220	1.74	40
Carbon high modulus	7	2.4	380-500	1.81	60-120
Aramid (KEVLAR 49)	12	2.9	130	1.45	35
Glass (S or R)	9	3.6-4.5	85	2.55	5-22
Glass (E)	5-14	2.6	70	2.59	1-1

Fig. 4 Physical Properties of Fibers

Matrices may be chosen from an almost infini.. ariety of polymers but the most commonly used for laminates are epoxy, polyester, phenolic, all of them thermosetting (i. e. materials that cure upon heating and the process is irreversible).
Typical properties of epoxy-matrix composites are given in Fig. 5. Short fiber composites may have polymer (thermoset and thermoplastic) matrices with chopped fibers, these being any of those given in Fig. 4 or natural fibers such as asbestos, jute, sisal, etc. which have interesting reinforcing properties.
The effect of different forms of glass fiber reinforcement on the properties of polyester composites is illustrated in Fig. 6.

		E-Glass	S-Glass	Aramid KEVLAR 49	Carbon T 300	Carbon HMS
Fiber Volume	%	60	60	60	60	62
Density	g/cm^3	2.10	2.10	1.30	1.50	1.55
Tensile Strength	MPA	1240	1620	1700	1750	1300
Tensile Modulus	GPA	40	60	75	135	230
Flexur. Strength	MPA	1380	1860	620	2060	970
Flex. Modulus	GPA	48	50	70	150	170
Compr. Strength	MPA	900	1000	280	1800	700
Interl. Shear	MPA	60	95	60	110	50

Fig. 5: Room Temperature Properties of Commercial Unidirectional Epoxy-Laminates

		Chopped Strand Mat	Satin Weave Cloth	Continuous Rovings
Glass Contend	% weight % volume	30 18	55 38	70 54
Density	g/cm^3	1.4	1.7	1.9
Tensile Strength	MPA	100	350	1000
Tensile Modulus	GPA	10	18	40
Compr. Strength	MPA	150	280	800
Flexur. Strength	MPA	150	500	1100
Flexur. Modulus	GPA	7	20	45

Fig. 6: Typical Physical Prooerties of GRP with Different Types of Glass-Reinforcement

A variation on the laminate structure, which also provides high strength isotropic properties without complex layer lamination, is obtained by the use of woven fabrics of either one fiber or a mixture (hybrids).
The technology associated with such raw material is very cost effective.
Although, in theory any mixture of materials may be made, the actual useful combinations are determined by

- properties obtainable
- fabrication possibilities
- costs.

In general terms, composite materials are divided into conventional and advanced.
The economical and technical relevant advanced composites cover all polymeric matrices containing advanced fibers such as glass, carbon and aramid.
The present major utilisation sector is aerospace with increasing incursions into sports goods and large R & D efforts on their application to transportation and general engineering.
Fig. 7 presents a short comparison of the major attributes and limitations of the advanced fibers.

Type	Major positive Attributes	Major Limitations
Aramid	highest specific strength high impact strength	poor compress. strength fiber difficult to cut
Carbon (PAN)	lowest coefficient of thermal expansion electrical conductor	brittle fiber relatively poor impact strength electrical conductor
Carbon (PITCH)	low cost	low tensile strength

Fig. 7: Comparison of Major Attributes of Currently Available Fibers

Conventional composites cover polymeric matrices containing glass fibers, the most common example of which is

- glass fiber reinforced polyester for pipes and sports goods.

They have been utilised for many years in everyday applications but the thrusts in aerospace have led to their improvement through utilisation of design and fabrication technology developed for the advanced composites.
The background knowledge is considerable, as evidenced by the multitude of references and conferences, examples of which are cited in references (Appendix).

2.2. Advantages and Limitations of Composites

Composite materials are in general employed where there can be advantages of

- stiffness and/or strength, either in absolute terms or on a spezific basis (i. e. stiffness per unit of weight), as in aerospace
- weight savings: as in land transport and automobiles in particular
- longer, maintenance-free utilisation
- corrosion, fatigue, impact
- cost savings either on an initial investment basis or an overall life-cycle cost basis.

Convential composites such as glass fiber reinforced polyester are finding increasing applications due to the above advantages.

Advanced composites, mainly chosen in aerospace for increased stiffness reasons, can only be introduced in the industrial sector on the basis of cost effectiveness. The direct material cost comparison with conventional materials as invariably unfevourable.

This cost effectiveness can be obtained through performance advantages, reduced manufacturing costs or by a combination of the two. In terms of performance, advanced composites may lead to more efficient operation (e. g. higher stresses), lower maintenance and longer operating life. Also, direct moulding of complex structures (e. g. helicopter rotor blades) reduces the number of (metallic) components and eliminate expensive machining.

Limitations on composite usage remain:

- prediction of properties; although 'simple' rules exist for small samples, the reproduction in larger production units is problematic and leads to sometimes severe penalties in the way of security factors which lead to heavier, costlier structures
- control of the quality of the basic components and of the structure that is produced, especially for critical, highly stressed structures such as in aerospace or general engineering (pipes, tanks, ...)
- engineering design specifically developed for composites; this problem applies more to general engineering than aerospace where complex solutions can be, and often are, amployed.
- education in composites at all levels of design, fabrication and utilisation

2.3. Design

The important design aspects of composite materials are a function of the end utilisation.
For composites in highly stressed structures such as pipes and tanks, continuous fibers in laminate or fabric form are invariably utilised.
Design procedures are relatively well-established.
The effectiveness of the design depends to a large extent on the fabrication technique and its control. Optimum utilisation of the reinforcing effect of the high performance fibers is obtained through

- control of the interface
- orientation and proportion of the fibers in the principle stress directions.

For random (short) fiber composites the major design criteria are:

- the homogeneous distribution of the fibers
- the fiber content
- the fiber length.

The effectiveness of the reinforcing process is mainly controlled by the fabrication process as well as by design choice.

2.4. Fabrication Techniques

Polymer matrix composite fabrication depends on the form of the product, its dimensions, number, etc.
The major techniques are summarised in Fig. 8 and illustrated in Fig. 9.

Typical mechanical properties of E-glass fiber reinforced polyester resin structures produced by the different techniques are given in Fig. 10.
A wide variety of properties are obtainable, the highest coming from those techniques where continuous filaments are employed under some form of pressure moulding.

The main advantages / disadvantages of the most wide-spread techniques are as follows:

Contact moulding: the fibers in the form of a pre-cut fabric or mat are placed in a mould and impregnated with resin which cures at relatively low temperatures. The advantages are simplicity of the moulds, low temperature and flexibility. Disadvantages include its limitation to relatively low quality products and the wide-spread use of hand lay-up which may be rather expensive and does not ensure reproducible quality. Mechanised lay-up can increase productivity for large series where the capital investment expense can be justified.

Compression moulding: The fibers are normally introduced in the mould in the form of a prepreg (fiber material, preimpregnated with epoxy or polyester resin) or SMC (sheet moulding compound, chopped strand mat impregnated with polyester resin) and compressed at up to 200 C to cure the resin and consolidate the part. Advantages are mainly that the properties are good and reproducible. However, the tooling is expensive.

Autoclave moulding: Prepregs are draped in a mould in the desired orientations, the whole covered with a bag and placed in an autoclave for the curing process (typically 200 C at 15 bars). Complex and large structures may be manufactured with rather cheap tooling but the process is labour-intensive und limited to small series. It is widely used in the aerespace industry. The process is slow, operating energy costs are very high.

Continuous sheet moulding: The reinforcement, almost uniquely glass in the form of chopped strand mat or cloth, is unwound continuously, impregnated with resin (polyester or epoxy) and passed through rollers and a curing oven. The process is interesting for panels that do not have to withstand high stress.

Filament winding: The technique is used to produce pipes, tanks and spheres. The fibers may be in the form of rovings or prepregs.
Various processes are available and will be discussed in Part B.

Pultrusion: The fibers are continuously impregnated with resin and pulled through a heated die during which excess resin is removed, the cross-sectional shape of the part determined and the composite cured. Continuous fiber and fabric reinforced products may be made mainly with polyester matrices. Pultrusion, for the production of low-cost composite profiles, is well-established and provides high quality, high performance materials in a wide variety of cross-sectional shapes: tubes, profiles, rods, etc.

Reinforced reaction injection moulding (RRIM): This is a technique of increasing application in the rapid production of glass-filled elastomeric polyurethane thin wall automobile components such as bumpers and bonnets. The process consists of pumping separate streams of the polymer components (incorporating chopped fibers) into a heated, matched-metal mould and polymerising in-situ rapid (less than 30 seconds), which is essential in order to obtain an economic product.

Process	Contact moulding		
	Hand lay-up	Spray lay-up	Vacuum bag/pressure bag
Resin system	Liquid – polyester, epoxy, furane	Liquid – polyester, epoxy	Liquid – polyester, epoxy Prepreg – epoxy SMC – polyester
Reinforcements	Glass, carbon, other	Glass	Glass, carbon, other
Fibre content, glass (% by wt)	25–35	25–35	25–60
Normal laminate thickness (mm)	2–25, generally 2–10	2–25, generally 2–10	2–6
Typical cure temperature (°C)	Ambient to about 40	Ambient to about 40	Ambient to 50 for liquid resins, 80–160 for SMC and prepreg
Type of mould needed	Single – GRP, wood, etc	Single – GRP, wood, etc.	Single – GRP, epoxy or metal
Moulding size limitation	In principle – none	In principle – none	Capacity of vacuum equipment or compressor, capacity of autoclave
Moulded in – ribs	Yes	Yes	Yes
– inserts for fixing	Yes	Yes	Generally no
– foam panels	Yes	Yes	Generally no
Equipment needed	Rollers and brushes	Spray and chopper gun, rollers	Hand/spray lay-up, automatic tape laying machine, autoclave/vacuum pump/compressor
Number of mouldings to justify mould cost	From one upwards	From one upwards	From one upwards
Production rate	Low	Low	Low
Labour content	High	High	High
Quality of moulding	Dependent on operator, one smooth surface	More dependent on operator, one smooth surface	Two smooth surfaces
Typical products	Boats, building panels, general	Boats, building panels, general	Aircraft sections, various panels, general

Process	Transfer moulding	Injection moulding	Filament winding	Centrifugal moulding
Resin system	DMC – polyester, epoxy, other resins	DMC – polyester, epoxy, other resins	Liquid – polyester, epoxy Prepreg – epoxy	Liquid – polyester, epoxy
Reinforcements	Glass, carbon, others	Glass, carbon, others	Glass, carbon, other continuous fibres	Glass
Fibre content, glass (% by wt)	10–65	10–65	60–80	25–40
Normal laminate thickness (mm)	1–6	1–6	2–25	2–25
Typical cure temperature (°C)	155–170	Polyester 135–185, epoxy 160–220	Ambient to 170	Ambient to 50
Type of mould needed	Metal	Metal	Steel, plaster, etc.	Steel
Moulding size limitation	Machine capacity	Machine capacity	Machine size, generally 6 m diameter, 6 m long	Machine size, generally 6 m diameter
Moulded in – ribs	Yes	Yes	Externally, yes	No
– inserts for fixing	Yes	Yes	No	No
– foam panels	No	No	Yes	No
Equipment needed	Transfer moulding press	Injection moulding machine	Filament winding machine	Centrifugal moulding machine
Number of mouldings to justify mould cost	Over 1000	Over 1000	From one upwards	100 upwards
Production rate	High	Very high	Moderate	Moderate
Labour content	Low	Low	Medium	Low
Quality of moulding	Good, all smooth faces	Good, all smooth faces	Good, inside smooth	Good, both surfaces smooth
Typical products	Small-to-medium sized components	Small-to-medium sized components	Tanks, pipes and tubes	Pipes and tubes

Fig. 8: Summary of moulding processes

Process	Foam reservoir moulding	Resin injection/ resin transfer moulding	Vacuum impregnation	Compression moulding	
				Cold press	Hot press
Resin system	Liquid–epoxy, polyester	Liquid–polyester, epoxy	Liquid–epoxy, polyester	Liquid–polyester, epoxy	Liquid, prepreg, SMC/DMC–polyester
Reinforcements	Glass mat/open cell foam	Continuous strand mat	Glass, carbon, other	Glass, carbon, other	
Fibre content, glass (% by wt)	Variable	25–30	25–50	25–50	25–70
Normal laminate thickness (mm)	2 upwards	2–6	2–10	1–10	1–10
Typical cure temperature (°C)	Ambient to about 50	Ambient to about 50	Ambient to about 150	40–50	100–170
Type of mould needed	Double GRP or light metal	Double GRP or light metal	Matched metal, GRP	Double GRP, metal	Matched metal
Moulding size limitation	Mould dimensions	Mould dimensions	Mould dimensions	Press size	Press size
Moulded in					
–ribs	Yes	Yes	Yes	Yes	Yes
–inserts for fixing	Generally no	Generally no	Generally no	Yes	Yes
–foam panels	Yes	Yes	Yes	Generally no	No
Equipment needed	Hand equipment	Resin injection pump	Vacuum pump	Hydraulic press	Heated press
Number of mouldings to justify mould cost	From one upwards	Generally 100–1000	Generally 100	100–1000	1000 upwards
Production rate	Moderate	Moderate	Low	High	High
Labour content	Moderate to high	Moderate	Moderate	Low	Low
Quality of moulding	Good, two smooth surfaces	Good, two smooth surfaces	Good, two smooth surfaces	Good	Excellent
				All surfaces smooth	
Typical products	Automotive, furniture, various	Boats, various	Radomes, aircraft nose cones, various	Automotive, industrial, electrical	

Process	Continuous sheet moulding	Pultrusion
Resin system	Liquid–polyester, epoxy	Liquid–polyester, epoxy Prepreg–epoxy
Reinforcements	Glass	Glass, carbon, aramid
Fibre content, glass (% by wt)	25–35	60–75
Normal laminate thickness (mm)	2–6	600 x 250
Typical cure temperature (°C)	50–120	100–160
Type of mould needed	Metal rollers or sheet	Hardened steel die
Moulding size limitation	Width of machine	600 x 250 mm, die dimensions
Moulded in–ribs	No	Variety of cross-sections
–inserts for fixing	No	No
–foam panels	No	No
Equipment needed	Sheet moulding machine	Pultrusion machine
Number of mouldings to justify mould cost	Continuous output	Continuous output
Production rate	Up to 12 m/min	Up to 1 m/min
Labour content	Low	Low
Quality of moulding	Good	Good
Typical products	Roofing lights, etc.	Variety of cross-sections, rods, tubes, etc.

Fig. 8: Summary of moulding processes (continued)

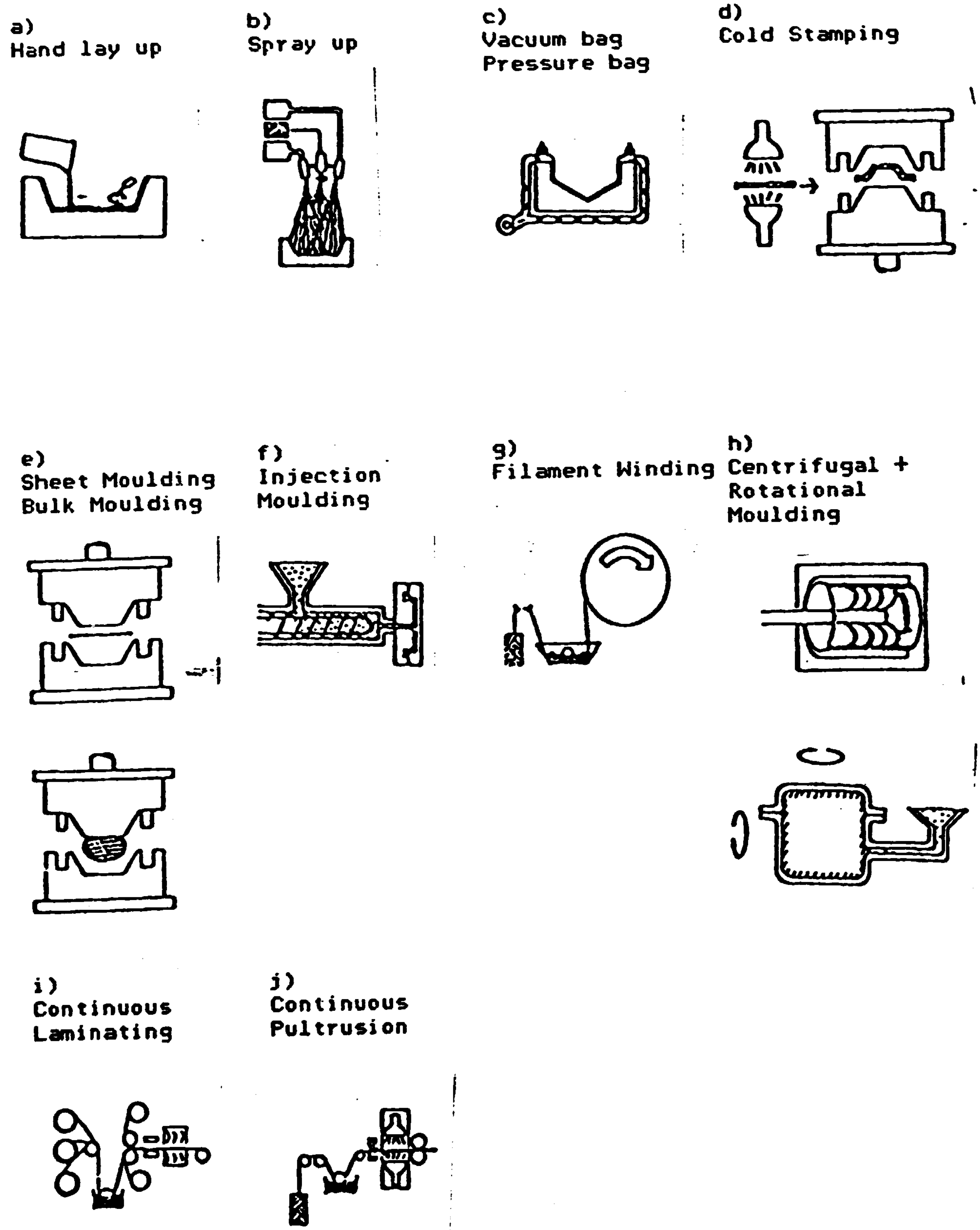

Fig. 9. Basic fabrication processes for fibre reinforced plastics

Moulding Process	Reinforcement	Tensile Strength MPa	Flexural Strength MPa	Elastic Modulus GPa
Contact Moulding	Chopped strand mat	60 - 150	80 - 120	5 - 7
	Glass woven fabric	150 - 250	120 - 180	8 - 11
Vacuum bag Moulding	Chopped strand mat	80 - 100	90 - 150	6 - 8
	Glass woven fabric	150 - 250	150 - 200	9 - 12
Compress. Moulding	Woven fabric	150 - 250	200 - 400	15 - 25
Centrifu-gation	Chopped stand mat	80 - 120	90 - 150	7 - 9
Filament Winding	Roving	600 - 1500	1000	25 - 60

Fig. 10: Mechanical Properties of Glass Reinforced Polyesters made by different Techniques

2.5. Properties

A wide variety of properties may be obtained with composite materials. It is impossible to discuss without reference to specific systems and applications, as wil be done in Part B. Nevertheless, in general terms, conventional composites exhibit very interesting strength characteristics at reasonable cost due to the relatively low cost of glassfibers and the possibility to employ rather simple fabrication techniques without strict control measures.

Stiffness is, however, not very high but may be improved by optimised design or by the addition of a limited amount of a stiffer, advanced fiber such as carbon or aramid.

The resulting improvement is illustrated in Fig. 11 while Fig. 12 illustrates the various types of hybrids that can be produced. Advanced composites possess exceptional stiffness characteristics as illustrated in Fig. 13, and even more so on a specific basis as seen in Fig. 14.

Warp Construction	V_f carbon at 60% total fibre content	Flexural strength MPa	Flexural modulus GPa	Interlaminar shear strength MPa	Tensile strength MPa	Tensile modulus GPa
All-glass	0.0	844	34.6	40	780	39.9
4:1	0.13	773	46.9	43	660	56.0
3:1	0.16	843	50.6	42	686	60.2
2:1	0.21	943	59.0	43	715	65.2
1:1	0.31	953	69.3	40	749	74.6
All-carbon	0.6	1240	101.2	38	1132	115.1

Fig. 11: Mechanical properties of glass-carbon-hybrids

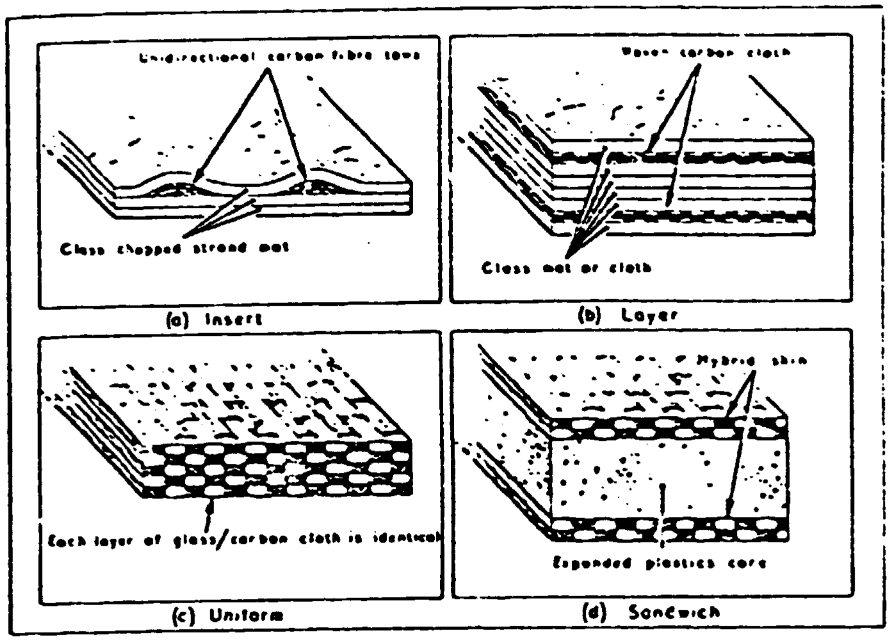

Fig. 12: Classification of Hybrids

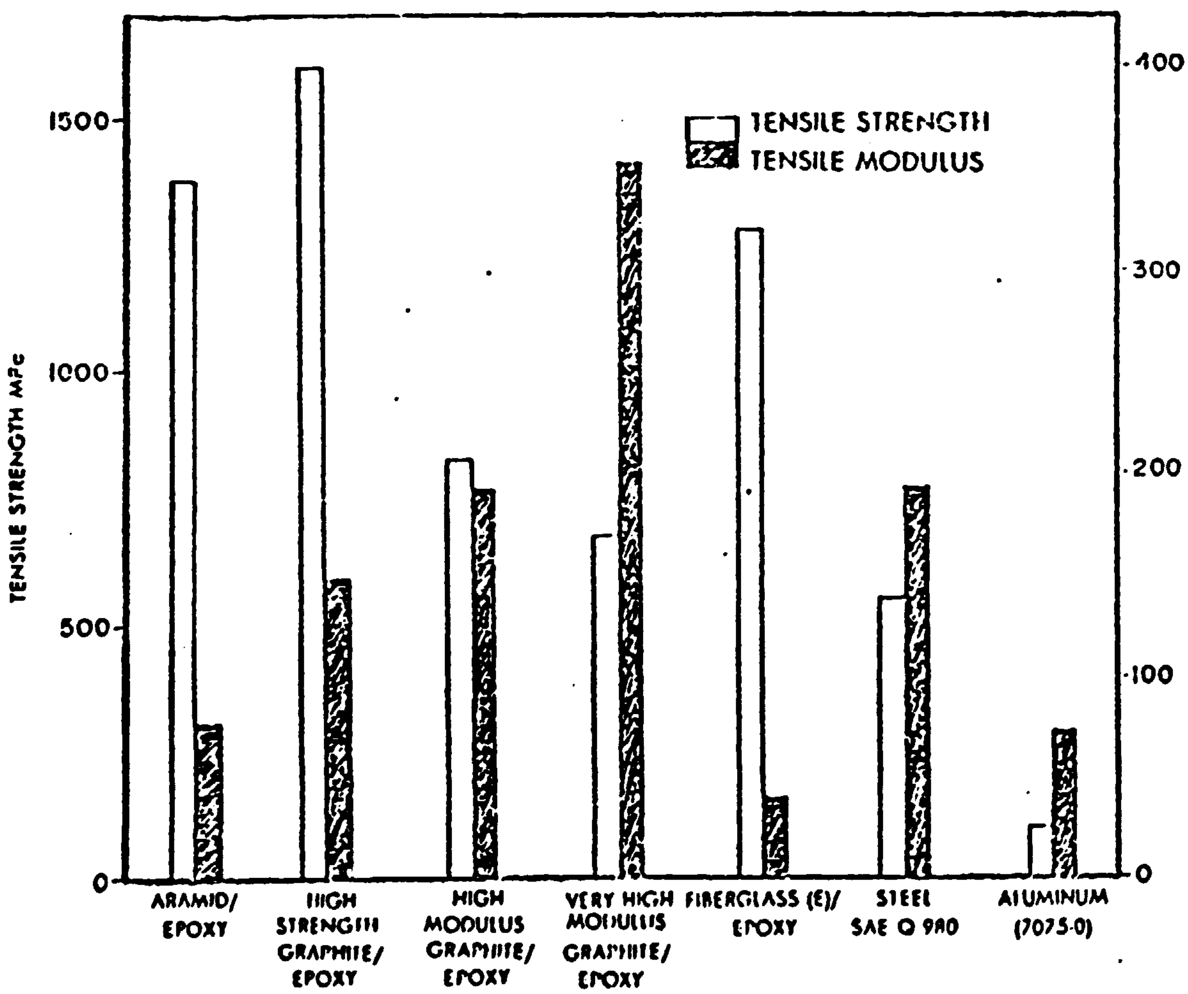

Fig. 13: Tensile Properties of Composites

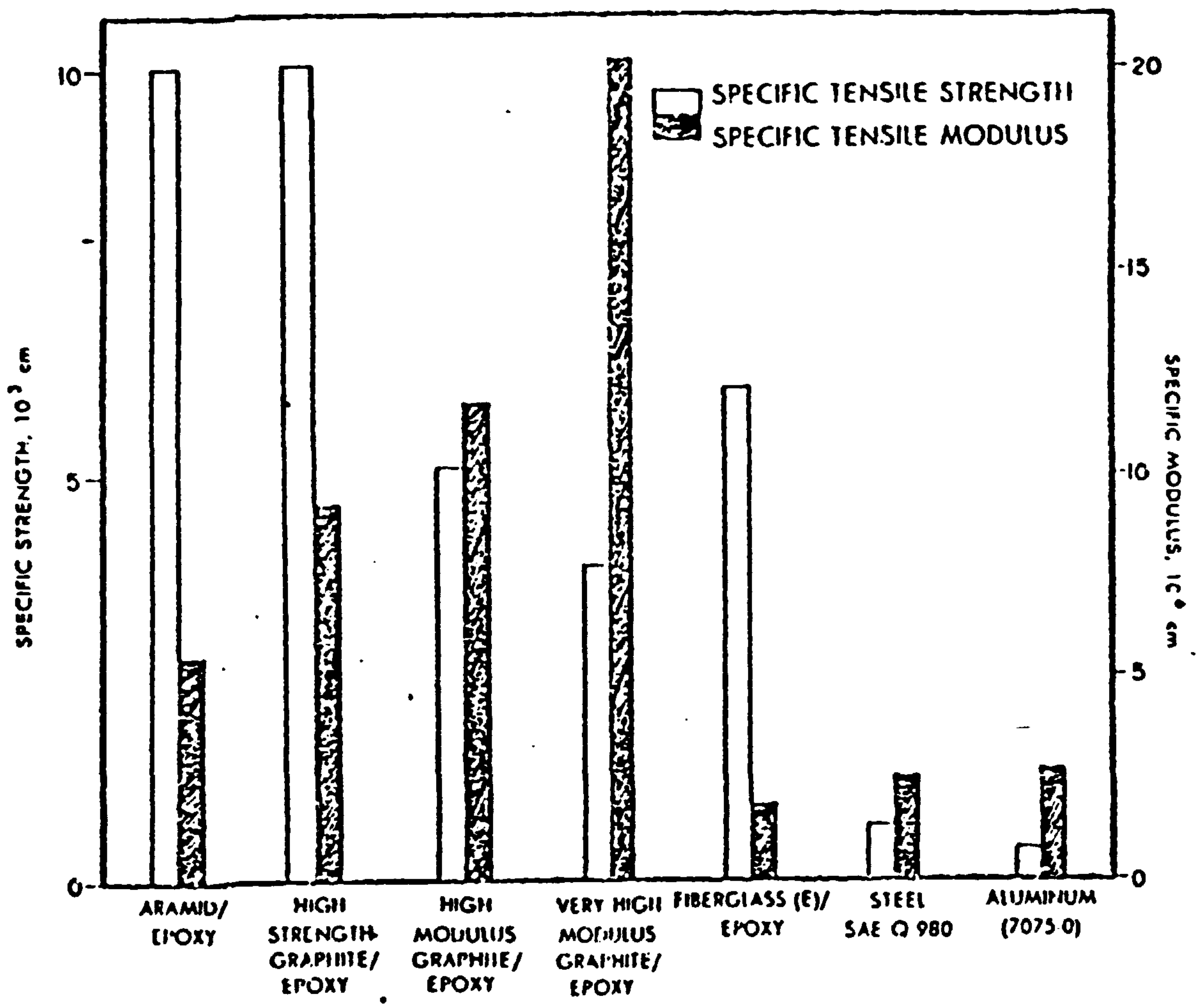

Fig. 14: Specific Tensile Properties of Composites

2.6. Sectors of Application

Composite materials find very wide utilisation in a variety of industries.
The major fibers used in advanced composites are carbon and aramid.
The 1982 carbon fiber world market has been around 1 000 tons, a growth of 10 % p. a. is forecast until 1990. 50% are used in aerospace, another 25 % in sports goods and 25 % in miscelleanaous applications.
Aramid fibers, of which KEVLAR is the best known, are aof various types and a total of 7 000 tons are used annually in the USA.

Military Aircraft	Composite Material	Weight/ Aircraft	% Weight of Aircraft Total
Empennage fin covers	carbon/epoxy	82 kg	2.5
Wing skins, surfaces, landing gear door, etc.	carbon/epoxy	500 kg	9.5

Helicopters

Rotor blades	glass/epoxy or aramid/epoxy	

Space Shuttle		Weight Savings Compared with Al-Alloys
Payload doors maneuvering pods	carbon/epoxy	620 kg
Thrust structure	boron/epoxy	410 kg
Pressure vessels	aramid/epoxy	290 kg

Wind Mills

Blades made of glass-, carbon- and aramid-epoxy an hybrids

Sports Equipment

tennis rackets, fishing rods, skis, canoes

Commercial and military boats

glass-epoxy and hybrids

Commercial Aircraft

In the last 5 years advanced composites are finding increasing utilisation in commercial aircraft.
The Lear Fan will be "all plastic" including much carbon or carbon/aramid, which leads to a 30 - 40 % weight saving over conventional construction.
The Boeing 767 uses around 3 tons of composites (3 % of total structural weight), the Airbus family (A300, A310, A320) will similarly use large quantities of composites in rudders, vertical fins, ailerons, horizontal tail, etc.

Automobiles

The driving force for utilisation of composites in automobile construction is weight savings, resulting energy and cost savings. Fig. 15 summarises the situation with respect to the FORD test car. When competed in 1979, the car contained some 220 kg of composites, the total weight savings was around 550 kg over the conventional steel version.
Specific articles apparently on the point of being introduced are leaf springs and lorry transmission drive shafts. Weights are around 25 % of equivalent steel parts.

	Weight in Steel kg	Weight in Composite kg
Body in-white	210	95
Frame	130	94
Front end	44	13
Hood	22	8
Deck lid	20	6
Bumpers	56	20
Wheels	42	22
Doors	70	28
Miscellaneous	32	16

Fig. 15: Comparison of the Weights of Conventional Parts and Composites Parts in the FORD Test Car

Mechanical Engineering

Given their high specific stiffnes and strength, carbon-epoxy composites are ideally suited for dynamic applications (e. g. robotics). Advantages include increasing speed and reduced noice.

Sporting activities

Gliders, yachts and airship gondola structures are using aramid and carbon fibers to achieve important weight savings and allowing rapid progress in performance.

The glass fiber reinforced plastics industry is already over 30 years old and has grown continuously to reach around 950 000 tons in 1981.
The major markets remain the industrialised nations of North America, Europe and Japan while 9.3 % or 88 000 tons are consumed in developing countries.
In the industrialised nations the structural reinforced plastics represent between 40 and 60 % of the total market.
The striking feature of recent years has been the enormous growth of usage in the Middle East mainly for water and sewage (i. e. corrosion resistance).
The utilisation in the other developing markets has also grown but at a much lower rate.
This lower growth and absolute utilisation has been put down to the fact that these countries have not the same material supply problems as the industrialised countries, so that substitution has not yet been necessary.

Reference to Part A

Only numbers 1, 2, 3, 4, 5, 7, 8, 11, 12, 14, 15, 16, 18, 19, 20, 24, 25 of the origine paper

B) POTENTIAL MANUFACTURE AND APPLICATIONS IN DEVELOPING COUNTRIES (SPECIFIC EXAMPLES)

For developing countries, the need will be to choose labour-intensive as well as modern technologies and fabrication techniques.
Materials development in general, and composites in particular, can, and already do, play a role in improving conditions.

1. Advanced Composite Materials in Energy Production and Energy Storage

1.1. Background

Advanced polymeric matrix composites containing glass, carbon and aramid fibers or mixtures of these (hybrids) represent the highest specific strengths and stiffnesses of all materials. They have been initially developed for use in aerospace, military and commercial aircraft and sports goods.
A wide variety of materials and structures exists, produced in the industrialised countries.
The advantages of increased properties will result higher costs of materials, manufacture and controll.

1.2. Stage of Development: Windmill Blades

An example of an advanced composite structure used in energy generation will serve the purpose of evaluating the potential of advanced composite production and utilisation in developing countries.
A windmill blade contains many of the features where composites are at an advantage.
It is interesting for the following reasons:

- light weight blades can rotate under low wind velocity (2 - 3 m/s) thus increasing its efficiency
- large blades can be made
- high fatigue resistance to withstand vibrations and strong winds
- corrosion resistance makes them applicable in coastal, high humidity regions and means that maintenance requirements are low.

Several projects are underway in Denmark, the Netherlands, USA and West Germany, where the largest blade is 25 m in length.

1.3. Potential Application in Developing Countries

<u>Raw material supply:</u> The highly stressed nature of the application implies the use of high quality components (epoxy resin and glass or glass/carbon hybrid reinforcement fiber).
Prepregs are a perfect raw material.
Until a local glass fiber production can be installed, all the raw material must be imported.

<u>Design:</u> The design procedures are established in industrialised countries and can be readily transferred. The outer skin of the blade is of composite with an inner core of rigid foam or honeycomb (Al or NOMEX).

Manufacture is by hand-lay up of prepregs in a mould. The core material is added, the top skin laid up in the same manner and the whole structure cured and consolidated (heated moulds, autoclave or vakuum bag).

Manpower requirements are of the rather skilled to semi-skilled variety for the lay-up. Developments are underway to mechanise the manufacturing thus decreasing the need for skilled labour while increasing productivity and structural reliabilty.

Energy and infrastructure requirements: Most composite manufacturing technologies are low energy consuming and do not require large factories to be profitable.

Quality control: In highly stressed components, such as windmill blades, the quality is all important.
In developing countries, advanced composite manufacture will have to depend on imported equipment, know-how and personnel which will make production costs extremely high.

Flexibility of Technology: Equipment investment and manpower training for windmill blade manufacture could be equally applied to many other advanced applications.

Utilisation: A cost-effective source of energy would be of great interest for housing needs, irrigation, etc. in developing countries with no indigenous fuel sources except a steady wind.

1.4. Conditions for Implantation

If the investment in equipment can be made, labour can be trained to a sufficient level of skill to allow windmill blades to be manufactured. The problem, however, lies in the fact that the blade is only part of a wind-power generating plant and blade manufacture on-site will probably only have a very small influence in the cost of the whole plant or on the cost of electricity production.
Wind-power generation plants must, however, at least be of interest for countries with little indigenous energy sources, especially for isolated villages in mountains or on islands.
An important condition for implanation of widespread composite blade wind-power in a developing country must be that the whole plant, not only the composite blade, be manufactured or assembled locally, from imported parts and materials eventually.
A second condition is that the plant be as maintenance-free as possible and this can be ensured by high quality mechanical and electrical equipment.
Furthermore, the technology should be used to produce composite parts for other sectors of industry and public consumption (buildings).

1.5. Limitations on Implantation

The limitations on the implantation of the fabrication of windmill blades are

- in most instances, the advanced composite is part of a larger structure or equipment that is chosen in order to make the whole system more efficient (economically or technically)

- advanced composite used in individual, consumer-type articles are limited to rather luxury, leisure activities such as ski, tennis, golf, fishing that are not needed in great numbers in developing countries
- product control is a very important part of the manufacturing cycle and as the composites are used in increasingly severe conditions, so do the controls increase in number, severity and complexity. Highly skilled personnel then become necessary.

2. Glass Fiber Reinforced Plastics (GRP) in Construction

2.1. Background

Of those established markets in industrialised countries, the most promising and exciting for developing countries is in construction where profit could be taken from the experience gained in the optimisation of composites for load-bearing aplications in order to design and construct cost-effective structures.

A list of potential applications in the building industry that is reproduced in Fig. 16 is taken from a UNIDO-Background-paper (Ref.).

The basic material is glass fiber reinforced polyester made by contact moulding - either hand or spray lay-up - into panels. A single mould (made of wood, GRP or metal) is used so that a moulding with only one smooth surface is produced. Between 500 and 1000 releases can be obtained with careful treatment of the mould.

As seen in Fig. 10 (Part A) the properties of GRP made by contact moulding technique are not the highest but, for large structures, they compare very favourably with other techniques and thickness can be increased very readily to give the required stiffness and strength.

Once the technology has been mastered for one type of structure, e. g. building panels, there is no problem of applying it to others.

Curing of the structure is either in an oven for small parts or with infrared lamps for larger structures.

2.2. Stage of Development

The uses of reinforced plastics in the construction industry are fairly general to all countries. Cladding panels, ceilings, roofing, domes and sanitary-ware are common applications.

Man developing countries have a great demand for low cost housir , but very little was being done to alleviate this pressing need.

2.3. Potential Aoplication in Developing Countries

Raw material supply: The raw materials are polyester and mainly chopped strand mat, what could very well be produced in some developing countries.

Design is well established for building panels but there is certainly room for specific designers to satisfy specific local conditions. For example, building panels that incorporate (foamed) insulation against heat and cold, panels incorporating some form of heat storage for cold countries, etc.

Application	Form of basic material	Advantages	Disadvantages
Rooflights	Corrugated or flat sheet	Stronger than glass, lower weight, easier to install	Light transmission less than glass. Deterioration of light transmission due to aging
Domelights	One piece moulded or fabricated components	Low weight; easy to install	As above
Domes and other roof structures	Modular components, single or double skins	Low weight, easy to erect	Stiffening with metal or timber may be necessary
Internal partitions	Corrugated or flat sheet	Convenient. Special decorative effects can easily be incorporated	Limited use because of cost
Cladding	Flat or profiled unsupported sheet or as surface "skin" to concrete or asbestos	Low weight, range of decorative effects, versatility for individual design	Fire performance limitations and adverse effects of prolonged weathering
Sectional buildings	Modular components, often double-skinned with "sandwich" construction	Low weight and ease of handling	As above
Bathroom units	Assembled modules	As above	No specific disadvantages
Tanks and cisterns	One or two piece press mouldings	Low weight, no corrosion, low thermal conductivity	No specific disadvantages
Pipes and ducts	Continuous profiles or as cladding on concrete or PVC pipe	Strengthens concrete pipes and protects them from chemical attack. Increases temperature range for PVC pipe	No specific disadvantages
Window frames	Assembled press moulded components or as sections for cladding timber	Reduces maintenance associated with most other materials	Less suitable than timber for non-standard dimension
Concrete moulds	Mouldings generally made by hand lay-up, but sometimes by press moulding	Low weight. Gives concrete of high quality and excellent finish. Provides a new medium for architectural designs on concrete	Low stiffness means that additional support is often necessary

Manufacture: The contact moulding process is quite straight-forward and should be readily introduced in developing countries. The pultrusion technique requires rather sophisticated equipment together with the associated technology.

Energy/Manpower: The energy cost involved in the contact moulding process is negligible compared to the materials cost and the cost of man-power. Thus, the process, and the resulting products are well suited for implantation in developing countries. Manpower requirements will be in the semi-skilled category.

Installation: Assembly of the panels will be by mechanical means so no special skills are required.

Utilisation: The panels should be maintenance free, but must be protected against heavy impacts or high stresses over a long period.
Fire remains a hazard for any structural applications of GRP and for cladding and ceilings because of flame spreading and smoke emission. Chemicals may, however, be added to the polymer matrix to act as fire retardants.

Tooling costs: The costs of a hand lay-up facility are low.

3. Large Diameter Fibre Reinforced Plastic Pipes

3.1. Background

GRP pipes are composed of resin (polyester or epoxy) and fiberglass reinforcements. Resin systems are available that provide a wide range of chemical resistance and mechanical properties. The strength properties of GRP pipes are related to the choice and arrangement of the glass fibers. The fiber reinforcement (E-glass) can be used - depending on the pipe design and the manufacturing technique - in different forms:

- continuous rovings; these consist of a multiplicity of glass fiber strands; in filament winding they are impregnated with the resin system and wound an a mandrel
- fabrics or tapes
- mats
- chopped fibers.

With continuous rovings and fabrics the strength properties obtained are directed by the choice of winding geometry. With mats and chopped fibers, isotropic properties are obtained. The basic properties depend also on the fibers volume content in the structure.
The general properties offered by GRP pipes can be summarised as follows:

- high strength-to-weight ratio
- high resistance against internal and external atteck
- good durability
- low thermal conductivity
- medium range of temperature resistance
- light weight coupled with easy handling and installation.

GRP pipes are made in diameters as small as 50 mm up to very large (3000 mm and more). They are made in various lengths. Working pressures of GRP pipes vary with pipe diameter: the smaller the pipe diameter the higher the design pressure, up to about 140 bars.
GRP pipes are designed with rather high security factors. These are applied either against the short time weeping strength or against burst strength, depending on the wall structure.

3.2. State of Development

There exist different types of GRP pipes and correspondingly the fabrication techniques also vary.
The most important are filament winding and centrifugal casting. Filament wound pipes are normally produced by winding specifically oriented resin-impregnated glass fiber rovings on to a mandrel.
Fig. 18 shows a schematic representation of basic filament winding machine types.
The application of the resin can be carried out either by using preimpregnated rovings or immediately prior to the winding of the rovings on the mandrel (wet impregnation). For the manufacture of GRP pipes virtually only the latter technique is applied because it involves lower cost, although the preimpregnated technique has some advantages such as closer control of the filament percentage, higher winding speeds, etc.
There exists different joining techniques for GRP pipes depending on the pressure range of application and the manufacturing technique employed.
GRP pipes constitute one of the most versatile pipe material classes since they cover both pressure and non-pressure pipe work over a wide range of diameters.
Although of relatively recent introduction on the market, GRP pipes already have proved themselves, in competition with existing pipe materials, in several traditional markets, such as water distribution, sewage and effluent disposal, chemical process work, etc.

3.3. Potential Application in Development Countries

Raw material supply: The glass fibers could eventually be fabricated in some developing countries, depending on the composition of the main component (sand). Otherwise glass fibers have to be imported.
The resin used exclusively for the larger diameter water and sewage pipes is polyester which again would have to be imported except in countries possessing a petrochemical industry.

Design: Pipe material design according to composite material principles is very well established so that pipes can be readily manufactured to meet specific operation conditions. The American Society for Testing and Materials (ASTM) has developed many standards and codes which can be used for specifying, testing and installing GRP pipes, as seen be the list in Fig. 19.

Manufacture: In the area of water and sewage and eventually slurry pipes discussed here, the resin matrix will be polyester and fabrication either by filament winding or centrifugal casting for both pressure and non-pressure pipe. The centrifugel casting technique has the advantage of beeing relatively simple, using fully automated equipment for resin and fiber feeding but the equipment itself is rather expensive.

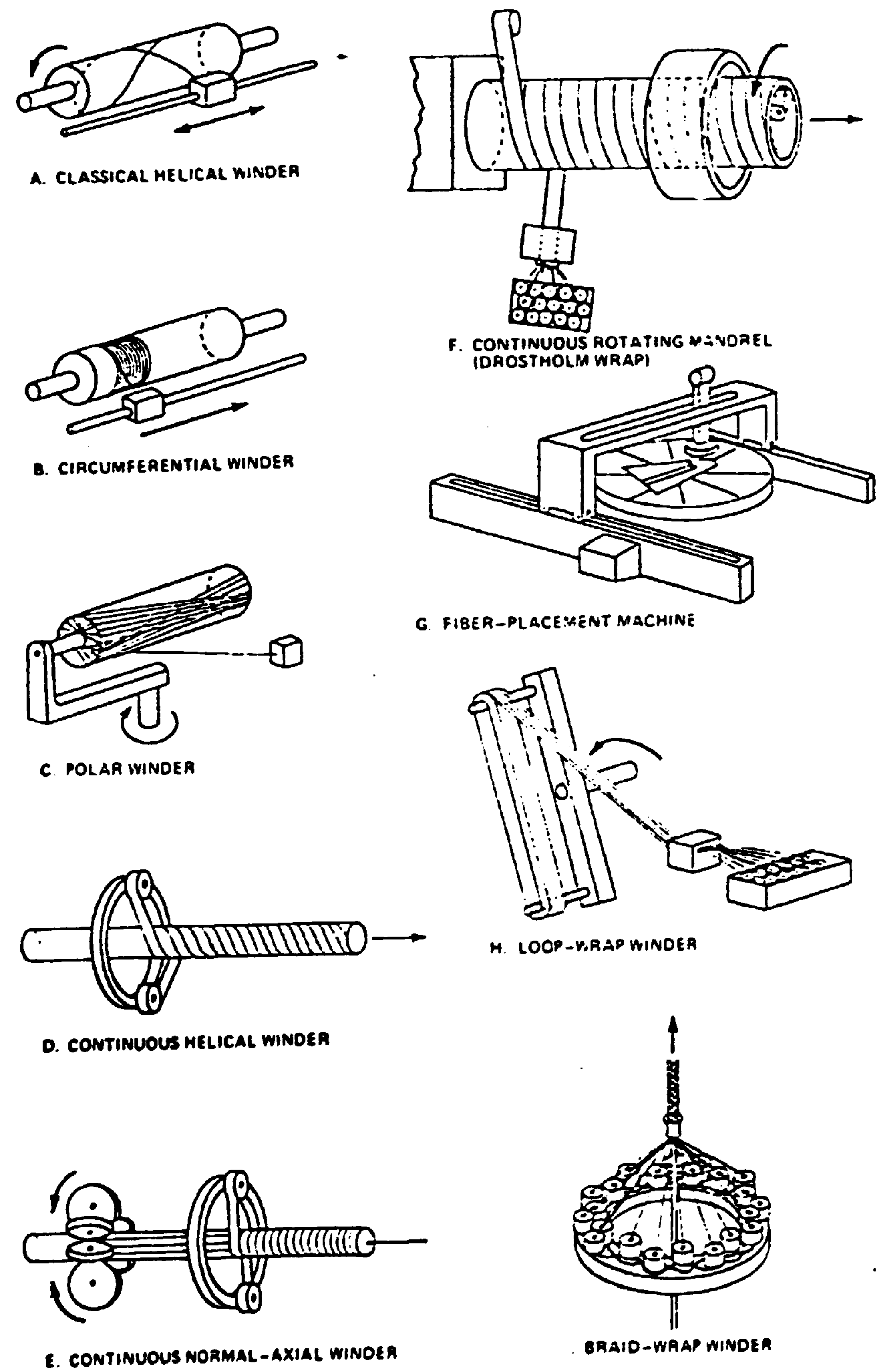

Fig. 17: Schematic Representation of Basic Methods and Types of Filament Placement

STANDARDS AND CODES

Raw Materials

ASTM C581	Test for Chemical Resistance of Thermosetting Resins used in Glass Fiber Reinforced Structures.
ASTM D638	Test for Tensile Properties of Plastics.
ASTM D648	Test for Deflection Temperature of Plastics Under Load.
ASTM D671	Test for Flexural Fatigue of Plastics by Constant-Amplitude-of-Force.
ASTM D790	Test for Flexural Properties of Plastics
ASTM D2343	Test for Tensile Properties of Glass Fiber Strands, Yarns, and Rovings Used in Reinforced Plastics.

Finished Products

ASTM D695	Test for Compressive Properties of Rigid Plastics.
ASTM D1598	Test for Time-to-Failure of Plastic Pipe under Constant Internal Pressure.
ASTM D1599	Test for Short Time Rupture Strength of Plastic Pipe, Tubing, and Fittings
ASTM D2105	Test for Longitudinal Tensile Properties of Reinforced Thermosetting Plastic Pipe and Tube.
ASTM D2143	Test for Cyclic Pressure Stren[illegible] of Reinforced Thermosetting Plastic Pipe
ASTM D2290	Test for Apparent Tensile Strength of Ring or Tubular Plastics by Split Disc Method.
ASTM D2310	Classification for Machine Made Reinforced Thermosetting Resin Pipe.
ASTM D2412	Test for External Loading Properties of Plastic Pipe by Parallel Plate Loading.
ASTM D2517	Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings.
ASTM D2583	Test for Indentation Hardness of Plastics by Means of a Barcol Impressor.
ASTM D2992	Test for Hydrostatic Design Basis for Reinforced Thermosetting Resin Pipe and Fittings.
ASTM D2996	Specification for Filament Wound Reinforced Thermosetting Resin Pipe.
ASTM D2997	Specification for Centrifugally Cast Reinforced Thermosetting Resin Pipe
ASTM D3262	Specification for Reinforced Plastic Mortar Sewer Pipe.
ASTM D3517	Specification for Reinforced Plastic Mortar Pressure Pipe.
ASTM D3567	Method for Determining Dimensions of Reinforced Thermosetting Resin Pipe and Fittings.
NSF Std. 15	Thermoset Plastic Pipe, Fittings, Valves, Tanks, Appartenances, Joining Materials and Thermoset Potable Water Supply Systems.
ASME Case 1792	Fiberglass Reinforced Thermosetting Resin Pipe (Section III, Division 1/Nuclear Power Plant Components/Cases of ASME Boiler and Pressure Vessel Code)
NBS PS15-69	Custom Contact — Molded Reinforced — Polyester Chemical — Resistant Process Equipment.
API Spec 5LR	Reinforced Thermosetting Resin Line Pipe (RTRP).
API Spec. RP5L4	Care and Use of Reinforced Thermosetting Resin Line Pipe.
Mil-P-22245 A (Docks)	Military Specification — Pipe and Pipe Fittings, Glass Fiber Reinforced Plastic.
USAF	Reinforced Plastic Mortar Pipe (RPMP).
SCS432G	Irrigation Pipeline — Reinforced Plastic Mortar.
USCE	Glass Fiber Reinforced Plastic Pipe
USBR C330	Reinforced Plastic Mortar Pressure Pipe

Standards in the Preparation or Approval Process

AWWA	Standard for Glass Fiber Reinforced Thermosetting Resin Pipe (RTRP and RPMP).
ASTM X-23.10-6-14	Standard Recommended Practice for Underground Installation of Flexible Reinforced Thermosetting Resin Pipe and Reinforced Plastic Mortar Pipe
ASTM X-23.10-17-2	Specification for Large Diameter Filament Wound Reinforced Thermosetting Resin Pipe.
ASTM X-23.11-4-3	Specification for Reinforced Plastic Mortar Sewer and Industrial Pipe.
ASTM X-23.13-9-7	Test for Determining the Chemical Resistance Properties of Reinforced Thermosetting Resin Pipe in a Deflected Condition.
ASTM X-23.14-14-4	Specification for Reinforced Plastic Mortar Pipe Fittings for Non-Pressure Applications.
ASTM X-23.14-15-5	Specification for Bell and Spigot Reinforced Thermosetting Resin Pipe Joints Using Flexible Elastomeric Seals.
ASTM X-23.15-2-5	Specification for Glass Fiber Reinforced Polyester Manholes.

Fig. 18: Glass Fiber Reinforced Plastic Pipes - US Standards and Codes

For many of the initial applications in developing countries, the working conditions will not be too severe so that hand lay-up pipes could be employed. Subsequently, however, quality will have to be ensured by automatic equipment such as the Drostholm machine (see Fig. 17).

Manpower: Manpower Requirements are quite high for hand lay-up pipes (skilled and semi-skilled workers). For automatic equipment the skilled labour will have to be increase (to include the machine maintenance) while semi-skilled and labourer total can be reduced.

Energy: As with most plastic-related fabrication, the energy requirements are low. Equally, the plant lay-out is relatively simple and requires no special facilities.

Applications: The actual use pattern of pipe materials depends on the local enviromental conditions and the pipe materials being offered.
Glass fiber reinforced plastics find their largest markets in applications where pipes are exposed to corrosive enviroments: either externally such as in agressive soil, or internally from sewage and industrial effluent, chemical process piping.
They are also utilised in water transport and distribution where they maintain the purity and allow no bacterial growth.
Apart from chemical plant which is a large and growing market for high quality filament wound pipes mainly with epoxy resin matrices, the water and sewage area has seen many applications of ployester resin pipe.
The biggest problem in extrapolating GRP to wide usage, for example in the Middle East, is that there are so many material variables involved that standard products can only be offered after a certain amount of local experience has been obtained.

3.4. Conditions for Implantation

The conditions for implantation of glass fiber reinforced plastic pipe production capacity in a developing country are as follows:

- a well established market must exist for water and sewage pipe
- the raw materials can be obtained locally or imported at competitive prices
- skilled and semi-skilled labour must be available
- initial know-how will have to be imported for hand lay-up on a relatively simple filament winding equipment
- the pipe quality offered must be guaranteed to be high and reproducible
- technical assistance must be offered on how best install and utilise the pipe
- a technical collaboration must be set up with a well-established pipe producer, at least in the initial stages
- last, but not least, the pipe material must be cost-competitive from the final installed cost point of view.

3.5. Limitations

Fig. 19 lists some of the major advantages and limitations of using GRP pipes. With respect to developing countries, the most severe disadvantage will be the cost and the fact that the material is relatively new.

Advantages	Main disadvantages and their consequences	
1. Excellent corrosion resistance 2. High strength-to-weight ratio	1. Long-term behaviour difficult to predict	a. High safety factors b. Pressures limited c. "Higher than necessary" costs
3. Light weight 4. Low thermal conductivity	2. Relatively expensive	a. Limitation on areas of application
5. Low flow resistance	3. Production steps not completely controlled	a. Structure defects
	4. Delicate laying	a. Stricter specification on backfill and handling than on AC b. Introduction of damage

Fig. 19: Glass Fiber Reinforced Plastic

4. Steel - Plastic Composite Pipes

4.1. Background

For special purposes (pipeline market sector between about 10 and 30 bars pressure at diameter above 300 mm) a pipe material and a manufacturing process have been recently developed, which furthermore satisfy the product requirements listed below:

- maximum cost effectiveness
- ease of fabrication, transport, installation
- high reliability during operation
- high corrosion resistance
- good, predictable strength characteristics
- possibility of wide variation in characteristics and dimensions to satisfy wide market.

The composite material is manufactured by the helical winding of several layers of high strength steel sheet (thickness around 0.5 mm) in an epoxy or polyester resin matrix.
It is a simple, continuous process not requiring high investment such as for steel pipes nor the sometimes complex winding machines for certain glass fiber pipes.
The structure of the pipe walls ensures a high, reproducible and predictable strength while the resin provides the necessary corrosion resistance.
Typical characteristics are presented in Fig. 20 .

Standard pressure classes	6, 10, 16 and 25 bars
Max. operating temperature	80 °C
Coefficient of thermal expansion	12×10^{-6} per °C
Chemical resistance	excellent

Fig. 20: Steel-Plastic Composite Pipes

4.2. Stage of Development

The status of the development has reached the stage where pipes from 200 to 2000 mm diameter are produced industrially in lengths up to 12 meters for uses in water and sewage transmission, slurry transport, etc.
Currently, opportunities of local manufacture are being researched in order to reduce transport and labour costs.
Raw materials remain steel (carbon steel, hot rolled) and epoxy resin, polyester resins are in investigation.
The cost structure is strongly dominated by the labour cost so that there is a large potential for developing countries to influence this.

4.3. Potential Interest for Developing Countries

A major factor which enters into the choice of a pipe material is of course the cost of installation, even in the event that the mechanical and chemical performance can be improved.
Comparison of calculated installed costs of the steel-resin pipe with those of steel and glass filament reinforced plastic pipe are presented in Fig. 22 for water transport under pressure.
Manpower, energy and infrastructure requirements are about the same as for GRP pipes.
Design techniques are also similar and the pipe can be installed and joined in a similar manner.
The cost of transport is a big factor in the final installation cost of a pipeline.
Manufacturing in developing countries is a big advantage for equivalent, or even improved mechanical and chemical performance.

4.4 Conditions for Implantation

In order that developing countries gain maximum sociological, economic, enviromental and technical benefits from the technology, the composite pipe fabrication, properties and industrial infrastructure should be developed to meet the specific local needs and conditions so as to avoid any technological transfer problems in the future.

4.5. Advantages and Limitations

The main conclusions are presented in Fig. 22.

COMPARISON OF INSTALLED COSTS OF PIPES OF 1.0 DIA.
FOR USE AT 13 BARS PRESSURE IN IRRIGATION

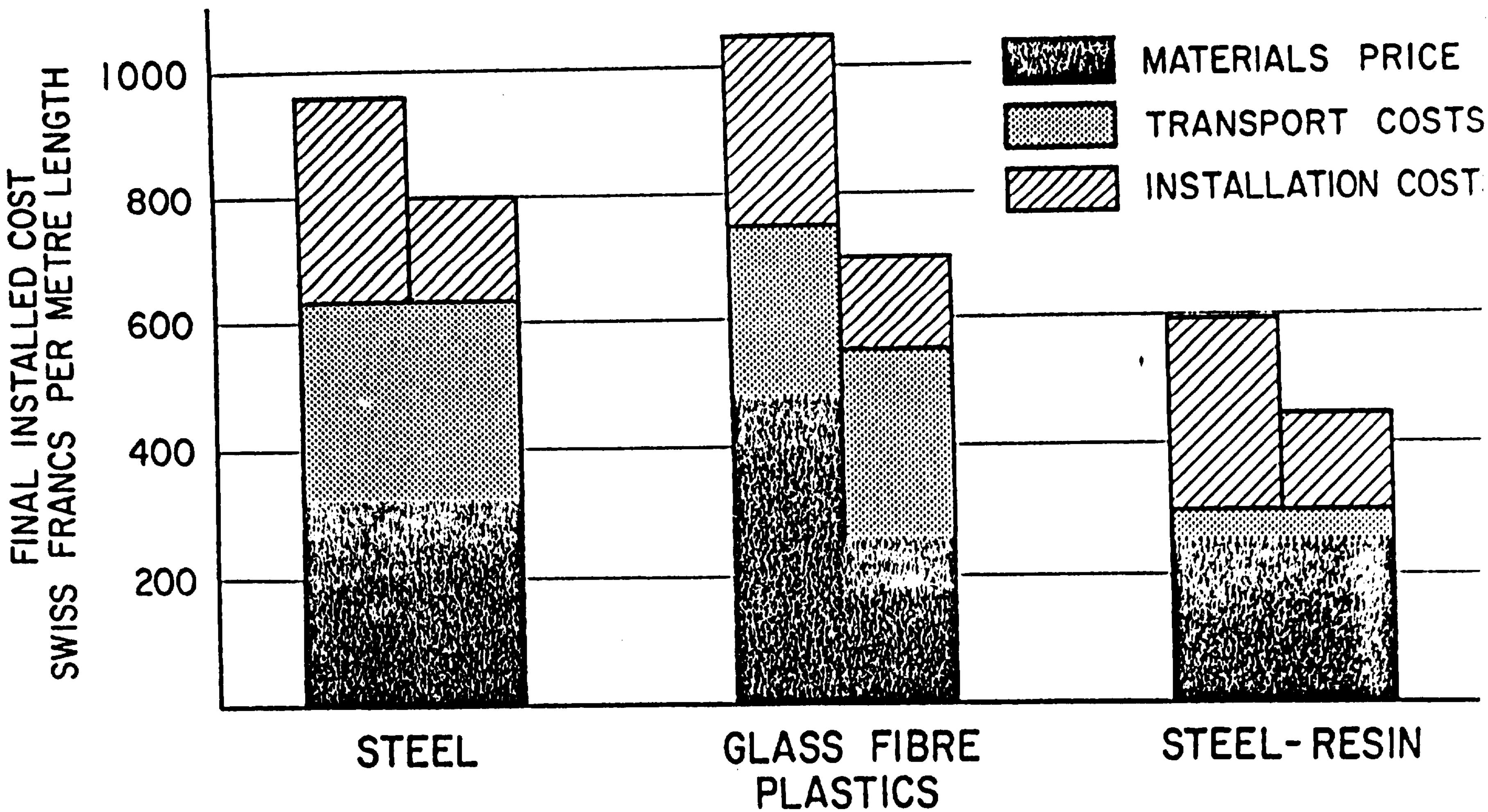

Fig. 21: Comparison of Installed Costs of Pipes

Advantages	- Meets growing need for pipe materials in medium-pressure range
	- High corrosion resistance
	- Relatively simple fabrication
	- On-site or within-the-country fabrication
	- Low transport costs
	- Low installed cost compared to competitive materials
	- Raw materials could be produced within the country: resin, filler, steel
Application	- Short-term in water treatment and transport slurries
	- Longer-term in energy product transport, well casings, chemical plant piping, etc.
Outstanding problems	- Development of suitable continuous fabrication techniques
	- Product of suitable continuous fabrication techniques
	- Product optimization for various chosen applications

Fig. 22: Main Conclusions Concerning Composite Pipes

5. Small Diameter Glass Fiber Reinforced Plastic Pipes

5.1. Background

The manufacture of small diameter GRP pipes (< 150 mm) is effected in the same general manner as for the larger diameter pipes already discussed. However, centrifugal casting is not favoured and two varieties of filament winding are employed:

- discontinuous on fixed length mandrels (Fig. 24)
- semi-continuous either in a modified version of the Drostholm machine or by pultrusion.

The pipes are mainly produced either with a polyester or epoxy matrix and may have an inner lining to provide increased corrosion resistance.

The pipes are employed in conditions where corrosion resistance is important, such as

- chemical and petrochemical industry
- waste water treatment
- long distance district hot-water heating
- mining
- oil and gas gathering lines.

The pipe is formed by first applying a resin-rich surface veil to the rotating steel mandrel to provide a smooth interior surface and corrosion protection.

The next step is to produce the structural wall. This is accomplished by winding filaments onto the mandrel under controlled tension. The composition of this layer consists of roughly 65 % glass fiber by weight.

The final step is to wind a resin-rich postcoat onto the structural wall that contains an ultraviolet screen.

For fittings and special pipe configurations, the open-mould method is used. This method utilises fiberglass mat placed onto the mould, and/or spray application of chopped strand fiberglass and resin.

The amount and type of fiberglass depends on the strength requirements.

5.2. Stage of Development

The stage of development of the materials and associated manufacturing technology may be dealt with in terms of the utilisation of the GRP pipes.

For high pressure, corrosive applications the pipes have an epoxy matrix and are manufactured by automatic filament winding on fixed length mandrels.

Various rapid installation mechanical joining systems are available which allow cost effective systems to be built.

GRP pipes are designed with rather high security factors ranging from 6 to 10; these are applied either against the short time weeping strength or against burst strength.

Working pressure of GRP pipes vary with the pipe diameter. The smaller the diameter the higher the design pressure, up to about 140 bars.

Low pressure, corrosive applications are used in the chemical industry, etc. The pipes are in this case either epoxy or polyester matrix made by hand lay-up winding processes.

They are widely used in gravity piping.
The high pressure pipes based on epoxy are high cost pipe materials to be used only in the most extreme conditions.
In piping systems, the fittings such as flanges, reducers, T-pieces and elbows are manufactured by compression moulding, hand lamination or filament winding.
The pipes may either be joined by flanges, adhesive bonding or rubber sealing with a sleeve, or by conventional couplings. Installation is readily carried out since the pipes are light.

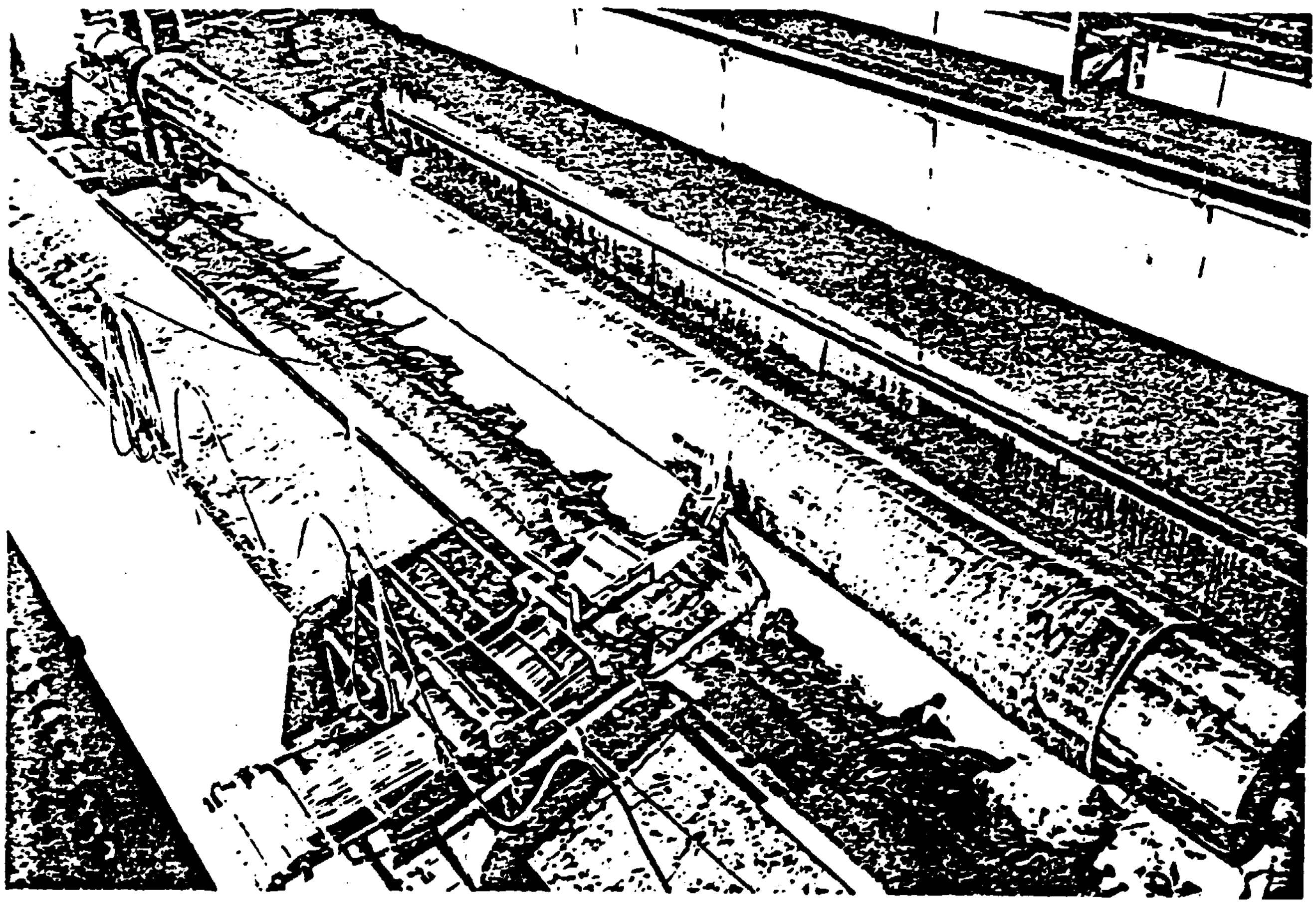

Fig. 23: Discontinuous Helical Winding of GRP Pipe

5.3. Potential Fields of Application

Raw materials: Glass fiber and petrochemical-based resins (thermosetting).

Design is done according to composite technology. In developing countries, some conventional, proven design should be chosen, based on established practice.

Manufacture/Manpower: Lay-up helical winding on a mandrel is a perfect technique, requiring low capital investment and being labour-intensive.

Energy: As with most plastic manufactuiring techniques, energy requirements are low and readily satisfied by electrical power in almost all countries.

Infrastructure: If piping systems are to be produced, capacity for the manufacture of fittings must equally be installed. The methods involved for fittings are normally labour-intensive and the costs are around five times that of the straight pipes on the weight basis.

Installation of GRP piping systems does not require heavy equipment but does require high quality workmanship in alignment, joining, final commissioning.

5.4. Conditions for Implantation

The conditions for implantation of small diameter GRP pipe production facilities in a developing country are as follows:

- there must exist an established or growing market in one of the sectors oil and gas field development, chemicals or petrochemicals, mineral extraction, food industry etc.
- the raw materials can be locally obtained or imported cost-effectively
- skilled or semi-skilled labour must be available
- initial know-how will have to be imported for hand lay-up on a relatively simple filament winding equipment
- investment will have to be available for more complex and automated filament winding or centrifugal casting equipment
- technical assistance must be offered on how best to install and utilise the pipe
- the pipes must be cost competitive with similar imported products or alternative materials (e. g. stainless, coated steel or plastic)
- local engineering and construction companies must be capable of accepting and installing the pipes.

5.5. Advantages/Limitations

The advantages of GRP piping systems are the following:

- Relatively low investment costs
- Labour intensive manufacture

- Built-in corrosion resistance
- Light weight
- Lower transportation costs
- Fast joining
- Low maintenance costs.

Major limitations to their production and utilisation in developing countries are:

- material is relatively unknown
- quality control must be high
- cost
- joining may require skill and carefull workmanship
- the smaller diameter, higher quality pipes may be imported more effectively than the larger diameter pipes because of quality requirements and lower transport costs
- the market may not (yet) be so large.

6. Glass Fiber Reinforced Tanks and Reservoirs

6.1. Background

Many technical processes involve highly corrosive chemicals that have tp be stored and transported and which are ideally suited to GRP applications as tanks and piping.
Examples are salt extraction, phosphate extraction, chlorine production, etc. Furthermore, water treatment and water storage facilities for industry and housing as well as petrol storage in (especially warm) developing countries expose materials to severe corrosion which can be alleviated by GRP storage tanks and reservoirs.
Grain or other food stuffs or crops storage has also to be effected in very large silos.
Four principle techniques are available for tank manufacture, the material invariably consisting of polyester reinforced with glass fibers:

- Hand or spray lay-up with chopped fibers for non-pressurised water or fuel storage tanks for housing or small industrial plants
- Filament winding as described for pipes, but of course on large diameter mandrels; the ends are fabricated by moulding and joined by adhesive bonding.
  Capacities of from 45 to 4000 litres are readily fabricated, and dimensions up to around 200000 litres are made by specialised companies
- On-site filament winding either rotating horizontal mandrels up to 6 m diameter and 20 m long or on vertical mandrels up to 25 m diameter around which the winding heads turn
- On-site assembly of preformed GRP sheets, assembled together with polyester putty and joints reinforced with pultruded rods and spray-lay-up.

6.2. Stage of Development

Glass fiber reinforced tanks and reservoirs are widely used in industrial countries in the food industry, agriculture, pulp and paper industry, caustic and chlorine plants, water treatment and storage, etc.
As well as stationary tanks, glass fiber reinforced plastics have been applied for transport purposes of corrosive materials on railsways, the biggest being 3 m diameter and 15 m length by filament winding.
The development of high quality tanks and the equipment to manufacture them has benefited enormously from advanced composite applications in missile tanks.

6.3. Potential Fields of Application in Developing Countries

<u>Raw material supply:</u> As in the case of the large diameter glass fiber reinforced pipes, the raw materials are E-glass fiber and polyester.

<u>Design</u> can follow the procedures and codes discussed for pipes.

Manufacture: Factory manufacture is by hand lay-up or filament winding and requires the same equipment as discussed above. Mandrels are of course larger and require heavier equipment.

Manpower: Skilled labour will have to be employed for the factory manufacture while the on-site operations will require a larger percentage of manual labour.

Energy/Infrastructure: Energy requirements are low. Plant layout will have to be larger than for pipes.

Applications: Sectors in developing countries will be in the storage of grain, cereals, milk, wine, caustic, salts extraction, sewage treatment, water storage, mineral extraction, fertiliser storage, etc.

6.4. Conditions for Implantation

They are as follows:

- a well established market must exist, either within the country or in neighbouring countries where the products can be cost-effectively exported
- the raw materials can be obtained locally or imported at competitive prices
- skilled or semi-skilled labour must be available
- initial know-how will have to be imported
- investment will have to be available for more complex and automated filament winding or centrifugal casting
- technical assistance must be offered on how best to install and utilise the tanks
- the tanks must be cost-competitive with similar imported products and with alternative materials (steel)
- local engineering and construction companies are capable of accepting and installing the tanks.

The drive to introduce tank manufacturing will depend on local conditions and requirements.

6.5. Advantages/Limitations

The advantages of GRP tanks are

- high corrosion resistance
- low maintenance compared with lined steel
- light weight for factory built tanks (easy handling)
- rapid on-site installation of larger tanks
- fabrication in the country will keep costs down and make the structures more cost-competitve with imported steel tanks
- the fabrication process is versatile and larger diameter tanks (without ends) can also be used as pipes.

Major limitations to their utilisation are:

- cost
- lack of rigidity in large dimensions, so a reinforcing structure is required
- lack of qualified personnel
- quality assurance
- joining.

These limitations are more severe for mobile tanks than on stationary.

7. Natural Fiber Composites

7.1. Background

Composites based on natural fibers have been employed in construction since early histroy. Apart from matting and textiles however, natural fibers are not widely employed in structures as reinforcements. Their utilisation is often as a filler without thought being given to optimising their effect on the mechanical properties of the structure. Serious thoughts is being given to developing composites based on natural fibers as coir, bagasse, banana, sisal, palmya and jute, because they are relatively low cost compared with synthetic fibers.
Natural fibers such as wood, cotton, sisal, jute and hemp are used to reinforce cement on an industrial scale.
On a specific stif.ness basis, the natural fibers fall far below asbestos or glass but compare well on a specific strength basis.

7.2. Stage of Development

The use of natural fibers to reinforce cement and thereby provide useful structural materials to fulfill the same purposes as asbestos-cement e.g. in stressed applications such as panels, roofing, piping, etc. faces severe handicaps due to degradation by moisture and organic attack. - Lower stressed applications such as building bricks remain valid.
The more novel and interesting composite approach to utilising natural fibers is as reinforcement for polymeric matrices.

7.3. Potential Application in Developing Countries

<u>Raw Materials:</u> The main driving force for considering the use of natural, locally found fibers is the lack of an indigenous supply of asbestos or the ready, cost-effective production capacity for glass. Most developing countries have resources of some of the natural fibers and use them in one form or another in everyday life.
The matrix could be polyester or a polymer also based on local biomass resources.

<u>Design:</u> Natural fiber composite design follows the rules laid down for glass composites with two basic reinforcement forms:

- discontinuous, short fiber mats
- yarns, cloth made up of short fibers

<u>Manufacture:</u> Techniques that may be use [illegible] rial scale are the same as for glass fiber re [illegible] ics, being mainly hand lay-up for mats and eventua [illegible] for cloths.

<u>Manpower:</u> The requirements will be the s [illegible] r hand lay-up GRP construction materials.

<u>Energy/Infrastructure:</u> No high energy requirements or spe [illegible] al infrastructure are required.

7.4. Conditions for Implantation

There mainly remains further development work to be done in order to determine the potential of introducing technology based on natural fiber composites. The work consists of the following tasks:

- Determination of the properties of local natural fibers and sensitivity to dimensions, form and surface quality
- Fabrication of composites and determination of their properties
- Tests im improve/optimise the properties
- Cost evaluations of the best composites produced and extrapolation to future production capacity
- Comparison with other structural materials and composites based on imported fibers.

Initial applications will be those not subjected to high operating stresses such as furniture, housing panels, roofing, household articles, containers, etc.

7.5. Advantages/Limitations

The immediately evident advantage is the possibility to use local resources to replace imported materials.

Limitations are mainly linked to the fibers themselves

- relatively low and variable dimensions and strength
- water absorption as well as decay and attack by fungi

and the composites

- low strength and stiffness
- wide variety of natural fibers available, so composite testing and design must be repeated many times.

References to Part B

(all references pages 132 - 134)

C) GENERAL CONCLUSIONS

1. Criteria For Production/Manufacture And Application Of Composite Materials In Developing Countries

1.1. Technology Flexibility

Composite material developments in industrialised countries have in recent times been stimulated by weight-reduction requirements in the aerospace industry, made possible by the invention and production of the so-called high performance ribers S-glass, carbon, aramid, etc.
The older industry of glass fiber reinforced plastics has also grown rapidly in the same period in weight-saving sectors (transportation) and in sectors where the corrosion resistance, low maintenance and rapid installation characteristics could be taken full advantage of.
The reasons why composite materials will be of interest for developing countries will almost be cost-effectively solving basic needs of the population with or without local raw materials and local labour.
The previous chapters have presented the overall composite material picture, highlighting the various types and current applications. Any particular country may find its strength lying in one ore more of the steps involved in the composite technology:

- Raw materials availabilty
- Fiber extraction or production
- Matrix production
- Semi-products manufacture
- Design, testing
- Fabrication of composite parts.

The composite material industry is currently characterised by a few specialised fiber producers, a similarly limited number of polymer matrix producers, several specialised semi-product manufacturers followed by a vast number of (sometimes small) industries that produce a wide variety of composite materials, articles and structures.
Upon deciding to enter the composite materials sector, a developing country will probably be more tempted to start at the fabrication end using imported basic components and technology. The two aspects, production/manufacture on the one hand and utilisation on the other, will be dealt in the following.

1.2. Production/Manufacture

1.2.1. Criteria for introduction of the technolgy

The first criterion for composite materials to be manufactured in developing countries is to satisfy an <u>important local utilisation need</u> or to <u>improve the quality of life</u>.
This concerns to the sectors housing, land transport, communication, provision of water and energy, sanitation and sewage transmission, industry.
The utility of certain composite materials in some developing countries is already established in housing, water and sewage transmission.

The satisfaction of the need by local production has to be made and justified on a cost-effective basis. Here the notion of profitable market size is contained which of course varies from product to product and country to country. In labour-intensive manufacturing processes an initial small market is sometimes sufficient to justify start-up of a new business.

The second criterion is the use of local raw materials to produce composites for internal or even external consumption. At the present time the production of organic fibers, mineral fibers, petroleum- or coal-derived polymers are in the hands of the industrialised countries but, given the right set of local conditions, there is nothing against them being produced in energy-rich eveloping countries. The problem is that, unless the local raw material source is cheaper, little economic advantage will be gained by local production since the processes are highly automated and of proprietary nature.

A third criterion is the more cost-effective on-site/local fabrication of the composite material or structure from the imported basic components.

The fourth criterion is to provide jobs to the indigenous labour force by manufacturing composite materials or structures that replace either already imported composites or substitute other local or imported materials.

Fifth criterion for considering a local composite material or structure production would be if a specific problem could only be solved by a composite material and that importation was impossible because of dimensions or the nature of the application (large storage tanks).

Sixth criterion is that the basic material and associated manufacturing and application technology is well-proven in industrialised countries.

A seventh criterion, that is purely political in nature, is that a composite material industry must be developed in the country in order to create jobs and establish an advanced industry. The decision may or may not be based on technical or financial arguments and the resulting products may be forced on the market at artificially low prices.

The last criterion, or rather sine qua non for introducing composite material production in developing countries, is the availability of <u>financement</u> for

- factory space
- equipment investment
- technology aquisition
- raw materials procurement
- wages, etc.

The initial financement for a composite material venture may be possible from the World Bank, local investors, industrialised country banks and investors or most probably through a joint venture with companies involved in the relevant technologies.

1.2.2. Advantages

Composite materials technology does not require very large markets and thus large production capacity investments to justify its introduction. Individual factories without heavy equipment may be kept small and many may be situated in different parts of the country to satisfy local markets.

In general terms, further advantages for the introduction are

- profit may be drawn from the large amount of R & D undertaken in the industrialised countries
- design procedures are state-of-the-art
- the basic components are for the most part very cost-competitive for importation.

1.2.3. Limitations

Limitations and handicaps for the introduction are:

- technology will almost certainly have to be initially imported
- technical assistance will be necessary
- in some cases joint ventures will have to be negotiated
- skilled or semi-skilled work force is required, sometimes highly skilled engineers
- new techniques and philosophy will have to be mastered that differ from those practiced for metal or wood
- cost comparison may be unfavourable when compared with alternative or similar imported products.

1.3. Utilisation

1.3.1. Criteria/Advantages

The criteria for justifying utilisation of composite materials are:

- cost-effective satisfaction of a local need or improvement of the quality of life
- accomplishment of some tasks that would be otherwise impossible or difficult
- improvement of the efficiency or cost-effectiveness of certain processes by increasing life-time
- reducing the need for maintenance.

Currently, the utilisation of composites in developing countries is mainly in corrosion resistant applications involving pipeline transport of water, sewage and corrosive media.

1.3.2. Limitations

The major limitations and arguments against the utilisation are essentially the same as those discussed under production:

- expensive imports unless locally produced
- semi-skilled and skilled labour required for installation
- confidence
- cost.

2. Potential Manufacture And Applications For Developing Countries

In this part, various composite materials and structures chosen on the basis of the criteria presented in Chapter 1 are discussed from the standpoints of their potential manufacture and application in developing countries.

2.1. Basic components production

2.1.1. Fiber production

Natural organic fibers exist in most developing countries and are more-or-less already utilised for clothes, textiles, ropes,.. The most common are cotton, jute, hemp, coconut fibers, bagasse.
Minerals: Astestos is the most widely used mineral fiber, but is not found in all countries. They requires strict security/health measures in its handling and treatment.
Metal wires: The best known are steel wires produced mainly by wire drawing and which are employed widely in the reinforcement of rubbers (tires, hoses) and cement.
Glass fibers: Some types are on the market for reinforcement purposes. E-glass is the most frequently used type. Presently, it constitutes th. standard reinforcement for all kinds of plastics. S-glass has a high tensile strength and elastic modulus. Typical uses are aircraft floorings, helicopter components, gas tanks, etc. Glass fiber production involves passing the molten glass through a platinium bushing consisting of several hundred holes. The freshly drawn continuous filaments are protected by a chemical agent and stored in the form of strands or yarns. For incorporation into composites, they are made into rovings and mats, chopped strand mats and chopped fibers and woven fabric. The technology is highly advanced and certainly transferable to any country.
Carbon fibers are made by pyrolitic degradation of a fibrous organic precursor so as to drive off the volatile components and orient the carbon atoms. The main precursor are rayon, polyacrylnitrile (PAN) and pitch fibers.
Carbon fibers are produced in tows of between 1000 and 160000 individual filaments. As with glass, the carbon fiber tows are surface treated for protection and subsequent compatibility with resins, and then wound on spools or woven to fabric.

Aramid fibers: At the moment, only two aramid fibers exists: KEVLAR (Du Pont) and TWARON (ENKA). The basic process involves the spinning at high temperature of a poly-p-benzamide polymer. It is a member of the polyamide (e.g. NYLON) fiber family.

2.1.2. Matrix Production

Cement and concrete: The basic raw materials exist in almost every country in the world.
Polymers: The principal raw material for polymers today is petroleum. Most polymeric materials, either alone or in the reinforced form, have further additions of fillers (carbonate, mica, talc) that may improve fabricability and the final properties as well as reducing costs.The mainly used polymers are thermosetting resins (epoxy, phenolic, polyester unsaturated, urea-melamine) and thermoplastics (polyamids, polyacetal, polyester, polyethylene, polypropylene, styrenics).

2.2. Semi-Products Manufacture

Semi-products include fiber tows, rovings, woven fabrics, mats and chopped fibers as well as prepregs and thermoplastic compounds.
Tows, rovings, mats and chopped fibers are normally produced directly by the fiber producer, whereas fabrics are the work of companies with textile experience.
Thermoset resin preimpregnated products (prepregs) consist of a preformulated mixture of fibers and partially cured resin that requires no further processing other than cutting to shape, laying up in correct form in a mould, curing under specified conditions of temperature, pressure and time.
Prepregs may contain non-woven fibers (unidirectional) or woven fabric and their use is the standard mode of advanced composites manufacture. Resins may be epoxy, polyester or phenole.
Sheet moulding compounds (SMC) of polyester and glass fiber are widely used for moulding furniture as well as bumpers, hoods, fenders, etc. in the automobile industry. SMC is made by depositing chopped fibers on a layer of resin carried as a continuous paste or film. The fibers are covered by a second layer of resin and pressed to remove excess resin. The resulting sheet is stored.

2.3. Composite Processing/Manufacture

The techniques have been described previously in Part A. The choice of the technique obviously depends on the product that has to be produced.
Most interesting for developing countries are contact moulding, centrifugal casting, filament winding, pressure moulding and hand lay-up.

3. Specific Suggestions

3.1. Analysis of Applications

Fig. 25 presents the results of the analysis carried out in Part B for the different composite materials and applications as they meet the criteria for introduction in developing countries.

3.2. General

The analysis conducted in this paper allows the conclusions to be drawn that

- in general terms, a composite material industry could be effectively introduced in developing countries, subject to certain conditions being fulfilled
- unless adequate local capabilities for R & D and commercialisation exist, the developing countries may find it advantageous to use what exists in the way of technology, design, manufacturing techniques; adaptations may be necessary
- raw materials should initially be those proven elsewhere; utilisation of local raw materials as replacement for imported should be studied parallel with production of standard materials
- the most suitable basic material is glass-fiber reinforced polyester
- plant investment and energy requirements are not excessive in the initial phases.

3.3. Impact Analysis in Developing Countries

3.3.1. Impact on Structural Materials

Introduction of composites, mainly/only GRP, will reduce demand for (eventually imported) steel, cement. Introduction of advanced composites will (propably) lie in a new field, so of no influence on current materials usage.

3.3.2. Impact of Raw Materials Supply

No problem can be foreseen from the raw materials supply side if composites are more widely introduced in developing countries.

3.3.3. Energy

The specific energy content of GRP is much lower than in the case of steel or aluminium. Therefore introduction of GRP manufacture in place of metal saves energy. Advanced composites such as carbon fiber reinforced polyester are equivalent to steel.

3.3.4. Transport

Large gains are to be made by introducing light weight materials into automobiles, trucks, trains, aircraft. The developing countries will benefit from this on imported goods but will probably have little impact through structures manufactured within the country itself.

CRITERIA	Raw Materials production glass fibre	polymere matrix	Windmill Blades	GRP in construction	Large Diameter Pipes AC	GRP	steel-plastic	Small diameter GPR pipes	GPR tanks	Natural fibre composites
Flexibility of technology	Na	Na	+	++	+	+	+	+	+	++
Satisfy local need	o	o	o	++	++	++	++	+	+	++
Improve quality of life	o	o	+	+	+/o 3)	++	++	+	o	++
use local raw materials	o	- 1)	o/-	+/o 2)	+/o	-	o 4)	-	-	+
Economic local production	o	o	o	+	+	+	+	+	+	+
Provide employment	+	-	+	++	++	++	++	++	++	++
Solve specific problems	Na	Na	+	++	++	++	++	+	+	++
Technology is proven	+	+	+	++	++	++	+	++	++	o
Financement available	o	-	o/-	+	+	+	+	o	o	-
Quality control straight forward	-	-	-	+	++	+	++	+	+	o
Introduction of new technology (political)	++	++	++	++	o	++	++	+	+	++
skilled labour requirement low	-	-	-	o	+	o	o	-	o	o

1) Readily met only in oil/gas/coal producing countries. Biomass source requires RAD

2) In low stress applications, natural fibres may be employed

3) Health question still outstanding

4) Where a steel mill is available.

++ No doubts on criterion fulfillment

+ Under certain circumstances the criterion is fulfilled

o No definite answer

- Does not meet criterion, or only with much development and expense.

Fig. 24 Evaluation of Composites on Basis of Choice Criteria for Developing Countries

3.3.5. Health

The potential impacts on health of the introduction of composites in developing countries all tend to be negative because of the

- small dimensions of the fibers that may, if no precautions are taken, lead to lung damage; the hazard potential is considered to be less than that of asbestos , coal dust or quartz -
- flammability of plastics
- resin handling, for which prescribed procedures must be adhered to.

3.3.6. Solid Wastes

resulting from scrapped composites are difficult to recycle and current use is in land fill.

3.3.7. Product Reliability Issues

In the initial phase of introduction of composites in developing countries uses should be restricted to non-critical structures or components where no major problems involving loss of life, pollution, etc. can result.

3.3.8. Technology Advances

The advance in composite technology in industrialised countries, mainly in the areas of manufacturing and product quality, will be of direct benefit to developing countries.

3.3.9. Research and Development and Education

The area of composite materials is one where considerable innovative work can be done in both developed and developing countries. Thus, introduction of composite manufacture and utilisation will stimulate R & D activities in universities and research establishments on material science, chemistry, chemical engineering, structural engineering, etc. By the same token, the teaching of materials technology-related subjects at universities will be greatly enhanced because of their relevance to national activities.

References to Part C

(all references pages 169 - 179)