INCREASING THE USE OF FIBRE-REINFORCED COMPOSITES IN THE SASOL GROUP OF COMPANIES: A CASE STUDY

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APPROVAL FOR FINAL SUBMISSION

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JANUARY 2007

DECLARATION

I declare that this dissertation is my own unaided work except where due acknowledgements is made to others. This dissertation has not been submitted previously for any other degree or examination.

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Date

ACKNOWLEDGEMENTS

The first plans for this research project developed during an evening of good food and lively discussions on the topic of the lack of knowledge of end-users regarding the application possibilities of composite materials. Its last pages were written about four years later during a busy but exciting time in the use of composite materials on numerous Sasol projects. Looking back over the last four years of full-time involvement in the development work; going through piles of notes and filing; travelling thousands of miles with my trusted Toyota, motivating and negotiating application possibilities, I am amazed and astounded at the progress made in the industry and Sasol. Although this thesis is closer to me than anything I have written and tries to articulate my work and progress, it definitely is the thesis that needed and received the most help.

Without the sincere interest, the critical response and original contributions of many in the composites industry, I would never have been able to distinguish between what is actually needed to inform hundreds of technical people in Sasol regarding the use of composites materials. Specifically, I need to mention the enormous contributions that were made by Dr. Arthur Carter of Fibre-Wound, Cecil Clarke of Sasol Polymers and Johnny Viviers of Sasol Technology.

I am grateful to Prof. Mark Walker of Durban University of Technology for his role as study leader and his careful assistance in helping me integrate in this text many ideas that were expressed by colleagues in the composites industry and Sasol. I also am very thankful to Sasol Technology and Sasol Polymer's Management for encouraging me to proceed with this project.

I owe a special word of thanks to Magdaleen Malan for her generous and skilful assistance in the typing of this thesis.

To my wife and our two daughters, who created the space where I could develop this project, I dedicate this thesis with love and affection.

Jacques Mouton
Vaaloewers, South-Africa

What you are, is God's gift to you
What you become, is your gift to God.

ABSTRACT

A composite material comprises two or more materials with properties that are superior to those of the individual constituents. Composites have become important engineering materials, especially in the fields of chemical plant, automotive, aerospace and marine engineering. The development of more advanced materials and manufacturing techniques in composites has grown from humble beginnings in the 1930s to a recognized and well-respected engineering discipline, providing solutions to conventional and challenging applications. At present, fibre-reinforced composites (FRCs) are amongst the most common types of composites used. They are produced in various forms with different structural properties, and designers, specifiers and end-users can choose from an almost endless list of these materials, providing design flexibility as well as low manufacturing and maintenance cost. Many suggest that composites have revolutionised the chemical and petro-chemical industries. Examples of applications include tanks and chemical reactor vessels that contains many hundreds of litres of hazardous chemicals, reinforced pipes measuring up to several meters in diameter conveying dangerous gases and so on.

The South Africa Coal, Oil and Gas Corporation Limited (SASOL) was established in September 1950. From a small start-up, the company has grown to be a world leader in the commercial production of liquid fuels and chemicals from coal and crude oil. Sasol manufactures more than 200 fuel and chemical products at its main plants in Sasolburg and Secunda in South Africa as well as at several other plants abroad. Its products are exported to more than 90 countries around the world.

The use of composites in general, and fibre reinforced composites in particular has received little support in Sasol through the years. Some sporadic use of these materials in the construction of process equipment, e.g. tanks, vessels and piping has taken place with varying degrees of success. While the use of equipment fabricated with fibre-reinforced composites has proven extremely successful in the chlorine producing facility in Sasolburg, catastrophic failures have taken place in Secunda in critical fire water systems made of these materials.

The history of correct use and application of fibre-reinforced equipment has shown that the cost of ownership of such equipment is significantly lower than similar metallic equipment, therefore reducing costs and safety risks. However, even though this technology brings a company like Sasol closer to the realisation of the vast number of advantages and solutions offered by these materials, the reality is that most engineering personnel are still applying traditional (viz. steel and wood) technology as used by our predecessors. The work presented here attempts to indicate the relevance of fibre-reinforced composites for Sasol, and to detail efforts aimed at the raising of awareness amongst appropriate personnel at Sasol to increase the use of these materials in major capital projects and day-to-day maintenance contracts, therefore taking advantage of the superior performance of fibre-reinforced composites in demanding applications. In support of this drive, part of the work presented indicates the status as well as progress of the composites industry in the last few years.

This project was therefore aimed at identifying the level of utilization of fibre-reinforced composites at Sasol, and the possible improvement in benefits of using these technologies. A methodology was developed, using engineering as well as marketing principles, to reach the engineering personnel in various divisions and seniority levels of Sasol to increase the awareness of the capabilities of composites materials, specifically regarding fibre-reinforced composites. Questionnaires were used to gauge the level of awareness while various methods, e.g. one-on-one meetings, seminars, conferences, electronic media, etc were used to upgrade the target groups' knowledge. The results of the initial survey to determine the status of various dimensions in the company are indicated as well as the outcomes at the end of the research period. In support of the process in Sasol, the development, interaction and cross-pollination of international and national role-players in the fibre-reinforcement industry with respect to chemical containment and Sasol are indicated. The importance of this two-legged process is demonstrated: it ensures a professional national support framework for companies like Sasol. Results are indicated, compared and discussed to give future direction in this ongoing process.

As important to this process was the development of appropriate technical resources (like design standards and codes) to enable their use within the group. It was recognised early on that raising the level of awareness of the target groups was not enough and that these resources had to be in-place down the line so that those who chose to could start to implement these material technologies with the aid of the resources. The development of the necessary resources is also discussed.

Finally, it will be shown that significant growth has taken place regarding the awareness within the group over the course of implementation of this project. Specifically, about 20% of the target groups have moved from a stage of no knowledge to higher levels of confidence. In terms of use of these materials, significant growth has also taken place judging by the number of plant requests, activity on major capital projects and so on. In fact, from almost nothing in 1999, over the last 5 years in excess of R137 Million has been spent on capital equipment manufactured from composite materials, with the majority in the last 2 years.

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TABLE OF ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
ACMA	American Composites Manufacturers Association
AECI	African Explosives Chemical Industries
AESP	Approved Engineering Service Providers
AIA	Approved Inspection Authority
ANMEM	Association of Non-Metallic Equipment Manufacturers
BMC	Bulk mouldings compounds
CCT	Certified Composites Technician
CFA	Composites Fabricators Association (also known as ACMA)
CI	Competent Inspector
CMSG	Composites Manufacturers Supply Group
COC	Code of Construction
CP	Competent Person
CPI	Chemical Processing Industry
CSM	Chopped Strand Mat
CTE	Coefficient of Thermal Expansion
CWGFC	Composites Working Group Facilitation Committee
D.I.T	Durban Institute of Technology
DMC	Dough Moulding Compounds
DN	Diameter Nominal
D.O.L	Department of Labour
DST	Department of Science and Technology
EC	Engineering Contractor
ECSA	Engineering Council of South Africa
EIT	Engineer in Training

E.O.J	End of Job
ETFE	Ethylene tetrafluoroethylene
ECTFE	Ethylene chlorotrifluroethylene
FEP	Fluorinated ethylene propylene
FRC	Fibre-Reinforced Concrete
FRP	Fibre-Reinforced Plastic (also known as GRP)
GDP	Growth Domestic Product
GFRP	Glass-Fibre-Reinforced Plastic
GRP	Glass-Reinforced Plastic
HDPE	High density polyethylene
HDT	Heat Deflection Temperature
IT	Information Technology
IPE	Inspector of Pressurized Equipment
MMC	Metal matrix composites
NDE	Non Destructive Examination
NDT	Non Destructive Testing
NRF	National Research Foundation
NQF	National Qualifications Framework
OD	Outside Diameter
OHSACT	Occupational, Health and Safety Act
PCISA	Polymeric Composites Institute of South-Africa
PED	Pressurized Equipment Directive
PESR	Pressure Equipment Systems Regulation
PISA	Plastics Institute of Southern Africa
PFA/MFA	Perfluoroalkoxy
PP	Polypropylene

PS	Maximum Allowable Pressure
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl Chloride
PVC-C	Polyvinyl Chloride-Chlorinated
PVC-U	Polyvinyl Chloride-Unplasticised
PVDF	Polyvinylidene fluoride
RBI	Risk Based Inspection
RRIM	Reinforced Reaction Injection Moulding
RTM	Resin transfer moulding
SABS	South African Bureau of Standards
SAIW	South Africa Institute of Welding
SASOL	South Africa Coal, Oil and Gas Corporation Limited
SAQCC	South African Qualification and Certification Committee
SCI	Sasol Chemical Industries
SGB	Standards Generating Body
SHE	Safety, Health and Environmental
SMC	Sheet moulding compound
SMME	Small, Medium and Micro Enterprises
SPNMTC	Sasol Polymers Non-Metallic Technical Committee
SSF	Sasol Synthetic Fuels
SWOT	Strengths, Weaknesses, Opportunities and Treats
TCO	Total Cost of Ownership
THRIP	Technology and Human Resources for Industry Programme
TMC	Thick Moulding Compound
TS	Design Tempearture
TWISA	Thermoplastic Welding Institute of South Africa

UD	Unidirectional
US	United States (of America)
UV	Ultra-Violet
WR	Woven Roving
VUP	Vessels Under Pressure
WR	Woven Roving

DEFINITION OF TERMS

Amorphous	The way in which molecular chains, such as PVC are loose, open and in no order.
Anistropic	Material of which the properties vary with the orientation or direction of the reference coordinates.
Atoms	Smallest possible unit of an element may combine with another atom or atoms to form a compound.
Carbon Fibre	A high strength-reinforcing fibre used in lightweight structural composites.
Chemical Processing Equipment	Vessels, piping, pipes, ducts, stacks and other ancillary equipment used for the processing or conveyance of chemical products.
Chopped Strand Mat	A fibreglass reinforcement consisting of short strands of fibre arranged in a random pattern and held together with a binder.
Closed Moulding	A two sided mold or vacuum bag in which a part is molded.
Competent Inspector	A person certified by the SAQCC –CP Committee having such theoretical and practical knowledge and experience of

	inspection which would enable him/her to detect defects or weaknesses.
Composite	A reinforcing fibre in a resin matrix whose cumulative properties are superior to the individual materials.
Compressive Strength	The capacity to resist a crushing or buckling force; the maximum compressive load a specimen sustains divided by its original cross-sectional area.
C-Glass	Calcium-aluminium-borosilicate glass with an alkali oxide content of approximately 8 percent.
Delamination	Separation of layers in a laminate because of failure in or near the adhesive joint.
Design Pressure	The internal pressure to be used in calculations to establish the required strength of the component part.
E-Glass	Originally formulated for use in electric circuitry. E-glass is the most common glass formulation used in fibreglass reinforcements. A Borosilicate glass with an alkali oxide content of less than 1 percent.
Epoxy Resin	A polymer resin characterized by epoxide molecule groups.

Exothermic Heat	Internally developed heat accompanying a chemical reaction, such as might be created when curing a thermosetting resin.
Fabricator	Manufactures of reinforced plastic products.
Fibre	Reinforcement material that is a major component in a composite matrix.
Fibre Content	Amount of fibre in a composite compared to the amount of resin.
Fibre Glass	Glass that has been extruded into extremely fine filaments. These fibres come in many forms such as roving, woven roving, mat, and continuous strands.
Fibre Reinforced Plastics	A composite material or part that consists of a resin matrix containing reinforcing fibres.
Filament Winding	A process where a resin saturated filament is wound around a rotating mandrel e.g. Filament Wound Pipe and tanks.
Fish Eye	The effect of surface contamination which causes a circular separation of a paint or gel coat.

Flexibility	That property of a material by virtue of which it may be flexed or bent repeatedly without rupture or the development of visible defects.
Gel Coat	An in-mould coating sprayed on the surface of the mould.
GRP	Glass Reinforced Plastics, also known as Fibre Reinforced Plastics (FRP), GFRP (Glass Fibre Reinforced Plastic), RP (Reinforced Plastic), and Composites.
Glass Filament	A form of glass that has been drawn to a small diameter and extreme length.
Hand Lay Up	The process of manually building up layers of fibreglass, with roll stock reinforcements and resin, using hand rollers, brushes and spray equipment.
Honeycomb Core	Strips of paper, plastic, metal, etc., joined together to form a honeycomb pattern. Used as a lightweight core in sandwich mouldings.
Impregnate	To saturate with resin.
Inhibitor	Substance used in small proportion to suppress a chemical reaction.

Initiator	Substance used in small proportion, that starts a chemical reaction, for example, by providing free radicals, e.g. catalyst, hardener.
Isophthalic Resin	A polyester resin based on isophthalic acid, generally higher in properties than a general purpose or orthophthatic polyester resin.
Isotropic	The description of equal strength properties in all orientations.
Laminate (noun)	Layers of a composite consisting of a resin and a reinforcement, bonded together to form a single structure.
Laminate (verb)	The act of processing resin and reinforcement into a bonded structure. Saturating glass reinforcement and rolling out air voids is to laminate.
Laminator	An operator employed in the process of GRP Moulding.
Level in Sasol	Refers to the ranking position in the management structure in Sasol with a 1 as the most senior.
Mandrel	The mould on which the laminating material is wound in filament winding.

Mat	The product made of filaments, staple fibres or strands, cut or uncut, oriented or not, held together in the form of a sheet.
Midlands	The name of the Sasol Polymers production facility on Sasolburg.
Monomer	A compound consisting of molecules each of which can provide one or more constitutional units e.g. the simple molecule capable of polymerizing. A polymer constituent of polyester or vinyl ester resins.
Non-Destructive Inspection	Methods of testing materials that involve sensors that do not affect the material.
Open Moulding	A single sided mould open to atmosphere
Orthophthalic Resin	A polyester resin based on orthophthalic acid, also known as a general purpose resin.(GP).
Phenolic Resin	Thermosetting resin produced by condensation of an aromatic alcohol with an aldehyde, particularly phenol with formaldehyde.
Pigment	Ground colouring materials added to gel coat or resin.

Plastics	Organic chemical compounds called polymers that can be formulated to produce a wide range of properties.
Polyester	A polymer in which the repeated structural unit in the chain is of the ester type.
Polyester Resin (unsaturated)	The product of an acid-glycol reaction commonly blended with a monomer to create a polymer resin.
Polyester Resin	The product of an acid-glycol reaction commonly blended with a monomer to create a polymer resin.
Polygauge	Digital thickness measuring equipment.
Polymer	A chain molecule composed of many identical groups, commonly found in plastics.
Porosity	Property of the material that contains very fine continuous holes which allow passage of gases, liquids and solids through one surface and out another surface.
Post-Cure	Heat treatment of articles moulded from thermosetting materials to complete cure.

Primary Stress	A normal stress or shear stress developed by the imposing load which is necessary to satisfy the simple laws of equilibrium of external and integral forces and movement.
Principal Direction	Specific coordinate axes orientation when stress and strain components reach maximum and minimum for the normal components and zero for the shear.
Pultrusion	A continuous moulding process for manufacturing composite profile shapes such as rods, tubes and structural shapes having a constant cross section. Roving and other reinforcements are saturated with resin and continuously pulled through a heated die, where the part is formed and cured.
Reaction Injection Moulding (RIM)	Injection moulding process in which reactive multi-components, with or without fillers, are mixed by high-pressure impingement in a mixing chamber immediately prior to being injected into a closed mould.
Resin	A liquid polymer that when catalysed cures to a solid state.
Resin Content	The amount of resin in a laminate, expressed as a percentage of either total weight or total volume.

Resin Rich	Localized area filled with excess resin, as compared to consistency of resin / fibre ratio.
Resin Starved	Insufficient resin in a laminate. Inadequate encasement of reinforcement in the resin, e.g. dry-spot
Rovings	A collection of parallel strands or filaments assembled with or without intentional twist.
Rovings Continuous	Single or multiple strands of parallel filaments coated with sizing and wound into a cylindrical package.
Shear Strength	Maximum shear stress sustained by a specimen during a shear test.
Shelf Life	Storage time under specified conditions during which a material may be expected to retain its essential properties, for example working properties and specified strength.
Shore Hardness	Arbitrary measure of hardness, in which the penetration of a specified indenter forced into the material is determined under conditions specified in ISO 868.
Stress Corrosion	Preferential attack of areas under stress in a corrosive environment, that alone would not have caused corrosion.

Styrene Monomer	A component of polyester resin that provides cross-linking sites and reduces the polyester to a workable viscosity.
Tensile Strength	Maximum stress sustained by a material before failure in tension.
Thermoplastics (noun)	A group of plastic materials that become elastic or melt when heated and return to their rigid state at room temperature. Examples are HDPE, PE, PP, PVC, Nylon, etc.
Thermoplastic (adjective)	Capable of being softened by heating and hardened by cooling through a temperature range characteristic of the plastic and that in the softened state of being shaped by flow repeatedly into articles by moulding, extrusion or forming.
Thermoset (noun)	Materials that undergo a chemical cross-linking reaction going from liquid to solid or semi-solid. This reaction is irreversible. Typical thermosets are polyesters, acrylics, epoxies and phenolics.
Thixotropic	A term describing the rheology (or flow characteristics) of a liquid that resists flowing or drainage during application.

UV Stabilizer	A chemical compound which improves resistance to degradation from ultraviolet radiation.
Wet Layup	A reinforced plastic which has liquid resin applied as the reinforcement is being layed up.
Wet-out	The action of saturating a glass fabric with resin. Also measure of the speed with which a fabric soaks up resin.
Winding Angle	The angle of wind application to filament winding, helical or hoop measured about the longitudinal axis.
Woven Roving	A heavy woven fabric constructed from rovings.
Yield Point	The point at which permanent deformation of a stressed specimen begins to take place.

Chapter 1

Introduction

1.1 Composite materials

1.1.1 Overview

A composite comprises two or more materials having characteristics that are derived from the individual constituents. Depending on how these constituents are combined, the resulting composite may have the combined characteristics of the constituents or substantially different properties to the individual constituents. Occasionally the properties of the composite exceed those of the individual constituents themselves (Gurdal, Haftka & Hajela, 1999:2). Composite materials may be selected to give unusual combinations of stiffness, strength, weight, high-temperature performance, corrosion resistance, hardness, or conductivity.

Wood is a good example of a natural composite. Wood is a combination of cellulose fibre and lignin. The cellulose fibre provides strength and the lignin is the "glue" that bonds and stabilizes the fibre. Bamboo is also a very efficient wood composite structure. The components are cellulose and lignin, as in all other wood, but bamboo is hollow and fibrous. This results in a very light yet stiff structure. Composite fishing rods and golf shafts copy this natural design. The use of natural composite materials has been a part of man's technology since the first ancient Egyptians builders used straw to reinforce mud bricks.

The 12th century Mongols made advanced weapons in their day, like archery bows that were smaller and more powerful than those used by their rivals. The bow shafts were composite structures made of a combination of cattle tendons, horn, bamboo, and silk, which was bound with natural pine resin. The tendons were placed on the tension side of the bow, the bamboo was used as a core, and sheets of horn were laminated to the compression side of the bow. The entire structure was tightly wrapped with silk and a resin adhesive. Recently some of these 700-year old museum pieces were strung and tested. They were about 80% as strong as modern composite bows (Composites Fabricators Association, 2000: 1-6). The use of composite pipes for the conveyance of water have been around for many hundreds of years and an example made in the 1600's is shown in Figure 1.1.

Figure 1.1 Wooden pipe reinforced with steel rods

1.1.2 Common Types of Composites

Composites can be placed into three categories based on the shapes of the materials, namely particulate, fibre and laminar as shown in Figure 1.2. Concrete, a mixture of cement and gravel, is a particulate composite; fibre-glass, containing glass fibres embedded in a polymer, is a fibre-reinforced composite; and plywood, having alternating layers of wood veneer, is a laminar composite. If the reinforcing particles are uniformly distributed, particulate composites have isotropic properties; fibre composites may be either isotropic or anisotropic; laminar composites always display anisotropic behaviour (Askeland, 1994:527).

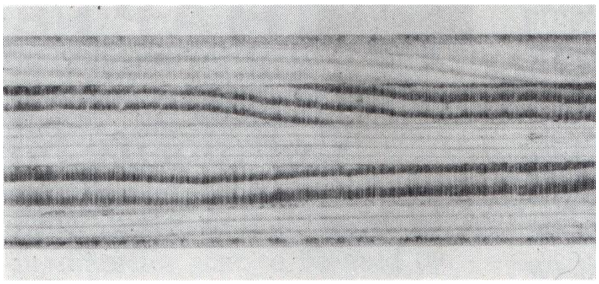


Figure 1.2a

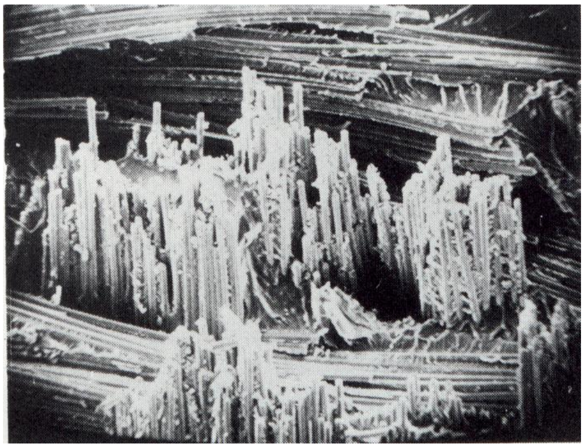


Figure 1.2b

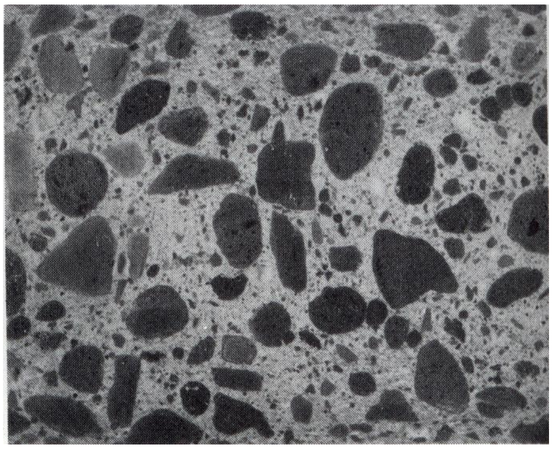


Figure 1.2c

Figure 1.2 Some examples of composite materials:
(a) Plywood, (b) Fibreglass (x175). (c) Concrete (reduced 50%).

Polymer matrix composites are particularly well known and used. Most polymer materials, both thermoplastics and thermosets, are available in glass-reinforced grades making it possible to form these materials in complex and useful shapes. Metal matrix composites (MMC) are used extensively in aerospace and automotive applications and include aluminium; magnesium, copper, nickel and intermetallic compound alloys reinforced with ceramic and metal fibres (Askeland, 1994:546).

Fibre-reinforced composite (FRC) materials are a commonly used form of these constituent combinations. The fibres of such composites are usually strong and stiff and serve as the primary load-carrying constituent. The matrix, being a softer material that supports the fibres, serves to distribute the loads evenly across the fibres. The matrix also redistributes the loads from a broken fibre to the adjacent fibres in the material when fibres start failing under excessive loads. This synergism is achieved by a combination of mechanisms that tends to keep cracks small and isolated, efficiently dissipating energy (Gerstrale, 1985:779).

A form of fibre-reinforced plastic (FRC) composite comprises thin layers (or plies) of materials completely bonded together to form composite laminates. The plies of a laminated composite material consist of different single layers of materials and may be composite themselves. These composite layers can be placed so that the different layers have different mechanical properties. This type of composite is the most commonly encountered laminated material used in the design of high performance structures and equipment.

1.1.2.1 Metal Matrix Composites

By stretching slightly our definition of a composite, we can consider a special group of dispersion-strengthened materials containing particles 10nm to 250 nm in diameter as particulate composites. These dispersoids, usually a metallic oxide, are introduced into the matrix by means other than traditional phase transformations. Even though the small particles are not coherent with the matrix, they block the movement of dislocations and produce a pronounced strengthening effect.

At room temperature, the dispersion-strengthened composites may be weaker than traditional age-hardened alloys, which contain a coherent precipitate. However, because the composites do not catastrophically soften by over-aging, over-tempering, grain growth, or coarsening of the dispersed phase, the strength of the composite decreases only gradually with increasing temperature. Furthermore, their creep resistance is superior to that of metals and alloys.

The dispersant must have a low solubility in the matrix and must not chemically react with the matrix, but a small amount of solubility may help improve the bonding between the dispersant and the matrix. Copper oxide (Cu_2O) dissolves in copper at high temperatures; thus, the Cu_2O-Cu system would not be effective. However, Al_2O_3 does not dissolve in aluminium; the Al_2O_3-Al system does give an effective dispersion-strengthened material.

Examples of Dispersion-Strengthened Composites. Table 1.1 list some materials of interest. Perhaps the classic example is the sintered aluminium powder (SAP) composite. SAP has an aluminium matrix strengthened by up to 14% Al_2O_3. The composite is formed by powder metallurgy. In one method, aluminium and alumina powders are blended, compacted at high pressures, and sintered. In a second technique, the aluminium powder is treated to add a continuous oxide film on each particle. When the powder is compacted, the oxide film fractures into tiny flakes that are surrounded by the aluminium metal during sintering.

Another important group of dispersion-strengthened composites includes thoria-dispersed metals such as TD-nickel (Figure 1.3). TD-nickel can be produced by internal oxidation. Thorium is present in nickel as an alloying element. After a powder metallurgy compact is made, oxygen is allowed to diffuse into the metal, react with the thorium, and produce thoria (ThO_2).

System	**Applications**
Ag-CdO	Electrical contact materials
Al-Al_2O_3	Possible use in nuclear reactors
Be-BeO	Aerospace and nuclear reactors
Co-ThO_2, Y_2O_3	Possible creep-resistant magnetic materials
Ni-20% Cr-ThO_2	Turbine engine components
Pb-PbO	Battery grids
Pt- ThO_2	Filaments, electrical components
W- ThO_2, Zr O_2	Filaments, heaters

Table 1.1 Examples and applications of selected dispersion-strengthened composites.

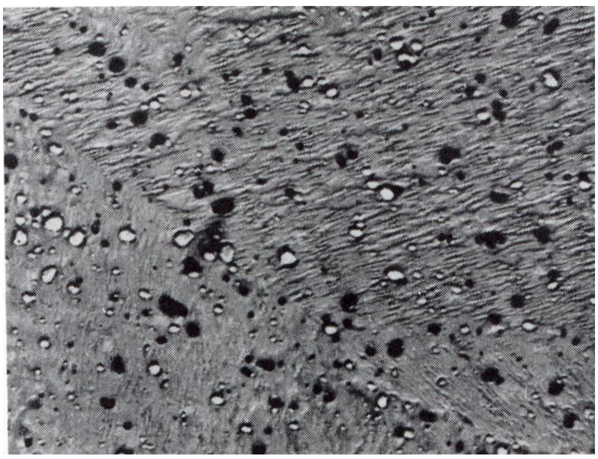


Figure 1.3 Electron micro-graph of TD-nickel. The dispersed ThO_2 particles have a diameter of 300nm or less (x2000 - Askeland, 1994:529).

Cemented Carbides. Cemented Carbides, or cermets, contain hard ceramic particles dispersed in a metallic matrix. Tungsten carbide inserts used for cutting tools in machining operations are typical of this group. Tungsten carbide (WC) is a hard, stiff, high-melting-temperature ceramic. Unfortunately, tools constructed from tungsten carbide are extremely brittle.

To improve toughness, tungsten carbide particles are combined with cobalt powder and pressed into powder compacts. The compacts are heated above the melting temperature of the cobalt. The liquid cobalt surrounds each of the sold tungsten carbide particles. After solidification, the cobalt serves as the binder for tungsten carbide and provides good impact resistance, as shown in Figure 1.4. Other carbides, such as TaC and TiC, may also be included in the cement.

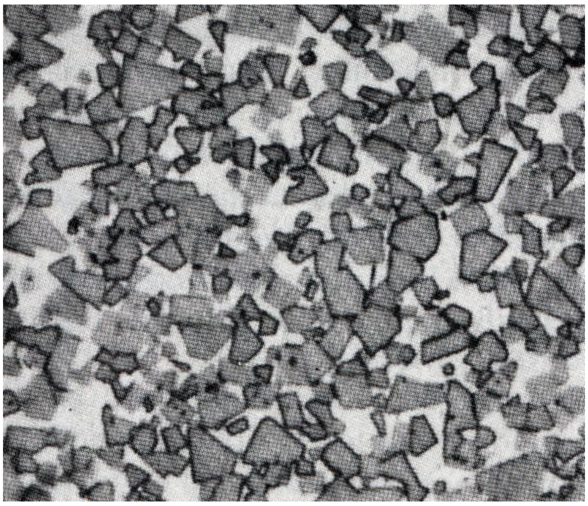


Figure 1.4 Microstructure of tungsten carbide – 20% cobalt cemented carbide (x13000).

Abrasives

Grinding and cutting wheels are formed from alumina (Al_2O_3), silicon carbide (SiC), and cubic boron nitride (BN). To provide toughness, a glass or polymer matrix bonds the abrasive particles. Diamond abrasives are typically bonded with a metal matrix. As the hard particles wear, they fracture or pull out of the matrix, exposing new cutting surfaces.

Electrical contacts

Material used for electrical contacts in switches and relays must have a good combination of wear, resistance and electrical conductivity, otherwise the contacts erode, causing poor contact and arcing. A tungsten powder compact is made using conventional powder metallurgical processes, shown in Figure 1.5, to produce high-interconnected porosity. Liquid silver is then vacuum infiltrated to fill the interconnected voids. Both the silver and the tungsten are continuous. Thus, the pure silver efficiently conducts while the hard tungsten provides wear resistance.

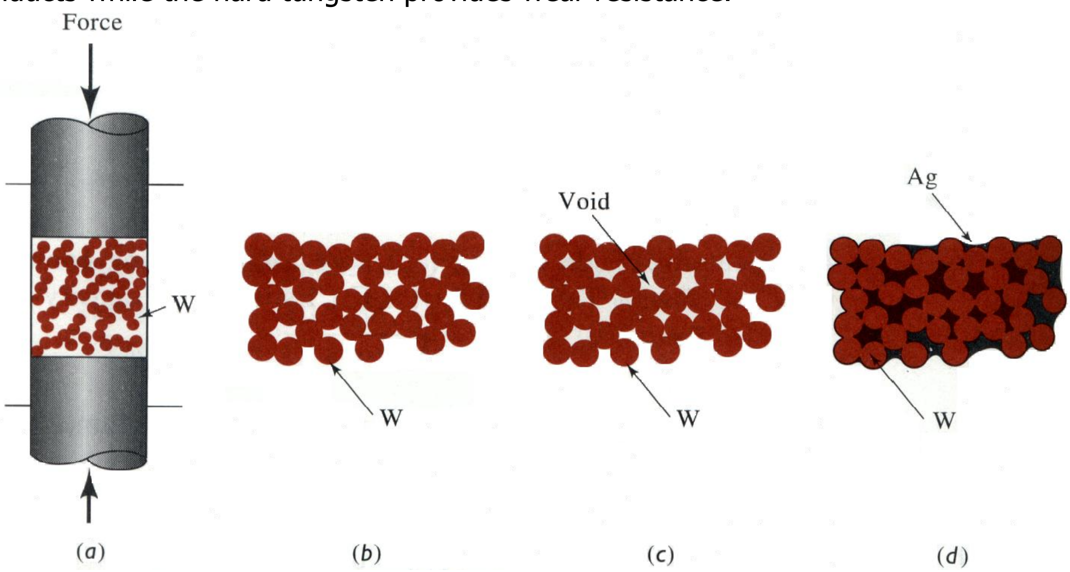


Figure 1.5 The steps in producing a silver-tungsten electrical composite: (a) Tungsten powders are pressed, (b) a low-density compact is produced, (c) sintering joins the tungsten powders, and (d) liquid silver is infiltrated into the pores between the particles (Askeland, 1994:532).

Cast metal particulate composites

Aluminium castings containing dispersed SiC particles for automotive applications, including pistons and connecting rods, represent an important commercial application for particulate composition. With special processing, the SiC particles can be wet by the liquid, helping to keep the ceramic particles from sinking during freezing.

An unusual technique for producing particulate-reinforced castings is based on the thixotropic behaviour of partly liquid-partly solid melts. A liquid alloy is allowed to cool until about 40% solids have formed; during solidification, the solid-liquid mixture is vigorously stirred to break up the dentritic structure. A particulate material is introduced during stirring. The resulting solid-liquid slurry displays thixotropic behaviour – the slurry behaves as a solid when no stress is applied, but flows like a liquid when pressure is exerted. Consequently, the thixotropic slurry can be injected into a die under pressure, a process called compocasting (see Figure 1.6). A variety of ceramic particles and glass beads have been incorporated into aluminium and magnesium alloys by this technique.

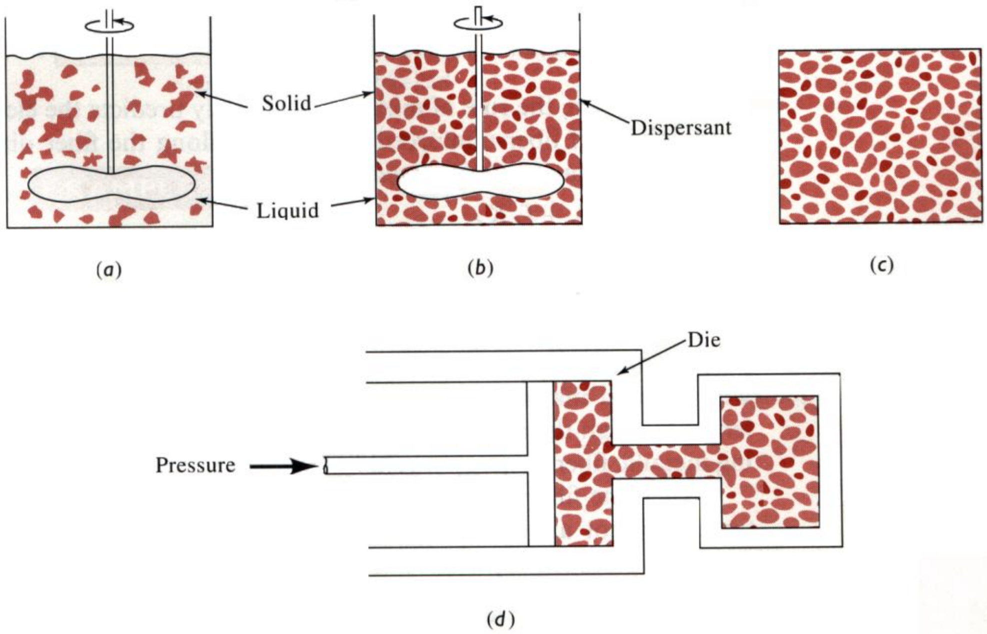


Figure 1.6 In compocasting, (a) solidifying alloy is stirred to break up the dentritic network, (b) reinforcement is introduced into the slurry, (c) when no force is applied, the solid, liquid mixture does not flow, and (d) high pressure causes the solid liquid mixture to flow into a die.

1.1.2.2 Fibre-Reinforced Composites (FRCs)

Most fibre-reinforced composites provide improved strength, fatigue resistance, stiffness, and strength-to-weight ratio by incorporating strong, stiff, but brittle fibres into a matrix. The matrix material transmits the loading to the fibres, which carry most of the applied force. The fibres are strong in tensile applications while the matrix is more effective in compression loading. The strength of the composite may be high at both room temperature and elevated temperatures.

Many types of reinforcing materials are employed. Straw has been used to strengthen mud bricks for centuries. Steel reinforcing bars are introduced into concrete structures. Glass fibres in a polymer matrix produces fibreglass for use in many sectors including transportation and aerospace. Fibres made of boron, carbon, polymers, and ceramics provide exceptional reinforcement in advanced composites based on matrices of polymers, metals, ceramics and even intermetallic compounds.

The Direction Dependence of the Properties of Fibre-Reinforced Composites

FRC properties (i.e. strength, stiffness, thermal, etc.) depend on the form of the reinforcement. The directional nature of the fibres introduces directional dependence to most of the properties. Materials whose properties are independent of direction are called isotropic materials. A special case of anisotropy is the existence of two mutually perpendicular planes of symmetry in the material properties. Such materials are referred to as orthotropic. Continuous fibre composites are orthotropic in nature and their properties are defined in the plane of the layer in two directions; the direction along the fibres and the direction perpendicular to the fibre orientation.

The Rule of Mixtures in Fibre-Reinforced Composites

The rule of mixtures always predicts the density (ρ) of fibre-reinforced composites:

$$\rho_c = f_m\rho_m + f_f\rho_f \tag{1.1}$$

where f is defined as volume fraction and the subscripts m and f refer to the matrix and the fibre. Note that $f_m = 1 - f_f$.

In addition, the rule of mixtures accurately predicts the electrical and thermal conductivity of fibre-reinforced composites along the fibre direction if the fibres are continuous and unidirectional:

$$K_c = f_m K_m + f_f K_f \tag{1.2}$$

$$\sigma = f_m \sigma_m + f_f \sigma_f \tag{1.3}$$

where K is the thermal conductivity and σ is the electrical conductivity. Thermal or electrical energy can be transferred through the composite at a rate that is proportional to the volume fraction of the conductive material. In a composite with a metal matrix and ceramic fibres, the bulk of the energy would be transferred through the matrix; in a composite consisting of a polymer matrix containing metallic fibres, energy would be transferred through the fibres. When the fibres are not continuous or unidirectional, the simple rule of mixtures may not apply (Askeland, 1994:536). For example, in a metal fibre-polymer matrix composite, electrical conductivity would be low and would depend on the length of the fibres, the volume fraction of the fibres, and how often the fibres touch one another.

Modulus of Elasticity. The rule of mixtures is used to predict the modulus of elasticity (*E)* when the fibres are continuous and unidirectional. Parallel to the fibres, the modules of elasticity may be as high as:

$$E_c = f_m E_m + f_f E_f \qquad (1.4)$$

However, when the applied stress is very large, the matrix begins to deform and the stress-strain curve is no longer linear, as shown in Figure 1.7. Since the matrix now contributes little to the stiffness of the composite, the modulus can be approximated by:

$$E_c = f_f E_f \qquad (1.5)$$

When the load is applied perpendicular to the fibres, each component of the composite acts independently of the other. The modulus of the composite is now:

$$\frac{1}{E_c} = \frac{f_m}{E_m} + \frac{f_f}{E_f} \qquad (1.6)$$

Again, if the fibres are not continuous and unidirectional, the rule of mixtures does not apply (Askeland, 1994:536-537).

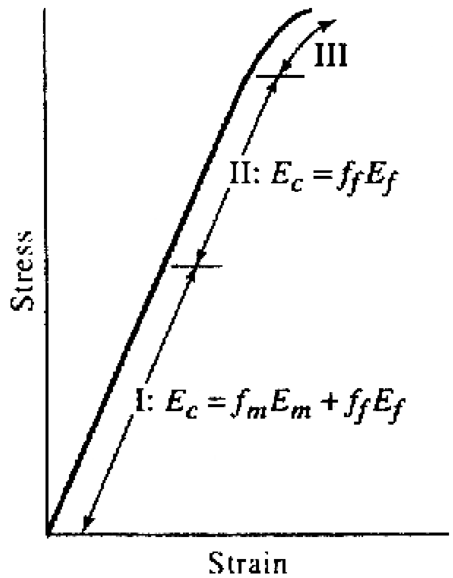


Figure 1.7 The stress-strain curve for a fibre-reinforced composite. At low stresses, the modulus of elasticity is given by the rule of mixtures. At higher stresses, the matrix deforms and the rule of mixtures is no longer obeyed (Askeland, 1994:537)

Strength of FRCs. The strength (σ) of a fibre-reinforced composite depends on the bonding between the fibres and the matrix. However, the rule of mixtures is sometimes used to approximate the tensile strength of a composite containing continuous, parallel fibres:

$$\sigma_c = f_f \sigma_f + f_m \sigma_m \qquad (1.7)$$

where σ_f is the tensile strength of the fibre and σ_m is the stress acting on the matrix when the composite is strained to the point where the fibre fractures. Thus, σ_m is not the actual tensile strength of the matrix. Other properties, such as ductility, impact properties, fatigue properties, and creep properties, are difficult to predict even for uni-directionally aligned fibres.

Characteristics of Fibre-Reinforced Composites

Many factors must be considered when designing a fibre-reinforced composite, including the length, diameter, orientation, amount, and properties of the fibres; the properties of the matrix; and the bonding between the fibres and the matrix.

Fibre Length and Diameter. Fibres can be short, long, or even continuous. Their dimensions are often characterized by the *aspect ratio l/d*, where *l* is the fibre length and *d* is the diameter. Typical fibres have diameters varying from 10 microns (10×10^{-4}cm) to 150 microns (150×10^{-4}cm). The strength of a composite improves when the aspect ratio is large. Fibres often fracture because of surface imperfections. Making the diameter as small as possible gives the fibre less surface area and, consequently, fewer flaws that might propagate during processing or under load. Long fibres are also preferable. The ends of a fibre carry less of the load than the remainder of the fibre; consequently, the fewer the ends, the higher the load-carrying ability of the fibres. In many fibre-reinforced systems, discontinuous fibres with an aspect ratio greater than some critical value are used to provide an acceptable compromise between processing ease and properties. A critical fibre length l_c, for any given fibre diameter *d*, can be determined (Askeland, 1994:538):

$$l_c = \frac{\sigma_f d}{2T_i} \tag{1.8}$$

where σ_f is the strength of the fibre and T_i is related to the strength of the bond between the fibre and the matrix, or the stress at which the matrix begins to deform. If the fibre length *l* is smaller than l_c, little reinforcing effect is observed; if *l* is greater than about $15l_c$, the fibre behaves almost as if it were continuous. The strength of the composite can be estimated from

$$\sigma = f_f \sigma_f \left(1 - \frac{l_c}{21}\right) + f_m \sigma_m \tag{1.9}$$

where σ_m is the stress on the matrix when the fibres break.

Amount of Fibre. A greater volume fraction of fibres increases the strength and stiffness of the composite, as we would expect from the rule of mixtures. However, the maximum volume fraction is about 80%, beyond which fibres can no longer be completely surrounded by the matrix.

Orientation of Fibres. The reinforcing fibres may be introduced into the matrix in a number of orientations. Short, randomly oriented fibres having a small aspect ratio – typical of fibreglass – are easily introduced into the matrix and give relatively isotropic behaviour in the composite. Long, or even continuous, unidirectional arrangements of fibres produce anisotropic properties, with particularly good strength and stiffness parallel to the fibres. These fibres are often designated as 0º plies, indicating that all of the fibres are aligned with the direction of the applied stress. However, unidirectional orientations provide poor properties if the load is perpendicular to the fibres, as shown in Figure 1.8.

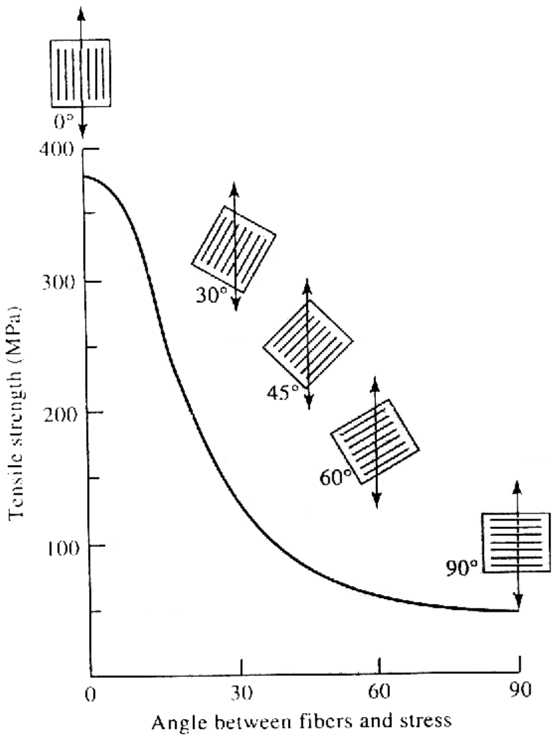


Figure 1.8 Effect of fibre-orientation on the tensile strength of E-glass fibre-reinforced epoxy composites (Askeland, 1994:542)

One of the unique characteristics of fibre-reinforced composites is that their properties can be tailored to meet different types of loading conditions. Long, continuous fibres can be introduced in several directions within the matrix, as shown in Figure 1.9 in orthogonal arrangements (0º/90º plies), good strength is obtained in two perpendicular directions.

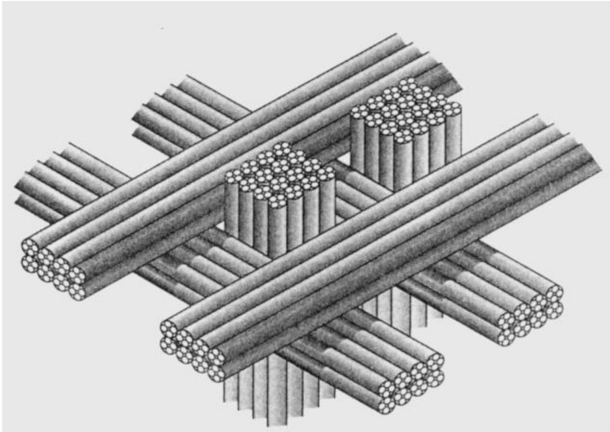


Figure 1.9 A three –dimensional weave for fibre-reinforced composites
(Askeland, 1994:543)

More complicated arrangements (such as 0º/±45º/90º plies) provide reinforcement in multiple directions. Fibres can also be arranged in three-dimensional patterns. In even the simplest of fabric weaves, the fibres in each individual layer of fabric have some small degree of orientation in a third direction. Better three-dimensional reinforcement occurs when the fabric layers are knitted or stitched together. Very complicated three-dimensional weaves as shown in Figure 1.9 can also be used.

Fibre Properties. In most fibre-reinforced composites, the fibres are strong, stiff, and lightweight. If the composite is to be used at elevated temperatures, the fibre should also have a high melting temperature. Thus the *specific strength* and *specific modulus* of the fibre are important characteristics**:**

$$\text{Specific strength} = \frac{\sigma_y}{\rho} \tag{1.10}$$

$$\text{Specific modulus} = \frac{E}{\rho} \tag{1.11}$$

where σ_y is the yield strength, ρ is the density, and E is the modulus of elasticity.

The highest specific modulus is usually found in materials having a low atomic number and covalent bonding, such as carbon and boron. These two elements also have a high strength and melting temperature. Aramid fibres, of which Kevlar is the best-known example, are aromatic polyamide polymers strengthened by a backbone containing benzene rings and are examples of liquid-crystalline polymers in that the polymer chains are rod-like and very stiff. Specially prepared polyethylene fibres are also available. Both the Aramid and polyethylene fibres have excellent strength and stiffness but are limited to low-temperature use. Because of their lower density, polyethylene fibres have superior specific strength and specific modulus.

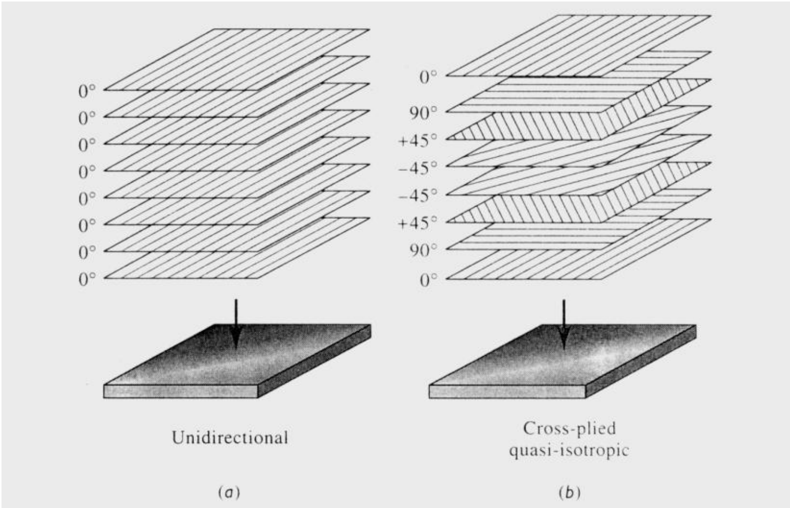


Figure 1.10(a) Tapes containing aligned fibres can be joined to produce a multi-layered unidirectional composite structure. (b) Tapes containing aligned fibres can be joined with different orientations to produce a quasi-isotropic composite. In this case, a 0º/±45º/90º composite is formed (Askeland, 1994:543).

Ceramic fibres and whiskers, including alumina, glass and silicon carbide, are strong and stiff. Glass fibres, which are the most commonly used, include pure silica, S-glass (SiO_2 – 25% Al2O3-10% MgO), and E-glass (SiO_2 –18% CaO-15% Al_2O_3). Although they are considerably denser than the polymer fibres, the ceramics can be used at much higher temperatures. Beryllium and tungsten, although metallically bonded, have a high modulus that makes them attractive fibre materials for certain applications (Askeland, 1994:540-544).

Material	Density (g/cm^3)	Tensile Strength (MPa)	Modulus of Elasticity ($x10^3$ MPa)	Melting Temperature (°C)	Specific Modulus ($x10^7$ mm)	Specific Strength ($x10^6$ mm)
Poymers:						
Kevlar	1.44	4480	124	500	1.36	0.44
Nylon	1.14	827	2.75	249	0.04	0.11
Polyethylene	0.97	3309	172	147	0.28	0.54
Metals:						
Be	1.83	1275	303	1277	3.05	0.11
Boron	2.36	3448	379	2030	2.55	0.19
W	19.40	4000	406	3410	0.33	0.03
Glass:						
E-glass	2.55	3448	72.4	<1725	0.45	0.22
S-glass	2.50	4480	96.8	<1725	0.55	0.28
Carbon:						
High Strength	1.75	5654	275.8	3700	2.5	0.51
High Modulus	1.90	1860	531	3700	4.41	0.15
Ceramics:						
Al_2O_3	3.95	2068	379	2015	1.53	0.08
B_4C	2.36	2275	492.6	2450	3.24	0.15
SiC	3.00	3930	492.6	2700	1.86	0.21
ZrO_2	4.84	2068	345	2677	1.13	0.07
Whiskers:						
Al_2O_3	3.96	20684	427.5	1982	1.71	0.83
Cr	7.20	8895	241.3	1890	0.53	0.19
Graphite	1.66	20684	703	3700	6.69	1.98
SiC	3.18	20684	482.6	2700	2.39	1.03
Si_3N_4	3.18	13789	379		1.88	0.69

Table 1.2 Properties of selected fibre-reinforcing materials.

Matrix properties. The matrix supports the fibres and keeps them in the proper position, transfers the load to the strong fibres, protects the fibres from damage during manufacture and use of the composite, and prevents cracks in the fibre from propagating throughout the entire composite. The matrix usually provides the major control over electrical properties, chemical behaviour, and elevated-temperature use of the composite.

Polymer matrices are particularly common. Most polymer materials – both thermoplastics and thermosets – are available in short glass fibre-reinforced grades. Sheet-moulding compounds (SMCs) and bulk-moulding compounds (BMCs) are typical of this type of composite. Thermosetting aromatic polyimides are used for somewhat higher temperature applications.

Metal matrix composites include aluminium; magnesium, copper, nickel, and intermetallic compound alloys reinforced with ceramic and metal fibres. A variety of aerospace and automotive applications are satisfied by the MMCs. The metal matrix permits the composite to operate at high temperatures, but producing the composite is often more difficult and expensive than producing the polymer matrix materials.

Manufacturing fibres and composites

Producing a fibre-reinforced composite involves several steps, including producing the fibres, arranging the fibres into bundles or fabrics, and introducing the fibres into the matrix.

Making the fibre. Metallic fibres, glass fibres, and many polymer fibres (including nylon, aramid, and polyacrylonitrile) can be formed by drawing processes, e.g. wire drawing of metal and using a spinnerette for polymer fibres.

Boron, carbon and ceramics are too brittle and reactive to be worked by conventional drawing processes. Boron fibre is produced by chemical vapour deposition (CVD) (Figure 1.11a). A very fine heated tungsten filament is used as a substrate, passing through a seal into a heated chamber. Vaporized boron compounds such as BCl_3 are introduced into the chamber, decompose, and permit boron to precipitate onto the tungsten wire (Figure 1.11). SiC fibres are made in a similar manner, with carbon fibres as the substrate for the vapour deposition of silicon carbide.

Carbonising, or pyrolizing, an organic filament, which is more easily drawn or spun into thin, continuous lengths, makes carbon fibres (Figure 1.11b). The organic filament, known as a presursor, is often rayon (a cellulose polymer), polyacrylonitrile (PAN), or pitch (various aromatic organic compounds). High temperatures decompose the organic polymer, driving off all of the elements, but carbon.

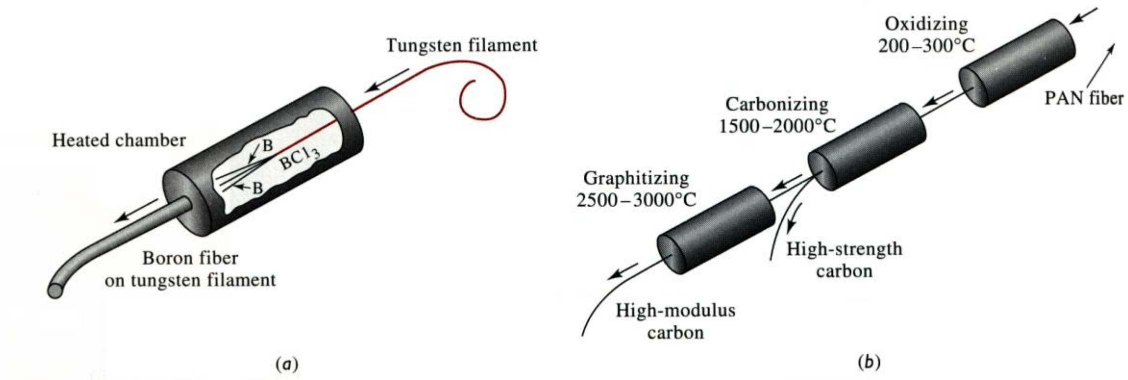


Figure 1.11 Methods for producing (a) boron and (b) carbon fibres.

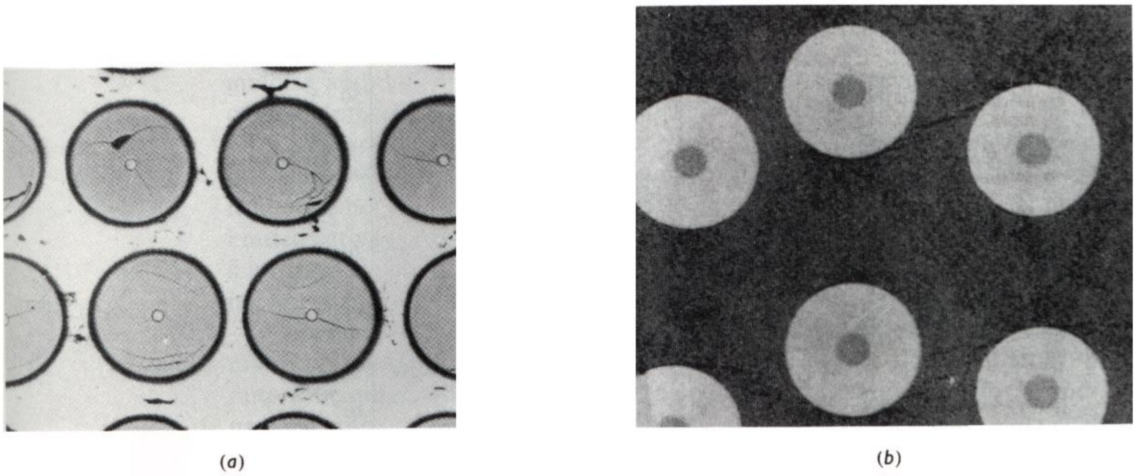


Figure 1.12 Photomicrographs of two fibre-reinforced composites: (a) In Borsic fibre-reinforced aluminium, the fibres are composed of a thick layer of boron deposited on a small-diameter tungsten filament. (x1000). (b) In this microstructure of a ceramic fibre-ceramic matrix composite, silicon carbide fibres are used to reinforce a silicon nitride matrix. The SiC fibre is vapor-deposited on a small carbon precursor filament (x125).

Producing the composite. A variety of methods for producing composite parts are used, depending on the application and materials. Mixing the fibres with a liquid or plastic matrix, then using relatively conventional techniques such as injection moulding for polymer-base composites or casting for metal matrix composites normally form short-fibre-reinforced composites. Polymer matrix composites can also be produced by a spray-up method, in which short fibres mixed with a resin are sprayed against a form and cured.

Fibre Reinforced Applications

Advanced composites

The term advanced composites is often used when the composite is intended to provide service in very critical applications, as in the aerospace industry (Table 1.3) The advanced composites normally are polymer matrix composites reinforced with high-strength polymer, metal, or ceramic fibres. Carbon fibres are used extensively where particularly good stiffness is required; aramid – and, to an even greater extent, polyethylene – fibres are better suited to high-strength applications in which toughness and damage resistance are more important. Unfortunately, the polymer fibres lose their strength at relatively low temperatures, as do all of the polymer matrices.

Advanced composites are also frequently used for sporting goods. Tennis rackets, golf clubs, skis, ski poles, and fishing rods often contain carbon or aramid fibres because the higher stiffness provides better performance. In the case of golf clubs, carbon fibres allow less weight in the shaft and therefore more weight in the head. Fabric reinforced with polyethylene fibres is used for lightweight sails for racing yachts.

A unique application for aramid fibre composites is armour. Tough Kevlar composites provide better ballistic protection than do other materials, making them suitable for lightweight, flexible bulletproof clothing.

Hybrid composites are composed of two or more types of fibres. For instance, Kevlar fibres may be mixed with carbon fibres to improve the toughness of a stiff composite, or Kevlar may be mixed with glass fibres to improve stiffness. Particularly good tailoring of the composite to meet specific applications can be achieved by controlling the amounts and orientations of each fibre.

Tough composites can also be produced if careful attention is paid to the choice of materials and processing techniques. Better fracture toughness in the usually rather brittle composites can be obtained by using long fibres, amorphous (such as PEEK and

PPS) rather than crystalline or cross-linked matrices, thermoplastic elastomer matrices, or interpenetrating network polymers.

Material	Applications
Borsic aluminium	Fan blades in engines, other aircraft and aerospace applications
Kevlar-epoxy and Kevlar-polyester	Aircraft, aerospace applications (including space shuttle), boat hulls, sporting goods (including tennis rackets, golf club shafts, fishing rods), flak jackets.
Graphite-polymer	Aerospace and automotive applications, sporting goods
Glass-polymer	Lightweight automotive applications, water and marine applications, corrosion-resistant applications, sporting goods equipment, aircraft and aerospace components.

Table 1.3 Examples of fibre-reinforced materials and applications

Aluminium is commonly used in metal matrix composites. Al_2O_3 fibres reinforce the pistons for some diesel engines; SiC fibres and whiskers are used in aerospace applications, including stiffeners and missile fins; and carbon fibres provide reinforcement for the aluminium antenna mast of the Hubble telescope. Polymer fibres, because of their low melting or degradation temperatures, are not normally used in a metallic matrix. Hot-extruding aluminium powder and high-melting temperature liquid crystalline polymers however produce Polymets. A reduction of 1000 to 1 during the extrusion process elongates the polymer into aligned filaments and bonds the aluminium powder particles into a solid matrix.

Metal matrix composites may find important applications in components for rocket or aircraft engines. Super alloys reinforced with metal fibres (such as tungsten) or ceramic fibres (such as SiC or B_4N) maintain their strength at higher temperatures, permitting jet engines to operate more efficiently. Similarly, titanium and titanium aluminides reinforced with SiC fibres are considered for turbine blades and discs.

Ceramic matrix composites. Composites containing ceramic fibres in a ceramic matrix are also finding applications. Carbon-carbon composites are used for extraordinary temperature resistance in aerospace applications. Carbon-carbon composites can operate at temperatures of up to 3000°C and, in fact, are stronger at high temperatures than at low temperatures. Carbon-carbon composites are made by forming a polyacrylonitrile or carbon fibre fabric into a mould, then impregnating the fabric with an organic resin, such as a phenolic. The part is pyrolyzed to convert the phenolic resin to carbon. The composite, which is still soft and porous, is impregnated and pyrolyzed several more times, continually increasing the density, strength and stiffness. Finally the part is coated with silicon carbide to protect the carbon-carbon composite from oxidation. Strengths of 2100 MPa and stiffnesses of 345000 MPa can be obtained. Carbon-carbon composites have been used as nose cones and leading edges of high-performance aerospace vehicles such as the space shuttle, and as brake discs on racing cars and commercial jet aircraft.

1.1.2.2.1 Fibre Reinforced Plastics (FRPs)

Backgound

In the early 1930s two chemical companies who were working on the development of polymer resins were American Cyanamid and Du Pont. In the course of their experimentation, both companies independently formulated polyester resin for the first time. During the same period, the Owens-Illinois Glass Company began weaving glass fibre into a textile fabric on a commercial basis.

Between 1934 and 1936, experimenter Ray Green, working in Ohio, combined these two new products and began to mould small boats. This marked the beginning of modern Fibre Reinforced Plastics. During World War II the development of radar required non-metallic housings, and the U.S. military advanced the fledgling composites technology with many research projects.

During the years immediately prior to the Second World War, great emphasis was placed on the development of a modern plastic material that could be used extensively in the equipment necessary to wage a war. In Germany in particular great pressure was put on the scientists to produce these new materials. Plastic production figures for 1937 show that 0.5 kg/person was produced in Great Britain, 0.7 kg/person in Germany and 0.6 kg/person in the USA. In 1939 the USA was the world's leading producer of plastics with 125 000 tones. Germany was second with 75 000 tones, and Great Britain third with 30 000 tones.

By 1945 however the output had risen enormously, particularly in the USA where it had increased by 4 000 tones, due mainly to the requirements of the war. Plastics available in those days were polystyrene; a wide range of vinyl plastics; acrylic plastics and their various copolymers, and polyethylene. This last material made airborne radar systems possible. As well as plastics, synthetic rubbers were also invented. In 1945 the total US production of all synthetic rubbers was 3 600 tones. Later on in 1947 regular production of polytetrafluorethylene (PTFE) was established.

The composites manufacturing industry began in earnest in the late 1940's and developed rapidly throughout the 1950's. Most of the composites processing methods used today were developed by the year 1955. In the 1960s and 1970s, advanced fibre composites - those reinforced with fibres having a higher performance (and higher cost) than glass fibres - were developed and applied/used primarily in military and aerospace applications. Despite the increase in the cost of fibre, the requirements of enhanced performance and reduced maintenance in military applications, and weight reduction in spacecraft and large commercial aircraft made composites cost effective.

In the United States composites manufacturing is a 25 billion dollar a year industry with an average growth rate of 7% per year since 1960. (MacNeil, 2001: 10-11). Composite materials are found in many of the products used in our daily lives – from the cars we drive, to the boats, recreational vehicles and even golf clubs we use.

Glass Material as the Reinforcement

The reinforced plastics industry originated using glass as the fibre and today a wide range of various glass fibre materials are available. Therefore, the most common reinforcement material today is glass and therefore the combination is called Glass Fibre Reinforced Plastic, or GFRP for short. This is usually abbreviated to GRP (glass reinforced plastic). There are variations on this abbreviated description. In America all glass fibre materials are referred to as Fiberglass, so instead of GRP, the designation FRP is normally used (fiberglass reinforced plastic) or just Fiberglass. In the United Kingdom, Fibreglass (with a different spelling of "fibre") is a registered trade name of Fibreglass Ltd., the foremost manufacturer of glass fibres in Britain (Warring, 1983:8).

There are many different types of glass, but for practical reinforcement only six types are produced in fibre form. Out of these only one is used on a very wide scale. This is 'E' glass, or electrical grade, which has excellent all-round properties and is suitable for almost all applications. The other common type 'A' glass or alkali glass is a little lighter and nearly as strong, but far less water resistant than 'E' glass. Being cheaper it was originally used for GRP mouldings, but is no longer in commercial production. All the other glass types are specials with only a limited production in fibre form. These are 'C' glass, a special chemical-resistant type-'S' glass and 'R' glass-special high-strength types used where very high performance is required (e.g. in mouldings for aerospace applications).

Glass fibre is produced in a range of filament diameters and strand dimensions to close tolerances for different uses. Typical size ranges for reinforcement materials are: -
Rovings and chopped strands-8-14μm, chopped strands mats-9-14μm, special rovings - 10μm, continuous strand mats – 14-15μm and reinforcement fabrics – 4-10μm.

All glass fibres must be treated with a liquid (e.g. known as size) when produced, the choice of sizing being a critical part of the product of glass fibre reinforcement materials. The size must not only protect the glass from abrasion whilst it is being drawn but also acts as a process aid during moulding. A typical 'forming' size used on reinforcement fibres comprises: -

(i) A keying agent to promote adhesion between the matrix and the glass. An organic silicon compound is most frequently used.
(ii) A film former, usually a polymer in emulsion form. In the past this has frequently been polyvinyl acetate.
(iii) A lubricant, usually acid amides.

Other materials can be added to give specific properties, such as anti-static, etc.

Reinforcement Materials

Continuous filament reinforcement grade glass fibres are converted into a variety of different materials for the production of GRP mouldings, etc. The most common form is chopped strands mats produced by chopping continuous filaments into lengths of about 50mm which are drawn down a hood to build up a loose mat form on a moving, open mesh conveyor. Binders are applied to hold the strands together and, after heating, the mat is compressed slightly and the bonded product is wound into rolls. Two principal binders are in use: powder and emulsion. Internationally, a polyester powder is the most widely used binder. When heated, this sticks the mat together where the glass strands cross each other. Powder-bonded mat is used for all types of moulding throughout the world.

The other type of binder is polyvinyl acetate emulsion used to coat each strand completely and again to stick the mat together. This type of binder has the particular advantage of dissolving rapidly in resin. Thus emulsion or 'liquid' bonded mats can be moulded much more easily into complicated shapes, compared with powder binder mats. In addition the form of the mat can also be varied to provide faster, easier wet cut, or controlled wet-cut, as required.

Chopped strands are also used on their own, particularly for producing polyester and alkyd moulding compounds for hot press mouldings and also for reinforcement of injection-moulded thermoplastics. The length of chopped strands available ranges from a minimum of about ⅛ in (3mm) to 2 in (50mm). The sizing of the fibres together with the length and diameter of the strands can be selected to provide high strand integrity, low filamentation and compatibility with different polymers. Again therefore, there is a choice of chopped strand material available for specific purposes.

Yarns are produced from continuous filament by a twisting process which puts from 20 to 40 turns per metre into strand before being wound on to bobbins for weaving etc. Twisting several single yarns together produces plied yarns.

Rovings take the form of cylindrical 'packages' wound from several strands of reinforcement gathered into a bundle with no twist. They are used for weaving cloths, for filament wound GRP mouldings, and as chopping rovings for 'gun' applications with hand or mechanical chopping process. Chopped rovings are also used in the production of dough moulding compounds (DMC) and bulk moulding compounds (BMC). Woven fabrics have higher strength than mats as reinforcement materials, but one of their chief advantages is consistency of form (e.g. uniform thickness and weight). They are produced from yarn (woven glass cloth) and rovings (woven rovings).

Woven glass cloths are obtainable in various thicknesses - e.g. in weights from about 300g/m^2 upwards. Woven cloths drape well and "wet out" (with resin) fairly easily. They are often used as a reinforcement layer or layers in conjunction with glass fibre mat, or as a simple means of adding bulk to increase stiffness.

Woven rovings are normally used for reinforcing glass mat layers, and also to add bulk and improve stiffness. They are widely used for strength purposes in boat hull construction.

For many applications a heavy fabric made from rovings is a preferred choice because it is the least compacted form of woven glass fibre, wets out more quickly and picks up far less resin than other fabric materials. The construction of a woven fabric can be varied to provide particular characteristics required from the reinforcement material. Tensile strength can be balanced in all directions, or given a maximum value in a particular direction by suitable arrangement of warp and weft directions. The type of weave also largely governs the drape characteristics of the fabric as well as affecting the ease of wetting out.

The plain types of weaves used are: -

Plain weave (see Figure 1.13) - having a simple structure in which each warp and weft yarn passes over one end or pick and under the next. This construction gives a reinforcement fabric that is widely used in general applications and can be relied upon to give reproducible laminate thickness. Tightly woven plain weave fabrics are sometimes difficult to quickly saturate with resin.

Figure 1.13a Schematic of plain weave strands alternately crossing over and under.

Figure 1.13b Schematic of twill weave in woven cloth for general purpose use.

Twill Weave - the number of wrap ends and weft picks which pass over each other can be varied to give twills of various constructions, such as the 2x1 example shown. The diagram shows how the weft yarn passes under two warp ends and then over one warp end. The interlacing is arranged regularly forming a distinct diagonal line on the cloth surface. Twills will follow contours more easily than plain fabrics and are much easier to wet out.

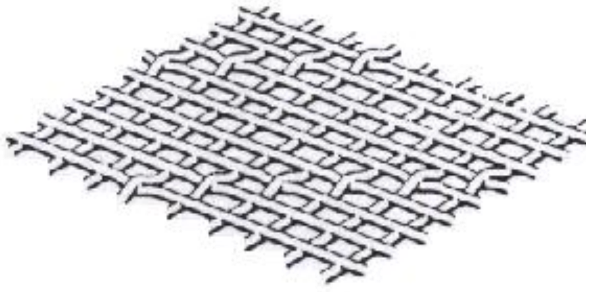


Figure 1.14a Schematic of satin weave. Satin weave produces a smooth cloth.

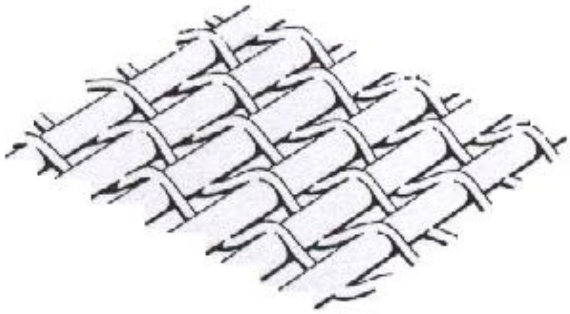


Figure 1.14b Schematic of unidirectional weave where the cloth is appreciably stronger in one preferred direction.

Satin Weave - similar to twills, but the number of ends and picks which pass over each other before interlacing is greater. The interlacing is always with one crossing threat so that one side of the fabric is comprised mainly of warp yarns and the other of weft yarns, as illustrated in Figure 1.14a. Among the several characteristics that make satins eminently suitable as reinforcement fabrics are: excellent drapeability, smooth surface, minimum thickness, and high tensile and flexural strengths.

Matt Weave - have two or more threads woven as a single thread in both directions and can be produced in plain, twill, satin and other weaves.

Unidirectional Construction - gives a fabric with mechanical properties most favourable in one direction (see Figure 1.14b). The fabric may be of plain, satin or any other weave. In addition various hybrid constructions are produced for special applications, or to provide a glass fibre product competitive with cotton fibre or aramid fibre reinforcements.

Glass fibre tissue or surfacing tissue was originally developed to hide the pattern of glass cloths when laid up in matched metal moulds, and also to be used as a 'cushioning' layer between the gel coat and the main reinforcement layers in any moulding or lay-up produced in a female mould. For general use it has two main applications: -

(i) as a finishing layer on a chopped strand mat lay-up to cover up the coarse glass pattern of the mat before adding a final gel coat,

(ii) as a finish applied over a set gel coat. Again this will prevent any glass pattern appearing in the finished surface. It also provides some reinforcement for the gel coat.

Modern surfacing tissues are produced in 0.25mm (0.01in) and 0.4mm (0.016in) thickness from chemically resistant glass giving maximum resistance to both acids and alkalis. The thicker tissue gives a better surface finish in laminates with a heavy fibre pattern, therefore improving the weathering properties. Another form of surface tissue known as overlay veil is produced specifically for use in closed mould processes and has special crease resistant properties. It would not normally be used for hand lay-up moulding, largely because of its low binder content (4% as against 7-11% in surfacing tissues). A styrene binder is used with glass fibre tissues, being highly soluble in polyester resins (Warring, 1983: 8).

Sandwich Structures

Sandwich materials have thin layers of a facing material joined to a lightweight filler material, such as a polymer foam, as shown in Figure 1.15. Neither the filler nor the facing material is strong or rigid, but the composite possesses both properties. A familiar example is corrugated board. A corrugated core of paper is bonded on either side to flat, thick paper. Neither the corrugated core nor the facing paper is rigid, but the combination is.

Another important example is the honeycomb structure used in aircraft applications. Bonding (e.g. gluing) thin aluminium strips at selected locations produces the honeycomb material. The honeycomb material is then expanded to produce a very low-density cellular panel that, by itself, is unstable. When an aluminium facing sheet is adhesively bonded to either side of the honeycomb, however, a very stiff, rigid, strong and exceptionally lightweight sandwich with a density as low as 0.04 g/cm^3 is obtained.

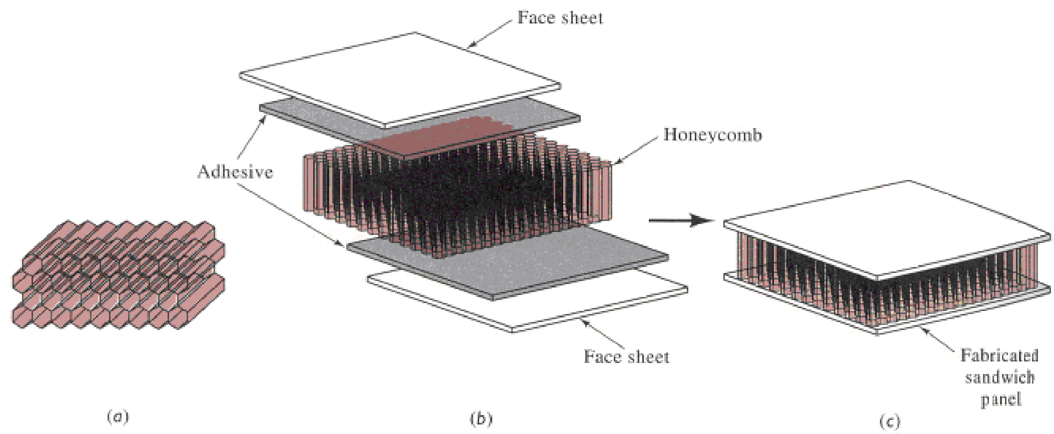


Figure 1.15 A hexagonal cell honeycomb core (a) can be joined to two face sheets by means of adhesive sheets (b), producing and exceptionally lightweight yet stiff, strong honeycomb sandwich structure (c).

The honeycomb cells can have a variety of shapes, including hexagonal, square, rectangular, and sinusoidal, and they can be made from aluminium, fibreglass, paper, aramid polymers, and other materials. The honeycomb cells can be filled with foam or fibreglass to provide excellent sound and vibration absorption. Figure 1.16 illustrates one method by which the honeycomb can be fabricated.

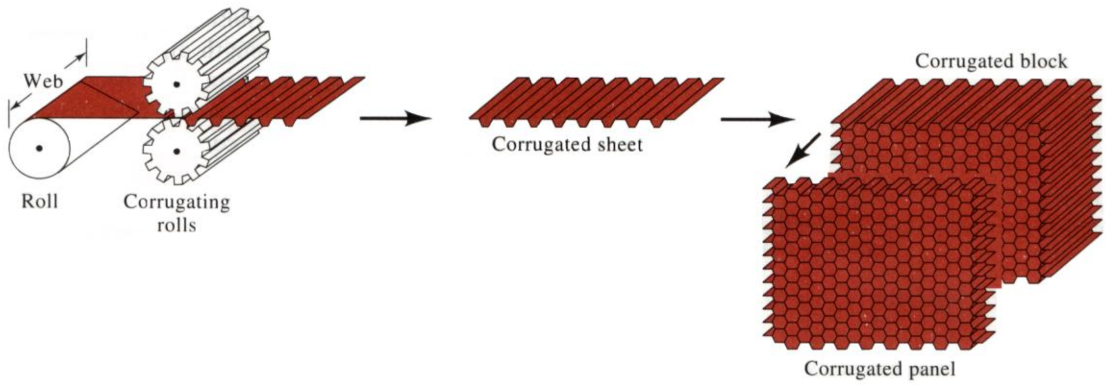


Figure 1.16 In the corrugation method for producing a honeycomb core, a roll of the material (such as aluminium) is corrugated between two rolls. The corrugated sheets are joined together with adhesive and then cut to the desired thickness.

Resins

By far the majority of GRP mouldings are produced using unsaturated polyester resins. 'Unsaturated' means that the resin is capable of being 'cured' from a liquid to a solid state, this being brought about by dissolving the polyester in a suitable monomer, usually styrene. A polyester resin of this type can be made to set in the form of a hard and permanent solid by the addition of a catalyst, and satisfactorily moulded without the use of pressure. In this state the resin is said to be cured, or polymerised.

Curing with just the addition of a catalyst also requires heat to complete the process. However, the resin can be made to set at room temperatures, or 'cold cure', by the further addition of an accelerator. The two types of cure are essentially the same. With cold curing, heat is actually produced exothermically (or internally, as far as the resin is concerned), and so the end result is exactly the same. Resin plus catalyst, hot cured, has the same characteristics as resin plus catalyst plus accelerator, cold-cured. While the wide range of different polyester resins available covers the requirement of most GRP mouldings, other resins may be used for particular application (e.g. for better resistance to attack by certain chemicals). These are (Warring, 1983:21-28):

(i) Epoxide resins (or epoxy resins) - which are a typical alternative choice where polyester resins may not show all the properties required. They are, however, appreciably more expensive than polyester resins;

(ii) Furane resins - which are produced by the self-condensation of Furfurol with Furfurol alcohol have even better resistance to certain chemicals than epoxy;

(iii) Silicone resins - an expensive type of resin, also with less strength than polyester or epoxy resins but capable of withstanding higher temperatures without degradation. They have very limited applications, however, and are little used except for very specialised applications;

(iv) Phenolic resins - these resins are produced by condensing phenol with formaldehyde. These resins have only specialised applications and until recently such moulding resins were only available in powder form for use with compression moulding techniques. Some liquid types are now available, however, which are suitable for hand lay-up mouldings.

Gel coat resins are formulated in a different way from resins used for laminating. They need to be an air-inhabited type, which sets rapidly on the surface in contact with the mould but remains tacky on the other side of the film whilst still exposed to air. This ensures a good bond to the first layer of the laminate. Gel coats, when applied, need to dry to a high gloss finish, and provide a certain degree of resilience as well as a thin surface layer which will not readily crack or deteriorate - properties which have to be provided by the resin itself since the gel coat contains no reinforcement. The resin gel is also the one layer in which coloured pigments (and sometimes also filler) are incorporated to produce a moulding with colour.

A *general-purpose resin* is the most common type of laminating resin, which is also the lowest in cost. It is suitable for all types of GRP work and is most widely supplied in pre-accelerated form, with a standard catalyst.

Fire-retardant resins are another category of resins used. The description "fire-retardant" is sometimes given to resins specially formulated to improve resistance to flame, or to give self-extinguishing properties. A more accurate description is "reduced-flammability resin" since such resins are not 'fireproof' as such. Basically they provide a low fire hazard whereas an ordinary polyester resin will burn freely once ignited.

Special chemically resistant polyester resins are formulated to provide enhanced resistance to mineral acids, inorganic salts, fats, oils, etc. at moderate temperatures.

Reduced Styrene Emission resins are general purpose resins formulated with additives to give substantially reduced styrene volatilisation during lamination - also called environmental resins because of the improved working atmosphere resulting.

Thixotropic or 'non-sag' resins may be of various types; the main feature being the incorporation of an additive which prevents the resins running and thus draining off vertical surfaces in a lay-up. Ordinary resins can also be made 'non-running' by the addition of thixotropic agents.

Non-thixotropic resins are used for particular applications where the property of the resin being free to 'run' is an advantage-e.g. the production of castings, or for flow coatings used in certain commercial productions.

Casting resins are specially formulated for casting work. Their properties are 'tailored' to the characteristics required, e.g. good optical properties for resins used for decorative work or embedding botanical or zoological specimens, or good dielectric properties for resins used to encapsulate electronic components. Low volumetric shrinkage is also important in a casting resin.

Flexible resins are used for blending with a more rigid resin to vary the 'elastic' properties, and thus control the resilience of the finished GRP moulding.

Plasticised resins are softened resins, produced by the addition of a plasticising agent such as dimethyl phthalate. They are used in the formulation of resins as thread locking compounds, and resins for the production of large castings.

Clear resins are also known as 'rooflite' resins, translucent resins, etc., and are light-stabilised resins, intended for use in the production of translucent rooflight sheeting, decorative panels, etc. They are formulated to give optimum optical properties with freedom from discoloration with age, i.e. are particularly resistant to ultra violet light.

'Rapid' resins are pre-accelerated resins where the accelerator used, and matching catalyst, produce fast gel and hardening times. They are intended mainly for emergency repairs work, but can also be used for general work in colder weather provided the mouldings involved are not too large.

Special-purpose resins are formulated to enhance specific properties and are not normally generally available. They are intended for commercial productions calling for properties not met by standard resins. Examples are resins produced specifically for moulding by resin injection or cold pressing processes.

Additives

Pre-accelerated resins are normally the most convenient to use since the accelerator proportions are already adjusted to give the most suitable gelling and hardening characteristics, once the catalysts is added to start the curing reaction at room temperature. If a 'straight' resin is used, the accelerator and catalyst must be added separately, the order of mixing depending on the particular application involved. With a pre-accelerated resin, addition of the catalyst (or hardener, as it is often called) will immediately start the cold-curing process, causing the resin to thicken and gel, and finally set hard. The resin has a usable pot life over a period during which it is thickening, but still remains workable. The gel time is governed mainly by the amount of accelerator present. The less the amount of accelerator used the longer the gel time will be. Cutting down the amount of catalyst will also increase the gel time, but here there is a danger of having insufficient catalyst present, which can lead to an under cured moulding.

Quite a number of different chemical compounds are effective as accelerators in promoting cold setting of polyester in the presence of a catalyst. Some have only a limited use (such as tin, vanadium and zirconium salts and certain ammonium compounds). Others are highly reactive, and normally used. These include metallic soaps (usually cobalt soap); and tertiary amines (such as dimethyl amine). An amine accelerator tends to produce a yellow discoloration in time. If the two types of accelerator are used together, however, much faster gelling and setting times can be realised. This method is used to produce a 'rapid' accelerator.

The catalysts used with polyester resins are almost invariably organic peroxides. These are unstable on their own - and can even explode. They are therefore normally supplied dispersed in a plasticiser in the form of a paste or a liquid, or in dry powder form mixed with an inert filler.

The main peroxide based catalysts are (Warring, 1983:30):

(i) Methyl-ethyl-ketone-peroxide - which is probable the most reactive type, normally produced as a liquid.

(ii) Cyclohexanone-peroxide - which is less reactive, but more stable. It is normally prepared in paste form.

(iii) Benzole-peroxide - which again very reactive and is normally available in either paste or powder form.

The catalyst or hardener initiates the setting action of the resin. The accelerator merely takes the place of heat - i.e. in the absence of the accelerator the catalysed resin can be cured by heat; or in the presence of accelerator the catalysed resin will cure at normal room temperatures. The accelerator must, therefore, be present in sufficient quantity to activate the catalyst, if complete cold curing is to be produced in a short period of time. If there is a small deficiency of accelerator the gel time will be increased, while a larger deficiency of accelerator will result in undercuring, or very slow hardening. The proportion of accelerator, therefore, is not critical, provided there is enough. Usually this is between 1 and 4% of resin weight, with the normal 'strength' of the accelerator as manufactured (e.g. typically a dilution giving 1% metal in the case of a cobalt soap) (Warring, 1983:30).

From the moment the catalyst is activated (either by heat or contact with the accelerator), the resin starts to set. Setting takes place over four definite stages:

(i) *Pot life time* - during which the resin still remains in workable liquid form although it is continuing to thicken.

(ii) *Gel time* - or the time taken for the resin to set to a soft gel.

(iii) *Hardening time* - which is the further time taken for the resin to become hard enough for the moulding to be removed from its mould.

(iv) *Maturing time* - which is the further period of time over which the moulding will continue to gain hardness and, eventually matured the moulding will have its maximum strength, hardness, chemical resistance and stability.

The hardening time can vary a lot depending on the size and thickness of the moulding, and also the proportion of resin present. The air temperature will also again affect it; the warmer the air the more quickly the moulding will harden off. The majority of general-purpose FRP mouldings can be considered suitable for use 24 hours after their hardening time has elapsed. Where the application is more critical, such as FRP boats hulls, water or petrol tanks, etc., or articles which must have good chemical resistance, a maturing time of several days, or even weeks may be necessary.

Common manufacturing processes in the fibre-reinforced plastics industry

There are two general divisions of composites manufacturing processes: open moulding (sometimes called contact moulding) and closed moulding. During open moulding, the gel coat and laminate are exposed to the atmosphere during the fabrication process. In closed moulding, the composite is processed in a two-sided mould set, or within a vacuum bag. There are a variety of processing methods within these moulding categories (Warring, 1983:9-12):

(i) Open mould processes - hand lay up that includes manual and mechanical resin application; chopped laminate processes that include atomised and non-atomised spray –up.

(ii) Closed mould processes - Vacuum Bag Moulding; Resin Transfer Moulding (RTM).

(iii) Hot mould processes - Sheet moulding Compound (SMC); Bulk Moulding Compound (BMC).
(iv) Continuous processes - Pultrusion; Filament Winding; Centrifugal Casting

Other moulding techniques are also available, e.g. Reinforced Reaction Injection Moulding (RRIM), Vacuum Infusion Processes, etc. These techniques are not commonly used in South Africa.

Open Mould Processes

Open mould processing, which is also called low-pressure moulding or contact moulding, accounts for the majority of reinforced plastic products manufactured in South Africa. This covers processes such as hand lay-up, spray-up and reinforced plastic vacuum forming. The open mould process is ideally suited for the production of large complex industrial mouldings and involves low tooling cost, simple processing and relatively low investment in processing equipment. It is important to note that for reasons of health, adequate ventilation of the working area is a critical consideration. As the name implies, the open-mould processes employ a single cavity mould (usually female), which produces parts with only one finished surface.

Hand lay-up

Hand lay-up is the simplest method of manufacturing reinforced plastic products. It is best suited to low volumes of production and to large parts requiring high strength. The process is labour intensive, requiring both a high labour output per unit and a fairly high level of skill on the part of the operator. The reinforcement which is in the form of a mat, roving or woven fabric is cut and fitted to the contours of the mould as shown in Figure 1.17. In products where a high surface finish is required, a gel coat is applied inside the mould before the reinforcing is applied. The number of layers of reinforcement used varies according to the strength required from different parts of the moulding.

The reinforcing is then saturated with resin, which is applied by pouring, brushing or spraying the resin onto the reinforced material. The equipment used in this process includes squeegees, paintbrushes and specially designed rollers. These hand tools are used to wet the reinforcement thoroughly and expel any entrapped air (see Figure 1.18). The formation of bubbles could alter the structural integrity and also negatively affect the visible appearance of the product.

The bonding resin hardens at room temperature, but for very large mouldings or to increase production output, the mouldings are often placed in very large heated rooms which are regulated at temperatures approximately 10 – 20 degrees above ambient. The resin that is used needs to be pre-mixed with a hardener or catalyst, and therefore volume-measuring equipment is used to measure liquids.

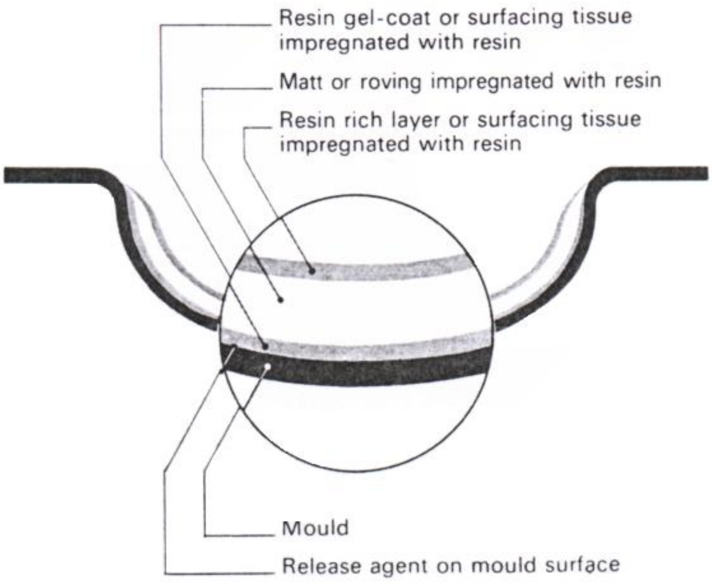


Figure 1.17 Hand lay-up (Warring, 1983:9)

Low-density core materials, such as end-grain balsa, foam, and honeycomb, are commonly used to stiffen the laminate. The hand lay-up system is used to manufacture a broad variety of products, such as tanks, pools, boats, truck cabs, building panels and housing for industrial equipment. With the present increase in labour cost, there is a tendency to mechanize parts of the process.

Figure 1.18 Hand lay-up process

Spray-up (chopping)

The spray-up process is a more mechanized version of the open mould processing system as shown in Figure 1.19 It is based on a process very similar to the spraying of paints. The moulds that are used are very similar to those used in the hand lay-up process, but the material is applied by means of a spraying machine.

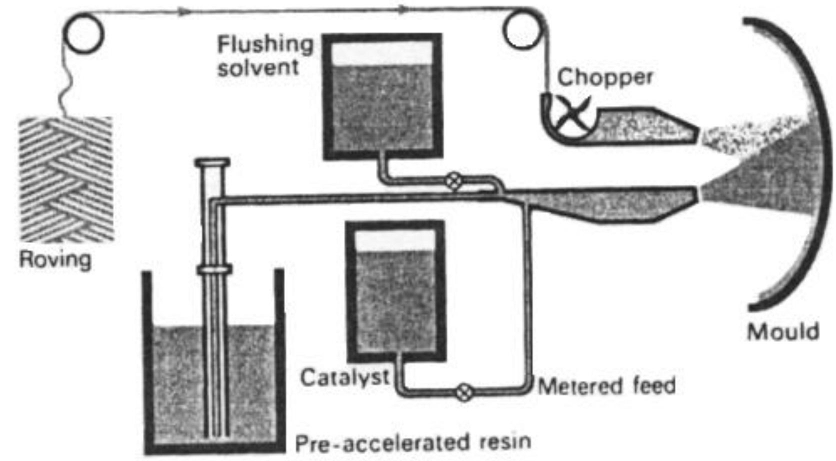


Figure 1.19 Spray-up (chopping) process (Warring, 1983:9-10)

Machines for spray-up are designed around a spray gun, which is similar to a paint spray gun. The more recent machines make provision for the mixing of resin and catalyst. The machine has an attachment to chop glass fibres, which are fed into the machine as continuous strands. The fibres are chopped and fall into the resin spray. The resin spray then projects the glass fibre onto the surface, which is coated with a mixture of resin droplets and glass fibres.

The main disadvantage of this method is that the wall thickness of the article is controlled by the amount of the material sprayed onto a particular area. This means that it is not as easy to control as hand lay-up where a certain thickness of glass mat is used.

The product range is very similar to that of hand lay-up, namely boats, panels, display signs, but in addition it is very useful for "in situ" operations such as tank linings, roofing and construction forms.

Closed moulding process

Vacuum bag moulding

The mechanical properties of open-mould laminates can be improved with vacuum bagging. By reducing the pressure inside the vacuum bag, external atmospheric pressure exerts force on the bag. The pressure on the laminate removes entrapped air, excess resin, and compacts the laminate. A higher percentage of fibre reinforcement is the result. Additionally, vacuum bagging reduces styrene emissions. Vacuum bagging can be used with wet-lay laminates and prepreg advanced composites. In wet lay-up bagging the reinforcement is saturated using hand lay-up, then the vacuum bag is mounted on the mould and used to compact the laminate and remove air voids as shown in Figure 1.20.

In the case of pre-impregnated advanced composites moulding, the prepreg material is laid-up on the mould, the vacuum bag mounted and the mould is heated or placed in an autoclave that applies both heat and external pressure, adding to the force of atmospheric pressure. The prepreg vacuum bag-autoclave method is most often used to create advanced composite aircraft and military products.

In the simplest form of vacuum bagging, a flexible film (PVA, nylon, Mylar, or polyethylene) is placed over the wet lay-up, the edges sealed, and a vacuum drawn. A more advanced form of vacuum bagging involves placing a release film over the laminate, followed by a bleeder ply of fibreglass cloth, non-woven nylon, polyester cloth, or other material that absorbs excess resin from the laminate. A breather ply of a non-woven fabric is placed over the bleeder ply, and the vacuum bag is mounted over the entire assembly.

Pulling a vacuum from within the bag uses atmospheric pressure to eliminate voids and force excess resin from the laminate. The addition of pressure further results in high fibre concentration and provides better adhesion between layers of sandwich construction. When laying non-contoured sheets of PVC foam or balsa into a female mould, vacuum bagging is the preferred technique to ensure proper secondary bonding of the core to the outer laminate.

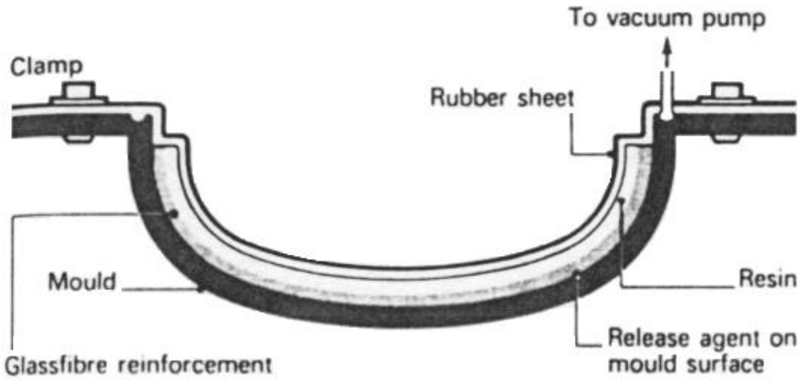


Figure 1.20 Vacuum bag moulding (Warring, 1983:9-11)

The advantage of bag processing is that it can produce laminates with a uniform degree of consolidation, while at the same time removing entrapped air, thus reducing the finished void content. Structures fabricated with traditional hand lay-up techniques can become resin rich and vacuum bagging can eliminate this problem. Additionally, complete fibre wet-out can be accomplished if the process is done correctly. Improved core bonding is also possible with vacuum bag processing.

Resin transfer moulding (RTM)

Resin transfer moulding is an intermediate volume moulding process for producing composites. The RTM process is to inject resin under pressure into a mould cavity. RTM uses a wide variety of tooling, ranging from low cost composite moulds to temperature controlled composite of metal tooling (see Figure 1.21). This process can be automated and is capable of producing rapid cycle times. Vacuum assist can be used to enhance resin flow in the mould cavity. If required, the mould set is conventionally gel coated. The reinforcement (and core material) is positioned in the mould and the mould is closed and clamped.

The resin is injected under pressure, using mix meter injection equipment, and the part cured in the mould. The reinforcement can be either a preform or pattern cut roll of stock material. Preforms are reinforcements that are pre-formed in a separate process and can be quickly positioned in the mould. RTM can be done at room temperature; however, heated moulds are required to achieve fast cycle times and production consistency.

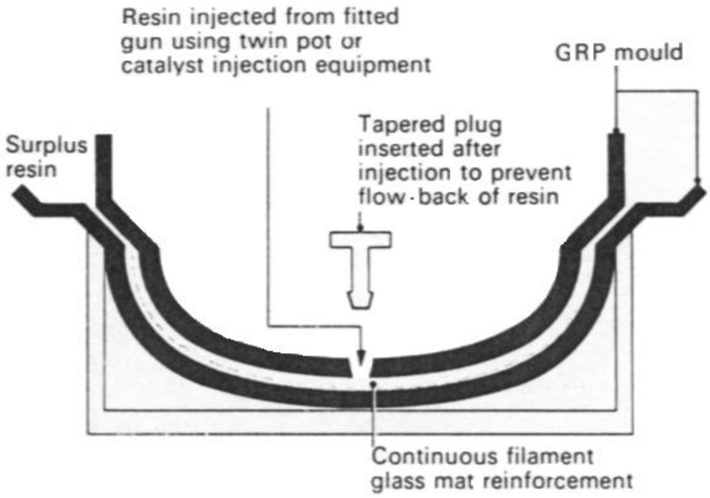


Figure 1.21 Resin Transfer Moulding (Warring, 1983:12)

One of the major advantages of this closed moulding process is that it produces parts with two finished surfaces. By laying up dry reinforcement material inside the mould, any combination of materials and orientation can be used, including 3-D reinforcements. Part thickness is determined by the tool cavity. Fast cycle times can be achieved in temperature-controlled tooling and the process can range from simple to highly automated.

Hot Mould Processes

Compression moulding is a high-volume, high-pressure method suitable for moulding complex, fibreglass-reinforced plastic parts on a rapid cycle time. There are several types of compression moulding including: sheet moulding compound (SMC), bulk moulding compound (BMC), thick moulding compound (TMC), and wet lay-up. Compression moulding tooling consists of heated metal moulds mounted in large presses (Composites Fabricators Association, 2000:2-4).

Sheet moulding compound (SMC) is a glass-fibre reinforced resin composition that can be manufactured in a highly mechanized continuous-flow process. As the name implies, SMC is supplied in sheets, which are produced by depositing glass fibres and a layer of resin paste onto a carrier film. During the moulding the heat of the die melts the material and allows it to flow in the moulds before polymerisation. In SMC, generally speaking, longer fibres are used than is the case in Bulk Moulding Compound (BMC) and thus the products made from SMC has better physical properties.

Bulk mouldings compounds (BMC) are a mixture of resin and short glass fibres (up to 10 mm in length). The resin contains fillers, catalyst, pigment and other additives depending on the requirements for flame retardancy, shrink resistance, etc. Its consistency is similar to that of modelling clay and it can be provided in bulk or extruded into rods for easy handling.

The BMC is introduced into the matched – die mould in pre-determined quantities and the same cycle as in normal matched - die moulding is used. This material is used mainly for complicated mouldings such as electrical switchgear, appliance housings, impeller blades and pump housings.

The major advantages of compression moulding processes are that they produce fast moulding cycles and high part uniformity. The processes can be automated. Good part design flexibility and features such as inserts, ribs, bosses and attachments can be moulded into the design. Good surface finishes are obtainable, contributing to lower part finishing cost. Subsequent trimming and machining operations are minimized in compression moulding therefore labour costs are low.

Continuous Processes

Pultrusion

The pultrusion process is an automated open-end moulding method that continuously produces reinforced composite profile shapes with a consistent thickness, limited in length only by the size that can be conveniently handled. The shapes that are made by this process are structural forms (with a constant cross section) such as I-beams, channel, wide-flange beams, solid bars, rods, round and square tubing, rectangular beams, angles and flat sheet. In essence, this process consists of a mixture of continuous glass-filaments, which are drawn together with a predetermined ratio of resin through a profile die, thus forming a profile with longitudinal glass-fibre reinforcement.

During the process the die, which is usually oil or electrically heated, cures the resin and is therefore a continuous method with no subsequent curing needed. Moulded urethane pulling blocks, shaped to fit both the top and bottom of the pultrusion, grasp the pultrusion and pull it from the die at a pre-determined speed, as shown in Figure 1.22. This pulling action draws the combination of glass-fibre and resin into the desired shape.

In pultrusions, the glass content ranges from 30% glass: 70% resin sheet to a combination of 75% glass and 25% resin in solid pultruded bars and rods. In pultrusion systems, generally speaking, fillers are incorporated in the mix system, except when solid round and square rods are pultruded (Plastics Federation of South Africa, 1990:6-6). To increase weatherability of the finished product, polyester woven fabric is incorporated as a surfacing material. This is continuously fed during the pultrusion process.

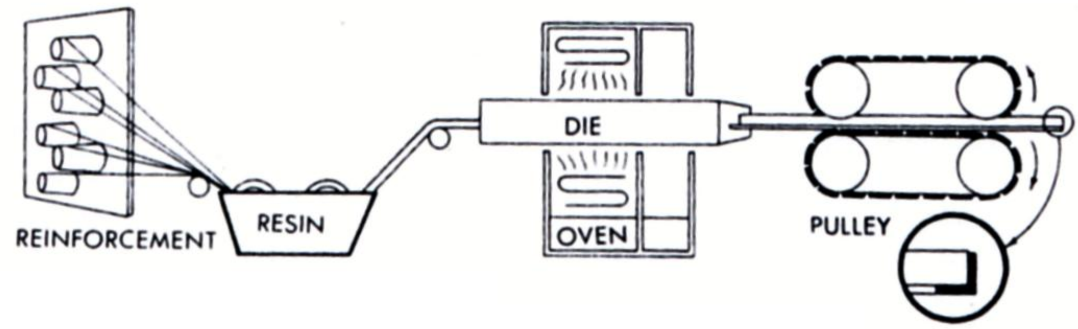


Figure 1.22 Basic scheme of continuous pultrusion
(Richardson, T.L, Lokensgard, E, 1997:219).

A pultrusion machine consists of a series of bobbins from which glass fibres can be unwound through a chamber in which the resin component is fed into the total system. This leads into the heated chamber, which cures and forms the product virtually simultaneously through the drawing block system. This passes into a cutting station, where the pultrusion is cut into the lengths required as ordered by the customer. As is the case with all machinery processing glass-containing products, there is a fairly high degree of abrasion, which affects the die shape. To minimize this wear, all pultrusion dies are hard chrome-plated.

Many structural shapes in the chemical industry have major corrosion problems. These units can be manufactured from reinforced plastics using the pultrusion method. Products such as frameworks, supports, bridging, walkways, handrails and other structural units that need to be corrosion resistant are perfect examples. In other special constructions, reinforced plastic pultruded sections have been used where a low mass and favourable strength-to-mass ratio, as well as corrosion resistance properties were required.

Filament winding

As shown in both Figures 1.23 and 1.24 filament winding uses the principle of winding continuous glass-fibre around a mandrel and simultaneously saturating the wound glass-fibre with the resinous binder. The mandrel usually is a male surface with the outer surface having exactly the same dimensions of the inner surface of the product required. The limitation with filament winding is that all products that are made by this process are, of necessity, cylindrical in shape. The main products manufactured using this method are tanks and pipes.

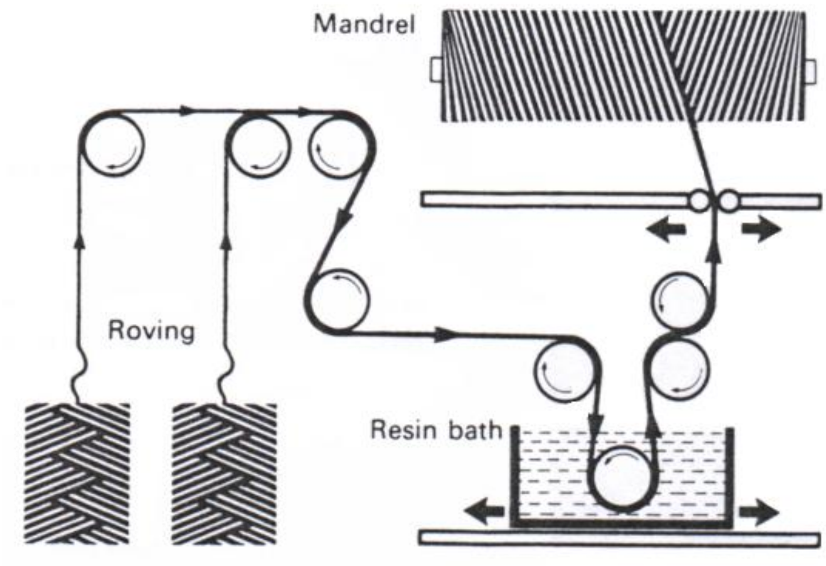


Figure 1.23 Filament winding (Warring, 1983:10)

Filament winding is generally classified by the filament orientation to the longitudinal centre-line of the body of revolution being wound. There are only two fundamental modes (Composites Fabricators Association, 2000: 2-4):

(i) Helical, where the filament is placed at some angle other than 90 or 0 degrees to the longitudinal centre-line, and
(ii) Polar, where the filament is placed in circles through the poles of the body revolution as nearly parallel to the longitudinal centre-line as the mandrel shaft or other end fittings will permit.

Filament winding machines are normally fairly large pieces of equipment and the products that can be manufactured range from as small as the caps on swimming pool filters to tanks 8m in diameter and 14 m in height. Filament-wound products are produced for their favourable strength-to-mass ratio. The thermoset resin favoured is not only temperature resistant but is also resistant to most corrosive materials. For this reason filament-wound acid and alkali storage tanks are quite common.

Figure 1.24 Filament winding of a GRP pipe

Other products are corrosion resistant piping and stack-liners for treating gaseous corrosive effluents. A major use of this process is to reinforce other types of materials. For example, the burst resistance of metallic cylindrical structures such as air tanks, is increased when overwrapped using the filament winding process.

Centrifugal Casting

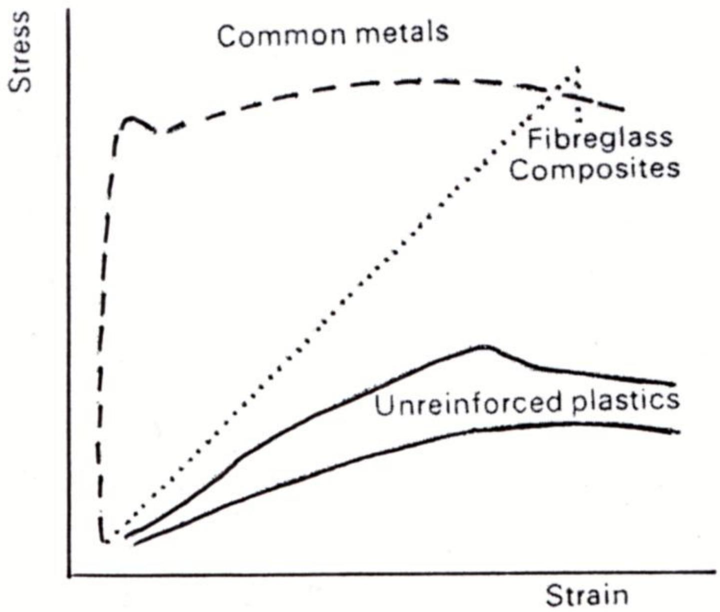
Hollow cylindrical parts such as tanks, containers, pipes or tubing can be produced in high volumes by centrifugal casting. There are two variations on this system (Plastics Federation of South Africa, 1990: 6-7).

The two-way process. Here, a hollow cylindrical mould is used. A glass fibre mat is placed inside the mould for reinforcement and the whole assembly is rotated. Resin is then sprayed into the hollow mould via a spray gun mounted to a telescopic arm, which can reach the total inner surface area of the cylinder. By rotation, the hollow mould, the glass and the resin are forced tightly against the wall of the cylinder and a dense moulding is ensured.

The one-step process. This process is basically a development of the original two-way process. It is more sophisticated in that the resin and the glass fibres are applied in one single operation instead of just having a spray gun attached to the telescopic arm that can move on the axis of the cylinder. An attachment to chop fibres as in the spray-up method is also included. Apart from that the process is similar to the two-step method. The wall is built up from resin and fibre and after the acceptable wall thickness has been reached, the product is cured inside the mould and subsequently removed.

Properties of Fibre-Reinforced Plastics

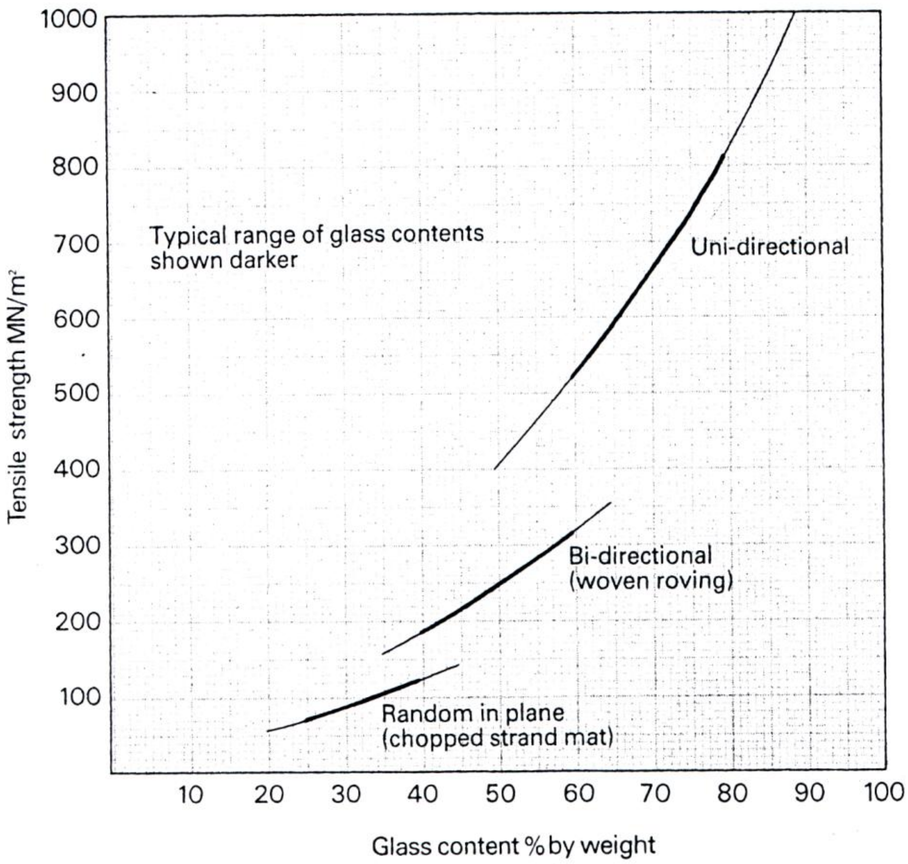
The stress/strain characteristics of fibre-reinforced plastics are different to most metals and plastics. Short term testing gives a linear stress/strain curve and there is no yield. Graph 1.1 illustrates the difference. The design of GRP is usually carried out on the basis of ultimate strength, using a safety factor, whereas with steel, design is usually based on the yield strength with a safety factor.



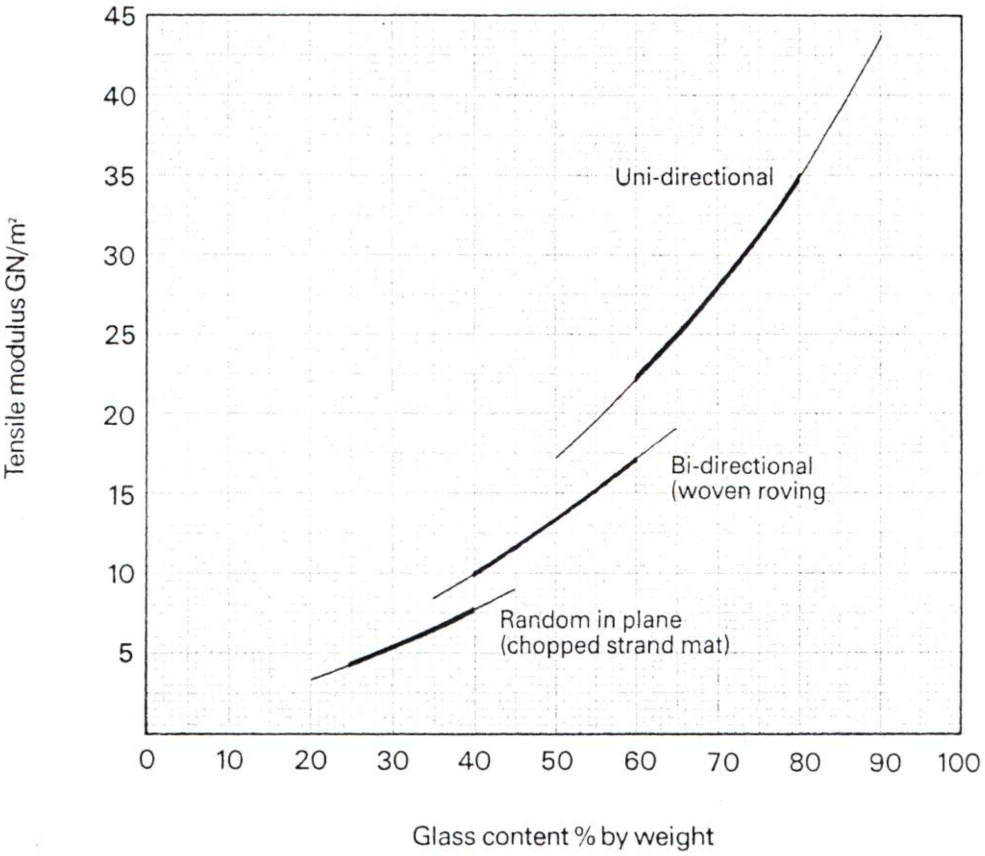
Graph 1.1 Stress/Strain Curves

The main difference between design using composite materials and design using conventional materials is that the designer is not compelled to select the most suitable material from a fairly small range. He is also able to design the material itself to have the particular properties that he wants. This greatly enhances the versatility of the materials and when fully utilized can enable the designer to produce highly competitive designs.

Extrapolation from empirical data and mathematical models may be used to predict the properties of composites with reasonable accuracy as shown in Graphs 1.2 and 1.3.



Graph 1.2 Tensile strength vs. glass content



Graph 1.3 Tensile modulus vs. glass content

In B.S. 4994 (*See section 1.1.4*) a term is used which is the equivalent of ultimate strength. It is the ultimate tensile unit strength (U.T.U.S.) in which the strength of the material is measured not simply in terms of load per cross sectional area, but in terms of load per width per mass of reinforcement, i.e. N/mm per kg/m² of glass fibre.

Conservative values of U.T.U.S. for glass fibre/polyester may be taken to be N/mm width per kg/m² of glass fibre for random reinforcement. Values used are: 300 N/mm width per kg/m² of glass fibre for bi-directional reinforcement and 490 N/mm width per kg/m² of glass fibre for uni-directional reinforcement.

Similarly, the equivalent of the elastic modulus may be quoted in the same units. This is known as the extensibility, and the values generally used are: 12700 N/mm width per kg/m² glass for random reinforcement, 16200 N/mm width per kg/m² glass for bi-directional reinforcement and 21000 N/mm width per kg/m² glass for uni-directional reinforcement.

Of course, one potential drawback to this method is that the strength attributed to the resin is taken to be the same, regardless of actual strength. However, over a fairly restricted range of glass contents the error is negligible, as can be seen in Graph 1.3 (Pilkington Glass Reinforcements, 1985:69-72).

Mechanical properties

The mechanical properties of a composite will be influenced by the mechanical properties of its constituent parts. It is therefore useful to examine the basic properties of cast, un-reinforced resins with those of various reinforcing fibres. Table 1.4 compares the typical properties of various resins and reinforcing fibres used in composite manufacture.

	Unit	Polyester	Vinyl ester	Epoxy	'E' Glass fibre	Carbon fibre	Polyaramid fibre
Specific Gravity		1.23	1.04	1.14	2.55	1.75-1.95	1.45
Tensile strength	MPa	70	85	75	3500	3500-4000	2900
Tensile modulus	GPa	3.80	3.30	3.00	76	230-250	130
Elongation at break	%	2.3	5.0	5.0	3.0	1.0-1.5	2.9
Thermal expansion coefficient	$\times 10^{-6}$ /°C	100-180	65	80-120	5.0	-0.5-1.5	-4.2

Table 1.4 Comparative properties of cast un-reinforced resins and fibres
(Scott Bader, 2003:45)

As well as the obvious effects of resin and fibre type, the mechanical properties of a composite will be influenced greatly by the resin to fibre ratio achieved in the laminate and by the orientation of the fibres. Figure 1.25 shows the affects of different resin to glass ratios and glass orientation on the tensile properties of glass reinforced polyester resins.

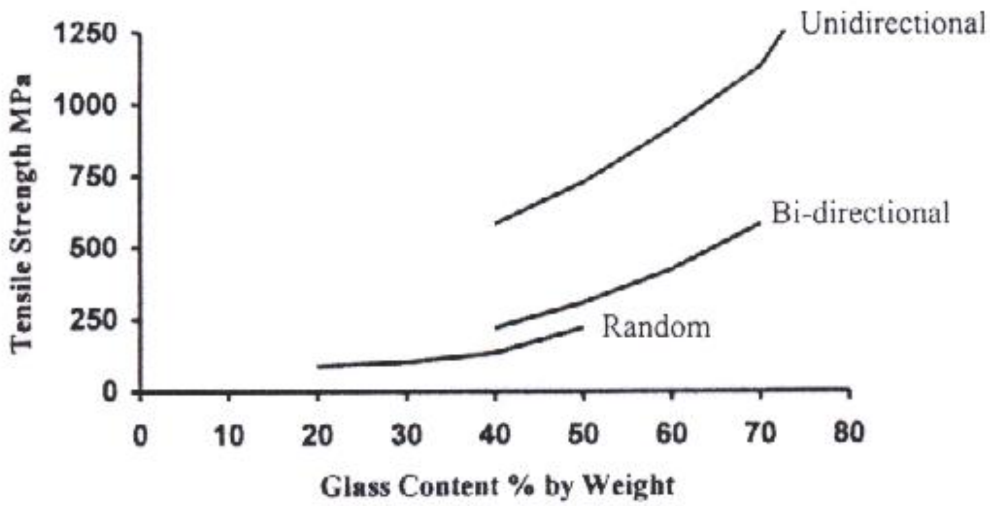


Figure 1.25 Effect of glass content and orientation on the tensile strength
(Scott Bader, 2003:46)

Glass fibre is the reinforcement still most commonly used in conjunction with polyester resins. The use of both polyaramid and carbon fibres was initially restricted to very specialised application, due to their inherent disadvantages (low compressive strength and prohibitive cost respectively). However, the development of hybrid reinforcements such as polyaramids/glass, polyaramid/carbon and carbon/glass has largely overcome these disadvantages by combining the best properties of each reinforcement, resulting in material that fabricators now use to best advantage in a wide range of applications. Table 1.5 shows typical properties of various glass reinforcements and compares them with some of the metals that they often replace.

	CSM	WR	Satin Weave Cloth	UD-CSM Combination	WR-CSM Combination	Mild Steel	Aluminium Alloy
Resin	Ortho-Polyester	Iso-Polyester	Iso-Polyester	Iso-Polyester	Iso-Polyester	-	-
Post Cure	16h 40°C	16h 40°C	28 days RT	16h 40°C	16h 40°C	-	-
Resin:Glass Ratio (by weight)	2.33 : 1	1 : 1	0.81 : 1	1.3 : 1	1.16 : 1	B.S.15	-
Stress direction	-	0°/90°	0°/90°	0° 90°	0°/90°	HE15WP	-
Specific Gravity	1.46	1.7	1.7	-	-	7.8	2.8
Tensile Strength (MPa)	110	220	260	300 25	180	450	300
Tensile Modulus (GPa)	8	14	17	16 7	12	207	70

Table 1.5 Typical properties of fibre-reinforced composites compared with steel and aluminium alloy (Scott Bader, 2003:47)

(Table 1.5 continue on next page)

	CSM	WR	Satin Weave Cloth	UD-CSM Combination	WR-CSM Combination	Mild Steel	Aluminium Alloy
Charpy Impact Strength (kJ/m²)	75	-	-	-	-	50	25
Specific Tensile Strength (MPa)	75	-	-	-	-	31	154
Specific Tensile Modulus (GPa)	5.5	-	-	-	-	27	27

Table 1.5 Typical properties of fibre-reinforced composites compared with steel and aluminium alloy (Scott Bader, 2003:47)

	Unit	Glass (WR)	Polyaramid	Carbon	Glass /Polyaramid	Glass/Carb on	Polyaramid /Carbon
FibreFraction By Weight	%	56.2	40.5	45.3	25.7	27.2	21.13
Laminate Thickness	mm	3.23	4.08	4.13	4.05	3.42	4.47
Tensile Strength	MPa	333	345	410	403	352	364
Tensile Modulus	GPa	15.2	20.9	36.1	19.0	29.1	29.5
Flexural Strength	MPa	389	301	378	349	324	298
Flexural Modulus	GPa	13.6	14.6	28.4	15.0	24.6	23.2
Lap Shear Strength	MPa	6.7	7.1	9.6	9.0	6.5	8.0

Table 1.6 Comparative properties of glass, polyaramid and carbon reinforced polyester laminates (Scott Bader, 2003:47)

Similarly, Table 1.6 compares the properties of glass, polyaramid, carbon and hybrid reinforced composites, using isophthalic resin as the matrix.

The fatigue and creep properties of glass fibre reinforced polyester composites will be specific to the loading criteria applied and the material tested. For instance, glass cloth laminates will give a superior performance in creep to random glass mat laminates. Although the fatigue characteristics of FRPs compare favourably with many metals, it should be borne in mind that metals are isotropic materials, so predicting fatigue and creep is relatively easy. This is not the case with composites, which are anisotropic. There are several differences between glass fibre reinforced polyester and metal. For instance, ductility is relatively poor in FRPs, which have an elongation at break of about 2% compared with about 40% for steel. On the other hand, deformation of unidirectional GRP is elastic almost to the point of failure, whereas the elastic limit for steel is about 0.2%

From an engineering design standpoint, lack of stiffness has always been the most distinctive feature of FRPs when compared with metal. Although developments in reinforcement technology have enabled up to four fold increases in their modulus for little or no increase in thickness, glass reinforced composites still do not approach the stiffness characteristics of steel, as can be see in Tables 1.5 and 1.6. There are various ways of increasing the stiffness of FRPs, the simplest of which is to increase thickness. However, a three-fold increase in thickness would be required for a random glass mat laminate to achieve a similar stiffness to steel. This would increase cost and, more importantly, weight, thus negating one of the principle reasons for choosing composites in the first place.

In practice, one or more of the following methods has been commonly used to increase the stiffness of composite mouldings:

(i) Localised increases in thickness. Progressive local edge thickening or flanging along the edge of a panel will improve its stiffness;
(ii) Laminating integral ribs into the reverse side of the laminate. This method is often used on large boat hulls;
(iii) Introducing compound curvature or local corrugations. If corrugations are introduced as part of the general styling of a moulding, they need not be unsightly. This method can be further elaborated by a folded plate construction where the

overall geometry of the structure gives the necessary rigidity. These system stiff structures can be produced from very thin sheets, making it an important method for producing large structures;

(iv) Sandwich construction (see page 28).

In sandwich construction, the FRP skins resist bending stresses and deflections, whilst the core resists shear stresses and deflections, withstands local crushing loads and prevents buckling of the FRP skins in compression. Sandwich construction can be used for localised stiffening (e.g. boat hull ribs) or to produce complete lightweight rigid structures and the type of core material used will depend on the nature of the application.

For high performance applications such as those in the aerospace industry, honeycomb cores are used extensively. These may be manufactured from aluminium, or from fibre papers such as phenolic-coated polyaramids. In the case of non-structural or less demanding structural applications, balsa, foam or non-woven core materials are more commonly used. Figure 1.26 illustrates the rigidity of sandwich laminates in bending, using various CSM and WR skin and core thickness.

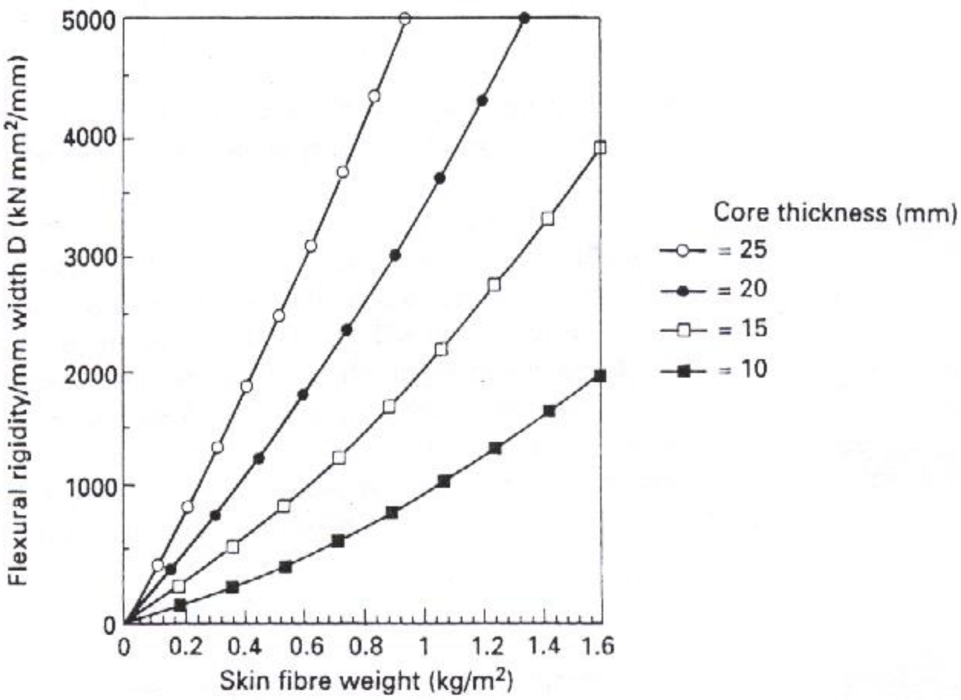


Figure 1.26 The effect of CSM skin construction (at Resin to Fibre ratio=2.3:1) and core thickness on flexural rigidity for balanced double skinned sandwich laminates (Scott Bader, 2003:49)

The temperature at which a composite structure is to operate may have an effect on its mechanical properties, and in some applications the retention of properties at elevated temperatures will be an important parameter. At low temperatures properties often improve compared with room temperature values, but as temperature increases and approaches the Heat Deflection Temperature of the resin matrix, there will be a dramatic reduction in properties.

Table 1.7 illustrates the percentage retention of room temperature properties for fully cured isophthalic polyester/chopped strand mat laminate.

Property	Temperature (°C)					
	-68	-40	23	70	130	225
Tensile Strength	98%	98%	100%	104%	56%	33%
Tensile Modulus	105%	94%	100%	65%	34%	-
Elongation	100%	129%	100%	143%	143%	-

Table 1.7 Percentage retention of tensile properties at various temperatures (CSM reinforced isophthalic polyester resin with an HDT of 116°C) (Scott Bader, 2003:50)

The uniqueness of composites lies in the fact that the material of construction and the end product are produced simultaneously, so the material itself can be designed to have the particular properties required by the designer. This increases the versatility of composite design and also design necessitates accurate property prediction.

Thermal and Electrical Properties

The coefficient of thermal expansion (CTE) of fibre-reinforced composites will depend greatly on the type and alignment of fibres used, as well as on the temperature of the resin matrix. The CTE of laminate reinforcement with uni-directional (UD) fibres will exhibit different CTE values in the 0° and 90° direction. The CTE of uni-directional carbon or polyaramid reinforcements will be negative in the 0° plane, and positive in the 90° plane. It is therefore possible to design composites to meet almost any required thermal expansion characteristics.

The CTE of a random glass reinforced composite is close enough to the CTE of steel to enable the lining of mild steel tanks with a glass reinforced matrix. This is only the case, however, for operating temperatures below 60°C as the CTE of the two materials differs considerably above this temperature. Table 1.8. compares the thermal properties of various FRPs with mild steel and aluminium alloy.

GFRP and polyaramid composites offer good electrical insulation, whilst carbon composites conduct electricity.

Material	Thermal Conductivity (W/m°C)	Coefficient of Thermal Expansion ($\times 10^6$/°C)	Maximum Working Temperature (°C)
UD GFRP 0°/90°	0.3 -	9 14	250 -
UD Carbon 0°/90°	34 0.8	-0.5 25	- -
UD Polyaramid 0°/90°	1.7 0.14	-4 57	- -
WR GFRP	0.24	15	-
Random GFRP	0.2	30	175
Mild Steel	50	12	400
Aluminium Alloy	200	23	200

Table 1.8. Comparative thermal properties (Scott Bader, 2003:52)

Environmental Properties

The weather and water resistance of GFRP laminates is largely a function of the gelcoat since in most application this is the surface that is exposed to attack. Where general resistance to weather or water or ambient temperature is the main criterion, a quality isophthalic gelcoat will give adequate protection, but where hot water and/or mild chemicals are involved an isophthalic/NPG gelcoat is recommended.

Fire retardant laminates present unique challenges in terms of their weather resistance. Without the protection of a gelcoat their resistance to outdoor exposure is poorer than of standard laminate systems. However, the use of a gelcoat can adversely affect the fire performance of such laminates.

Long-term immersion in water can result in a loss of mechanical properties, especially where a laminate is not protected by a gelcoat. Table 1.9. shows the effect of long term immersion on the flexural strength of orhophthalic polyester resin/glass mat laminates with sealed and unsealed edges, but no gelgoat.

Immersion Time	Unsealed Edges		Sealed Edges	
Days	Flexural Strength MPa	Retention %	Bend Strength MPa	Retention %
0	204	--	204	--
7	192	94	199	98
28	186	91	193	95
63	182	89	190	93
112	181	89	190	93
300	181	89	190	93

Table 1.9 Strength retention of FRP composite after immersion in distilled water at 20°C (Acid resistant Orthophthalic resin & glass laminate) (Scott Bader, 2003:61)

Chemical Resistance

For mouldings with optimum chemical resistance combined with structural performance, a resin rich surface is essential on the face that is to be exposed to a hostile environment, and a chemical laminating resin should accompany this. A resin rich surface can be achieved by the use of a gelcoat, or for contact with more aggressive environments, by means of resistant veils that take up large quantities of resin. This is normally the case in the chemical processing and containment industries. The most suitable laminating resin will depend on the particular chemical environment, but generally, orthophthalic resins have good resistance to acidic conditions, whilst alkaline conditions require the improved resistance of an isophthalic. Bisphenol based polyester resins exhibit high mechanical strength and excellent strength retention in many chemical environments at temperatures up to 95°C. Vinylester resins and epoxide resins are also widely used in the chemical containment industry. The type of surfacing veil to be used will also differ with the type of chemical involvement. Polyester veils are recommended for acidic conditions, whilst polyacrylonitrile veil are more resistant to alkaline environments. Although the chemical resistance of fully cured polyester resins is generally good, there are other plastic materials that are more resistant to certain chemical environments. These can be used to produce a composite construction in which the mechanical strength is provided by a GRP laminate and the chemical resistance by a thermoplastic liner such as PVC or scrim – backed polypropylene. An important example of this type of composite construction is the filament winding or wrapping of PVC pipes with glass rovings and resin. Tanks and pipes for the chemical industry are commonly made in this way.

In a study to compare the susceptibility to degradation of fibreglass and other polymeric materials by chemicals in well casings, it was found that fibreglass-reinforced epoxy (FRE) and secondly fibreglass-reinforced plastic (GRP) pipes were far more suitable for use in organic solvent applications, compared to PVC and ABS. This research also indicated that although stainless steel is not subject to solvation by organic solvents, it is subject to corrosion by a variety of environmental conditions (Parker and Ranney, 1997: 1-6).

General standards for the design, fabrication and use of GRP vessels and tanks are laid down in BS 4994: 1987 entitled 'Specification for Vessels and Tanks in Reinforced Plastics'. A new European Standard, pr EN 13121, is currently being developed, and may eventually replace BS 4994:1987

The influence of defects, flaws, damage and design factors

Glass fibre-reinforced plastics are widely used in the chemical industry, due to their strong chemical resistance to many of the chemicals that corrode metals. Depending on the nature of the duty, the quality of workmanship and maintenance, GRP equipment can give many years of trouble free service. GRP vessels, tanks or pipes seldom fail catastrophically, without first giving some indication of deterioration of the laminate. If the deterioration is detected timeously, and appropriate repair procedures are carried out, the life of the equipment can be extended considerably and catastrophic failure can be prevented.

Defects and flaws are potential precursors to failure. They may originate in the fibre, in the matrix, in the interface between the two, and in areas of non-uniformity of distribution of fibre in the matrix, i.e., resin-rich and resin-starved areas. Defects may arise during production and installation, or even in the fibre and resin before production. Service conditions, such as impact, creep under load; fatigue and environmental exposure also create damage that may cause failure abruptly or gradually as damage accumulates.

For thermosetting resin matrixes, the degree of cross-linking is a factor in overall strength. Voids or porosity in the resin are a source of weakness, acting as stress concentration sites. Voids may be introduced into a composite by poor mixing techniques entrapping air (Restiano and James, 1993:4199), by poor fibre wet-out (Blumenfeld, 1980), or from volatiles present or produced during reaction of the resin (Restiano and James, 1993:4199). Fibres may have microscopic scratches that can lead to fibre fracture. Both resins and fibres, but more likely resins, may have foreign contaminants that could adversely affect performance. Such inclusions constitute the sites of stress concentration possibly leading to localized resin cracks. Matrix resins and fibres both have chemical or environmental limitations that affect lifetime and possible applications. For example, polyesters are not recommended for use in strong alkalis, and polyurethanes are not recommended for use with strong acids and alkalis, steam, fuels and ketones. E-glass, a very common fibre in composites, has poor resistance to acids (Kaverman, 1991:511).

Conditions during production or in service that adversely affect the interfacial bond between resin and fibre also contribute to failure. Poor interfacial bonding may result in exposure of the fibre to moisture or other chemicals so that fibre facture or degradation becomes a limiting factor in strength. Also, replacement of a tight bond between fibre and matrix with a weak or non-existent bond means that the reinforcement feature of fibres that is fundamental to strength and toughness is compromised.

The effect of exposure to heat, moisture, hydrocarbons, fatigue and static loads, etc, and more importantly a combination of these parameters may also degrade the stiffness and strength. The lack of long-term data for fibre-reinforced composites as well as an accelerated ageing methodology (e.g. that will predict effects such as degradation might have on the residual properties and future life of the structure) are two of the major issues hindering the wider use of these materials (Martin & Campion, 1996: 1). It was found by Martin and Campion (1996:5) that ageing occurs from the surface inwards and requires time to penetrate the fibre-reinforced laminate fully. In addition, fluid diffusion rate and the subsequent chemical ageing rate can be anisotropic and is dependant on the applied stress of the laminate. Furthermore, a consistent method was found to accelerate the effects of ageing from thermal or moisture exposure. They also concluded that although an Arrhenius plot may be used for chemical properties, this approach is less well studied for changes in mechanical properties in fibre-reinforced composites and may not apply to realistic service exposures.

Design features that constitute potential contributors to failures are holes, free edges, bolted and bonded joints, and ply drops in laminates (Kaverman, 1991:511). Such design features are sites of interlaminar stress concentration, so that delamination may be initiated and grow under fatigue or static loading leading to significant lowering of strength (Grove and Smith, 1987).

Damage tolerance and long-term behaviour of fibre-reinforced composites

Almost all fibre-reinforced composites are designed to include some degree of damage tolerance. The objective is to survive defects and damage that might occur during manufacturing or while in the field service. There is often confusion as to the difference between 'damage tolerance' and 'durability' (Beckwith, 2001: 31). 'Durability' normally pertains to how long a FRP structure can survive the operational environment and loads under typical field conditions. Typical design for durability includes static and dynamic loading, shock and vibration loading, environmental effects, temperature extremes, fatigue, long term loads (creep) and aging. 'Damage tolerance' is normally the ability of the FRP structure to tolerate a reasonable level of damage or defects that might be encountered during manufacture or while in service. Typical defects pertaining to damage tolerance include delaminations, scratches, cuts and gouges, abrasion and surface wear, dents, and impact damage.

Most composite structures, whether they utilise advanced composite materials or FRP, are designed to meet certain 'composites durability' requirements, which are typical of expected structural loads and environments the part will be exposed to during service.

For example, design within the composite durability area focus on the loading that will be applicable to the product or structure while it is in service. Bridge decks made using FRP materials such as glass vinyl/vinylester or glass epoxy/epoxy are designed to sustain static (bridge weight, vehicle weights) and dynamic (moving vehicles, earthquake) loads. Shock and vibration loading is something that must be considered in designing marine and pleasure boat products that utilise fibreglass, core materials, adhesives and other FRP materials.

Environmental effects from ultraviolet (UV) exposure, rain, hail, dust, sand, snow, solvents, fuels and temperature must all be considered during the design phase. The effects of these parameters on material response properties (like stiffness) and their failure characteristics must be accounted for in the durability design phase. Temperature extremes, typically defined as the operational bounds for the composite product, are critical areas of design assessment. Fatigue or repetitive loading factors are most often applied as 'knockdown factors' to the material or structural strength (and sometimes stiffness) (Beckwith, 2001: 32).

Creep failure, or even just changes in composite part deflections can become a problem over time. FRP composites undergo changes with age and environmental exposure to the resin matrix, adhesives, polymers, various interfaces, and in some cases the reinforcement fibres themselves. Consequently, durability pertains to normal or anticipated design loading conditions, which the FRP materials and structures are designed to encounter during their lifetime. However, advanced composites and FRP might be exposed to rough handling, over and above 'normal' use conditions, as well as to anomalous or spurious load conditions, or other 'non-standard' loading events. The manufacturing process incorporates certain defects that are accounted for during the product design. However, defects and damage that occur outside of typical processing, and for the duration of the product service life, are usually included as part of damage tolerance considerations.

If the designer can anticipate the end use of FRPs by understanding typical manufacturing and field damage events, damage tolerance can often be designed into the process and the composite part. Dents, scratches, gouges, abrasion and cuts might be expected to fall most in the category pertaining to 'cosmetic damage' rather than structural performance limiting events. It depends, however, on the extent of the event damage. For example, dents in the outer surface may be an indicator of a more severe impact damage event. Gouges and surface cuts which create broken reinforcing fibres can easily reduce the operating structural performance, and acceptable criteria should be developed to define damage limits by specifying acceptable defect sizes.

Cracks can represent matrix micro-cracking, matrix/fibre interface cracking, and even structural fibre breakage. Delaminations between composite plies or layers can result in much lower strengths in compression loading. Consequently, these two areas are usually considered more carefully than dents, scratches, abrasion and gouges.

Impact damage is of major concern because the impact event is almost impossible to predict with a large number of possible impact variables. Numerous technology programs have been conducted over the years in order to better understand impact damage. Currently only general guidelines regarding material selection, laminate orientation, inspection techniques and protection methodology are available.

The question of durability (based on the above) has been raised by many concerning the type of application and the constituents of the composite material and the interaction between physical and chemical ageing and its affect on the long-term behaviour of these materials. Guedes et al (2000:184) found that the long-term behaviour of composite materials may be affected by physical (e.g. changes in temperature) and chemical ageing (change in molecular weight, oxidation, change in density of reticulation). In fact, swelling, plasticization and slow attack by a liquid of the resin/fibre interface corresponds to loss of properties which affect the creep and fatigue behaviour. Furthermore it was found that certain factors like stress and temperature accelerate and influence the long-term properties and that moisture, the ageing effects and mechanical degradation should also be included to ascertain the coupling of effects. Environmental effects significantly alter a materials' behaviour and these effects are not reversible after an absorption/desorption cycle, probably due to an internal reorganisation of the material structure. It was therefore found that the influence of moisture and temperature are not equivalent and also not additive.

Failures and failure mechanisms that occur in a chemical plant

The following sections give examples of the most common failures and failure mechanisms experienced in a chemical plant environment. These examples were taken from the Sasol Polymers non-metallic specification P-EG 5 (Guide to detection of in-service deterioration of non-metallic equipment).

Discolouration. Colouration appears in the form of patches on the surface of the equipment, is different in colour from the rest of the vessel or pipe. In a lined vessel, discolouration probably indicates liner failure.

Discolouration may also be caused by delamination of the glassfibre reinforced composite, where the areas of delamination show up as different coloured patches. Figure 1.27 shows a vessel with large discoloured patches. In this case, the patches were caused by the separation of the thermoplastic liner from the GRP. This vessel is beyond repair.

Figure 1.27 Example of discoloration

Leaking, Weeping or Swelling. Leaking or weeping will appear either as small beads of liquid or crystallisation or as damp patches on the vessel or pipe surface. Swelling will occur as bulges on the surface, possibly accompanied by discoloration. Figure 1.28 shows a cracked elbow that is leaking.

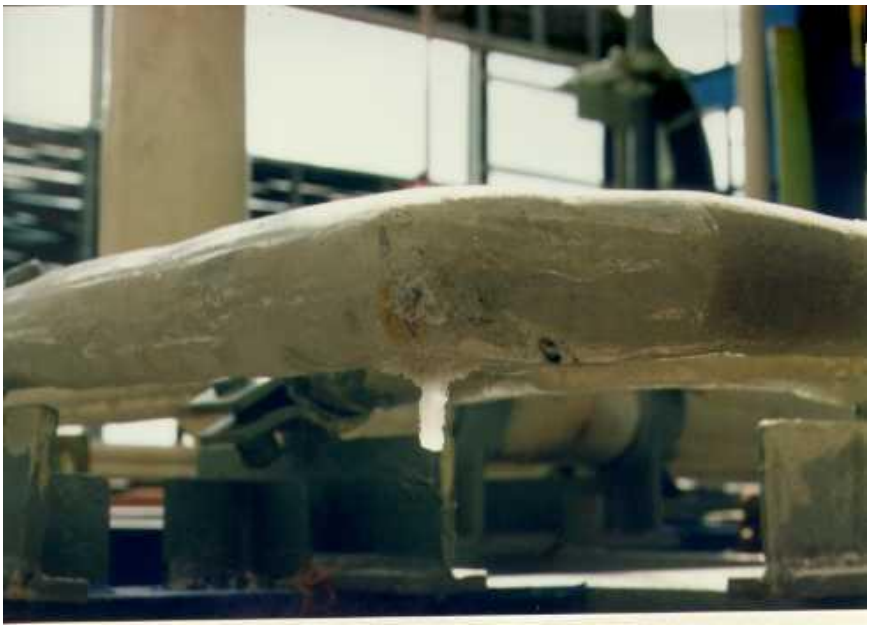


Figure 1.28 Example of leak at the bottom of a GRP pipe elbow

Delamination. Separation of layers within the glass fibre reinforced composite may be visible on the surface as slightly raised patches, which are different in colour from the rest of the GRP. Separation of the liner from the GRP in a lined vessel or pipe may look like patches of discolouration of the glass fibre reinforced composite. Internally, this may resemble a blister in the liner. Delamination may be due to chemical attack, as in the case of the vessel shown in Figure 1.29. Mechanical stress, poor inter-laminar adhesion and poor workmanship can also cause delamination.

Figure 1.29 Layers of a composite vessel that have separated / peeled off

Cracking and Mechanical Damage. GRP composites are brittle and overstressing, mechanical impacts or cyclic stressing will often result in brittle cracking. Overstressing may be the result of incorrect design, resulting in a vessel or pipe which is not strong enough to handle the intended duty. However, it is more likely to be caused by overloading a vessel or pipe due to operation outside of the intended design parameters, or because a vessel or pipe is used for a duty other than that for which it was originally designed (in which case it may not be strong enough to handle the alternative duty). Incorrect installation may also cause the vessel or pipe to be subject to a load that exceeds the design capabilities of the structure. This may result in overstressing and ultimately cracking.

Mechanical impact can range from a severe collision of a vehicle with equipment to dropping a tool onto a vessel or pipe. Even dropping a tool can result in micro cracking of the GRP, which can damage the corrosion barrier, resulting in localised corrosion of the damaged area. The effect of a mechanical impact, unless it breaks the item altogether, can be difficult to detect immediately. Figures 1.30 and 1.31 show a test laminate that was struck with a hammer. The laminate was struck on the surface opposite the corrosion barrier (i.e. the external side). The corrosion barrier cracked due to the transfer of the force through the thickness of the laminate, but no cracking occurred on the surface that was struck. This suggests for example that if a vehicle bumps into a glass fibre reinforced composite vessel, there may be no damage visible on the exterior, but the chemical barrier may suffer damage. Cyclic stressing may be caused by cyclic loading, such as emptying and filling a tank or temperature cycles caused by the night- or day-time temperature variations or by repeatedly filling a tank with a hot liquid and allowing it to cool down.

Figure 1.30 Test laminate that was struck with a hammer

Figure 1.31 Opposite external surface of same test laminate

Failure of corrosion barrier. General deterioration and failure of the corrosion barrier is often visible only if the vessel or pipe is opened. The interior may look as though it is full of cobwebs, as shown in Figure 1.32. Glass surface tissue can be seen hanging from the walls where the resin has been removed. As it corrodes further, the structural laminate becomes exposed, leading to leaching away of the resin, leaving glass only.

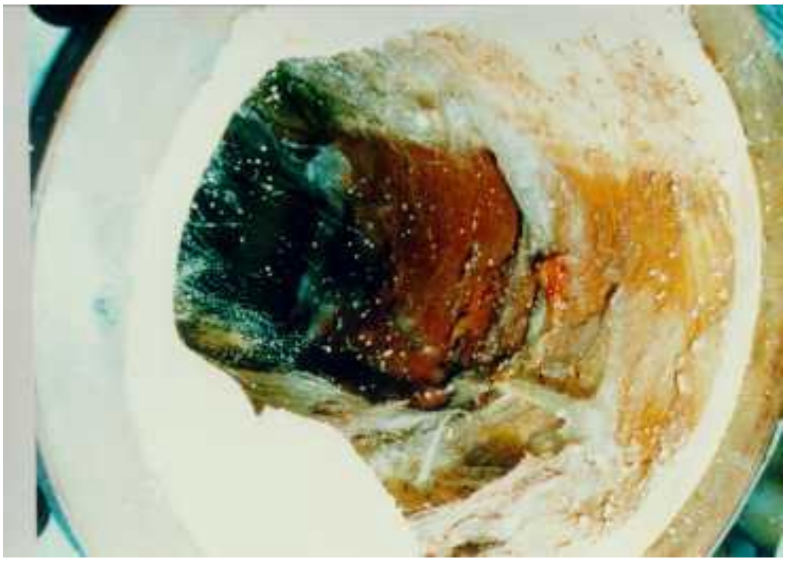


Figure 1.32 The "cobwebs" of surface tissue hanging from the surface

Liner failure. The early stages of liner failure are only visible from the inside of a vessel or pipe. When lined pipes or vessels are opened, look out for cracking along welds, corners, nozzles and other high stress locations. If the liner failure progresses, the GRP laminate will be attacked and the vessel or pipe will probably be damaged beyond repair. Figure 1.33 shows a PVC liner that has failed along the weld and along the bend line of the flange, which is also an area of high stress.

Figure 1.33 Failure of a PVC liner at the weld and the edge of the flange

Ultraviolet Degradation. UV degradation may occur on pipes or vessels that are exposed to direct sunlight. UV inhibitors should be added to resins when laminating the exterior of any vessel or pipe. In some cases they may not be effective, or their effect may wear off after a number of years. UV degradation may be identified as discolouration or flaking of the surface on the exposed side of a vessel or pipe, as can be seen in Figure 1.34. If similar degradation is visible on the unexposed side, the problem is not UV degradation.

Figure 1.34 Flaking caused by UV exposure

Mechanical damage and weathering or glass fibre reinforced composite walkways. The resistance of GRP to environmental corrosion has led to its use in grating for walkways. The grating is made by pultrusion or moulding, which results in a very glass rich material, with very little resin to bind the glass fibres together. Therefore, any attack of the resin or mechanical damage leaves the glass fibres exposed. For the safety of plant personnel, all grating for walkways, steps etc. should be in good condition, since failure of the grating could results in injury and even loss of life.

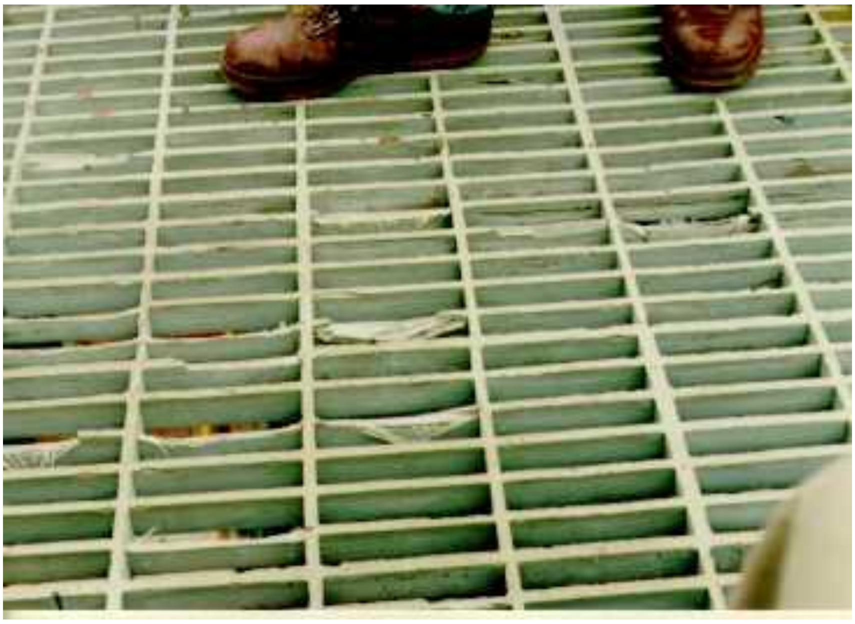


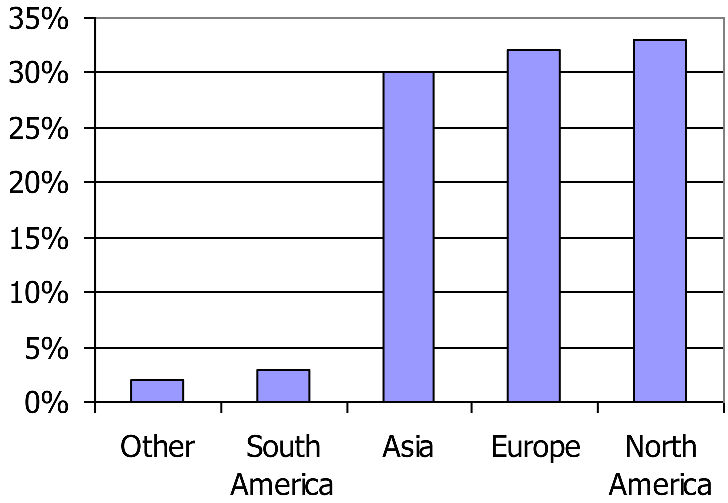
Figure 1.35 GRP grating with mechanical and weathering damage

1.1.3 The Use of Composite Materials Internationally and Nationally

The U.S. economy has always been the prime indicator of the state of the worldwide economy. Detailed reports could be found as to the use and growth of fibre-reinforced materials in world markets based on U.S. indicators while little information is available on similar trends in the rest of the world. According to MacNeil (2001: 10-45), the U.S. composites industry has enjoyed nine consecutive years (up to 2000) of rising demand thanks to a robust economy and strong, basic demand for the benefits composites deliver in terms of light weight, high strength, dimensional stability, resistance to corrosion as well as economical cost. As mentioned, a broad but very strong indicator of how the composites business will do is in the forecast of overall economic activity or the gross domestic product of a country. In the case of the U.S., the composites industry has grown from 1960 at average of 7% a year. Furthermore, in rough terms, while the use of steel has doubled from 1960 to 2000 and aluminium has quadrupled, the use of composites has grown 15 times (MacNeil, 2001:45).

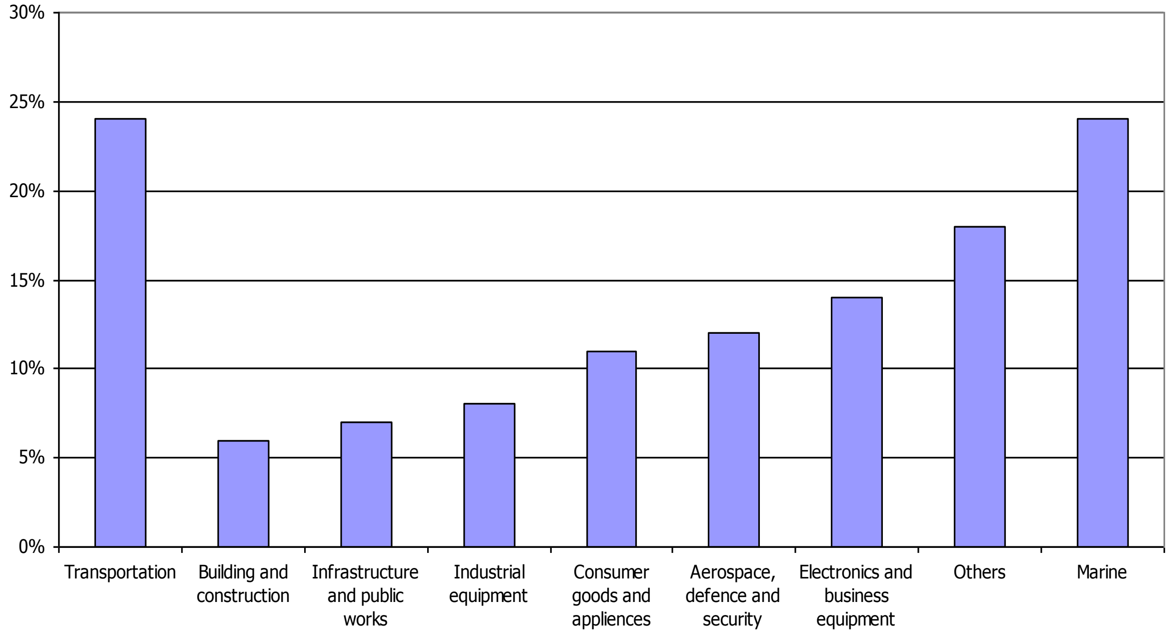
Market Survey: Glassfibre, Carbonfibre, Resin.

Glassfibre: 2.2 million tons in 2002. According to statistics communicated by industrialists, the worldwide market for composite solutions (fibres + resins) was calculated to be around 7 million tons for 2002. The worldwide glass reinforcement market was about 2.2 million tons in 2002 (glass mat and alkali resistant glass excluded). From 1996 to 2002, this market showed an average growth of 4 to 5% per year, almost twice the average growth rates of GDP for the industrialised countries.



Graph 1.4 Worldwide market by geographical area (Business Market Survey, 2003:21)

As indicated in Graph 1.4, there is now a balance between the three main areas, e.g. Europe, America (North and South) as well as Asia. Worldwide growth rate remains high at 4.2% with Europe and North America, the oldest areas in the composite sector enjoying a more moderate growth (close to GDP growth). The bulk of growth is being sustained in Asia where new production sites are being built.

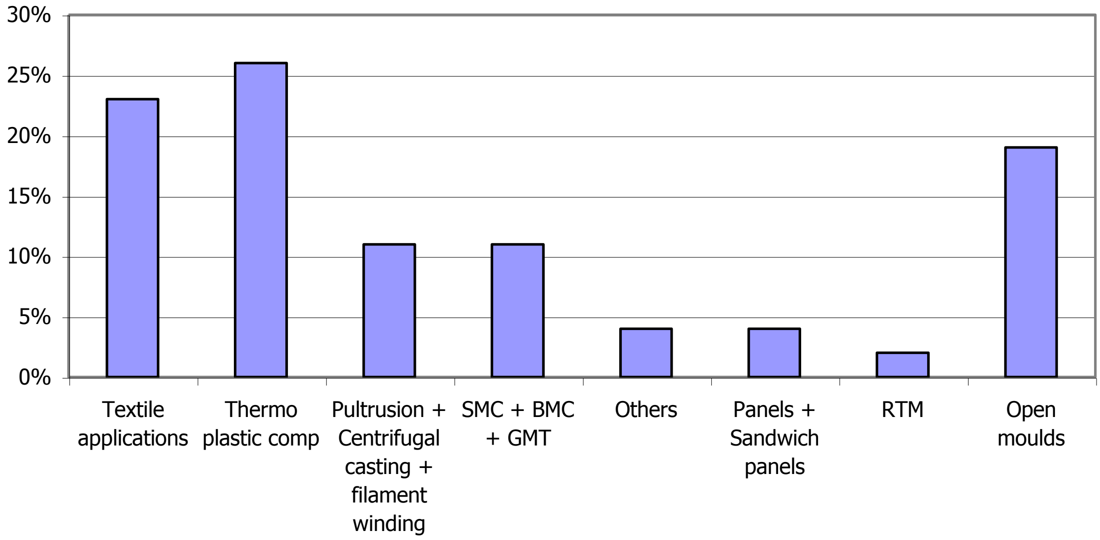


Graph 1.5 Worldwide market by application (Business Market Survey, 2003:21)

Graph 1.5 indicates that worldwide, the two main markets are transport (24%) and construction in all its forms – building, infrastructures, public buildings and works (25%)

that consumes most of the composites production. The third sector is electronics, preceding industrial equipment.

Graph 1.6 shows that converting thermoplastics represents more than one quarter of the worldwide composite industry. It is the key growth sector. Open-mould processes remain important worldwide with nearly 20% of the market. Weaving processes sustain the largest part of the electronics sector.



Graph 1.6 Worldwide market by process (Business Market Survey, 2003:21)

Composites designed for installation in corrosive environments serve a variety of market segments such as the chemical processing industry (CPI), oilfield exploration, gasoline underground storage tanks, pulp and paper processing, water-sewage systems, electric utilities, mining and metal processing, and semiconductor manufacturing plants. Most of these businesses experience very cyclical demand with on-off capital spending programs.

The biggest segment of the entire composites industry is the manufacture of filament-wound epoxy line pipe and down-hole pipe used in petroleum exploration. Demand for drilling equipment is driven by the price of crude oil, which has nearly tripled from record lows in 1997-1998 to record highs in 1999-2000. With crude oil prices likely to remain in the $22-26 per barrel range, this market sector is likely to continue earning strong profits and spending generously on capital equipment for exploration. At these prices operators of the oil fields can afford to undertake secondary and tertiary recovery techniques where corrosive brine solutions are injected down-hole to force the crude oil to the surface. Ordinary carbon steel pipe will not withstand the harsh working environment whereas composite pressure pipe does the job successfully.

Other segments of the corrosion market are generating demand at normal rates of growth. The $175 billion pulp and paper industry appears finally to be moving to comply with the integrated air-water regulations that were first proposed in 1993 in the US and published in the Federal Register in 1998. Some 155 of the US industry's 565 paper mills will be affected by this multi-year program to reduce the air pollutants and toxic liquid wastes inherent in the papermaking process (MacNeil, 2001:45).

Water supply and treatment is another important market served by fabricators of corrosion-resistant wide-diameter pipe and other components. Demand for water is very mature - something close to the growth rate of the nation's population (1%) but the upside is that the U.S. water supply consists primarily of publicly owned facilities, many of which are operating beyond their useful lives and need capital improvements.

The U.S. market for this kind of civic works is incredibly fragmented - there are 58 000 community water systems, 21 000 municipally owned collection systems and 16 000 public wastewater treatment plants. Fabricators of wide-diameter composite pipe and providers of in-place repairs are well positioned to service the demand from the many systems that need upgrades. The 10-year US compliance deadline to upgrade or replace gasoline underground storage tanks came and went on December 22, 1998. It stimulated demand especially in the final years of the program with some spill over demand in 1999. Industry participants remark that demand inevitably flattened out in 2000, but growth resumed in 2001 at a rate similar to the rate of overall economic growth (MacNeil, 2001:46).

The South African Fibre-Reinforced Plastics Industry

Although the number of manufacturers in South Africa is relatively small compared to European countries or the United States of America, major capital investments, specifically in the field of composites, have been undertaken in the last thirty years. The composites industry in South Africa is considered by most as small and only capable of producing relatively small equipment. Figure 1.36 and 1.37 indicates examples of large installations that were completed by the end of 2001.

Figure 1.36 Western Platinum scrubbers and ducting

The value of projects per industry in South Africa awarded for the period 2001 to 2003 was (in millions): pulp and paper (R20 m), platinum refining (R120 m), chlor alkali (R25 m), mineral/metal benefaction (R200 m), petroleum refining (R30 m), desalination (R30 m), iron and steel (R40 m), fertilizer (R60 m) and gas cleaning (R50 m).

Figure 1.37 Chlorine Expansion Project, Sasol Polymers, 2001

The split between equipment and piping was roughly: custom equipment and fabrications (5 to 7,5%), storage tanks (10 to 15%), pressure vessels (3 to 5%), ducting

(10 to 15%), process piping (24 to 40%), linings (5 to 10%) and grating, handrails, etc (3 to 4%) (Carter, 2001:5). By 2001, the total industrial pipe market was estimated at R460 million, and the mining pipe market at R345 million. The total pipe market for industrial and mining applications was estimated to be ± R806 m. Only half (± R391 m) was for pipe applications above 100 mm OD. In this latter market GRP piping holds a market share of 9,2% (± R36 m). Furthermore, 10% of carbon steel pipe competes in the "aggressive" industrial market as lined (rubber or plastic) carbon steel pipe. Maritz and Meissner estimated the 1995 GRP pipe market at R12 m for chemical treatment applications. The 2001 figure of R36 m therefore represented an annual growth rate of 20% (nominal) over the period – this growth rate has been achieved despite low economic growth of 2% per annum and constant levels of fixed investment by the mining and manufacturing sectors (Maritz and Meissner, 2001:3-6).

The Association of Non Metallic Equipment Manufacturers (ANMEM) was formed by a group of manufacturers concerned with the competency of manufacturers of vessels, tanks, piping systems, containing hazardous, dangerous, toxic and corrosive mediums operating under pressure/vacuum at elevated temperatures. The most significant fabricators at the start of 2001 were and still are Fibrewound, Speedmark, Plastics and Fibre Glass Productions, Wren Fibre Glass and FAM Systems.

By all accounts Fibrewound is the industry leader with a solid reputation in terms of products and services. It has been responsible for the development of the GRP pipe and tank industry in Kwazulu-Natal initially, but is now active countrywide.

Speedmark is probably the second largest fabricator, and is viewed, together with Fibrewound as the only two reputable GRP pipe/tank fabricators in South Africa.

The main players in the industrial market are the project management houses, turn key contractors and end users (customers). The end users are mainly big industrial corporation and mining houses. The groups have different requirements and interact as follows:

(i) Project Management houses: do the detail design and are responsible for specifying equipment in conjunction with the end users. Equipment is usually specified in a specific material but alternatives are almost always allowed. Project Management houses do play a major roll in that they draw up the tender document, call for tenders on behalf of the end user and write a recommendation report to the end user and are also responsible for the project management and commissioning.

(ii) End users: are the most important group as they provide the funding and will become the owners of the commissioned installation.

(iii) Turn key contractors: take responsibility for supply, installation and commission of equipment. They have to provide a total solution to the client and therefore take nearly all the risk. Reliable supply and good track record in quality of work and ability to deliver within time schedule and budget are crucial.

General uses of fibre-reinforced plastics products

In an international market of over 50,000 different types of components, it is clearly impossible to provide anything like a definitive list. However some indication of the all-round engineering, industrial and infrastructure diversity is provided by the following application breakdown guide that details important market sectors and industries which have been defined by the World Composites Institute. There is obviously some crossover between individual sectors (Composites Processing Association, 2000:14-15).

Agricultural industry: containers and enclosures, equipment components, feed troughs, fencing, partitions, flooring, staging, silos and tanks.

Aircraft & Aerospace industry: containers, control surfaces, gliders and light aircraft construction, internal fittings, partitions and floors, window masks, galley units and trolleys, structural members, satellite components, aerials and associated enclosures, ground support equipment components and enclosures.

Appliance & Business industry: equipment covers, enclosures and fittings, frameworks and other moulded items and assemblies for internal use, switchgear bodies and associated electrical and insulation components.

Construction & Building industry: external and internal cladding, permanent and temporary formwork and shuttering, partitions, polymer concrete, pre-fabricated buildings, kiosks, cabins and housing, structural and decorative building elements, bridge elements and sections, quay facings, signposts and street furniture, staging, fencing and walkways.

Consumer Products: components for domestic and industrial furniture, sanitary ware, sporting goods, caravan components, garden furniture, archery and playground equipment, notice boards, theme park requirements, swimming pools, aqua tubes, diving boards, seating and benches, simulated marble components, skis and snowboards.

Corrosion Resistant Equipment industry: chemical plant, linings, oil industry components. Pipes and ducts, chimneys, grid flooring, staging and walkways, pressure vessels, processing tanks and vessels, fume hoods, scrubbers and cooking tower components, assemblies and enclosures.

Defence industry: aircraft, vehicles, aerospace and satellite components, enclosures and containers, personnel armour, rocketry and ballistic items, shipping and transit containers, radomes, simulators and allied.

Electrical & Electronic industry: internal and external aerial components and fittings, circuit boards, generation and transmission components, insulators, switch-boxes and cabinets, booms, distribution posts an pylons, telegraph poles, fuse tubes, transformer elements, ladders and cableways.

General Engineering & Industrial Assemblies: this sector includes fittings, sundry enclosures, safety helmets, pallets, bins, trays, profiles and medical items, assemblies and equipment components.

Marine industry: canoes and boats, yachts, lifeboats and rescue vessels, buoys, boat accessories and sub-assemblies, surf and sailboards, window masks and internal mouldings and fittings for ferries and cruise liners, work boats and trawlers.

Transportation: automotive, bus, camper and vehicle components generally, both under-body, engine and body panels, truck, rail and other vehicle components and fittings, land and sea containers, railway track and signalling components, traffic signs, seating, window masks and partitions.

Water Control Engineering: sewage pipes, process and storage vessels, tanks, pump components, staging, walkways, partitions, scrubbers and weirs.

1.1.4 Designing with Fibre-Reinforced Plastics for the Chemical Industry in South Africa

In the chemical industry end users constantly seek more cost effective corrosion equipment that will reduce the total life cycle cost. The result is that metallic (steel) equipment such as vessels and tanks are now being replaced by composite vessels. The greatest advantage of GRP equipment over conventional materials is the ability to design and build as a whole or as an assembly part. An assembly part can be joined together with another to form a product, which is light in weight and durable. It is thus important that designers and initiators think of composites and not of steel.

It is mandatory in South Africa that vessels that are used for the processing and conveyance of hazardous chemicals be designed and manufactured to recognized standards and specifications (South Africa 1996: Vessels under Pressure Regulations. (Notice No. 5775) *Government Gazette.* 17468:4 October). These specifications indicate the correct non-metallic methods of construction, and prescribe the various tests that are required to be conducted on the raw materials and the finished product.

One of the design specifications used is the ASME RTP CODE and the ASME committee defines its role as follows: "the function of the Reinforced Thermoset Plastic (RTP) Corrosion Equipment Committee is to establish rules of safety governing the design, fabrication, and inspection during construction of such equipment, and to interpret these rules when questions arise regarding their intent. In formulating the rules, the committee considers the needs of users, material manufacturers, fabricators, and inspectors of this equipment. The objective of the rules is to afford protection of life and property and to provide a margin for deterioration in service so far as to give a reasonably long safe period of usefulness. Advancements in design and material and the evidence of experience are recognized" (ASME RTP-1, 1992:iii).

It must be noted that unlike steel, (where the manufacturer purchases a certified sheet of steel, with known properties, and forms it to construct a product), the GRP material and its properties are created at the same time as the composite product is fabricated.

Although this is essentially an advantage, care needs to be exercised to ensure that the correct material properties are achieved. The design specifications stipulate the various test procedures that should be undertaken and the requirement to have the tests witnessed and accepted by an Approved Inspection Authority (AIA).

The following are the most commonly used design specifications:

(i) *BS 4994 – British standard specification for design and construction of vessels and tanks in reinforced plastics.*

The BS 4994 specification is a detailed code of construction with a minimum factor of safety of 8 that focuses on safeguarding the user of such equipment. The code is conservative in its approach in terms of design (minimum of 5 mm structural wall thickness for vessels under pressure) and manufacturing, e.g. it does not provide for superior resins, glass or manufacturing techniques but forces the use of stated material properties. It also penalizes for example filament winding angles of between 15 and 75 degrees. Irrespective of these disadvantages, this code is used widely in industry due to its approach which ensures equipment that provides robust and reliable service.

(ii) *AD Merkblatter*

This German code of construction is very detailed in its approach, but gives the designer and manufacturer the freedom to use previously tested stress values in strength calculations, therefore optimising on material properties and manufacturing methods under the control of the manufacturer. Like BS4994, it also excludes the chemical barrier from strength calculations, but does not stipulate a minimum required wall thickness. Filament winding is also not penalized, therefore making it more cost effective. With respect to factors of safety, this code uses a value of 4 as a minimum.

(iii) *ASME RTP 1-Reinforced thermoset plastic corrosion resistant equipment.*

The American ASME code of construction is also very detailed but unfortunately also complex and difficult to use. Like the AD Merkblatter code, it also allows the optimisation of material properties as well as manufacturing methods. No minimum wall thickness is specified nor any penalizing of filament winding angles (Engelsman, 2000:2-6).

Non-destructive testing of fibre-reinforced composite equipment

The inspection and particularly the non-destructive testing (NDT) of glass fibre reinforced composite equipment presents more problems than the same inspections and tests on metallic equipment. The material is not homogeneous which renders most NDT inspection methods unsuitable.

There are numerous methods available to inspect for composite defects and damage during lifetime. Details of techniques such as acoustic emission, computed topography, shearography and so on will not be given here. They are valid methods, but the emphasis will be on those used most often for composite structures. The following are, however, applicable to certain aspects of glass fibre reinforced composite vessels and pipelines. These methods can be divided into two groups. The first group test the integrity of the whole vessel or large section of a pipeline. Included in this group are pressure testing, acoustic emission and holography. The second group is applied more locally and includes spark tests and thickness tests. The following information was sourced from the Sasol Polymers specification P-EC 10 (Code of practice for inspection of in-service glass fibre reinforced composite equipment).

Visual inspection. Visual inspection methods are called the "first line of inspection". Visual examination is often the first method utilized by the end-user or fabricator to document and initiate a more thorough examination of the damaged region on the part. While these methods will certainly document what the naked eye sees immediately, they will not necessarily be able to discern between broken fibres and matrix cracking. They will not be able to indicate whether the damage goes deeper than the visible outer surface plies. Therefore they often provide a very reasonable description of the localized damage and can be used to map out the area for further study by other methods.

Tap testing. Tap testing, or the so-called 'Poor Man's Ultrasonic' test method, is often used as much as the visual examination. It certainly is not the most precise method, but it can quickly pinpoint potential delamination areas and areas of very high porosity. Tap testing is often done by using a small coin (like a R2 coin) to tap the outer surface and listen for changes in sound feedback. Areas of disbond, delamination and high porosity sound different to areas of good continuous bonds. It can be used to detect areas requiring further investigation by more definitive methods, for example ultrasound testing, but experience is required.

Acoustic emission. This method is particularly suitable for determining the integrity of whole systems, such as newly fabricated vessels or fairly long lengths of pipelines. This method can also be applied during routine maintenance inspection of equipment. The major advantages of this method are the speed with which the whole system can be inspected. The major disadvantage is the lack of trained operators and the cost of the equipment.

Optical holography. This method may be used to inspect whole vessels or sections of pipelines. The technique uses reflected laser light and can be used only in "line of sight" situations. Unlike acoustic emission it will not work on clad vessels, but adhering paint will not materially affect the test. The major advantage of this method is that it can be used to detect small defects in complex structures. Specific applications of this technique would include the detection of disbonding in laminates. The disadvantages include the cost of equipment and the lack of trained operators. Development of this method is being carried out in the Mechanical Engineering department at the University of Cape Town. It is still largely in the experimental stage, but it would be worthwhile monitoring its development.

Hydraulic pressure test. This method is usually specified in most codes as a final acceptance test for pressure retaining vessels and pipelines. The advantages are that it can be used to detect substantial leaks and structural failures and that it is relatively easy and cost effective to perform. The disadvantages are that very small leaks will not easily be detected by this method. This testing method could cause structural damage to the vessel being tested and in some instances water left after the pressure test may react with the intended operating medium during commissioning.

Liquid penetrant. The liquid penetrant test can be performed on a lined or unlined vessel of sufficient diameter to allow internal examination. The only precondition is that the surface may not be porous. This method is particularly suitable for the inspection of welds in plastic liners of vessels. The main advantages of this method are the low cost and ease of application. The major disadvantage is that there is a small risk of contamination.

Spark testing. This method can only be applied where an electrically conductive layer is available on the opposite side of the surface to be tested. In plastic liner welds this can be achieved with a strip of carbon fibres behind the weld area. Spark testing is usually carried out during the fabrication stage to test the integrity of welds made in plastic liners for glass fibre reinforced composite tanks.

The spark test detects discontinuities by applying a high potential difference across the material to be tested such as the vessel wall. Care must be taken not to damage the lining while spark testing. The operator must be familiar with the limits of each material. A record must be kept of every occasion on which spark testing was carried out on a vessel, noting the voltage that was used. Each subsequent test should use a lower voltage, to minimize the chances of damaging the liner.

C-Scan and A-Scan Ultrasound Testing. Ultrasonic through-transmission (C-scan) and ultrasonic pulse echo (A-scan) techniques are widely used for glass fibre reinforced composites in numerous applications. Sound waves are sent through composite structures and the waves are attenuated by imperfections such as voids, cracking, and delaminations. Sound waves are reflected back at these same interfaces or regions and provide an estimate of the size and location of the damage areas. Through-transmission techniques require that the sound wave is transmitted from one side, and detected and analysed from the other side of the structure. Unfortunately the opposite side of the glass fibre reinforced composite is not always readily available to the necessary instrumentation.

Three methods for ultrasonic C-scan inspection of fibre-reinforced composites are available (National Physical Laboratory, 2003:1):

(i) Method 1: Pulse echo (both immersion and contact)
(ii) Method 2: Single through-transmission (both immersion and water-jet)
(iii) Method 3: Double through-transmission

Pulse echo is used because it only requires a single side examination. A pulse technique is used to send a sound wave into the composite structure. It is a very reliable technique and can be used efficiently in the field for conducting inspections. These methods are suitable for use with carbon and glass fibre-reinforced thermoset and thermoplastic composites incorporating unidirectional or non-unidirectional reinforcements in either a continuous or discontinuous format. This includes mat, woven fabrics, woven rovings, chopped strands, combination reinforcements and hybrid rovings (National Physical Laboratory, 2003:2). Both A and C-scan are limited to locating areas of high porosity or void content, micro cracking in large quantities, delaminations, unbonds, and adhesive bonds. Unfortunately it has not yet been shown to be effective in distinguishing quantitatively between resin matrix cracking, fibre breakage, and "kissing unbonds" where the interface has not adequately separated within the structure.

Thermography. Thermography relies on heat transfer rather than sound wave techniques to detect unbound in composites. However, the technique seems to perform better picking up delaminations and unbounds in honeycomb core structures unless there is a 'kissing unbond' present. It can also be used in the field on glass fibre reinforced composite structures, as it has been with glass fibre reinforced composite commercial and civil engineering infrastructure applications. Thermography relies on heat transfer rather than sound wave techniques to detect unbound in composites.

Radiography. The last technique, X-ray, is excellent for inspecting at various composite structures and interfaces for porosity and delaminations. However, because the equipment is fairly bulky and very expensive, it is not a viable field inspection technique. The results require a highly trained technician to ascertain the type and the extent of the damage problem.

1.1.5 Life cycle case studies in FRP equipment

The "Bath-Tub Curve"

Most maintenance engineers are at least aware of the so called "bath tub-curve" (Coetzee, 1997: 62-65). The curve, illustrated in Figure 1.38 is a special case of the Hazard Function and depicts the risk of failure of a typical component or system, with three failure regions. The early failure or mortality region is a fairly short period in the life of a component during which a relatively high risk of failure is experienced. This is normally due to quality problems in manufacturing and assembly. The second region is very long compared to the other two regions and spans the working life of the component. During this period a constant and fairly low risk of failure is experienced. The third region which is known as the wear out phase sets in when structural changes due to operation start to degrade the component. The risk of failure thus increases fairly rapidly in this phase.

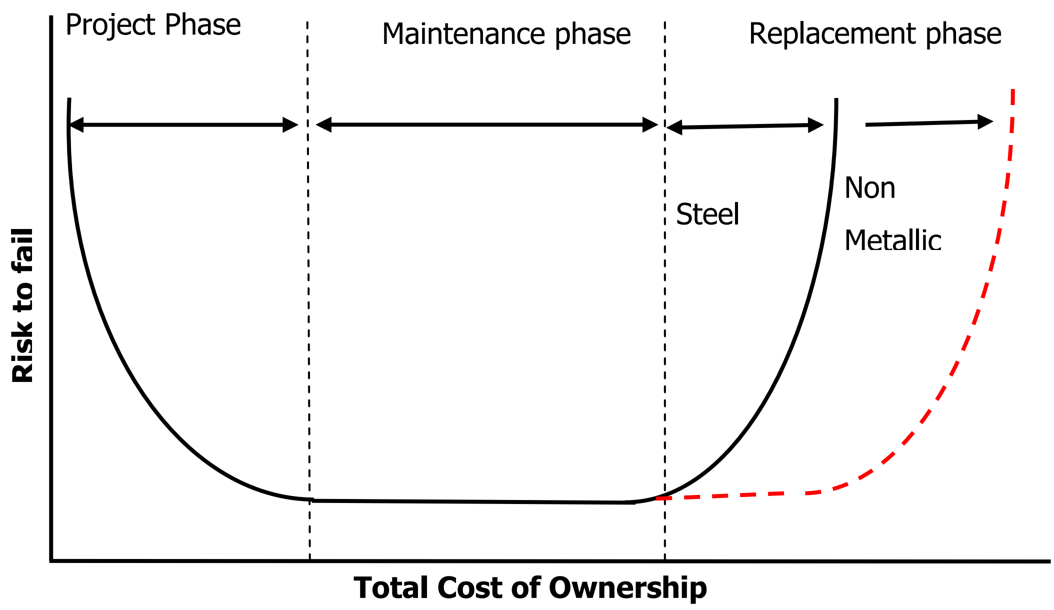


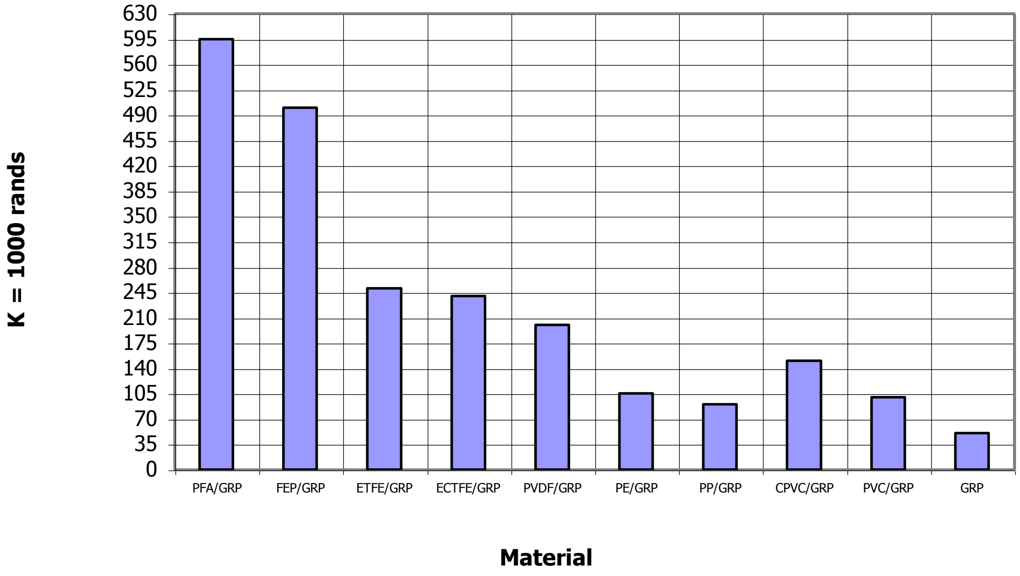
Figure 1.38 "Bath-Tub" Curve

Although the bath-tub curve has received wide recognition and is well known, it is not without criticism as an inadequate way of handling the failure process (Coetzee, 1997: 64). Irrespective of this, it is useful to indicate the advantages and limitations of using non-metallics during each phase of the bathtub curve with respect to the life expectancy and Total Cost of Ownership (T.C.O). It can be shown that non-metallics can in fact reduce T.C.O. as indicated by the extention of the replacement phase.

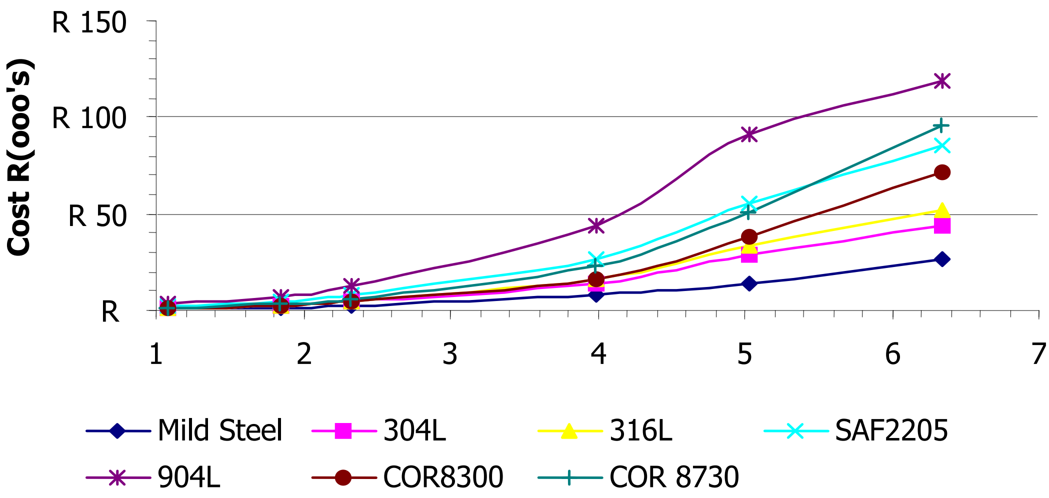
The First Phase – Project Phase. The first phase in terms of maintenance strategy of a component in, for example, a vessel or plant made of composites, is defined as early failure. As this phase is the direct result of the input into the project phase, the following case studies indicate the advantages and limitations of considering non-metallics as a material of construction.

Example 1 – Cost relationships of non-metallics versus steel. Graphs 1.7 and 1.8 show different comparisons that were done by Carter (2000: 6-7) in 2000. Graph 1.4 specifically indicates the cost comparison between different non-metallic materials most commonly found in use in industry in South Africa whilst Graph 1.5 shows cost versus lid diameter for tanks containing hazardous substances made from different materials. Note that the abbreviations 304L, 316L, 904L and SAF 2205 refer to different well-known high chromium steels used in highly corrosive conditions. COR8300 and COR8730 are examples of vinylester resin systems available that are also used in highly corrosive plant conditions.

As can be seen in Graph 1.7 and Graph 1.8, for steel alternatives, the total cost increases as higher corrosion resistance is required. The high cost is directly related to more exotic non-metallic materials. Furthermore, the cost of composite material vessels are directly comparable with the steel vessels. Although initial fabrication costs are only part of the T.C.O., it again emphasizes the fact that non-metallic engineered equipment can ensure savings on the total life span.



Graph 1.7 Comparative Costs for a Typical 28m³ Vertical Cylindrical Atmospheric Storage Tank with Flat Bottom and Semi Torispherical Top (Carter, 2000: 6)



Graph 1.8 Cost versus lid diameter of different materials of construction (Carter, 2000:7)

Example 2 – GRP: An alternative material of construction for chemical plant. Many engineers are under the impression that GRP tanks and vessels can only be fabricated with small diameters or relatively short lengths. In 1998 a South African manufacturer of GRP equipment manufactured a 150 m^3 Sulphur Dioxide storage tank with a length of 13,3 meters, weighing 3500 kg, in one piece, without sectional joints. This tank was made by using the filament winding technique.

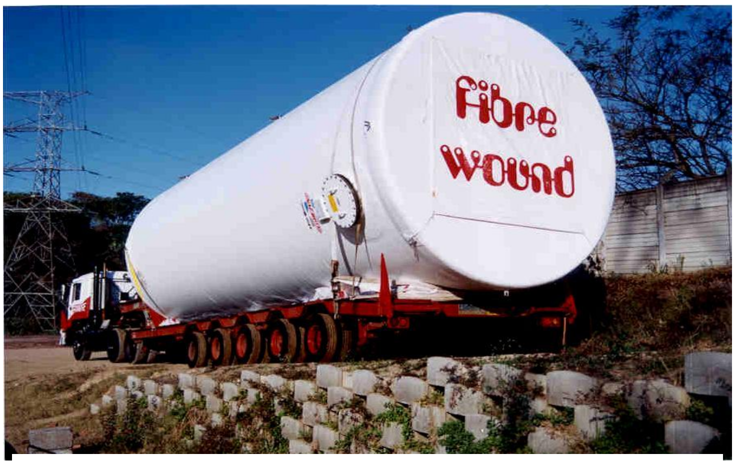


Figure 1.39 Sulphur Dioxide Storage Tank

Figure 1.40 Piping systems at Sasol Polymers - Umbogintwini

Figure 1.40 shows a pressurised piping system in a Chlor-Alkali plant, containing and conveying hazardous chemical substances. The use of GRP for difficult geometric and colour coding of the piping systems is illustrated.

Example 3 – Floating roofs. Throughout the chemical and petrochemical industries, gases and liquids are stored in vessels or tanks of various shapes and sizes. A large number of storage vessels are used by these industries to store large quantities of petroleum and other products at atmospheric or low pressure. Because of the large quantities, the American Petroleum Institute has established the API 620 & 650 specifications governing the design of these vessels (Mouton, 1990:85). Figure 1.41 shows a conventional floating roof storage tank designed to API 650. The disadvantages of this type of floating roof include the high initial installation costs, high maintenance, compatibility with the tanks operating cycle, and inefficient rim sealing.

Figure 1.41 Conventional floating roof storage vessel

Figure 1.42 Fibreglass internal floating roof

Fibreglass internal floating roofs (see Figure 1.42) combine seamless, unsinkable construction with the strength of reinforced fibreglass to provide a full contact floating roof designed to resist any product normally stored in floating roof tanks. These types of floating roofs float in full contact with the liquid, preventing the evaporation of the product stored within. Normally, a double seal mechanism is used to ensure a gas tight, leak proof and unsinkable roof structure. Other advantages of this design are the relatively low cost and simple/manageable installation (need only a 24” manhole nozzle), minimum reduction in tank capacity, as well as full compliance with the API 650 requirement in terms of allowable roof loading (supporting workers, toolboxes, etc) (Carter, 1999:2).

The Second Phase – Maintenance and Operation. The maintenance and operation phase is the part of the "bath-tub curve" where the number of failures has decreased significantly. Fortunately this is also the part of the curve where significant costs can be saved by selecting the correct material of construction for specific applications (especially in corrosive environments). This increases the life expectancy and reduces TCO costs. The reasoning behind this is to increase life expectancy before the replacement phase is reached for any equipment or plant resulting in lower life cycle cost.

Example 4 – Structural applications. Figure 1.43 shows severe corrosion and pitting of a metal structural beam in a highly corrosive environment, in this case an HCL plant. This is a classic example of the corrosion found in most plants operating in hostile environments.

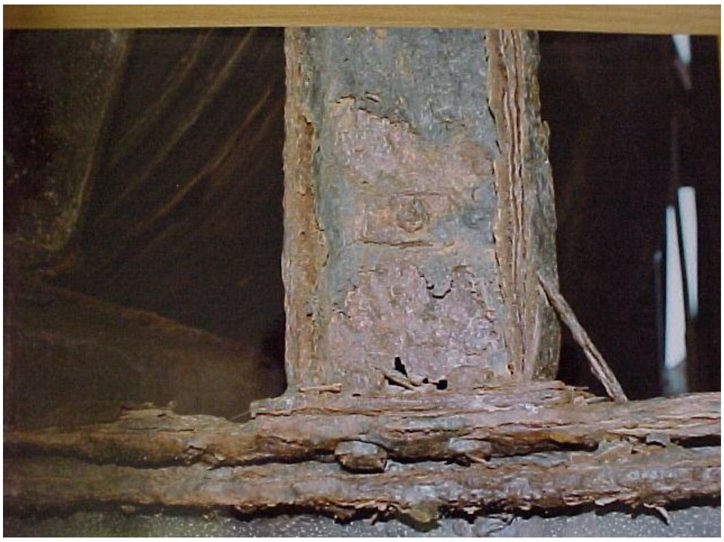


Figure 1.43 Corrosion on a steel beam in a chemical plant

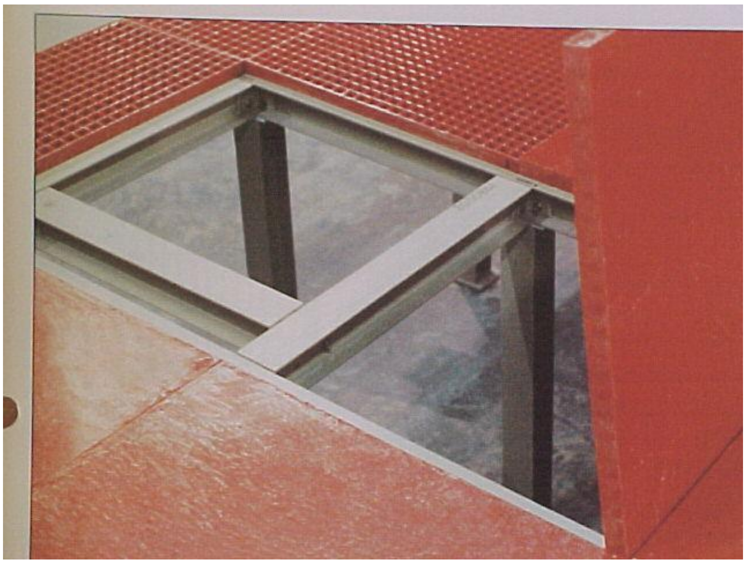


Figure 1.44 Example of non-metallic beams and grating

Total life cycle costs can be reduced by the installation of non-metallic beams and grating systems in highly corrosive environments, as shown in Figure 1.44.

Example 5 – Fire mains at Sasol Polymers. The importance of making use of non-metallic pipelines for fire-main systems versus the use of conventional steel lines is illustrated here (Viviers, 2000: 16-19). The most important reason is due to the corrosion resistance of the non-metallic alternative. The photographs shown below were taken on the Sasol Polymers Midland site, which is situated in Sasolburg. The photographs indicate the effect of corrosion on the interior (Figure 1.45a and b) as well as on the exterior of steel fire mains (Figure 1.46a and b).

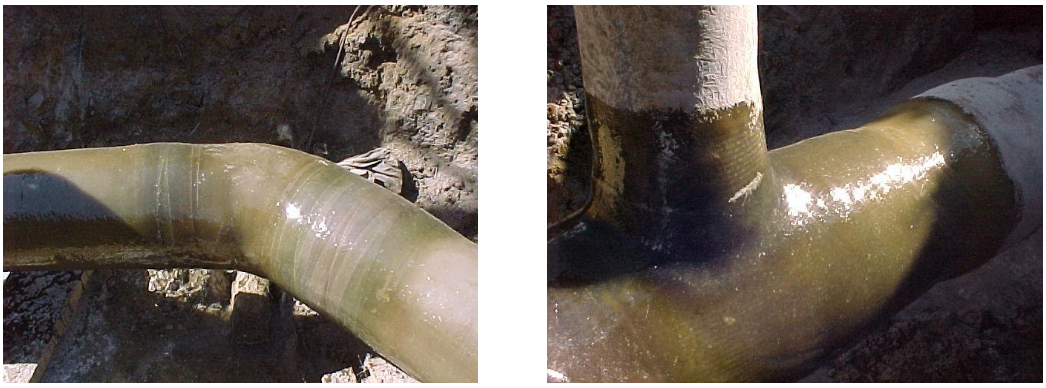
(a) (b)

Figure 1.45 Effect of corrosion on the interior of steel fire mains

(a) (b)

Figure 1.46 Effect of corrosion on the exterior of steel fire mains

Examples of GRP fire main systems are shown in Figure 1.47a and b, and HDPE systems in Figure 1.48a and b The non-metallic systems have been exposed to the same environmental and operating conditions as those made from steel shown above, and have suffered very little corrosive damage, by comparison.



(a) (b)

Figure 1.47 Examples of GRP fire mains systems

(a) (b)

Figure 1.48 Examples of HDPE fire main systems

Example 6 – HCL Tank Application. In 1982 an extension to the existing HCL stock tank farm at AECI at Umbogintwini was made to increase capacity. The vessels and piping shown in Figure 1.50 replaced the externally rubber-lined steel vessel as shown in Figure 1.49. It should be noted (see Figure 1.49) that the steel parts exhibit severe external corrosion while the non-metallic pipes (polypropylene material) are still in excellent condition.

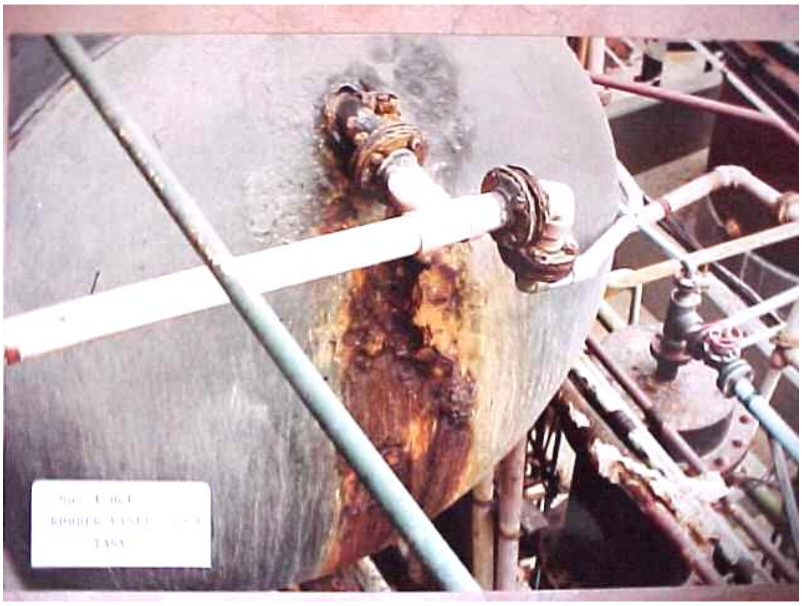


Figure 1.49 HCL rubberlined vessel

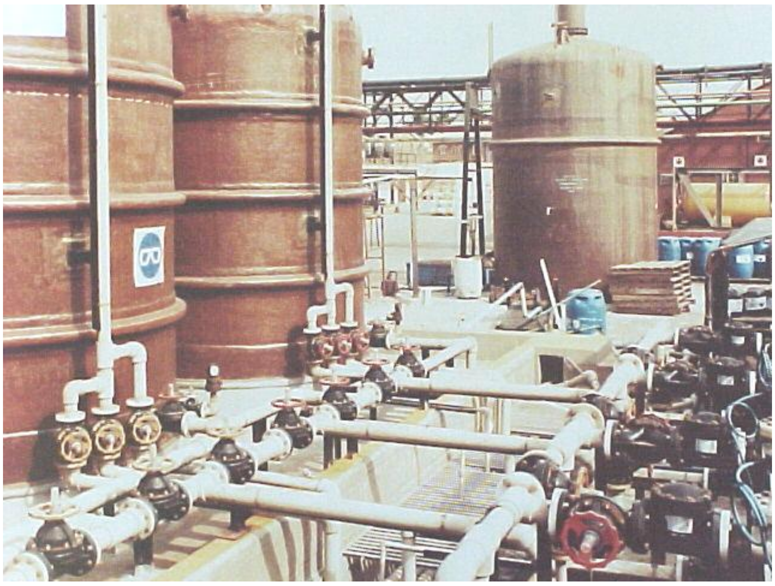


Figure 1.50 HCL stock tank farm

The Third Phase – Wear out and Replacement

Example 7 – Chimney stack. In Figure 1.51 a 46 metre high GRP chimney stack that was installed in 1978 at the Minerals Processes Plant, Impala Platinum Ltd, Bophutatswana is shown. This stack, which has a diameter of 3,3 m, and weighs 6,5 tons, was designed to withstand highly corrosive environments at temperatures of up to 150 ºC and wind loading of 112km/h. The main reasons for using non-metallic material of construction for this replacement chimney stack instead of the replaced steel stack was (1) that the overall costs were substantially less than stainless steel or lined mild steel systems, (2) the ease of transport of the 4 sections of the stack and (3) the reduced maintenance of non-metallic equipment.

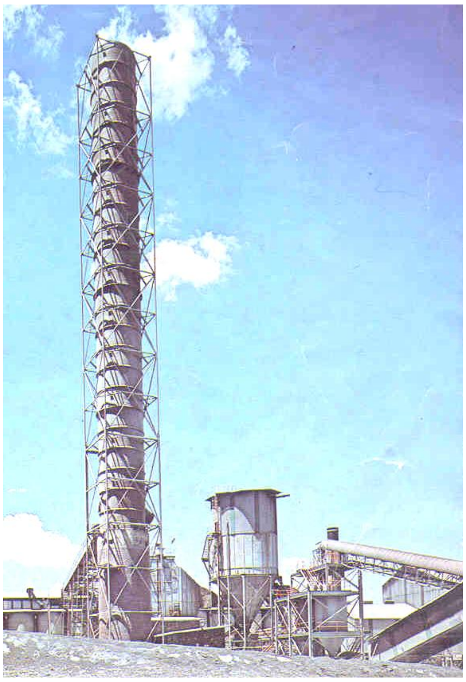


Figure 1.51 A 46-meter high GRP chimney stack

Example 8 – Lining of steel equipment. The TCO of equipment can be reduced significantly by re-lining existing equipment after a number of years of service. Lining of new equipment can also significantly increase the life expectancy after fabrication. An existing steel tank at Sasol, handling a wide range of acid and solvent wastes, up to 60 ºC (pH can vary between 2-12) was lined with a vinyl ester resin system with flakes of C-glass and put into service in 1977. This tank (see Figure 1.52) is still in service today with only minor repairs done to it as part of the plant's maintenance program (Ghetea, 2001).

Figure 1.52 Neutralization tank lined with GRP

2.5 Summary

Modern composites offer a wide range of advantages compared to conventional structural materials, e.g. steels and aluminum alloys. Although composites were originally defined for aerospace applications, they are now used in many varied applications to ensure low costs and improved safety. Replacing existing steel components with composites will result in even stronger but lighter constructions.

In summary, the following advantages of using composites can be noted:

(i) stronger than steel on an equal weight basis
(ii) ability to tailor properties to meet wide-ranging performance specifications
(iii) savings in transportation and handling costs
(iv) good impact, compression, fatigue, abrasion, erosion and corrosion properties
(v) excellent chemical and environmental resistance
(vi) good structural integrity
(vii) ability to fabricate massive one-piece mouldings
(viii) proven in-service track record
(ix) low-to-moderate tooling costs for the manufacturer
(x) cost-effective manufacturing processes with medium-to-high productivity rates
(xi) comparable initial capital costs for the user
(xii) design flexibility to customer needs
(xiii) lower maintenance costs

The limitations of composites include:

(i) lower allowable operating temperatures than steel
(ii) high thermal expansion, especially above 60 degrees
(iii) piping systems above ground need more support
(iv) process upset conditions e.g. temperature can lead to failure

3. Conducting Surveys

A survey is a systematic method of collecting information from a selected group of people by asking a series of questions. Surveys can be used to collect various types of information. They can collect information on people's behavior, job performance, knowledge, preferences, attitudes, beliefs, feelings, etc (Houston, 2000:2).

Houston (2000:3) also states that without a clear purpose why a survey needs to be done, the likelihood will increase that the survey effort will flounder. This can result in wasted resources, useless data, and disappointment on the part of those who initiated the survey and those who responded to it. Furthermore, conducting a survey can draw attention to an organization or initiative from the people who receive the survey and from those who learn that it is being conducted. This attention can led to expectations that executive or management actions will soon follow.

Collecting data on business organizations is very different from collecting data on individuals, according to Cox and Chinnappa (1995: 9). Questions that survey designers need to consider include the following:

(i) what level of the business organization is best able to answer survey questions, meaning the establishment, the enterprise, or something in between?
(ii) in terms of job title or position, who is the person within the business organization most likely to know or be able to find the answers to survey questions?
(iii) will permission have to be obtained from the owner or chief executive officer prior to completing the questionnaire?
(iv) what records are available to the firm for use in answering survey questions?
(v) can survey questions be structured to conform to the business' record-keeping practices, including its fiscal year?
(vi) are there particular times of the year when data is more readily available?

(vii) what is the best way to collect data that may be viewed as confidential business information?

There may be a variety of purposes for which information is collected. Most frequently, however, interest has centered on four characteristics of the universe or population under study. These are:

(i) population total (e.g. the total number unemployed);
(ii) population mean (e.g. the average number of persons engaged by an industrial establishment)
(iii) population proportion (e.g. proportion of cultivated area devoted to grain);
(iv) population ratio (e.g. the ratio of expenditure on foods to that on rent). The populations are considered as finite in the sense that the number of objects contained in them (such as persons, farms, firms, stores) is limited.

Population and sampling. The population can be defined as the entire collection of events which one is interested in (Howell, 1989:3). Broadly speaking, information on a population may be collected in two ways. Either every unit in the population is enumerated (called complete enumeration, or census) or enumeration is limited to only a part or a sample selected from the population. A sample survey will usually be less costly than a complete census as it will take less time to collect and process data from a sample than from a census. But economy is not the only consideration; the most important point is whether the accuracy of the results would be adequate for the expected end-result. It is a curious fact that the results from a carefully planned and week-executed sample survey are expected to be more accurate (nearer to the aim of the study) than those from a complete census that can be taken. A complete census ordinarily requires a huge and unwieldy organization and therefore many types of errors creep in which cannot be controlled adequately. In a sample survey the volume of work is reduced considerably (Raj, 1968:14).

In order to cover the population decided upon, there should be some list, map or other acceptable material (called the frame), which serves as a guide to the universe to be covered. The list or map must be examined to be sure it is reasonably free from defects. A list of possible survey planning considerations in covering the population includes:

(i) define objectives of the survey

(ii) define population to be covered
(iii) define the frame for the data
(iv) divide up the population into sampling units
(v) determine the sampling parameters: size, manner of selecting, estimation of population characteristics, margin of uncertainty allowed, estimated cost
(vi) define information to be collected: relevance, completeness
(vii) define method of collecting data (and calculating its actual cost)
(viii) specify survey time scale, completion dates of steps
(ix) construct questionnaire or schedule
(x) train interviewers and establish supervision
(xi) design procedure for inspecting raw results and editing
(xii) define how to handle non-respondents
(xiii) analyze the data
(xiv) present results to decision makers (Raj, 1968:14).

Methods of sampling. The current method, perhaps most widely employed in the selection of respondents in market surveys and in polls of opinion, is that of "in ratio" or "quota" sampling. This method of sampling has been especially attractive because of the ease with which it can be administered and because of its apparent success in some of the better-known public opinion polls (Hauser & Hansen, 1944:26).

The first and usually the best method, when available, is that of working from a complete listing of names and locations of the persons, stores, families, or other populations that are to be surveyed. However, a list of all of the elements in the universe that are to be sampled is not available. In such a case, various methods have been found feasible and practical for developing a sample prelisting, most of which might be classified under the general heading of "area sampling". The approach in area sampling is to subdivide the universe to be sampled into a set of small areas. Ordinarily, it is entirely feasible to develop a complete list of areas, and to obtain a sample of areas from this list. This sample makes use of the fact that when a sub-sampling design is used, there may be considerable gain in sampling efficiency if the units are so defined as to maximize the heterogeneity of the population within each unit.

One of the most important advantages of area sampling over that of quota sampling is that which reduces the dependence of the investigator on knowledge of the characteristics of the population. The use of areas as sampling units implies that clusters of elements instead of individual elements ordinarily will be sampled, and considerable theory has been developed recently around efficient methods of sampling clusters of elements from finite populations. Although the design of such a sample involves greater initial investment than does the design of a sample under the quota sampling method, the costs involved usually are not prohibitive and the investment may be calculated to more than pay for itself (Hauser & Hansen, 1944:31).

In conclusion it should be noted that area sampling is the preferred methodology where the population is scattered across a large geographic area. As stated, quota sampling will have to be implemented once the area sampling is done.

Constructing survey items. Once the decision has been made to conduct a survey, the survey needs to be constructed, the response format selected, the survey pilot tested, results analyzed and the conclusions about the results communicated to the respondents and decision makers (Houston, 2000:6).

Constructing the survey items. Houton (2000:6) states that survey questions should cover the topics of interest and must be clearly written, concise and to the point, focusing on one idea at a time. They should also be explicit.

Selecting the response format. Survey items are used to ask people how much they agree with some statements, how important something is, or how often something happens. Methods used and recommended by Houston (2000:7) are: rating scales, ranking items, selecting options as well as open-ended questions. Demographic questions is also typically used as to segment respondents into smaller groups based on specific characteristics such as rank, age, or organizational level.

Reviewing items. After the potential survey items and response scales have been developed, they need to be reviewed to make sure they are relevant to the purpose of the survey, appropriate for the individuals being surveyed and that the respondents will be capable of providing the type of results expected. Care should be taken for items that are ambiguous, overlapping or leading (Houton, 2000: 11-12).

Pilot testing the survey. Conducting a pilot test assists in further checking and refining the survey. A small group is normally used to request their comments, measure the time required to complete the survey and to obtain a general "feel" if the survey is acceptable for its intended use.

Administering the survey. Two common methods of administering written surveys are by mail or in-person. Houston (2000: 13) states that posted surveys mailed to local respondents may take 2-3 weeks to return, and the possibility of losing the mail must be considered. An alternative to this approach is to overcome the said problems is the use of electronic mail or even conducting online surveys. The major advantages are less cost to produce and administer the survey, quicker response time, larger respondent universe and faster availability of the results as well as more visual appealing survey structure (Business Survey Methods, 2003:1).

Analyzing the survey results. After surveys have been administered, they need to be summarized, analysed, and interpreted as to provide useable results. The most common methods to summarize and analyze the results are Frequency distributions, percentages, and Pareto charts.

Communicating the survey results. Houston (2000: 17) states the most important action after collecting and analyzing the survey data is communicating the results in tailor-made presentations to the different groups in the organization.

In conclusion, it can be stated that surveys can be used to provide information to support improvement efforts. Surveys can be used to obtain information on external customer/colleagues requirements, current satisfaction levels, ideas on how to improve, and effects of previous efforts. Based on this information, decisions can be mode on where to focus the organization's improvement efforts. Therefore, the following should be kept in mind when beginning a survey:

(i) have a clear purpose for conducting a survey
(ii) tailor the survey to the particular respondents and issues being assessed
(iii) keep surveys short and simple
(iv) communicate results to managers and respondents
(v) use results to guide future improvement efforts (Business Survey Methods, 2003:18).

4. The role-players in the composites industry in South-Africa in 2000

The composites industry consisted out of the following main role-players in the beginning of the year 2000:

(i) Users

A complete spectrum of users from petrochemical, pulp and paper, mining, minerals, metals, marine, sewerage, effluent, food, beverage, military, aerospace, transport, etc. exists in South Africa. Sasol is included in this group.

(ii) Associations and Institutes, including

ANMEM The Association of Non-Metallic Equipment Manufacturers was formed by a group of manufacturers concerned with the competency of manufacturers of vessels, tanks, piping systems, containing hazardous, dangerous, toxic, corrosive fluids and gases operating under pressure/vacuum at elevated temperatures.

CMSG the Composites Manufacturers Supply Group is a group of reputable manufacturing and supply companies.

(iii) Providers of Education, Training and Research

The main providers were the University of the Witwatersrand (Composites Facility), the DIT with its *Cadence* research centre as well as Technikon Free State. Some accredited industry providers were also providing experiential "In Service Training".

(iv) Providers of Quality Assurance, Inspection and Testing, including

SABS The South African Bureau of Standards (SABS) provides national standards.

AIAApproved Inspection Authority (AIA). The Department of Labour in accordance with SABS 0227 Code of Practice approves inspection authorities.

VUP Adv. Com.
The Vessels under Pressure Advisory Committee to the Department of Manpower is tasked with developing the framework and guidelines for new legislation and competencies required regarding the design, manufacturing, testing, quality assurance and routine inspection for vessels under pressure.

VUP Tech. Com.
The Vessels under Pressure Technical Committee to the VUP Adv. Com. is tasked with addressing technical issues regarding interpretation of existing legislation and proposals for future legislation.

ECSA The Engineering Council of South Africa has initiated the process for the formation of a working group to develop the unit standards for the registration and certification of competent Inspectors of Pressurized Equipment for non-metallics.

(v) Fabricators

The main fabricator in the composites industry are discussed in Section 1.1.3.

4.1 Statutory requirements for Vessels under Pressure

The OHS act 85 of 1993 defines the meaning of (South Africa 1996:17468) a *vessel under pressure* as being a vessel which operates under pressure and includes a boiler, pressure vessel, pressurized system or portable gas container. On the other hand a *pressure vessel* is defined as being a any pressure vessel of which the interior or jacket is under pressure or in which a cushion of gas or vapor can form above the liquid at a pressure in excess of the atmosphere, including a diving bell, but does not include:

(i) A boiler
(ii) A vessel in which the pressure is exerted by a liquid, the temperature of which does not exceed the boiling point of the liquid at atmospheric pressure and in which a cushion of gas or vapor cannot form above the liquid.
(iii) The working cylinders or chambers of a steam heat or air engine.

(iv) A vessel under pressure which forms an integral operating part of a motor vehicle or locomotive running on railway lines.
(v) A portable gas container
(vi) A pressurized system.
(vii) A vessel of which the product of the design pressure in Pascal and the capacity in cubic meters is less than the figure 15 000.
(viii) A vessel of which the design pressure is less than 40 000 Pascal gauge pressure.
(ix) A vessel with a nominal internal diameter of less than 150mm; or
(x) A hand-held fire extinguisher.

A *pressurized* system is defined as being an assembly of vessels under pressure and includes connections by pipes or similar ducts, fittings and valves which operate under gauge pressure equal to or greater than 40 000 Pascals for the process and conveyance of a flammable liquid, hazardous chemical substance, saturated steam or superheat steam.

The legal requirements as determined by the OHS Act and by SABS 0227:2000 'The evaluation of the technical competence of inspection authorities for the certification, re-certification, modification or repair of vessels under pressure', were the same for non-metallic vessels under pressure as they were for metallic vessels under pressure. It should be noted that in the Vessels under Pressure regulation, as well as the SABS 0227:2000, no reference was specifically made regarding the competency required to inspect or to verify the design of composite vessels. As no accreditation or certification scheme was available for IPEs for composite vessels or design verifiers, the door was left open for the industry to utilize the 'metallic' scheme to fill the void.

4.2 Nationally recognized and used codes and standards

By the end of 2000, most of the major suppliers of composite equipment e.g., vessels, tanks and piping were using the codes listed in paragraph 1.4.2. It is interesting to note that only the Vessels under Pressure Regulation in the OHSACT list the BS4994 – Design and Construction of Vessels and Tanks in Reinforced Plastics is recognized as a code of construction. (South Africa 1996: 17468). Regardless of the inadequacy of the OHS Act to address the composites industry, the most commonly used codes are the British Standards.

Chapter 2

Introduction to Sasol and the composites industry

2.1 The Sasol Group of Companies

The South Africa Coal, Oil and Gas Corporation Limited (SASOL) was established on 26 September 1950. From a very humble beginning, the company has grown to be a world leader in the commercial production of liquid fuels and chemicals from coal and crude oil. The company has a turnover of more than US $6-billion per year and is listed on the JSE Securities Exchange (SOL) with a market capitalization of more than US $5 billion and on the NASDAQ (SASOL) in New York.

Sasol manufactures more than 200 fuel and chemical products at its main plants in Sasolburg and Secunda in South Africa as well as at several other plants abroad. Its products are exported to more than 90 countries around the world. Sasol has developed world-leading technology for the commercial production of synthetic fuels and chemicals from low-grade coal as well as the conversion of natural gas to environmental-friendly diesel and chemicals (Monala, 2000).

For the financial year 2000/2001, the Sasol Employee Report 2000 (Maphathe, 2000: 4-5) indicates total wealth created of R12 606 million, with R4 674 million (37,1%) re-invested in the group in terms of new plant and upgrading of existing facilities. The South African portion of Sasol consists mainly of the following companies: Sasol Synthetic Fuels, Sasol Chemical Industries, Sasol Coal, Sasol Oil, Sasol Polymers, Sasol Agri and Sasol Technology.

2.1.1 The acquisition of Polifin by Sasol in 1999

Sasol Polymers originated as a joint venture by South African chemical industry giants Sasol and AECI. Then called Polifin, the company was created to provide a strong, integrated cost base and a leading market position in polymers and chemicals in order to compete against imports over low-duty barriers. AECI had access to the polyethylene and PVC polymer markets and Sasol to the polypropylene market. In addition, Sasol brought competitive ethylene and propylene feedstocks to the mix. The new company, of which Sasol owned 60 percent and AECI 40 percent was registered in January 1994 (Truter, 1998: 206). A JSE listing followed in July 1995 changing the ownership structure to 42 percent and 40 percent, respectively. The remaining 18% was offered to the public.

In September 1999 Sasol acquired AECI Limited's shares and the company was delisted. In September 2000 the business changed its name to Sasol Polymers and now operates as a division of Sasol Chemical Industries (SCI). For clarity and ease of explanation, the author will use the term 'Polifin' in the rest of the thesis when referring to AECI or Sasol Polymers.

2.2 The availability of infrastructure and resources for composites: Summer 2000

At the start of the year 2000 (or summer of 2000, as referred to by this author), the newly acquired Polifin division of Sasol was still encapsulated in a cloud of uncertainty, causing difficulty for the author to carry out an audit of the infrastructure, resources and procedures in place to support non-metallics. The main focus areas therefore in the field of non-metallics for the audit in both Polifin and Sasol were the involvement and/or existence of:

- (i) professional bodies
- (ii) technical Committees
- (iii) specifications
- (iv) tertiary research facilities
- (v) supplier interaction
- (vi) information Technology
- (vii) professionals in the field of non-metallics

The audit on the above mentioned and level of knowledge was conducted in the first four months of 2000.

2.2.1 Professional bodies

Representation by Sasol. Although Sasol is represented on numerous industry related bodies, no evidence could be found of any formal representation on non-metallic related industry bodies. One of the main reasons was that until the acquisition of Polifin, Sasol was not involved in the downstream activities of the manufacturing of polymers. Therefore, involvement in non-metallic industry related bodies were not seen by Sasol as a strategic driver.

Representation by Polifin. The Non-Metallic Committee (see Section 2.2.2 below) was represented at the annual GRP conference held at Wits University on 4 July 1991 where papers on GRP composites in the chemical industry were presented. John Kohler, one of the committee members, presented a paper 'Some Background, Current Status and Future Trends of GRP Composites in the Chemical Industry'. The paper was well received and amongst other things called for a National Forum in GRP composites where users, suppliers and research institutions could resolve common issues. This motion received widespread support. However, it never took off and it is only of late that Technikon Natal in conjunction with industry has formed the 'Polymeric Composites Institute of South Africa' (PCISA). By the end of 1999, Polifin as the leading producer of polymer related products, was actively involved in various industry related non-metallic bodies. Through the years Polifin (as well as AECI) has actively contributed to the development of the non-metallic industry by participating in SABS technical committees, presenting technical papers at local conferences, etc.

2.2.2 Technical Committees

Technical Committees in Sasol. In the field of non-metallics, no reference could be found of the existence of permanent committees or work-groups in the field of non-metallics.

Technical Committees in Polifin. The Polifin Non-Metallic Technical Committee had its origin in AECI Limited when it was established in January 1989 with a view to assisting operating companies in the AECI Group in achieving soundly engineered non-metallic equipment and ensuring uniformity in applied standards and design. A committee was formed with representatives at that stage from the main production sites of AECI in South Africa, namely Umbogintwini (Natal Province), Modderfontein (Gauteng Province) and Midland (Free State Province), and included the author. The objectives of the original committee initially and later the Polifin Non-Metallic Committee were as follows:

(i) to review relevant standards and codes and prepare addenda where necessary for suitability for the company's use
(ii) to assist the Operating Companies with particular problems
(iii) investigate manufacturing techniques and recommend improvements
(iv) investigate and keep abreast with developments in materials of construction
(v) determine the company's needs in informing and training of technical personnel in non-metallics and arrange seminars where necessary to address shortcomings
(vi) resolve matters of a general nature related to materials of construction for particular chemicals, corrosion charts and relevant literature, which require to be shared (Clarke, 2000:7).

This committee has worked diligently in achieving the objectives through the years; sometimes within tight budget and manpower constraints. Following the acquisition of Polifin by Sasol in 1999, the committee continued with its function and objectives. It is important to note that the Polifin Non-Metallics Committee was the driving force regarding the awareness and use of non-metallics in operating plants in Polifin. Reference made to Polifin regarding non-metallics implies the workings and duties of the Polifin Non-Metallics Committee.

2.2.3 Company Specifications in the field of non-metallics

Specifications developed by Sasol. Specifications developed by Sasol at the start of 2000 were:

SP-41-4 Tanks in Glass Fibre Reinforced Plastics
SP-90-2A Welding of Thermoplastic piping (draft)

It is worthwhile to note that in over fifty years of existence Sasol has only developed one specification dealing with composite material. The main reasons for this were:

(i) the petrochemical industry, because of its higher operating conditions in terms of pressure and temperature, tends to be metallic/steel orientated
(ii) lack of competent personnel in all the disciplines regarding composites
(iii) composites and composites technology was seen as a "black art" with too many unknowns.

Specifications developed by Polifin. The starting point in 1989 for the Polifin committee was to obtain copies of all applicable internationally recognized standards and codes. These were scrutinized and the most appropriate to the chemical industry were selected.

For the design and manufacture of vessels, the code BS 4994 was selected from a host of codes and an addendum prepared to incorporate AECI's/Polifin's particular requirements.

Appendices included issues like handling and transport procedures, stress-relieving requirements for PVC and example drawings for vessels and tanks.

For the design and manufacture of piping, the codes BS 7159 and BS 6464 were examined and the update and preparation of the Polifin standards and specifications are now carried out in conjunction with these codes.

Even with these codes the committee in isolation could not carry out development of the standards and specifications to meet SA requirements. A great deal of the development and testing work was carried out in conjunction with suppliers and the factories. To finalize the details for the various liner materials and lay ups involved several years of work. Other matters which were attended to were items such as GRP flooring and solid plastic vessels both fabricated and molded.

At the end of April 2000, the committee which was by then a Sasol Committee, and still included the author, had completed eighteen standards, specifications and guidelines; had four under review (old AECI & approved Polifin Standards); three awaiting issue and seven on the waiting list for development (Marais, 2000). They are:

P-EA 1 Non-Metallic Piping Standard
P-EA 2 Non-Metallic Piping Supports

P-EA 5	Tapered Socket / Spigot GRP Fittings
P-EA30	Handrailing, Grating, Stairs & Catladder
P-EA 42	Non-Metallic Piping Identification Tag (Under Review)
P-EA 45	PFA Pipe Fittings (Under Preparation)
P-EA 46	Fabricated Thin Wall Liner Dimensions (Under Preparation)
P-EA 58	CPVC Pipe Fittings (Under Preparation)
P-EA 60	MFA Pipe Fittings (Under Preparation)
P-EA 101	Metallic & Non-Metallic PV Nameplate & Bracket
P-EB 2	Piping Specification
P-EC 4	Procurement & Handling Of Non-Metallic Piping, Tanks And Fittings
P-EC 7	Fire Mains: Code of Practice (Under Review)
P-EC 9	Plastic Welding Requirements
P-EC 10	Code of Practice for Inspection of In-Service GRP Equipment
P-EC 136	Rubberline Specification (Under Preparation)
P-EF2	Guide To Auditing Suppliers (Under Review)
P-EF 5	Polypropylene & HDPE Pipe Fittings
P-EF 6	PVC Pipe Fittings for Solvent Cement Jointing
P-EF7	GRP Piping Fittings
P-EF 8	PVDF Pipe Fittings
P-EF 9	Coatings & Linings for Steel & Concrete
P-EF10	Non-Metallic Piping Nozzle Stub-Ins
P-EF11	ECTFE Pipe Fittings (Under Preparation)
P-EF 313	Addendum To BS 4994 (Under Review)
P-EG 3	Laminate Post Cure Procedure (Under Preparation)
P-EG 4	Resins Selection Guide
P-EG 5	Guide To Detection of In-Service Deterioration of In-Service GRP Equipment
P-EG 6	Recommended Piping In-Line Equipment

2.2.4 Tertiary Research Facilities

Involvement by Sasol in research. In the field of non-metallics, there was no involvement from Sasol in any tertiary institution.

Involvement by Polifin in research. The Polifin Non-Metallic Committee investigated the GRP testing, design and development facilities that existed at Wits University. In 1998 Polifin became an Industrial Partner of the University.

A testing facility was also initiated at the Technikon Natal and officially opened on January 27, 2002. The main partners of this venture were Technikon Natal, Fibre-Wound and Polifin. The author was involved with the testing facility from the initial idea until present, with the specific function of representing Sasol Polymers and therefore the Sasol group's interest in the facility.

The main objective of this facility is to quantify the design and manufacture of GRP, thermoplastic-lined GRP and thermoplastic piping and fittings, based on current international codes and standards and to establish a database for the New SABS Draft Standard: 1748-2 'GRP Pipes and Fittings for Industrial Applications'. In addition, a computer model has been designed and verified with the physical test results and used to simulate some of the long-term tests in the future to reduce time. Finally, characterization of the pipe failures is being carried out, to identify the failure mechanisms involved.

2.2.5 Supplier interaction

Sasol Approved Supplier List. In the field of non-metallics, no specific guidance or evidence could be found regarding a Sasol company-wide non-metallic supplier list, supplier categories or detailed auditing procedures.

Polifin Approved Supplier List. In the early days non-metallic suppliers for AECI/Polifin were assessed by way of visits to their respective works and enquiries for equipment to ascertain capabilities regarding vessels and piping. The suppliers also responded by submitting specific composite samples for evaluation to AECI/Polifin. Assessments of suppliers were formally carried-out using the Engineering Standards 'Guide For Auditing Of Suppliers / Fabricators'. Suppliers were rated by a team of auditors, from which the supplier obtained a rating status ranging from 'A' to 'E' as follows:

A *Preferred supplier* - A quality system which fully conforms with, or exceeds all Polifin requirements. The supplier displays excellence in discipline and execution of the quality system. This rating gives the supplier preference in sourcing decisions, development programmes, long term commercial agreements and industry award nominations.

B *Approved supplier* - A quality system which mostly conforms with, or exceeds, the majority of all Polifin requirements. This rating gives the supplier an acceptable basis upon which to receive requests for quotations issued by Polifin.

C *Restricted business* - A quality system which partially conforms with Polifin requirements. It may exceed some of the requirements, but is deficient in others. This rating allows the supplier to have restricted business with Polifin within the limitations defined by the findings of the Supplier Quality Assessment. A confirmed Quality System Improvement Programme is required to allow this supplier to upgrade to the 'Approved Supplier' status.

D *Unsuitable for business* - A quality system which reflects non-conformance with Polifin requirements. If the supplier is rated 'D', Polifin shall recommend that further business with Polifin should be withheld until the supplier demonstrates that immediate action has been taken to correct deficiencies to the satisfaction of the Polifin representative.

E *Unsuitable for business* - A quality system which reflects major non-conformance with Polifin requirements. This supplier is considered not suitable for further business with Polifin and steps may be taken to resource current business.

The number of Approved Suppliers by Polifin for non-metallic services and products per category were as follows during the audit (AESP, 2000: 14):

Companies audited	03
Companies recommended by the non-metallics committee (Recommended but not audited)	16

Companies were categorized as follows based on their capabilities and the outcome of audits:

(i) rubber lining of piping
(ii) rubber lining of equipment
(iii) various non-metallic spray coatings
(iv) GRP vessels up to 5 m^3 hand lay-up
(v) GRP vessels larger than 5 m^3 hand lay up
(vi) GRP vessels up to 5 m^3 filament wound
(vii) GRP vessels larger than 5 m^3 filament wound
(viii) lined GRP vessels
(ix) solid thermoplastic vessels
(x) molded tanks
(xi) GRP piping
(xii) GRP piping lined
(xiii) extruded thermoplastic piping
(xiv) piping erection
(xv) special GRP equipment
(xvi) vacuum formed equipment
(xvii) machined plastics
(xviii) plain thermoplastic piping fabrication
(xix) fabrication of thermoplastic lined piping
(xx) thermoplastic and GRP repairs

2.2.6 Information Technology in Sasol and Polifin

No reference could be found from both the Sasol and Polifin Internet/Intranet with respect to the use and application of non-metallic related technology.

2.2.7 Professionals in the field of non-metallics

During the study the author focused on the existence of departments/sections with specific competencies in composites or non-metallics. Specific categories in terms of professional registration were engineers or technologists, technicians and inspectors.

Professionals in the field of non-metallics appointed in Sasol. At the time of the audit, no registered professionals were employed on a permanent basis by Sasol in either of the above mentioned categories in the field of non-metallics.

Professionals in the field of non-metallics appointed in Polifin. Polifin employed the following registered professionals on a full time basis at the time of the audit:

-	engineers or technologists	1 (the author)
-	technicians	1
-	inspectors	3 (with respect to the IPE scheme – metallics)

The Plastics Federation has held, on a few occasions, a course called 'Introduction to Plastics for Non-technical Personnel' for non-metallic committee members and some additional AECI/Polifin personnel. This course proved most valuable to the members with limited non-metallic experience.

2.3 Level of Awareness in the Sasol Group Regarding Non-Metallics

The rationale and motivation for this study by the author was to raise the awareness of the use of non-metallic materials in the Sasol group of companies. Sasol, a company employing over 3000 tertiary qualified personnel in the engineering field, has identified the need for raising the awareness regarding non-metallic material, to ensure the continuous safe and cost-effectiveness of production of its operating plants. The author was therefore appointed as the *Sasol Group Non-Metallic Specialist* effective from October 1, 2000 to raise the awareness and implement strategies in support of this initiative. A further need that was identified was to increase the use of these materials in capital projects to reduce the total cost of ownership over the lifetime of the equipment where the use of non-metallics had a clear advantage over steel.

The author realized from the outset that evaluating the existing level of awareness and knowledge regarding non-metallics had to be done by selecting target groups and by using questionnaires as a measuring tool. The processes that were proposed and used were:

(i) identifying/selecting the target companies and groups in the Sasol Group of companies

(ii) evaluating the existing level of awareness and knowledge regarding non-metallics of the selected groups via questionnaires

(iii) identifying/selecting possible methodologies (e.g.: seminars, conferences, publications, Intranet, incorporating the Polifin Non-Metallic specifications into the Sasol system and training of participants, etc.) to install a culture of non-metallics

(iv) selecting/implementing the most suitable methodologies for the different target groups

(v) evaluating the level of awareness/knowledge after a certain time period of exposure to the selected methodologies

The first two steps of the process will be discussed in this chapter.

2.3.1 Identifying/selecting the target companies and groups

The target divisions in the Sasol Group were selected based on the possibility of using equipment fabricated of composite materials. These divisions also represent the larger users of capital equipment as well as investment in new capital projects. They are:

(i) Sasol Synthetic Fuels (Pty) Limited - responsible for converting coal into liquid fuels, pipeline gas and a broad spectrum of chemical feedstocks

(ii) Sasol Mining (Pty) Limited - responsible for the group's coal mining and marketing activities

(iii) Sasol Technology (Pty) Limited - engineering & Project Management. Responsible for providing conceptual design, engineering support and project management services to the group

(iv) Sasol Chemical Industries (Pty) Limited - co-ordination of Sasol's chemical, polymer and related manufacturing, marketing and sales

Divisions of Sasol Chemical Industries that were included in the survey were (Sasol, 2002):

(i) Sasol Olefins and Surfactants South Africa - manufacturing and marketing of alpha olefins and their derivatives

(ii) Sasol Ammonia - manufacturing and marketing of ammonia, sulphur and other inorganic compounds

(iii) Sasol Carbo-Tar - manufacturing and marketing of carbon and tar products

(iv) Sasol Solvents - manufacturing and marketing of various solvents, including alcohols, alcohol blends

(v) Sasol Polymers - manufacturing and marketing of monomers (ethylene and propylene)

(vi) Sasol Agri - the holding company of the fertilizer and related product interests of the Sasol group

Target groups in the target divisions were Mechanical or Chemical tertiary qualified technical personnel who are involved in either the procurement, design, maintenance or testing of process equipment containing hazardous chemical substances.

In both disciplines (e.g. mechanical or chemical engineering), the following functional positions were selected:

(i) Project Managers / Design Managers
(ii) Project Engineers / Design Engineers
(iii) Maintenance Engineers
(iv) Technicians (Maintenance) and Foremen

2.3.2 Reaching the individuals in the target groups

Defining the target companies and groups in Sasol confronted the author with the problem of identifying the individuals in these groups. Initially, an e-mail (see Appendix A) was sent to all the level 3 managers of the target companies, explaining the process and requesting of them to submit names of persons who met the target group requirements.

Unfortunately, the response was extremely poor and the author decided to pursue alternative approaches.

The author then requested the Human Resources Department to provide from their database the names of the persons who met the target group requirements. After two months this request was cancelled due to the fact that (1) records of individuals were kept per site per company and not on a single database and (2) job categories were not well defined, therefore making it impossible to identify individuals who met the target group requirements.

As a last option, the author used the following approach:

(i) Using the information on the "Global e-mail address list", all individuals that possibly met the set requirements, were identified (total number of 1645).

(ii) E-mail was forwarded to them, requesting them to confirm that their profiles complied with the target group requirements. A total number of 1054 respondents confirmed their compliance with the requirements and their willingness to take part in the process.

2.3.3 Survey to determine level of awareness

The first questionnaire (see Appendix B) to determine the level of awareness regarding non-metallics in Sasol was sent out on January 18, 2001 to the target groups in the different target companies.

Furthermore, respondents receiving the questionnaire were reminded that they needed to be:

(i) Tertiary qualified in the field of Mechanical / Chemical Engineering (Diploma, BTech, BSc Eng, BEng, etc) and

(ii) Involved in any way in either the design/manufacturing/testing/maintenance of process equipment (at least one of the fields).

The questionnaire consisted of the following two sections:

Part A - Biographical data regarding sex, race, age, qualification, years of relevant engineering experience, level in the company, line of responsibility (e.g. Technician, Specialist, etc)

Part B - Non-metallic knowledge and awareness questionnaire

The questions were structured giving the respondent the option to indicate *Good Knowledge, Above Average Knowledge, Some Knowledge or Undecided/Don't know*. The structure and questions can be seen in Appendix B. Numerous follow-up e-mails were sent out as reminders to the target group to ensure that the completed questionnaires would be returned. A total number of 813 individuals responded giving a return percentage of 77, 13%.

2.3.3.1 Results of the survey

Biographical. The following serves as a summary of the biographical data of the respondents:

1	Gender	Male 90.5%	Female 9.5%				
2	Race	White 79.1%	Black 10.2%	Coloured 3.0%	Asian/Indian 7.7%		
3	Age	<25 9.2%	25–34 49.1%	35-44 3.0%	45-54 2.1%	>55 6.6%	
4	Highest Qualification	Matric 7.5%	Diploma 16.1%	Degree 49.9%	Post Graduate 26.4%		
5	Years of Experience	<1 yrs 5%	1–5 yrs 31.5%	6–10 yrs 19.7%	11–15 yrs 16.6%	16-19 yrs 7.3%	20 yrs 19.9%
6	Level in Company	7 19.2%	6 29.0%	5 30.8%	4 16.9%	Other 4.2%	
7	Line of Responsibility	Technician 6.0%	Technical Manager 25.0%	Specialist 23.7%	Management 16.7%	Other 28.5%	
8	Company	SSF 37.5%	SCI 23.5%	Mines 10.1%	Technology 10.0%	Polymers 10.8%	Others 8.1%

Table 2.1 Results of biographical data of respondents

The results show that the main respondents were, in all likelihood, white males aged between 25 – 34 years with a degree and up to 5 years working experience. Furthermore, most of the respondents are either Technical Managers or Specialists working for SSF or SCI, the two larger Sasol businesses in the Sasol Group of Companies.

Non-Metallic Knowledge And Awareness

		Good Knowledge	Above Average Knowledge	Some Knowledge	Undecided/ Don't Know
1	Various shapes, sizes and forms of non-metallic products	6.9%	18.7%	62.7%	11.7%
2	Application possibilities of the different types of non-metallic materials	4.8%	18.1%	61.1%	16%
3	Procurement instructions	1.1%	6.9%	31.1%	60.9%
4	Specifications	7.4%	38.7%	49.9%	4.0%
5	Design	2.7%	10.2%	35.9%	51.2%
6	Roles/Responsibilities of the Inspection Authority	6.3%	14.4%	34.3%	45%
7	Roles/Responsibilities of Consultants/Engineering Contractors for non-metallic equipment	2.3%	12.2%	37%	48.5%
8	Fabricator's required Technical Capabilities & Resources	3.7%	6.2%	35.5%	54.6%
9	Fabrication Techniques	3.7%	9.6%	43.8%	42.9%
10	Transportation; Erection and Installation	2.7%	6.9%	47%	43.4%
11	Maintenance Requirements/ Techniques	2.5%	5.0%	39.1%	53.4%
12	Statutory Inspection requirements	3.1%	8.0%	29.6%	59.3%
	Average per column	3.9%	12.9%	42.3%	40.9%

Table 2.2 Summary: Results on Non-Metallic Knowledge and Awareness Questionnaire

The table indicates that the majority of respondents believed they had some knowledge of most of the issues dealing with the basics (e.g. shapes, applications, specifications) but that most had very little awareness of the procurement of composite products or services, or the legal requirements pertaining to the use of composites (e.g. roles and responsibilities of the Inspection Authority, statutory inspection requirements). The results also indicate that most of the respondents had little knowledge regarding the manufacturing and maintenance processes of composites products (e.g. fabrication techniques, transportation, maintenance techniques).

Three questions were added to the bottom of the questionnaire, and the outcome was as follows:

1. *Are you aware that twenty-two Sasol Non-metallic Specifications exist?*
   22.9% responded positively

2. *Are you aware of the Sasol Non-metallic Intranet on web-site address - [http://intwww.sasol.com/Sastech/Functions/Non-Metallics/Index htm] ?*
   42.8% responded positively

3. *Would you consider to use non-metallics for future, new and replacement projects/maintenance?*
   92.6% responded positively

General Summary of the results of the survey. The following trends and observations were of importance in this initial survey:

(i) almost half (49.1%) of the respondents were in the age group of 25 to 34 years, therefore a younger generation that would most probably be more open to new ideas and technologies
(ii) almost half (47.7%) of the respondents were level 4 and 5 representing the majority of the decision makers in terms of technical issues on projects and operating plants
(iii) the number of respondents in terms of company working for closely resembles the actual size of the company in the Sasol group
(iv) disturbing but expected was the level of *good knowledge* and *above average* knowledge in terms of non-metallics, giving a positive average indication of 3.9% and 12.9% respectively

(v) of specific interest was the extremely low affirmation of knowledge of procurement policy as well as maintenance requirements; explaining the reluctance up to that stage to actually use non-metallics

(vi) even more disturbing was the response on Statutory Inspection requirements, indicating the lack of knowledge on operating plants in terms of VUP requirements

(vii) at the time of the survey, the incorporation of the Polifin Non-Metallic Specifications was still in the initial phase and therefore not known to the respondents, explaining the low 22.9% confirmation of knowledge regarding the existence of the specifications

(viii) the 92.6% positive response in terms of the consideration by respondents that they would use non-metallics served as inspiration to the author that the unenlightened could be enlightened.

2.3.4 Additional Comments

It is generally agreed by representatives of the composites sector that the industry is very fragmented and fragile. This view has prevailed in open discussions at numerous events attended by such representatives, but the solution is not clear. No leadership is evident, forcing suppliers to take a defensive attitude towards collaboration and cooperative support in order to grow the pie and not the slice.

In addition, the non-metallic supplier industry is often seen from the user's point of view as a "black art", with little regulation and control, often creating little confidence in products supplied by this fragmented industry. Policy, including standards and so on, created by the likes of AECI/Polifin (now Sasol) and the large end-users, have played a key role in driving some companies within the sector to a more advanced level, but the majority of the sector is still backward by comparison to similar sectors in the first world.

Furthermore, although, as mentioned, the larger end-users like Sasol have helped regulate the industry to some extent, the picture is clouded by the low levels of competence in non-metallics of most of the decision makers etc employed by end-users. The author is of the opinion that an enormous effort is needed to further structure and generally enhance the interface between suppliers and end-users, and the industry in general. It is for this reason that this study is of importance. Because Sasol is so large, it must not only continue to drive the industry forward with increased energy by way of assisting with the formulation of policy (including standards etc – and in this regard the author's key role will be demonstrated later in this thesis), but also get its own house in order with regard key competencies of those employees who should know more about non-metallics.

Chapter 3

Increasing the use of non-metallics in Sasol

3.1 The benefits to Sasol in using non-metallics

Non-metallics in the chemical industry have developed a terrible reputation through the years due to failures that can be attributed to incorrect design, manufacturing or application. Furthermore the general perception is that the use of non-metallics is not feasible due to expense and that the fabrication of non-metallic equipment is a 'black art' i.e. not designed and manufactured according to engineering codes and specifications.

The purpose of this section is to show:

(i) that non-metallics can be considered as an engineering material for process equipment, by comparing initial capital costs between steel and non-metallic process equipment

(ii) the comparative fabrication methods and the international engineering specifications that can be used in fabrication. It should be noted that Sasol has additional specifications to which the equipment must be manufactured

(iii) lifecycle cost considerations

3.1.1 Costing Analyses

The costs reflected here are budget costs only and hidden costs such as ground treatment, foundations, etc are not reflected in the results.

Vessels. For vessels the analysis was done comparing costs of steel vessels against non-metallic vessels.

The two major costs involved are:

(i) initial capital cost (manufacturing, transportation, etc)

(ii) maintenance cost

Three different vessels for specific operating conditions were designed and costed to verify the results. The code of construction specified for the vessels were:

(i) Steel Vessels according to ASME VIII Division 1 (Sasol specifies minimum corrosion allowance of 3mm)

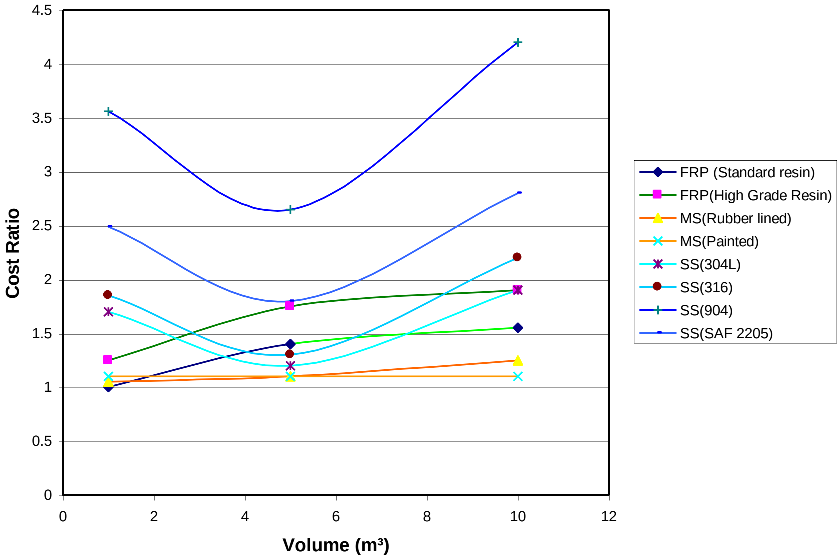
(ii) GRP vessels according to BS 4994

The following assumptions were made:

(i) The medium was assumed to be of a nature such that no special linings were required i.e. that the entire vessel was made of the base material

(ii) Atmospheric temperature was assumed

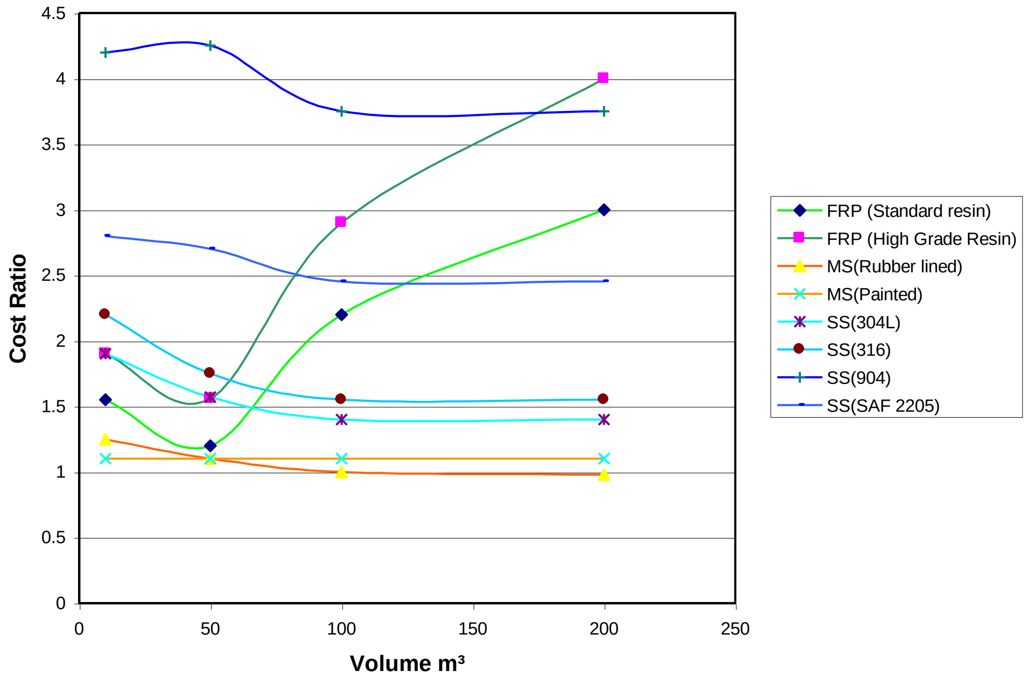
(iii) Atmospheric pressure was assumed



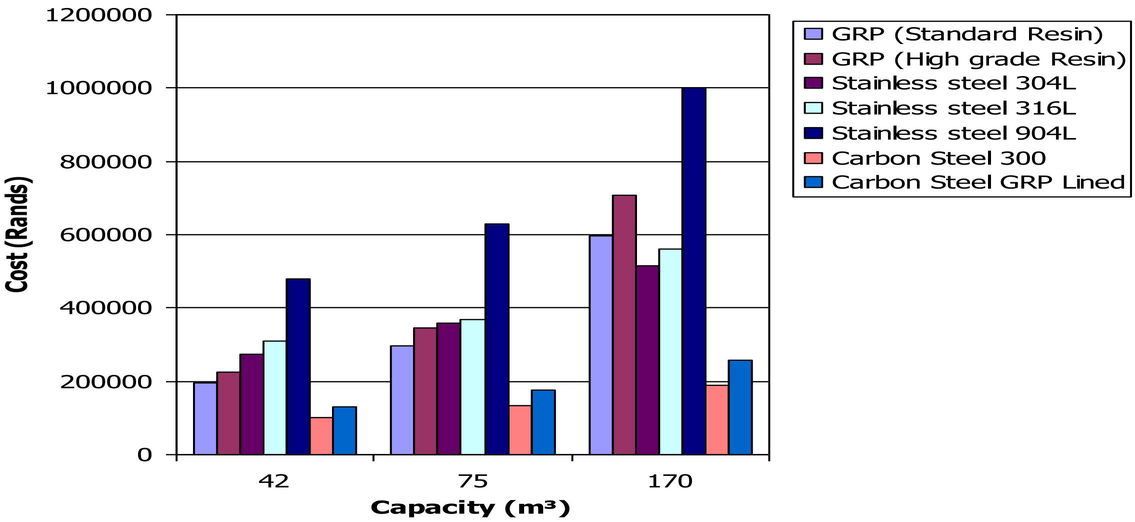
Graph 3.1 Cost ratio for vessels up to 10m³

In both the metallic and non-metallic cases submitting quotes to the relevant fabricators generated the costs for the equipment. It should be noted that the cost of a tank is a function of its holding capacity (m³).

The results for vessels with capacities up to 10 m³ are indicated in Graph 3.1 and for vessels with capacities 10 – 200m³ in Graph 3.2.



Graph 3.2 Cost ratio for vessels 10-200 m³



Graph 3.3 Cost comparison between alternative materials for vessels with cylindrical shape with flat box and conical roof.

It is interesting to note that:

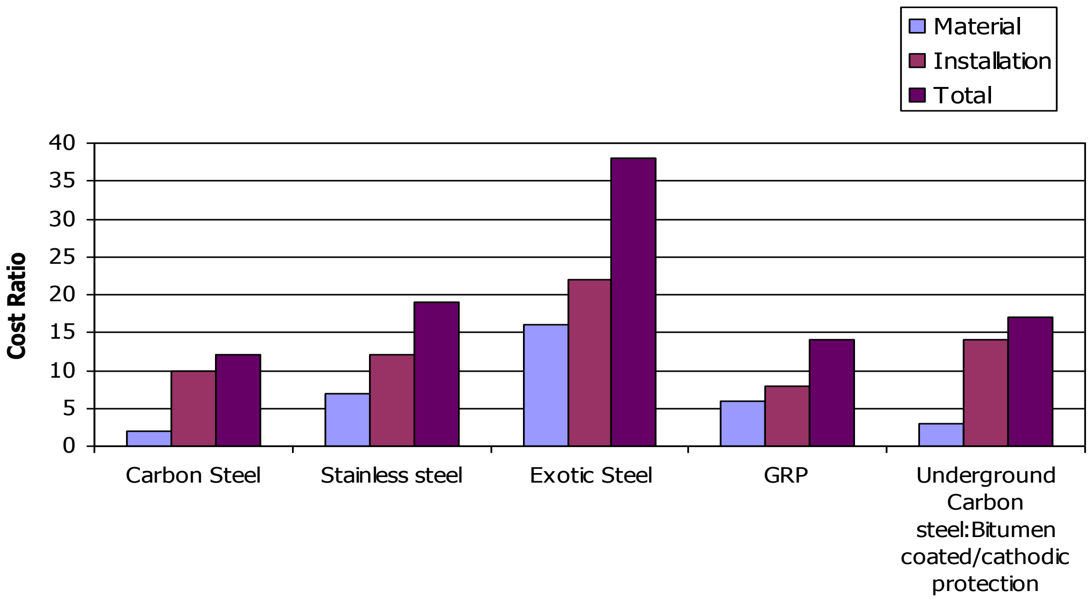
(i) above 50m³ the fabrication cost for a GRP vessel becomes uneconomical if compared with the metallic options. This is mainly because of the difficulty in producing large diameter moulds and handling of such large vessels in the manufacturers works

(ii) if corrosion resistance is of importance, GRP vessels initial capital cost is significantly less if compared with high grade alloy steels. GRP vessels constructed using high-grade resins are therefore more cost effective than stainless steel vessels for volumes less than 2.5m^3 as well as volumes between 10m^3 to 55m^3

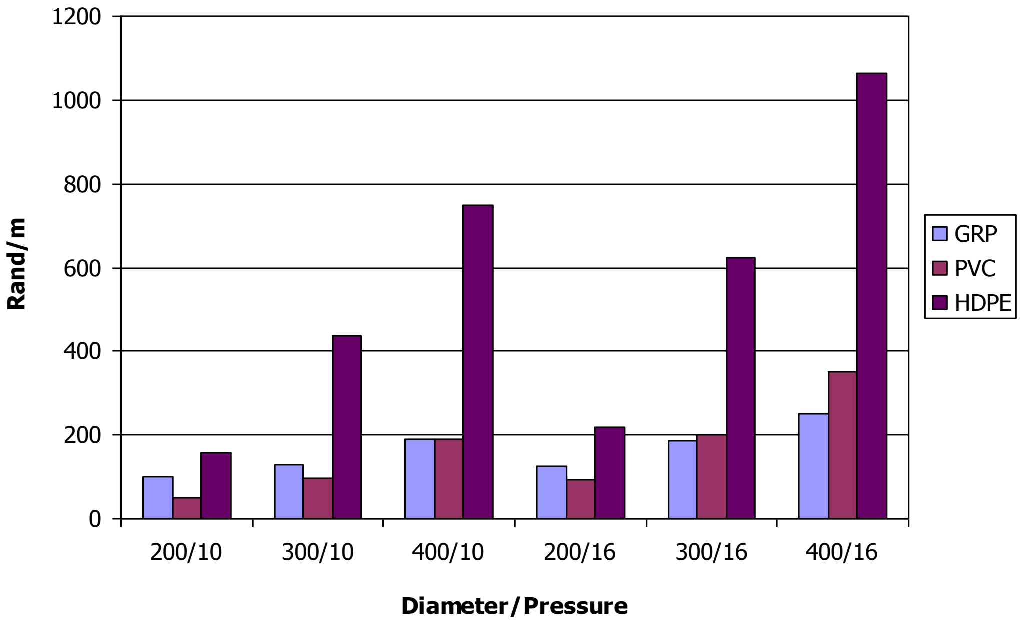
(iii) GRP vessels are more cost effective than carbon steel vessels for capacities less than 1.5m^3. Above 1.5m^3 carbon steel vessels become more cost effective

(iv) GRP vessels constructed using standard resins are cheaper than stainless steel vessels for volumes less than 4.5m^3 as well as volumes between 6.5m^3 to 60m^3

Pipes. For piping an analysis was done comparing steel pipes of a particular pressure class with non-metallic alternatives. Additional costs not accounted for are, for example, foundations, expansion loops and support construction for expansion loops and valves. The results for piping systems (indicating total installation cost of GRP versus steel alternatives) are indicated in Graph 3.4. Graph 3.5 shows total installation cost of different alternatives of non-metallic piping systems. Note that the designation method used in Graph 3.5 for e.g. 300/16 means 300 mm nominal diameter class 16 pipe.



Graph 3.4 Installed pipe cost comparison



Graph 3.5 Installed pipe cost comparison per diameter and pressure class

It should be noted that:

(i) the total cost of GRP piping is significantly lower than high alloy steel alternatives, giving an added advantage of corrosion resistance compared with conventional carbon steel

(ii) installation costs of GRP piping is the lowest of the available alternatives because of its lightweight construction, ease of handling and less rigid supporting structures

(iii) for piping PVC and HDPE should be considered for small diameters (300mm) and low pressures (less than 10 bar)

(iv) GRP should be considered for high pressure (10bar-35 bar) and large diameters (greater than 300mm). GRP piping is cheaper than stainless steels, exotic materials and underground piping that require cathodic protection and corrosion protection tape wrapping

Armour plate pipe repair for exterior corrosion. External corrosion to equipment is often caused by corrosive fumes (as a result of samples being taken, leaks, etc), or due to low temperature applications with moderate to high humidity, causing water to condense on the surface. Several corrosion preventative methodologies have been applied through the years with varying degrees of success.

Therefore, unscheduled shutdowns on operating plants due to severe external corrosion on equipment are not preferred. The integrity of such a system that normally conveys hazardous chemical substances must be weighed against production loss. A temporary pipe repair methodology that is available is a system that restores sufficient integrity to pipe systems until the next scheduled plant shutdown. The principle used by this pipeline repair method is the use of a combination of epoxy putties and resins in conjunction with a fibreglass matting material.

Figure 3.1 GRP pipe wrap repair on a carbon steel line

The author suggested the abovementioned alternative repair methodology to the operating plant. The total cost saving for Sasol amounted to R7 million resulting from the prevention of an unscheduled shutdown (Pienaar, 2001).

3.1.2 Total Life Cycle considerations

The lifecycle cost of equipment (see also Section 1.1.5) is particular to the service, chemical resistance and conditions of said equipment. As Polifin has over 40 years experience in the operation and maintenance of GRP equipment in Chlorine duty, the following serves as lessons learned in considering total cost of ownership:

Consider vessels storing chlorine gas at 40 degrees Celsius at atmospheric pressure:

(i) carbon steel vessels would require replacement every 6 months or less
(ii) with vessel failure is the potential of risk to human life and potential fatalities
(iii) carbon steel vessels with a GRP or rubber lining would require re-lining at least twice in a twenty-year period. If the corrosion barrier (rubber lining) should fail

(hence the need for re-lining) then the potential for vessel failure is increased. As there would be no/little exterior indication of impending vessel failure, the potential risk to human life and potential fatalities costing to the company would be increased

(iv) most grades of stainless steel cannot withstand chlorine chemical attack and therefore would be not suitable as a material of construction. There will be no/little exterior indication of impending vessel failure

(v) GRP vessels can withstand chemical attack by chlorine gas, but would require re-lining at least twice in twenty years. If the internal chemical barrier should fail, external discoloration of the vessel would give early indication that the laminate structure has been compromised. The damaged vessel can be easily repaired and re-lined with minimum potential for loss of human life as well as production. For the aforementioned case, GRP is the most suitable and cost effective (over twenty years) material of construction.

3.2 Raising awareness in the Sasol Group of Companies

From the outset it was clear to the author that in order to raise the awareness of the use of composite materials in a company that traditionally uses steel, enormous efforts would be needed to change the conventional thinking of the Sasol mechanical and chemical engineering personnel. Therefore, the target groups that were identified in the summer of 2001 (see Section 2.3), needed to be reached effectively over a time period of approximately two years. The two-year period with end target date November 2002 was significant for two reasons:

(i) the changeover from coal gas to natural gas at the end of 2004 will provide enormous opportunities for the use of composite materials. The procurement decisions in the project phase will be an important period for Sasol employed project personnel to ensure that they consider alternative materials of construction

(ii) several proposals for new operating plants were awaiting Sasol Board approval by the end of 2001, providing opportunities for the use of composite materials

3.2.1 Proposed process

Raising the awareness of composite materials was the first step in the process. The two other important steps linking onto this were secondly the period of increasing the use of composite materials and thirdly sustaining the energy or enthusiasm generated by the first two phases of the process. The last two steps of the process are not part of the study of the author. As this chapter is the heart of the work carried out by the author over a period of more than three years, it is important to keep in mind that most of the awareness and technical actions were parallel activities. Numerous suggestions were made from various interest groups during the years, sometimes changing or altering the initial course of action. At the end of the two years of raising the awareness (first part of the process and the subject of the study by the author), possible outcomes expected in the field of composites were:

(i) improved knowledge regarding the application possibilities of composites
(ii) composites Intranet for the Sasol Group of companies
(iii) revised Sasol Non-Metallics Specifications
(iv) audited / Approved Suppliers to the Sasol Group of companies
(v) strong links with Approved Suppliers
(vi) active Sasol Polymers Non-Metallics Technical Committee (old Polifin)
(vii) legislation covering equipment constructed of composite materials
(viii) approved CP and IPE inspector schemes in this field.
(ix) effective Sasol Polymers Non-Metallic Testing Facility
(x) membership participation in PCISA
(xi) SABS Technical Committee participation

3.2.2 Approval by and involvement of top management

One of the first important milestones that had to be reached was to involve management and to get their support for the proposed process.

The first presentation to management was on Wednesday May 24, 2000. Several role-players as well as both the Managing Director of Infrachem (the old SCI) and the Engineering Manager of Sasol Technology were present at this meeting. This first presentation focused on:

(i) advantages of composite materials

(ii) importance of using correct specifications
(iii) history of the Polifin Non-Metallic Committee
(iv) objectives of the Polifin Non-Metallic Committee
(v) work since inception in meeting the objectives of the committee
(vi) proposed process to raise the awareness regarding composites materials
(vii) identifying the role-players in this process
(viii) explanation, time scale and target groups
(ix) issues that need to be addressed

At the conclusion of the meeting, the author stated that: Non-Metallic equipment and piping systems correctly designed and manufactured have replaced and will continue to replace many metal equivalents, especially exotic metals. The behaviour of non-metallics and their limitations, if clearly understood, will, because of competitive initial and maintenance cost advantages, become more and more attractive in new projects as well as retrofits. It is a science that is continually improving, based on research, innovation, user feedback and interaction with manufacturers. Therefore, we as engineers can make a difference to the performance of the company by getting involved in non-metallics. (Mouton, 2000:15).

While the first meeting was a discussion on a one-to-one basis, the author realised that future management discussions would involve larger groups and that alternative presentation techniques would need to be developed. The author compiled a 60-slide presentation covering the following agenda points:

(i) normal perceptions regarding composites, e.g. boats, swimming pools, etc.
(ii) development in the recreational markets
(iii) define composites
(iv) examples of major non-metallics capital projects in South Africa
(v) discussion on the Total Life Cycle Cost principle
(vi) project phase - advantages/disadvantages in using composites
(vii) replacement phase – advantages/disadvantages in using composites
(viii) maintenance phase - advantages/disadvantages in using composites
(ix) international and national trends in the composites industry
(x) role of the SPNMTC in the Sasol Group
(xi) future direction and focus points

Based on the approval and support shown at the first meeting, several meetings with management representatives were held.

Another milestone was reached on May 18, 2001 when the author presented the proposed plan to raise awareness regarding non-metallics at the Sasol Specification Steering Committee. The objectives of this committee are to oversee: Policy, Strategy, Funding and Approval of all specifications for use by the Sasol Group, and the appointment of specification technical committees (Sasol Specification Steering Committee. Minutes of Meeting. 2001:6) The following management and/or technical responsible representatives were present at this meeting (Sasol Specification Steering Committee. Agenda, 2001:1):

Managing Director of SCI
Engineering Manager Sasol Technology
Maintenance Manager Natref Refineries
Welding and Quality Assurance Manager Sasol Technology
Project Director – Sasol Technology
Managers of Civil, Electrical, Instruments and Mechanical Engineering
Several Maintenance Managers of operating divisions.

In conclusion it can be stated that the Sasol management representatives were extremely positive regarding the awareness drive in order to grow the use of composites to provide cost effective solutions in corrosive environments.

3.2.3 Raising support at the Sasol approved fabricators for the process

Part of the process to raise interest and awareness regarding composite materials in the Sasol Group of Companies was to ensure that the fabricators and suppliers of these materials were part of the drive and objectives. This process was divided into two sections: fabricator/supplier awareness and auditing of fabricators/suppliers.

Fabricator/supplier awareness. In the first year of the process, the author visited the Polifin Approved Suppliers to discuss with them:

(i) the plan to raise awareness in the Sasol targeted companies as was agreed with management
(ii) inquiries about specific points of uncertainty regarding future workloads etc.

(iii) the future auditing procedures
(iv) the national drivers and action points in the industry (e.g. inspector schemes, testing facilities, possible research involvement, SABS technical committees involvement)
(v) the activities of PCISA, and to invite them to join and promote PCISA.

All the approved fabricators were visited during the year of 2001. The fabricators made numerous excellent suggestions during such visits.

A web-page was developed for the fabricators as a means to advertise themselves as well as providing the opportunity for Sasol employees to communicate electronically directly with the fabricator regarding technical advice, etc.

Auditing of Suppliers. The author recommended to the AESP committee on February 16, 2001 (Mouton, 2001:1) that:

(i) all existing Polifin Approved Suppliers be audited before being placed into the Sasol suppliers database to ensure continued quality and adherence to quality systems
(ii) coating and lining suppliers would be excluded from the auditing process, as these are not seen as part of the non-metallics drive in Sasol, but rather as an alternative corrosion protection methodology
(iii) that the existing Approved Suppliers List for Non-Metallics be expanded to accommodate future Sasol expansion project requirements

The abovementioned recommendations were accepted by the AESP committee. A further 17 non-metallic fabricators/suppliers were audited of which 12 were confirmed/added to the approved list while 6 received D-Supplier ratings (not approved to conduct business with Sasol). The author acted as the liaison as well as audit leader during these audits. The 3-day audit process per fabricator covered the following:
(i) Quality Management System
(ii) manufacturers' capability and size of the company
(iii) financial capability
(iv) environmental and risk
(v) Black Economic Empowerment

Interaction between Sasol, Engineering Contractors and Fabricators. During the 3 years of 2000 to 2002 a few non-metallic capital projects were executed in Sasol with varying degrees of success. As Sasol is using Alliance Partners (e.g. Engineering Contractors) to execute projects for and on behalf of Sasol, the author proposed that a Non-Metallics Alliance Partner Workshop be held with the following objectives:

(i) to align non-metallic suppliers of process equipment and engineering contractors in terms of the future direction of non-metallic equipment supplied to Sasol
(ii) feedback on Awareness Campaign
(iii) the interaction between Sasol and the industry for the betterment of society and the environment

Specific focus points for the seminar were:

(i) informing the fabricators about the latest Sasol specifications that have been approved
(ii) encouraging the use of the Handbook of Guidelines for Contract Execution of Projects (see Section 3.4.2)
(iii) encouraging fabricators to inform and educate Sasol employees on a 'one-to-one' base who are ignorant of non-metallic Sasol specifications during enquiries
(iv) feedback on awareness campaign
(v) Composites Africa 2002 conference
(vi) commercial - Sasol standard terms and conditions regarding procurement
(vii) future audits
(viii) future requirements –Training of CP/Laminators/Welders
(ix) projects / project related problems - Causes and Prevention
(x) involvement in tertiary institutions, SABS technical committees, ANNEM, etc.

This first ever Sasol Non-Metallics Alliance Partners Seminar was organized by the author and was held on August 22, 2002. The tertiary research facilities that are supported by Sasol, companies on the Sasol Approved Supplier Non-Metallic Supplier List as well as engineering management contractors were invited to be represented by no more than 2 representatives each. The focus was on senior managers, Quality Assurance Managers, Engineering Managers, Designers as well as Construction and Site Managers.

3.3 Initiatives in support of the local composite industry

With the 1993 – 1994 Midlands restructuring project, a number of vessels were procured from the non-metallic industry. The author's role in this project was as Lead Vessel Engineer to ensure the total quality and delivery on time of vessels that complied with the local OHS Act and code of construction. It became clear during the project that the non-metallic industry was mostly incapable of supplying at that stage quality fabricated equipment for the local chemical industry. Numerous technical problems, design errors as well as fabrication faults indicated that lack of quality systems and the non-availability of qualified inspectors were the main reasons for the poor quality of the delivered equipment. With one vessel, a lifting lug broke off in the lifting process, which clearly indicated that there was a problem with the industry. The frustration of not knowing how to handle products made of these materials, as well as the apparent efficiency of the conventional metallic equipment suppliers to supply similar equipment at that stage, made it obvious that the author had to obtain a better understanding of the functioning of the non-metallic industry. As Sasol is a supplier and user of non-metallic materials, cross-pollination would have to take place on a national basis. At the start of 2000, because of the lack of formal approved legislation (e.g. Composite Vessels Under Pressure, etc.) and approved qualified inspectors / designers / design verifiers, the author volunteered for and on behalf of Sasol to assist the industry to formalize these systems and structures.

The author assisted Sasol, the non-metallic industry and the Department of Labour in developing applicable Composite Vessels Under Pressure regulations, SABS standards, the formation / participation in the Polymeric Composites Institute of South Africa – Gauteng Chapter, and development of unit standards for the IPE / Competent Persons Schemes. Again it should be emphasized that a holistic approach towards the assistance in the development of the industry was followed with numerous parallel actions taking place simultaneously. Assisting the industry while generating and enhancing the use of non-metallics in Sasol were the two legs of the process. Initially the focus was on the industry, getting their buy-in into the process.

3.3.1 Sasol Polymers Non-Metallic Technical Committee

During the three years of the authors' involvement in raising the awareness regarding the use of non-metallics in Sasol, the role, representation, responsibilities as well as influence of this committee has changed from a company to a nationally focused committee. Numerous role-players have contributed to the growth and transformation of this committee.

Change in strategy. Moving from Polifin to a much larger Sasol group of companies implied that the committee had to change its way of operating to accommodate and meet the challenges presented. Therefore, the author proposed to the chairman of the SPNMTC at the start of 2000 that a strategy planning session should be held for the following reasons:

(i) possibility of loss of control due to the buy-out of Polifin, and therefore a threat to the future existence of the committee resulting from Sasol's lack of understanding of the function and involvement of this committee

(ii) possibility of loss of the financial backing as was provided by Polifin for the functioning of the committee

(iii) impractical Polifin Non-Metallic standards and specifications needed to be revised for incorporation in Sasol, otherwise they could lead to negative perceptions by Sasol users

This proposal was widely accepted by the committee members of that time and a two-day strategy planning as well as SWOT analysis were held (SPNMTC, 2000). The following were agreed upon during these sessions as a future direction for the SPNMTC Committee:

(i) Vision: Maximum continual derived value from non-metallic engineered products

(ii) Objectives:

- identify relevant non-metallic standards and codes, and where necessary, develop cost effective addendas, specifications, manufacturing and maintenance procedures
- assist the Sasol group of companies with problems or enquiries through research and development, training and existing knowledge
- educate, train and develop the Sasol group of companies' personnel in non-metallics

- represent Sasol on industrial bodies influencing legislation as well as assisting and ensuring compliance
- influence the commercial process with respect to Approved Suppliers
- create and sustain alliances

The committee structure was also changed, dividing the committee into eight subgroups with the sub-group chairmen representing their groups on the committee. The eight sub-groups are Research and Development, Design, SHE and Quality, Piping and Equipment, Inspection, Public Relations and Industrial Representation, Training and Education as well as Secretarial. The author was requested to be responsible for the Training and Education as well as Design portfolios. Specific guidelines were developed by the author to give clear direction to both these portfolios.

At the start of the awareness process in the summer of 2000, the committee consisted of 12 permanent members. At that stage, representation on this committee was predominantly from Sasol Polymers as well as one representative from an approved fabricator supplier.

By the end of the process and at the time of writing, the committee consists of 20 permanent members, with additional 32 corresponding members giving input into specifications, training events, etc. Representation on this committee is now from divisions in Sasol, the marketing department of Sasol Polymers, fabricators (e.g. ANNEM), Resin Suppliers, design firms as well as tertiary institutions.

3.3.2 Tertiary involvement

D.I.T/Sasol Polymers/Fibre-Wound Testing Facility. The author is responsible for the interaction with the testing facility. A total of 9 specimens of 150 nominal diameter made out of GRP designed for 16 bar, were subjected to cyclic loading from May 2000 to June 2001. Two specimen tests were aborted due to large random fluctuations in the pressure. From the results of Stress versus strain it was seen that 15 bar is the approximate infinite fatigue life pressure limit (Technikon Natal, 2001:04). Again the results from the facility have confirmed that these test samples of pipes made of composite materials were meeting all expectations, indicating the strength and durability to be expected in chemical plant operations. The next stage of testing was initiated by the end of 2001 to test GRP lined piping for cyclic loading.

Vaal Triangle Technikon Composites Materials Design Centre. The potential of SMME's for sustainable growth and employment creation is considerable. To unleash this potential, the Department of Science and Technology (DST), has identified technological innovation and related skills upgrading as being of vital importance to the competitiveness of South Africa SMME's.

A total of seven of these Technology Stations have been identified under the Tshumisano program (Venda word meaning co-operation or partnership) of which the Vaal Triangle Technikon Composite Materials Design Centre is one.

The author has initiated numerous discussions from 1997 onwards with the Dean of Mechanical Engineering of the Vaal Triangle Technikon about the possibility of setting up a composites facility in order to support the local industry by means of design, testing and education regarding non-metallics. Therefore, with the start of the Tshumisano program, the author as well as the Manager of the Sasol Polymer Research Facility was involved giving guidance to this process. The author made several recommendations to the Technikon Research Committee during 2002:

(i) to actively contribute and take part in industry initiatives, e.g. PCISA, SPNMTC, etc to foster good relationships and mutual understanding
(ii) educate students and lecturers about the application possibilities of non-metallics. Recommendations included possible handbooks that could be used as lecture material
(iii) lecturers involved in the Composites Materials Design Centre should obtain professional recognition for competence in this field, e.g. CCT
(iv) to investigate the possibility of offering the CCT program of CFA in South Africa, therefore raising the competence as well as giving recognition in this field
(v) the Research Committee was requested to interact with the existing Sasol funded facilities, e.g. Technikon Natal as well as Wits University to ensure effectiveness and avoiding duplication of activities

Subsequent to these recommendations being made, the author gave a half-day workshop at the Technikon to all the Heads of Faculties in Engineering regarding the field of non-metallics. Two lecturers attended the CFA 2002 in Atlanta and obtained their CCT qualification.

At the time of writing, this facility was still in its infancy, but promised to develop into a hub of excellence in the field of non-metallics.

Certified Composites Technician program (CCT). The Composites Fabricators Association (CFA of America) created the Certified Composites Technician program in response to the industry's need for uniform training in technical skills. The focus of the CCT is the fundamental technology used in producing a wide range of products using the open moulding process. The goal of the CCT program is therefore to enhance the overall professionalism of individuals who work with composites by raising their levels of skill and knowledge.

Based on the effectiveness of this program, as well as the lack and slow progress made in South Africa regarding recognized training schemes, the author initiated discussions with CFA management about the possibility of launching the program locally. These discussions started off at the CFA Composites 2001 convention in Tampa, in October 2001, with a mutual willingness to expand the CCT program. During the months of discussions about the implementation, it became clear that a tertiary institution with lecturing staff and facilities would be most suitable as a partner to the implementation of CCT.

As per the author's recommendation to the Vaal Triangle Technikon Research Committee (see previous section), a final agreement has been reached between CFA and the Technikon. The CCT program therefore will be launched in January 2003 and will be offered as part of the Mechanical Engineering syllabus as well as a short course.

Subsequent to this agreement, both lecturers from the Composites Design facility as well as the author have passed the CCT program.

3.3.3 Conferences

Sasol Polymers Non-Metallic Conference. In 1998 the Engineering Managers of the Midland Site decided to share good engineering practices as applied by them and their personnel. At that first conference for the Sasol Polymers Engineering personnel the author presented a technical paper with the title: *The advantages of ASME VIII Div 2 versus ASME VIII Div 1 equipment* (Mouton, 1998).

After the conference the idea was suggested by the author that the possibility existed to start a conference for the Non-Metallic industry with the specific aim of training in and raising awareness of the use of these products in the Sasol Polymers group. The first conference was held on 31 May 2000 at Maccauvlei Conference Facility (near Vereeniging) with 100 people attending. The majority of the attendees were from the Sasol Polymers group as well as representatives from the composites industry. Ten technical papers were presented which were well received. The theme of the conference was 'Into the future with non-metallics'. Because of the success of the conference, it was decided that such a conference should become a yearly event. The overall satisfaction ratio (as measured by questionnaires using various questions on a rating scale) of this conference was 79,8%, which was encouraging for the author as well as the committee that had assisted in the organizing.

In the early '90's the Wits University Composites Facility introduced an annual conference aimed at the non-metallic industry. Unfortunately the Wits effort died after a few years. For the 2001 Non-Metallic conference the author decided to form an alliance with Wits University. The idea was well received and the 2001 conference took place at Wits University on August 01, 2001. About twelve technical papers were presented with about 150 delegates attending. The conference was received very well and the overall satisfaction ratio of the conference was 73,4%. This conference was held in conjunction with the Polymeric Composites Institute of South Africa.

Composites Africa 2002 Conference. As a result of the success of the 2000 and 2001 Sasol Polymers Non-Metallic Conferences, the author recommended at the October 2001 Sasol Polymers Technical Committee (SPNMTC) meeting that the possibility should be investigated to expand this type of conference and training opportunity into a bi-annual event.

Specific recommendations made by the author regarding the format of future conferences were:

(i) the conference should be a visionary national event, addressing at the same time the need to educate, train and create awareness regarding the application possibilities of composite materials

(ii) the event should accommodate the wider composite industry, and not only be focused on the chemical corrosion sectors of the market, as the case has been with previous conferences

(iii) the event should fall in line with international protocol in terms of the number of papers, exhibitors, and demonstrations, as well as create possible marketing opportunities

(iv) the name of the conference should be changed in order to give a new flavour and feeling to the event

(v) co-sponsors should be sourced in order to spread financial risk as a trade off for marketing opportunities

(vi) a working committee should be formed in order to ensure representation and buy-in from the various sectors of the market.

Specific focus areas were:

(i) building stronger alliances between members of the industry and their client base

(ii) growing the industry by promoting non-metallics, ensuring their consideration for application in expansion, renovation and replacement programmes

(iii) recognising individuals for their dedicated service and contribution to the industry at an evening recognition awards ceremony

(iv) giving workers in the field of composites the opportunity to showcase their innovations and designs in non-metallic/composite materials.

A total number of 358 delegates registered for the conference (also see Appendix C – Abstract of Press Release) of which 93 were Sasol employees. Apart from the different Sasol divisions, 73 external interest groups (e.g. users, engineering contractors, etc) were present. The conference was rated a positive 82, 3% in meeting the delegates' expectations.

3.3.4 PCISA

The Polymer Composites Institute of South Africa (PICSA) has been formed (initial discussions started off in 1998 of which the author was part) to provide a forum for people widely involved in the manufacture, use and design of composite materials. The Institute consists of individual members, whose collective mission is to promote awareness and use of polymeric composite technologies. This covers a spectrum from traditional polyester resin/fibreglass to exotic high tech materials such as epoxies and carbon fibre.

One of the prime objectives of PCISA is to develop and encourage training initiatives for those who work with these materials. Other objectives of PCISA include: promotion of scientific research in the field, collaboration between industries in Research and Development programmes, standardization of terminology, techniques, equipment and design, and recognition of persons making significant contributions by way of work in the field. Another important activity is the provision of a forum for dissemination of new technology and knowledge of polymeric composites.

The first National Executive Council meeting was held on February 10, 2000 at Natal Technikon with the author representing the interests of Sasol. From the outset it was clear that branches would have to be formed to ensure effective growth of the PCISA initiative in the different regions. For this reason the Natal branch was formed to drive this initiative with information evenings and events for the non-metallic industry, sharing and informing about new technical developments, training needs, direction of future legislation etc. The first inaugural annual general meeting for PCISA took place on 26 January 2000. The author was elected as NEC member for PCISA for the year 2001. On 12 October 2000 the Gauteng branch inaugural meeting took place. The Author was elected as secretary for the PCISA Gauteng branch.

The author presented in April 2001 at the Sasol Polymer sponsored Inaugural Annual General Meeting of the Natal Chapter of PCISA a paper with the title 'The Sasol Non-Metallic Technical Committee - its role'. The author was also actively involved in organizing technical evenings for the Gauteng branch, like:

(i) developing a training initiative as well as recoup Skill's Levies
(ii) the use of advanced materials in aeronautical applications.

Unfortunately, a lot of the initiative and drive faded in the latter half of 2001, causing PCISA to lose momentum. It is only of late that a renewed enthusiasm indicates a better future for PCISA. These positive changes result mainly from:

(i) enthusiastic leadership on a national level
(ii) enthusiastic leadership at the Gauteng Branch, organizing events, etc. The author assisted in the formation of this new committee
(iii) the formation and appointment of a central administrative office and office bearers as proposed by the author. The author also assisted in the development of several administrative functions and procedures for the institute, as well as initiating an organizing committee for Gauteng for PCISA event evenings.

At the time of writing, several burning issues confronted PCISA, e.g.
(i) proposal to allow corporate membership
(ii) to ensure enthusiasm gained from PCISA involvement in the Composites Africa 2002 convention, is maintained and expanded to form a stronger institute
(iii) cooperative initiatives between PCISA and TWISA to ensure industry speaks with a single voice.

3.3.5 Committees to the Department of Labour

In the summer of 1998 the Department of Labour (DOL) decided to reinstate the Vessels under Pressure Advisory Committee to give guidance and assistance to the department in terms of the technical queries and input into future legislation changes. The author was nominated by the various interest groups in the non-metallic industry to represent the industry (Carter, 2000). The main reason for this decision was the author being a founder member of PCISA as well representative for the non-metallic industry on the AIA, SAQCC-IPE and -CP committees, etc.

The Chief Inspector of the Department of Labour accepted the proposal. The appointment of a permanent representative for the non-metallic industry on the Advisory Committee was a 'first-ever' occurrence in South Africa and therefore a major step forward for the industry. Most of the work carried out by these committees was done in the period 2000 to 2002.

Vessels under Pressure Advisory Committee. This committee started with its tasks in August 2000 after restructuring to incorporate possible future legislation changes. As part of this exercise of changing the reporting structure of the Advisory Committee, the committee was divided into three functional responsibilities, viz. Technical related issues, Failure investigations and Correspondence/Marketing.

The Advisory committee consists of about 12 representatives from various sectors of the metallic industry with the author representing the non-metallic industry. Bearing in mind that non-metallic materials are an alternative material of construction, this implies that input needed to be given over a wide spectrum of issues. Examples of topics of importance were changes to the Vessels under Pressure legislation, RBI, incidents, guidance regarding imported equipment (e.g. CE mark), Fuel Gas Systems, future requirements regarding inspector schemes, etc.

Vessels under Pressure Technical Committee. The author was requested by the Vessels under Pressure Advisory Committee to join the Vessels under Pressure Technical Committee as a representative of the non-metallic industry. This committee's primary focus from 2001 onwards was to concentrate on the development of a new proposed Vessel under Pressure regulation based on the current worldwide trends.

The committee used the PED 97/23 (Pressurized Equipment Directive) of Europe as the basis for the revision of the existing Vessels under Pressure regulation. Of specific significance is the fact that the South African regulation would be the first to specifically address non-metallic engineered equipment, defining the requirements of design, fabrication, inspection and maintenance of such equipment. At the time of writing, the author had just attended the 24th meeting of the Vessels under Pressure Technical committee, focusing on the revision of the Vessels under Pressure Regulation. Numerous hours have been spent by the author and the Vessels under Pressure Technical Committee for Non-Metallics ensuring that each paragraph is applicable to the non-metallic industry specifically.

Of specific importance is the change in scope of the VUP. Included for the first time is specific reference to equipment (also atmospheric) containing hazardous chemical substances and the applicable safe handling of such equipment. Keeping in mind that the majority of vessels fabricated by the non-metallic industry for the chemical containment industry are open to atmosphere, these proposed changes will have a significant influence ensuring integrity during manufacturing as well as maintenance phases.

The proposed scope of the PESR (South Africa, 2002) is as follows:

These regulations shall apply to all equipment with a design pressure equal to or greater than 50kPa, non-pressure vessels for human occupancy and vessels containing a fluid of a dangerous substance, regarding the design, manufacture, operation, repair, modification, maintenance, inspection (included now the Risk Based Inspection methodology) and testing.

New definitions of importance that are included are: *Competent Inspector, condition monitoring, conformity assessment, latent defect,* and *manufacturer* as well as *sound engineering practice.*

Vessels under Pressure Technical Committee for Non-Metallics. To ensure that the non-metallic industry had input into the process of reformulating the existing Vessels under Pressure regulation, the author initiated the formation of the Vessels under Pressure Technical Committee for Non-Metallics. This committee had its first meeting in May 2001 with representatives of the industry, including fabricators, supplier groups, Inspection Authorities as well as a variety of users. This committee has functioned effectively, giving input into the revision process of the regulation.

Definitions as agreed to by this committee for inclusion in the PESR are (South Africa, 2002):

Non-metallic means glass, thermoplastic or thermosetting polymeric reinforced and un-reinforced materials or combinations thereof;

Repair in terms of non-metallics, means the application of heat, welding, solvent cement, laminate or curing of thermoset and *repairing* has a corresponding meaning.

To inform the wider non-metallic industry, the author presented papers to the industry to ensure their buy-in into the proposed VUP changes. Papers were presented at the launch of TWISA on 7 March 2002 entitled 'VUP-The legal requirements in South Africa regarding Pressurized Systems' and also at Composites Africa 2002 titled 'Proposed new vessels under pressure regulation - how it will influence the industry' (Mouton, 2002).

These papers were well received and the author received the Best Technical Paper Award at Composites Africa 2002.

The next step in this process would be for this committee to give input into the PESR Code of Practice to guide the industry in the different phases of handling such equipment.

3.3.6 SABS committees.

Through the years the South African Bureau of Standards (SABS) has initiated the process of development of new standards and codes of practices for industry in general. From 1998 onwards the author has been actively involved in various technical committees at the SABS developing new standards and codes of practices. One of the first efforts was the development of SABS 10349 with the title 'Glossary of Terminology for the Composites Industry'. The main objective was to standardize the terminology used by all role players in the industry. Another objective of this standard was to streamline terminology used in the development of the unit standards under the Skills Development Act. The benefit for the industry as well as Sasol is that in the Sasol specifications reference can be made with ease to this document to make sure that all parties have similar understanding. To ensure minimum confusion, specific emphasis was placed in the development of this standard so that the definitions that are used do not conflict with existing industry definitions.

Another specification of importance is the development of SABS 1748 Part 2 (Pipes, fittings and joint assemblies for the conveyance of hazardous chemical substances in industrial applications). The second part of SANS 1748 specifies requirements for pipes, fittings and joint assemblies manufactured from glass-fibre-reinforced thermosetting resins. This standard covers pipes, fittings and joint assemblies for the conveyance of liquids and gases which are designed for general operation under conditions of internal pressure, or vacuum (to a negative pressure of –15 kPa), but which may also be used for non-pressurized applications.

This standard covers pipes, fittings and joint assemblies in systems where the product of PS (maximum allowable pressure, in bars) and DN (nominal diameter, in mm) does not exceed the value of 6 000 for liquids and gases for lined and unlined pipes, fittings and joint assemblies. This standard does not cover pipes, fittings and joint assemblies for the conveyance of steam or steam condensates, nor pipes of ribbed construction, or systems for which the main design feature is stiffness, (for example, where the pipes are to be buried, or are particularly large).

The design requirements for GRP pipes, fittings and joint assemblies for the conveyance of hazardous chemical substances in industrial applications follow.

Calculation of structural laminate wall thickness. In applications involving the conveyance of liquids where the design temperature (TS) exceeds HDT resin – 20 °C, or the maximum allowable pressure (PS) exceeds 16 bars, or the filament winding angle does not lie between 54° and 56°, or for the conveyance of gases where DN x PS > 3000, the design and manufacture shall be in accordance with BS 6464 and BS 7159, or in accordance with ASTM D 2992 and ASTM D 2996.

In applications involving the conveyance of liquids or gases, where the design temperature TS ≤ HDT resin – 20 °C and the maximum allowable pressure PS ≤ 16 bars, the structural laminate wall thickness for pipes (s_3) in millimetres, shall be calculated using the following general equation:

$$S_3 = \frac{d.PS}{20\sigma_{per} - PS} \tag{3.1}$$

where:

d is the internal diameter of the structural laminate, in mm;

PS is the nominal pressure, in bars; and

σ_{per} is the permissible circumferential stress, in MPa.

Values used for σ_{per} shall be as given in Table 3.1, for the appropriate pipe type and construction method.

Construction Method	Permissible stress, σ_{per} N/mm^2	
	Severe	**Mild**
Filament wound	27	33
Chopped strand matt and woven roving	10	12
Chopped strand reinforcement	8	10

Table 3.1 Values of permissible circumferential stress

The classifications of *Mild* and *Severe* service in Table 3.1 are determined by measuring the loss of flexural strength in unstressed specimens, caused by the chemical environment, using the method described in BS 7159.

Laminates comprising only chopped strand reinforcement are not permitted for nominal diameters greater than 50 mm. The value of the structural laminate used shall never be less than 1,7 mm. The value of the total supporting laminate thickness used shall never be less than 4,5 mm.

The benefit for the industry as well as the users of these equipment is the setting of minimum design and performance standards for the conveyance of dangerous substances. By having a national standard it makes it easier for the manufacturers to comply with a nationally accepted industry standard *as well as* Sasol specifications.

A further purpose of this standard is to standardize piping equipment supplied to users in South Africa for the conveyance of hazardous chemical substances to comply with the requirements of the proposed PESR. Standardization of design, manufacturing and testing to ensure compliance is therefore important. The author and the committee members put a lot of man-hours into the development of this specification.

By the latter half of 2002, the author was requested by SABS to act as Standards Leader for the newly proposed SABS 1748 Part 3: Fire Main Systems resulting from the development work undertaken by the author in this field. The technical committee has decided to use the Sasol SP-100-50-8 "Fire Mains - Underground Glass Reinforced Plastic (GRP)" specification as the draft standard.

3.3.7 Inspector schemes for the non-metallic industry

Competent Person-Non Metallics (Polymeric and Composites). The need for certified inspectors of non-metallic equipment as required by the Vessels under Pressure Regulation has been a long overdue requirement from both end-users as well as manufacturers. The process of getting the buy-in of the industry has also been long and tedious, met with apathy and poor response from various role-players. The steel industry has various guidelines and courses available for the effective training of inspectors responsible for ensuring the integrity of equipment on process plants. The courses available for the steel industry include Level 1 and 2 Inspector Course, CP (Competent Persons) and IPE (Inspectors of Pressurized Equipment). The courses are accredited through SAQCC, the organization approved by the Chief Inspector, which will accredit entrants on behalf of the Department of Labour. To be able to become a competent person one has to complete a theoretical examination and perform a number of practical inspections and generate inspection reports that must be forwarded to the accredited body for assessment.

Definition of a competent person. A competent person in South Africa is defined as a person *who is competent to do such inspections by virtue of their training knowledge and experience* and as a person *who is at least a holder of a Certificate of Registration issued by an organisation approved by the Chief Inspector.*

The problem identified was that there were no systems in place to ensure the competence of inspectors performing inspections on non-metallic equipment in the industry. A committee was set up to generate the competent person course for non-metallics after which an IPE course structure will be developed for the competent person wishing to perform inspections on new equipment. This initiative was further supported by the fact that the legislation in terms of vessels under pressure in South Africa is under revision and will in the near future include non-metallic pressure vessels, pressurized systems and storage tanks containing hazardous chemical substances.

The CP course is vitally important to the composite industry, as it legally and technically empowers a person to conduct an inspection on non-metallic pipelines and vessels. The CP course enables an inspector to make a valid judgment, balancing the interest of the environment and the business.

In 1998 the Engineering Council of South Africa (ECSA) initiated a process starting with the development of the requirements as well as training guidelines for inspectors of non-metallic equipment (ECSA, 1998). The author was requested by the committee to lead the IPE Assessment Sub Working Group in terms of the NQF framework. A few meetings were held with representatives of the industry during 1998, but this initiative collapsed after ECSA's financial withdrawal from the project.

The author as well as the chairman of the SPNMTC sub-committee on Industry Representation took over the process in June 2000, initiating discussions with SAQCC as well as DOL on the way forward. The author actively took part in the development of the criteria and training requirements for the inspector who could be declared competent in terms of knowledge and training to fulfil duties as a Competent Person-Non Metallics (Polymeric and Composites).

This five day course covers a range of issues such as personal conduct; ethics; confidentiality; professionalism and hands-on practical experience in a fabrication environment supplemented with lecture room tutoring and report writing in the field of non-metallics. The objectives of In-Service Inspections with regard to the user of such equipment are listed below and summarize the importance and need for the course:

(i) promote the health and safety of people in the workplace and public in general and protect the environment through proper control of and reduction of risk associated with pressure equipment under his control
(ii) ensure that the equipment is safe and performs and operates reliably under expected operating conditions until the next planned inspection
(iii) verify that fabrication and commissioning data are available and comply with design requirements
(iv) ensure that continuing maintenance and, where necessary, repairs and modifications are carried out without reducing the integrity of that equipment

(v) be positively aware of early warnings relating to potential repairs, replacements and modifications, and the need to assess remaining safe life of pressure vessels

(vi) comply with all relevant statutory and safety legislation.

Course Structure. The course structure includes a theoretical and practical part as mentioned before. The course is held over a period of 5 days ending with an exam paper on the contents covered throughout the week. The pass mark for the exam is 70%. The details of the course structure are as follows:

Day 1:

- Code of practice for the appointment of inspectors
- Legal requirements, OSH Act, Minerals Act, overview of in-service inspection codes
- Understanding the manufacturing environment
- Practical inspection and producing an inspection report

The first day starts with a definition of the competent person and the practice of appointment of inspectors in accordance with ANSI / API 510-19, Minerals Act 50 of 1951 and the Occupational Health and Safety Act (Act no 85 of 1993). A review of South African regulations is necessary. The following regulations are included:

Regulation 1: Definitions of design pressure, gauge pressure, pressure vessel, pressurized systems, repair, vessels under pressure etc.

Regulation 2: Scope of application

Regulation 3: This regulation covered the design, construction and manufacturing sections

Regulation 4: Manufacturer's data plate

Regulation 5: Registration of a boiler

Regulation 6: Appurtenances

Regulation 7: Automatic controls and indicators

Regulation 8: Access

Regulation 9: Door interlocks

Regulation 10: Portable gas containers

Regulation 11: Hand held fire extinguishers

Regulation 12: Gas fuel use, equipment and systems
Regulation 13: Inspection and test
Regulation 14: Record keeping
Regulation 16: Modification and repair
Regulation 17: Approved Inspection Authorities
Regulation 18: Offences and Penalties
Regulation 19: Repeal of regulations and Annexure.

The importance of these regulations to the competent person is that he should always be aware of regulations relevant to his scope of work. It is his duty and responsibility to ensure that the user of such equipment complies with all the relevant regulations.

A brief overview of the different design codes and specifications referred to in the Act is also presented, indicating the common ones used in the industry. Furthermore, a comparison is made between the OHS Act and the Minerals Act. The next section is an overview of the manufacturing environment of non-metal equipment and piping systems. The total manufacturing process is explained from cradle to grave and starts with all the requirements in the design stage of any piece of equipment. The information required from the end-user for the design is discussed as well as the implications and relevance to design and includes:

- Internal and external pressures
- Static head of contents
- Design temperatures
- Superimposed and wind loads
- Shock loads
- Fatigue
- Loads due to heating or cooling and thermal gradients

Elements in the code of construction (COC) addressing construction and workmanship are discussed and include conditions of manufacturing works while manufacturing. Additionally approvals of design and construction details, quality control and quality assurance procedures and manufacturing procedures are also discussed and the relevance thereof for the user.

In terms of the module on Practical Report writing, an example of a typical inspection report is distributed and the different elements of the report discussed. The inspection report is the outcome of the work performed by any competent person and should thus be done in a proper and correct manner.

Day 2:

- Understanding non-metallic materials
- Thermoplastic / Fluoroplastic welding
- Welding certifications
- External and internal inspections

Day two starts with the module on composites and composite material characteristics. Understanding composite materials is of prime importance to the inspector who must inspect equipment and interpret manufacturing tolerances. The idea is to understand the material so that defects can be identified and recognized in practice. This module covers the basic materials used such as resin, glass and additives as well as the differences between the types of resins e.g. vinylester resins systems, isothalic polyester resin systems and epoxy resins. The advantages and disadvantages of resins are explained as well as the characteristics of the different additives and curing systems. Factors effecting curing of resins such as temperature, amount of catalyst added, types of catalyst and type of accelerators are some of the topics that are covered. Glass is also explained in terms of e.g. different properties, its effect on the strength of the product, correct quantities to be used, different properties, grades and types.

The different manufacturing processes most commonly used in the manufacturing of equipment for the Process Industry are also discussed. Different open and closed moulding techniques are discussed and illustrated. Hand lay-up methods, Spray –up, Filament Winding, Compression Moulding, Resin Transfer Moulding, Vacuum Moulding and Pultrusion are also covered in this module.

A very important section that is discussed in detail with the students is the module on the quality control of composites manufacturing processes. The effects of incorrect reinforcement, incorrect resin selection, resin richness and curing of a composite product is covered.

The module on thermoplastic and fluoroplastic welding includes the following:

- Traceability and Identification
- Certificate of analysis
- Material safety data sheets
- Material suitability for specified duties
- Mechanical properties
- Basic principles of welding
- Welding Techniques
- Welder qualifications
- Procedure Qualification Records
- Welder Performance Qualification

Different inspection techniques are covered and include visual inspection, spark testing, tensile tests, bend tests etc. The most important part of this section is probably the detailed section on the modes of failure of thermoplastics covering micro cracking, chemical attack, UV degradation, de-bonding of liner, discoloration, weld failures, static build up, elevated temperature influences, mechanical failures etc. The information in this section will enable the competent person to make a judgment call on the integrity of a piece of equipment once inspected.

A practical approach to external and internal inspections is also discussed by an experienced inspector, indicating pitfalls and practical examples. This module serves as the introduction to the practical inspection module where the student needs to conduct an inspection and write an inspection report. This report is marked and moderated and included in the final pass rate of the student.

Day 3:
Day three includes a module on the different appurtenances that can form part of the inspection responsibilities of a competent person. These appurtenances includes pressure gauges (calibration, range and marks), nameplates (information required legally on any nameplate attached to a piece of equipment), earthing lugs, foundations, stairways and walkways, drains etc.

Of more importance are the safety systems attached to equipment. The over pressure protection devices e.g both reclosing and non-reclosing are covered. Reclosing devices include:

- Pressure relief valves
- Safety valves
- Relieve Valves
- Safety relieve valves

Non-reclosing devices include:

- Rupture or bursting discs
- Breaking Pin devices

All of these devices are discussed separately and their operational details are highlighted. Code requirements and legal aspects of these devices are covered as well as the advantages, disadvantages and typical problems of these types of valves. Important definitions are discussed such as design pressure, set pressure, accumulation, over pressure, superimposed back pressure etc.

The module on Non Destructive Examinations and techniques that could be used on non-metallic equipment is perhaps the most important part of the course, as these methods serve as the methodology and aid the inspector to make a judgement call on the condition of a piece of equipment. The different NDE techniques as well as the capabilities, advantages, disadvantages and limitations of each method are covered for the following most commonly used techniques:

- Leak / Pressure testing
- Water fill tests
- Acoustic Emission
- Radiography
- Dye-Penetrant Inspection
- Spark Testing
- Ultrasonic Testing

- Time of Flight Diffraction
- Hardness and cure tests

Day 4:

On day four of the course the general requirements with respect to the OHS act are covered. The section of the act that is covered includes:

- Important definitions such as *approved inspection authority*, *reasonable practicable* etc.
- General duties of employees at work
- Offences, penalties and special orders of court

Emphasis was placed on the safety that could be relevant before, during and after inspection tasks. These includes:

- Personal safety equipment and facilities
- Intoxication
- Work in confined spaces
- Work in elevated positions
- Working in danger of engulfment
- Ladders
- Cat ladders
- Scaffolding
- Portable electrical tools
- Portable electrical lights
- Electrical machinery in hazardous locations

The failure modes and natures of failures of non-metallic equipment are discussed by means of the bath tub curve theory. Process conditions as an important aspect of failure modes are discussed as well as risk factors during the project phase, the useful life phase and the wear out phase of a piece of equipment.

At the October 2000 SAQCC meeting, it was agreed that the proposed non-metallic CP scheme will form part of the existing inspector schemes and will be administered by the SAWI. Of importance was the decision that the existing SAQCC committees must be restructured to accommodate the non-metallic schemes. Therefore, the three ECSA Sub-Group Committee members (including the author) joined these committees. By August 2001 the Competent Person scheme for Non-Metallics was released and made known by information sessions and newsletters to the industry. The author wrote several articles for publications (e.g. Fusion Newsletter of the SAIW, Plastinews, etc), explaining the registration system, requirements as well as application procedures.

At the time of writing, an agreement was reached with SAQCC that under the guidance of PCISA, the first courses for CP in non-metallics would be presented in 2003. The author as a member of this working committee will also be one of the lecturers presenting these courses. Successful candidates who have attended the CP Course will now be able to register with SAQCC as a competent person if sufficient proof and documentation is provided detailing their practical knowledge and inspections performed on non-metallic equipment in industry. The competent person course will be offered bi-annually at the Vaal University of Technology and future actions include intervention with MERSETA to attain recognition of prior learning for candidates, as soon as the unit standards have been developed.

Inspector of Pressurized Equipment-Non Metallics (Polymeric and Composites). The oldest registration scheme for Inspectors in South Africa is the SAQCC-IPE scheme (for metallic equipment) that is also administered by the SAIW. The primary function and responsibility of an IPE is to verify code OHSACT compliance with newly fabricated vessels under pressure. Although no reference specifically was made in the OHSACT or in the IPE scheme on non-metallic equipment, the assumption in industry was that if someone was declared competent, it also implied competency in non-metallic equipment. As for the CP scheme, the same three ECSA Sub- Group Committee members (including the author) joined the SAQCC-IPE committee for the CP scheme. The author as well as other members generated the tasks for the inspector of non-metallic equipment. Also officially launched in August 2001 was the IPE scheme for the Non-Metallic Inspector based on at least ten years experience in the industry (also known as the Experienced Route). The author has given presentations about these schemes to various groups, e.g. AIA Association, etc.

3.3.8 Composites Industry Standards, and Composites Working Groups

In June 2001, an open letter about Composites Industry Standards Generating Working Groups was distributed to the Composites Industry by a Composites Working Group Facilitation Committee (CWGFC). This letter asked for volunteers from the industry to volunteer to form Working Groups in the main centres of South Africa, with a view to generating standards for lamination methods. This initiative was supported by the Standards Generating Body (SGB) – Plastics Manufacturing. The need for composite Unit Standards is one that is central to the requirements of the National Qualifications Framework, and is therefore relevant to all composites manufacturers.

The main objectives of this initiative are to set the requirements for establishing standards for training and improvement of skills of workers in the composites industry. Unfortunately, most of the manufacturers as well as other role-players viewed this request as an irritation to their day-to–day business, therefore poor response was received from the industry. Where the competitive industries (steel, wood, etc) have started with the process of training their workers, the composites industry is lagging behind by not setting the minimum standards of workmanship that are acceptable to the industry. The setting of minimum standards for workmanship and skills will ensure greater credibility in the industry as perceived by users compared with those who have no standards.

3.3.9 Sasol non-metallic specifications

Although the development of the Sasol non-metallic specifications could be seen as an internal action; experience through the years has shown that most of the existing Sasol specifications are used unofficially in relevant industries. In the process of developing and reviewing these specifications, numerous technical committee meetings have been organised to make sure that the experience of different parties is incorporated into them. Committee members include users from Sasol divisions, academics from tertiary institutions as well as suppliers and installers of such equipment for Sasol. These specifications are based on internationally accepted standards, but with lessons learned from various committee members (including the author) embedded. They are of a detailed technical nature and the rest of this section only indicates some of the specific requirements.

SP-100-20-3A: Non-metallic Grating and Stair Treads. The basis for this specification was the Polifin specification P-EA 30: Non-Metallic Grating and Stair Treads. However, the P-EA 30 Polifin specification was a design specification. During the update process this specification had to be changed to indicate the performance requirements that are needed in the Sasol plants as this grating is required for service in chemical and petrochemical environments. Frequent spillage of aggressive chemicals and exposure to fumes of a similar composition is normally encountered. The main technical requirements are:

(i) the grating products shall withstand frequent washing down with water and temperatures up to 80°C. The resin shall be a premium grade general purpose vinylester resin with a heat distortion temperature (HDT) of minimum 95°C

(ii) the resin and the grating profile shall be selected according to loading requirements and the chemical environment

(iii) stair treads shall have yellow or black nosing with a light grit top.

In addition, panels shall be capable of carrying a uniform load of 750 kg/m². Stair treads shall be capable of carrying a concentrated load of 250 kg. The applied loads shall not exceed 25% of the ultimate carrying capacity. For deflection, a 38 mm thick x 305 mm wide x 1000 mm long panel supported along its two ends shall deflect not more than 10 mm whilst carrying a concentrated load of 306 kg over an area of 305 mm x 25 mm. The design as well as material of construction of hold down clips and fasteners shall be verified by the supplier for the intended service, but hold-down clips shall be spaced a maximum of 1 200 mm apart with a minimum of four per piece of grating or 4 m².

SP-100-50-8: Fire Mains - Underground Glass Reinforced Plastic (GRP). The basis for this specification was the Polifin specification P-EC 7: Fire Mains Code of Practice. Before the conversion this specification was still a draft. Lessons learned by the author on projects where GRP fire mains were installed were also incorporated into this specification. In this specification all the requirements regarding the procurement, the design and installation of the equipment and the documentation are discussed. Below find some specific requirements that were added to the original draft specification are:

(i) Ordering of Fire Main. In this part of the document all the information that the manufacturer will need from Sasol to do a full design is given. If the information is not available, then the assumptions must be agreed and recorded in the End of Job (EOJ) documentation for the installed system.

(ii) Design. The manufacturer shall ensure that the following is included in the design of the fire main system e.g. process design; static design; dynamic design; anchor block system design; design installation requirements and applicable performance parameters. The design shall also be in accordance with Factory Mutual Class No.1610 as well as the requirements of this specification.

a. The minimum safety factor on GRP components shall be a minimum of 4 for pipes and 6 for fittings and joints.

b. The minimum wall thickness shall be limited to 5.0mm for all sizes and pressures. The internal chemical barrier will be a minimum of 1.0mm and the external corrosion barrier will be a minimum of 0.3mm.

c. The following pipe jointing systems were evaluated and approved: Hand-Laminated Butt and Overwrap Joint System; Bell and Spigot Joint with Double "O"-Ring Connection System; Bell and Spigot Joint that is adhesive bonded; Full Face Flange; Stub with Backing Ring; and Steel Couplings Bonded to the GRP.

(iii) Inspection and testing: Test Sample. The manufacturer needs to provide Sasol a representative sample of the proposed fire main pipe system in order to ascertain the effectiveness of design and fabrication of the proposed system. This sample needs to be representative of the proposed fire main system in terms of design, material of construction, geometry and manufacturing; must have a minimum length of 1.5m as well as the proposed jointing system; and the average sample pipe diameter shall be the same as the majority of the pipes to be installed. Furthermore, to ascertain the quality of the proposed installed system as represented by the sample, destructive tests will be conducted and verified, e.g. pressure test at ambient temperature to 1.3 times pipe pressure rating for 1 hour as well as a Rupture test in accordance with ASTM D1599. After these tests the pipe sample shall be cut and a Tensile test according to ASTM D2105 as well as a Burn-off test according to ASTM D2584 needs to be carried out.

SP-100-90-2: Thermoplastic Welding. This specification was originally the Polifin Specification P-EC 9: Thermoplastic Welding. The Polifin document was a specification that has been used extensively. However, changes had to be made to make this specification applicable for the Sasol Group of Companies. In its new format, this specification covers the following:

(i) Welding Basics
(ii) Thermoplastic Basics;
(iii) Welding Procedure Qualifications;
(iv) Welder Qualifications;
(v) Welding Equipment Requirements; and
(vi) Documentation and Testing Requirements

The scope of this specification covers welding of all typical thermoplastic materials with all the typical welding processes. The materials covered are: PVC-U; PVC-C; PP; PE-HD; PVDF; ECTFE; PFA; FEP and MFA.

The welding processes covered are:

(i) hot plate butt welding;
(ii) spigot and sleeve welding;
(iii) electrofusion welding;
(iv) hot gas welding with torch separate from filler;
(v) hot gas string bead welding;
(vi) hot gas extrusion welding; and
(vii) solvent cement joining.

There is also a possibility that the SANS documents that is used in this specification will be updated. When the revised SANS documents are published, this specification will have to be reviewed to incorporate applicable changes.

SP-100-90-17: Laminate Post Cure Procedure. This specification originated as P-EG 3: Laminate Post Cure Procedure in the Polifin system. This document was under review when the author took responsibility for it. In this specification the following is addressed:

(i) the stages of cure;
(ii) the various cure systems;
(iii) the benefits of enhanced corrosion resistance and design properties when post curing;
(iv) disadvantages of post curing laminates;
(v) recommended post curing temperatures and time periods;
(vi) methods of post cure; and
(vii) the procedure to be followed when post curing an item.

The following technical requirements are set out in this specification:
The resin manufacturer's chemical resistance charts should be consulted to verify in which particular cases the laminate should be post cured, in order to offer optimum chemical resistance, for the specified chemical. In order for the full tensile and flexural properties to be obtained the laminate should have reached full cure. Furthermore, the resin supplier should also be consulted regarding the cure temperature and the cure period for the particular type of resin and environment.

The following guidelines should be adopted in interpreting manufacturer's Maximum Operating Temperature data in terms of the k_5 factor (factor relating to post cure conditions in BS 4994). These factors are then multiplied together and used with other factors defined in BS 4994 to obtain the overall factor of safety, K.

POST CURE PROCEDURE	k_5 FACTOR
Complete curing procedure, including a full post cure at elevated temperatures	1.1
Not full post cure and a design operating temperature up to and including 45ºC	1.3
Not full post cure and a design operating temperature over 45ºC	1.5

Table 3.2 The effect of Full Post Cure on the k_5 Factor

SP-100-90-21: Resin Selection. This specification originated as P-EG 4: Resin Selection Guide in the Polifin system. This document was under review when the author took responsibility for it. This specification serves as a minimum requirement for the selection of a vinylester resin, but due to the low cost and suitability of polyester resins for water systems these resins were included in this specification. The major factor that affects a resin's temperature performance is its heat distortion temperature (HDT). The HDT of the resin should be 20ºC higher than the design temperature as specified in BS 4994. It is not wise to use a resin at a temperature too close to its HDT due to a rapid drop off in mechanical properties and chemical resistance as the temperature approaches the HDT.

Furthermore, although the different manufacturers have chemical resistance charts for most of their resins, which serve as a useful selection guide, there are a number of additional factors that need to be considered when using these manufacturers' guides:

(i) maximum operating temperature;
(ii) concentration of chemicals;
(iii) combination of chemicals;
(iv) the presence of trace amounts of organic solvents and aromatic compounds;
(v) varying duties;
(vi) maximum operating temperature for an intermediate concentration;
(vii) user experience;
(viii) chemicals that resins are not resistant to;
(ix) fabrication and additives that might affect chemical resistance;
(x) the degree of cure; and
(xi) upset conditions.

With the different types of resins available there is the concern that they may not be compatible with each other. Fortunately, good adhesion exists between different types of vinylester resins and vinylester resins with polyester resins. A repair kit containing one premium high temperature vinylester resin should suffice for any GRP repair work. This has been implemented as a maintenance strategy in the Sasol plants where GRP equipment is used.

SP-100-42-2: Composite and Dual Composite Vessels. Most of the installed vessels in Sasol made of non-metallic materials comply with the manufacturing code, BS 4994. This specification was therefore developed during the implementation phase of raising awareness regarding the use of non-metallics, due to importance of such equipment in a chemical plant. This specification consists of six parts as follows:

(i) Part A: Procurement of vessels manufactured from composites and dual composites

(ii) Part B: Design of nameplates for composite and dual composite Vessels
(iii) Part C: Design guidelines for the construction of vessels from composites and dual composites
(iv) Part D: Guide for stress relieving of PVC-U plates
(v) Part E: Storage, handling and shipping of composite and dual composite vessels
(vi) Part F: Installation of composite and dual composite vessels

The following technical requirements of critical importance were addressed in the specification:

Design: The design and construction of vessels from composites and dual composites will be in accordance with BS 4994. In terms of the factor of safety as determined during the design, the factor k_2 was increased to a minimum of 1.4 for vessels without a thermoplastic liner. The factor k_2 is related to the loss in strength of an unstressed GRP laminate when exposed to the process conditions for the design lifetime of the vessel. Once determined, this factor is then used to determine the overall K-factor that is the factor of safety of the vessel in accordance with BS 4994.

Furthermore, it was also specified that bolting torque values are to be stated on the drawings and on a label laminated into the vessel above the nozzle to minimise the risk of over-stressing the flanges.

Materials: In the cases of PE-HD, PP, PVDF, ECTFE, FEP, MFA and PFA lined vessels, synthetic fabric or glass cloth backed sheet needs to be used to ensure satisfactory bonding between the liner and the laminate.

For PVC liners, pressed or extruded stress relieved PVC-U plates shall be used.

Manufacturing: The following minimum nominal glass content by weight of laminate was specified:

In the Corrosion Barrier:

(i) chopped strand mat (CSM) = 25 %

In the Structural Laminate:

(i) chopped strand mat (CSM) = 30% to 40%
(ii) woven rovings (WR) = 40% to 60%
(iii) filament wound continuous rovings = 60% to 70%

The surface exposed to chemical attack shall be reinforced with "C" glass surface tissue and/or synthetic polyester veil and/or acrylic veil and/or ECTFE veils depending on the chemical duty. A backing layer containing not less than 1,2 kg/m² of chopped strand mat with a styrene soluble powder binder shall be applied to all vessels regardless of category. The first layer shall be not more than 0,3 kg/m². The use of 0.6 kg/m² CSM in the backing layer is prohibited.

Chlorine duty requires a minimum backing layer as described below:

(i) wet chlorine gas up to 95°C = 2,4 kg/m² CSM

(ii) chlorinated brine below 75°C = 2,4 kg/m² CSM

(iii) chlorinated brine up to 95°C = 4,2 kg/m² CSM

This layer forms an additional corrosion barrier and shall not be taken into account in any design calculations. For acidic duties, a minimum backing layer of 1,2 kg/m² of ECR-GLAS chopped strand mat with a soluble powder binder is specified.

The topcoat shall contain 0,4% to 0,6% paraffin wax, with a melting point of 55°C to 60°C, to minimise the effects of air inhibition. The topcoat shall also contain a UV stabilizer. Pigmentation shall only be allowed for identification (i.e. 100 mm band identification) purposes. Colour coding shall be included in the datasheet.

During lamination where thickening is required it must not be over specified and designers must state that lay-up be carried out in stages to allow dissipation of exotherm.

Installation: GRP is susceptible to reverse impact damage, which means that external mechanical knocks may lead to internal cracking with consequent loss of corrosion resistance. Therefore, external damage should be investigated by also having a look at the damaged area internally and repaired as required. All repairs must be conducted in accordance with approved procedures.

Due to many cases reported in the wider industry regarding the incorrect installation of non-metallic storage tanks, requirements were set that indicates how these vessels must be settled into the screed and how the installation of the reinforcing membrane and sealing of the vessel shall be done.

SP-100-50-3: Non-Metallic Piping Design and Fabrication. Originally this specification consisted mainly of information in the Polifin specification P-EF 10: Non-Metallic Piping Fabrication/Maintenance. However, when starting to work on the non-metallic piping specifications it was clear that it would be more beneficial to make the non-metallic piping specifications similar to the Sasol metallic piping system for ease of understanding and similarity. Based on guidance from the industry, the author decided that for GRP piping, the code of construction will be in general accordance with BS7159. For plain thermoplastic piping systems, the specification is based on DVS2210.

The following technical requirements of critical importance were addressed in the specification:

The allowance for corrosion or erosion in piping shall be determined by the intended service or as specified in the line class specifications. In the case of GRP piping, this may be in the form of an added thermoplastic lining, or corrosion barrier designed to withstand corrosive media.

In terms of the design requirements, flexibility analysis shall be made for the most severe temperature conditions imposed during start-up, shutdown, regeneration, or normal operating or cleaning conditions. Piping shall be so designed and supported that external forces and moments exerted on plastic equipment nozzles shall be negligible. To minimise initial capital costs, plastic lines 50mm and smaller may be supported by, or suspended from, steel lines 150mm and larger provided the larger diameter lines can support this increased load. Under no circumstances may plastic lines be used as support for other lines. Also, all valves and other appurtenances to plastic piping shall be adequately supported externally.

As a general rule, thermoplastic piping shall not be used for the transport of flammable products. This may however be done in GRP piping. Whenever flammable fluids are transported in plastic piping, adequate arrangements need to be made to ensure that static charge build-up on the pipe is prevented. This must also be done when the plastic piping is routed through a hazardous (explosive) area. Specific requirements were also set in the specification regarding shipping and storage.

SP-100-50-3A: Non-Metallic Piping Material. Included in this specification are the non-metallic line classes. Most of these line classes were adapted from the Polifin Non-Metallic Pipe Line Classes. However, a few new line classes were introduced with this specification.

One of the major changes to the line classes is the numbering system. The designation will now be NPX, where:

(i) N indicates that it is a non-metallic line class
(ii) P will identify the type of non-metallic used for the corrosion barrier:
   a. P – Polypropylene;
   b. H – High Density Polyethylene;
   c. U – PVC-U;
   d. F – PVDF;
   e. E – ECTFE;
   f. A – PFA;
   g. C – PVC-C; and
   h. G – GRP.
(iii) X will indicate the application
   a. 1 to 9 – reserved for existing line classes
   b. A to Z – duty specific line classes

The following topics are addressed in the line classes:

(i) Design of the Pipe;
(ii) Raw Materials;
(iii) Bends, Tees, Reducers and other Fittings as required;
(iv) Nozzles and Flanges;
(v) Gaskets;
(vi) Fasteners;
(vii) Valves and other in-line fittings;
(viii) Jointing and Welding as required; and
(ix) Testing and Inspection.

In Table 3.3 is a description of the new non-metallic line classes indicating the new line class numbers and the material of construction. The original Polifin number is also indicated for reference purposes. Some comments are given to clarify the difference between the line classes.

Polifin Number	New Sasol Number	Chemical Corrosion Barrier Material	Structural Material	Comments
PN1-N	NG1	GRP	GRP	Butt and Over Wrap Joints
PN1-S	NG2	GRP	GRP	Bell and Spigot Joints
(new line class)	NG3	GRP	GRP	Low Pressure Underground
PN1-U	NG4	GRP	GRP	High Pressure Underground
PN1-D	NG5	GRP	GRP	Ducting
PN2-P	NP1	PP	PP	Plain Thermoplastic
PN2-U	NP2	PP	PP	Underground
PN3-GEN	NP5	PP	GRP	Plain GRP Over Wrap
PN3-GEN NEW (not published)	NP6	PP	GRP	Thin Wall Liner
PN3-T	NP7	PP	GRP	Tape Used for Adhesion
PN3-FB	NP8	PP	GRP	Fleece Back Used for Adhesion
PN4-P	NH1	PE-HD	PE-HD	Plain Thermoplastic
PN4-U	NH2	PE-HD	PE-HD	Underground
PN5-GEN	NH5	PE-HD	GRP	Plain GRP Over Wrap
PN5-T	NH6	PE-HD	GRP	Tape Used for Adhesion
PN5-FB	NH7	PE-HD	GRP	Fleece Back Used for Adhesion
PN6-P	NU1	PVC-U	PVC-U	Plain Thermoplastic
PN7-G	NU5	PVC-U	GRP	Plain GRP Over Wrap
PN7-TW	NU6	PVC-U	GRP	Thin Wall Liner
PN8-P	NF1	PVDF	PVDF	Plain Thermoplastic
PN9-EX	NF5	PVDF	GRP	Extruded Pipe
PN9-FB	NF6	PVDF	GRP	Fleece Back Used for Adhesion

Polifin Number	New Sasol Number	Chemical Corrosion Barrier Material	Structural Material	Comments
PN10-P	NE1	ECTFE	ECTFE	Plain Thermoplastic
PN11-EX	NE5	ECTFE	GRP	Extruded Pipe
PN11-FB	NE6	ECTFE	GRP	Fleece Back Used for Adhesion
PN12-P	NA1	PFA	PFA	Plain Thermoplastic
PN13-EX	NA5	PFA	GRP	Extruded Pipe
PN13-FB	NA6	PFA	GRP	Fleece Back Used for Adhesion
PN14-P	NC1	PVC-C	PVC-C	Plain Thermoplastic
PN15-G	NC5	PVC-C	GRP	Plain GRP Over Wrap

Table 3.3 New Non-Metallic Line Classes

A decision was also made by the author to use SANS 1748-2 as the design basis for all composite and dual composite fittings and joints. This specification titled "SP-100-50-12: Non-Metallic Pipe Fittings" has been specifically developed to include all non-metallic pipe fittings and joints. This includes Tapered Socket / Spigot GRP Fittings, PVC Pipe Fittings for Solvent Cement Jointing, CPVC Pipe Fittings, Polypropylene and HDPE Pipe Fittings, PVDF Pipe Fittings and ECTFE Pipe Fittings.

SP-100-90-39: Quality System Requirements for Non-Metallic Fabricators. Due to the numerous quality problems experienced on projects with equipment manufactured from non-metallic materials, an audit document was developed that includes the requirements of ISO 9000:2000, ISO 14 000 and OHSAS 18 000.

The first section of the specification gives a quick overview of the specification with all the mandatory paragraphs for specifications. After this section 8 parts follow that address the audit and the audit process.

Part 1 – Quality System Assessment. In this part an explanation is given on how to use the document. This part helps to identify what parts have to be completed by different suppliers. The scoring system is also explained.

Part 2 – Quality Management System Assessment Guide. Each section that the supplier needs to address is discussed in this part. This part serves as a guide to the auditors and it gives a broad idea of what is expected from the suppliers. An indication is also given if there are specific questions for a specific type of supplier.

Part 3 – Assessment Documentation. All the forms and templates to be used throughout the auditing process is included in this part of the document.

Part 4 – Quality System Assessment Questionnaire. This is the most important part of this document. It is divided into 20 sections, each one addressing a specific part of the quality management system of the company. The auditors use this during the audit to determine what the rating will be of the supplier.

Part 5 – Inspection of Manufacturing Works for Composite and Dual Composite Suppliers. In this part the additional requirements for composite and dual-composite suppliers are listed. The information required to determine the scope of the work is also requested from the supplier.

Part 6 – Inspection of Manufacturing Works for Thermoplastic Suppliers. In this part the additional requirements for thermoplastic suppliers are listed. The information required to determine the scope of the work is also requested from the supplier.

Part 7 – Non-Metallic Design, Verification, Consulting and Inspection Service Providers – Facilities. In this part the additional requirements for the companies that provides non-metallic design, verification, consulting and/or inspection services are listed. The information required to determine the scope of the work is also requested from the supplier.

Part 8 – Non-Metallic Design, Verification, Consulting and Inspection Service Providers – Personnel. In this part the requirements for a person that provides non-metallic design, verification, consulting and/or inspection services are listed. The information required to determine the scope of the work is also requested from the supplier.

3.4 Implementation process to reach the target groups in Sasol

3.4.1 Implementation strategies and actions aimed directly at the target group

As discussed in Chapter 2, target groups were selected in target divisions. Although only 813 of the initial 1054 responded to the first questionnaire, the author decided to include all possible target group members in the implementation actions to raise the awareness regarding the use of non-metallic materials.

The process should be seen as an holistic approach towards increasing awareness, implying that all members of the target groups and divisions were given equal opportunity to learn, interact and participate in the process.

Training and education to increase awareness has been introduced using the following methodologies:

(i) e-mail
(ii) non-metallics web-site on the Sasol Intranet
(iii) mechanical Training Sessions
(iv) courses/Information sessions
(v) training of EIT's
(vi) Composites Africa 2002 Conference
(vii) specifications

E-mail. Based on the questions as per the first survey (see Chapter 2), e-mails were developed for each topic of interest. Twelve e-mails were sent in 3 week intervals to individuals in the target groups. The design of non-metallic equipment served as an example (see Appendix E). As seen from the example, each e-mail was linked to a site on the Non-Metallics Intranet, providing an in-depth technical paper developed by the author on a specific topic. Numerous positive comments, questions as well as guidance were received from individuals in the target groups.

Non-metallics web-site on the Sasol Intranet. The development of the Sasol Intranet on Non-Metallics has been an exiting experience, for the fact that this was the first ever specialized technical site to be added to the existing list of available sites. The development and set-up work was done by the Sasol Technology IT section while the information displayed was developed by the author. The web-site was initially divided into the following sections:

(i) about the SPNMTC, its history, vision, objectives as well as committee structure
(ii) best practices divided into Approved Suppliers List, professional bodies, inspection as well as a comprehensive section on codes, standards and specifications
(iii) the future, with the technical papers linked to the awareness e-mails as well comprehensive information regarding courses available, e.g. course content, costs, maps, etc.
(iv) technology information section that covers technical papers (as presented at conferences), links to related sites of manufacturers or suppliers, research reports from the Sasol Polymers/Fibre-Wound Testing Facility as well as a section on recommended trade journals and magazines in this field
(v) recent events, giving feedback as well as further contact information.

As part of the initiative to give approved manufacturers to Sasol wider representation, a space is provided on the Non-Metallics Intranet where manufacturers can provide a 50-word description of their company together with contact information.

The web page was first launched at end of September 2000 with e-mail to the wider Sasol Group announcing the launch of the site. Initial response was excellent, with 436 hits in the first month. This initial response unfortunately slowed down until January 2001 when the first survey was done to determine the level of awareness. From January 2001 onwards, the average hits per month worked out to 358 for the year 2001. Resulting from the Composites Africa 2002 Conference and the launch of Non-Metallic Training Courses in 2002, the average hits per month increased to 582.

Mechanical Training/Information sessions. Due to the fact that Sasol Technology regularly applies new technology in projects; operations and maintenance divisions are introduced to this technology. The Sasol Maintenance Forums serve as a platform to launch new technology in a spirit of partnership and therefore pave the way for acceptance of Sasol Specification revisions to include the new technology. In both Secunda and Sasolburg there are maintenance forums where maintenance decision-makers meet regularly.

The author realized that by using these forums, wider acceptance as well as fostering of interest for the use of non-metallics could be gained. During 2001, two presentations were given by the author at these forums, resulting in 8 requests for more detailed workshops to be held with specific interest groups. Workshops were held with interest groups e.g. Fire and Safety Department, Utilities (Cooling Water Systems), Project Groups (Butanol Project), etc.

Courses. The author identified from the start of the awareness process that a definite need existed and still does for training in the field of composites. The author could only find Thermoplastic Welding Courses (as presented by PISA) as well as some in-house courses by fabricators available for technical people to further their knowledge in this field. The rationale behind this part of the awareness drive was to provide the participants the opportunity to attend a series of short courses which serve as building blocks for future recognition, starting from basic knowledge. Additional requirements regarding the courses were set by the author and included specific outcomes, cost effectiveness and a course maximum duration of two days.

The next phase of this process was to convince manufacturers and suppliers to take part in this process by developing and presenting at their premises relevant non-metallic courses. Numerous visits as well as long in-depth discussions took place during 2000 and the first half of 2001, explaining the need from Sasol's side in terms of outcomes expected. Training manuals, lecturers, facilities as well as travelling logistics were addressed to ensure a positive and learning experience for delegates. The following courses were presented from January 2002 onwards:

(i) Basic Unsaturated Polyester and Glass Reinforced
(ii) Glass Fibre Reinforcement Course
(iii) Hi-Tech Glass Fibre Course
(iv) GRP Manufacturing Course
(v) Filament Winding Course

At the time of writing, 52 Sasol technical people have attended these courses with extremely positive feedback in terms of knowledge gained. By September 2002, these courses were also available on the Sasol - wide Organizational, Development and Training web-page under technical courses, providing all Sasol employees both nationally and internationally access to the latest available courses.

Training of Engineers In Training (EIT). Another focus area in the awareness campaign was the training of EITs in the Mechanical Engineering Department of Sasol Technology. Being part of this department, the author reached an agreement with the Sasol Technology Engineering Manager on 21 November 2001 (SPNMTC, 2001) that all junior engineers should rotate at the Non-Metallics section to raise their awareness of the materials and the technology.

The author initiated the process by which an agreement was reached with two large Sasol Approved Manufacturers to provide training for junior engineers because of the non-availability at Sasol for such training. In order to provide an effective learning experience, the author initiated a learnership program, which is results driven as well as competency based. The fourteen areas of competencies covered are personal attributes, personal competence, communication, computer literacy, management skills, design and drawings, manufacturing processes, maintenance, construction, legislation, quality, plastician skills, materials and business skills. During the training process, the trainee performs self-evaluation while the tutor, coach and assessor indicate if competencies were achieved in the skills required. This program has been well received with 6 EIT's completing it successfully.

Composites Africa 2002 Conference. This conference has served as a major awareness event in reaching target groups.

Specifications. The process of incorporation of Polifin Non-Metallic Specifications into the Sasol system commenced in November 2000, with the author making the following recommendations to both the SPNMTC as well as Sasol Technology management (Mouton, 2000):

(i) combine existing specifications which have a close resemblance / function.
(ii) obtain a Sasol specification number from Sasol Technology.
(iii) rectify shortcomings in the specifications and update to include technology changes.
(iv) incorporate draft Polifin Non-Metallic specifications in this process.

The proposal to combine the specifications with close resemblance was accepted by both parties by the end of 2000. This implies that the original 27 specifications or guidelines were combined to form 14 Sasol specifications (see section 3.3.9).

In terms of the Sasol specification number, it was agreed that the non-metallic specifications would have a 100 prefix, and would follow the same numbering allocation system for metallic products. For example, as SP-42-2 is the metallic pressure vessel specification, the non-metallic pressure vessel specification is therefore now known as SP-100-42-2. The major advantage of this unique numbering system is the ease of reference of Sasol personnel to non-metallic specifications based on their good knowledge of metallic engineered specifications and numbering allocations.

In Appendix A, a more detailed description can be found on the updating of the Polifin specifications during the integration process into the Sasol system.

3.4.2 Supportive implementation actions aimed directly at the target group

Handbook for project execution. During the three years of raising awareness regarding the use of non-metallics, various Sasol projects of different magnitude were executed with varying degrees of success. It became clear that lack of understanding as well as inadequate knowledge were the root causes. Project personnel tend to think and design in steel or concrete, and then endeavour to convert to non-metallics using the same engineering principles with little success.

One of the major non-metallic fabricators developed for and on behalf of ANNEM guidelines based upon previous experience to assist inexperienced project personnel in executing major or multi-disciplined contracts in non-metallics. This guideline, better known as the 'Handbook of guidelines for contract execution of projects with non-metallics', has received acceptance in the industry as well as in Sasol. It covers 29 topics as well as practical examples, from determining risk to the importance of closeout reports. The author made several recommendations and suggestions during the development phase of these guidelines. They have also been published on the Sasol Intranet.

Chapter 4

Evaluation of the process

The process of increasing the use of non-metallics in the Sasol Group of Companies stretched over a three-year period. In the initial phase, more attention was given to the role-players outside the company, e.g. manufacturers, technical committees, etc, while the latter half of the period was more focused on the target groups in the company. As discussed in Chapter 2, questionnaires were used to determine the success of the efforts invested in the process.

4.1 Format and timing of the questionnaire

In November 2002, a questionnaire was sent out to all personnel in the Sasol group who participated/received information regarding or used non-metallics in the past two years to ascertain their level of knowledge regarding the use and application of non-metallics. The questionnaire had the same basic format and layout as the one previously used. The following were additions or changes to the original form:

(i) under biographical data, reference to race was removed due to some negative comments from respondents of the first survey
(ii) under the section covering the Knowledge and Awareness, columns were added to enable the respondent to indicate the means by which knowledge was gained, e.g. e-mail, web-site, courses, conferences, specifications, etc
(iii) under the General section, an additional question was added to enquire if the respondent would like to receive more information on non-metallics in the future.

4.1.1 Results of the final survey.

The questionnaire was forwarded electronically to the 1054 target group members. A total number of 673 returned their response in the two weeks allocated time slot, providing a 63.75% response rate.

The following serves as a summary of the biographical data of the respondents:

1	Gender	Male 90.6%			Female 9.4%		
2	Age	<25 10.0%	25–34 48.4%	35-44 22.3%	45-54 12.1%	>55 7.3%	
3	Highest Qualification	Matric 8.2%	Diploma 16.5%	Degree 49.0%	Post Graduate 26.3%		
5	Years of Experience	<1 yrs 5.2%	1–5 yrs 30.8%	6–10 yrs 19.3%	11–15 yrs 16.4%	16-19 yrs 7.3%	20 yrs 21.0%
6	Level in Company	7 20.1%	6 28.3%	5 30.5%	4 17.1%	Other 4.0%	
7	Your Line of Responsibility	Technician 5.7%	Technical Manager 24.1%	Specialist 24.1%	Management 16.7%	Other 29.5%	
8	Company Working for?	SSF 46.7%	SCI 21.9%	Mines 3.7%	Technology 11.2%	Polymers 9.5%	Others 7.0%

Table 4.1 Results on biographical data of respondents (Second Survey)

The results show that the main respondents were, in all likelihood, white males aged between 25 – 34 years with a degree and up to 5 years working experience. Furthermore, most of the respondents are either Technical Managers or Specialists working for SSF or SCI, the two larger Sasol businesses in the Sasol Group of Companies. This corresponds well with the initial survey which is discussed in Chapter 2.

Table 4.2 serves as a summary of the responses on the section of non-metallic knowledge and awareness.

	1 E-mail	2 Non-Metallic website	3 Courses	4 Composites Africa	5 Specifications	6 Other	A Good Knowledge	B Above Average Knowledge	C Some Knowledge	D Undecided / Don't know
Various shapes, sizes and forms of non-metallic products	46.8 %	21.8 %	3.7 %	11.1 %	9.5 %	7.0 %	24.1 %	29.0 %	39.4 %	7.6 %
Application possibilities of the different types of non-metallic materials	37.4 %	29.6 %	7.1 %	14.7 %	10.1 %	1.0 %	8.6 %	27.6 %	55.6 %	8.2 %
Procurement instructions	35.2 %	18.4 %	8.2 %	11.3 %	18.6 %	8.2 %	14.9 %	15.9 %	46.2 %	23.0 %
Specifications	53.2 %	22.6 %	5.2 %	12.5 %	3.1 %	3.4 %	16.0 %	12.8 %	51.1 %	20.1 %
Design	37.0 %	28.1 %	3.4 %	3.0 %	14.9 %	13.7 %	17.5 %	14.3 %	42.3 %	25.9 %
Roles/Responsibilities of the Inspection Authority	42.2 %	18.7 %	15.9 %	4.5 %	5.6 %	13.1 %	27.2 %	18.4 %	31.6 %	22.7 %
Roles/Responsibilities of Consultants/Engineering Contractors for non-metallic equipment	54.8 %	29.0 %	5.6 %	4.3 %	5.6 %	0.6 %	12.5 %	26.0 %	30.2 %	31.4 %
Fabricator's required Technical Capabilities & Resources	31.2 %	28.8 %	16.8 %	9.7 %	10.1 %	3.4 %	6.4 %	15.2 %	59.9 %	18.6 %
Fabrication Techniques	26.0 %	22.9 %	22.7 %	17.1 %	9.8 %	1.5 %	3.9 %	21.8 %	65.1 %	9.2 %
Transportation; Erection and Installation	31.9 %	23.3 %	12.3 %	8.0 %	23.8 %	0.7 %	5.2 %	36.3 %	39.7 %	18.9 %
Maintenance Requirements/Techniques	32.1 %	31.6 %	8.0 %	7.9 %	10.0 %	10.4 %	3.3 %	27.3 %	35.5 %	33.9 %
Statutory Inspection requirements	32.8 %	19.8 %	3.4 %	18.7 %	2.1 %	23.2 %	12.2 %	17.1 %	34.5 %	36.3 %
AVERAGE	38.38 %	24.55 %	9.35 %	10.23 %	10.26 %	7.8 %	12.65 %	21.80 %	44.25 %	21.31 %

Table 4.2 Summary: Response on the section of non-metallic knowledge and awareness (Second Survey)

The table indicates that the majority of respondents believed they had gained knowledge via the different communication mediums of most of the issues dealing with the basics (e.g. shapes, applications, specifications), furthermore that significant progress had been made regarding awareness of the procurement of composite products or services, the legal requirements pertaining to the use of composites (e.g. roles and responsibilities of the Inspection Authority, statutory inspection requirements). The results also indicate that most of the respondents had gained knowledge regarding the manufacturing and maintenance processes of composites products (e.g. fabrication techniques, transportation, maintenance techniques). Furthermore, the results indicated that the electronic media proved to be the most effective in the process with the e-mail and website receiving the highest scores.

Under the General section, the response were as follows on the following four questions:

(i) 'Are you aware that twenty-two Sasol Non-metallic Specifications exist?'
95.8% responded positively.

(ii) 'Are you aware of the Sasol Non-metallic Intranet?'
97.6% responded positively.

(iii) 'Would you consider using non-metallics for future, new and replacement projects/maintenance?'
98.5% responded positively.

(iv) 'Would you like to receive more information on Non-Metallics in the future?'
98.2% responded positively.

4.1.2 Discussion of results of the second survey

Although numerous attempts were made to remind respondents to return their completed questionnaires, only 63.75% were returned. These questionnaires were sent out late in the year during an extremely busy period in Sasol in terms of projects, upcoming shutdowns, etc and hence the less favourable return compared to the initial survey.

Biographical. The biographical data is about the same as for the first survey, with the only significant exception of fewer respondents from the mines. This occurrence can perhaps be explained by a lower emphasis placed in this field at the mines by the author while more time was spent at SSF (which is supported by the result of 46,7% respondents from SSF).

Knowledge gained in this field by the respondents

(i) as expected, the most effective communication medium proved to be e-mail with the Non-Metallic web page as the second most effective/used source of information. With numerous e-mails that were sent out referring the receiver to the web page for additional or more comprehensive information, the results are an indication of the methodology used.

(ii) the low percentage of knowledge gained via specifications as a medium (3,1%) as well as the low knowledge level was discouraging. A possible explanation for these results is the tendency of Sasol technical employees not to get involved in detail technical issues but to source it out to service providers. To serve as confirmation for the previous point, 53.2% learnt of the specifications via the e-mail.

(iii) in terms of knowledge gained under the "other" heading, the average of 7.18% could possibly be attributed to other sources of information, e.g. recommended magazines and periodicals, own knowledge gained by recommended alternative web pages, etc.

(iv) as most of the respondents are employed in the operating divisions (SSF, SCI, Polymers and Mines), knowledge of maintenance was higher than average, although it is clear from the results obtained that in-depth knowledge in maintenance of non-metallic equipment is lacking.

(v) due to the strong presence of the Sasol Approved Inspection Authorities in Sasol, the higher than average awareness per column supports this fact.

4.2 Evaluation of results of initial and final survey

Table 4.3 compares the results of the first survey (carried out in January 2001) with those of the second survey (in italics).

	Good Knowledge	Above Average Knowledge	Some Knowledge	Undecided Don't Know
Various shapes, sizes and forms of non-metallic products	6.9% *24.1%*	18.7% *29.0%*	62.7% *39.4%*	11.7% *7.6%*
Application possibilities of the different types of non-metallic materials	4.8% *8.6%*	18.1% *27.6%*	61.1% *55.6%*	16% *8.2%*
Procurement instructions	1.1% *14.9%*	6.9% *15.9%*	31.1% *46.2%*	60.9% *23.0%*
Specifications	7.4% *16.0%*	38.7% *12.8%*	49.9% *51.1%*	4.0% *20.1%*
Design	2.7% *17.5%*	10.2% *14.3%*	35.9% *42.3%*	51.2% *25.9%*
Roles/Responsibilities of the Inspection Authority	6.3% *27.2%*	14.4% *18.4%*	34.3% *32.6%*	45.0% *22.7%*
Roles/Responsibilities of Consultants/Engineering Contractors for non-metallic equipment	2.3% *12.5%*	12.2% *26.0%*	37.0% *30.2%*	48.5% *31.4%*
Fabricator's required Technical Capabilities & Resources	3.7% *6.4%*	6.2% *15.2%*	35.5% *59.9%*	54.6% *18.6%*
Fabrication Techniques	3.7% *3.9%*	9.6% *21.8%*	43.8% *65.1%*	42.9% *9.2%*
Transportation; Erection and Installation	2.7% *5.2%*	6.9% *36.3%*	47.0% *39.7%*	43.4% *18.9%*
Maintenance Requirements/Techniques	2.5% *3.3%*	5.0% *27.3%*	39.1% *35.5%*	53.4% *33.9%*
Statutory Inspection requirements	3.1% *12.2%*	8.0% *17.1%*	29.6% *34.5%*	59.3% *36.3%*
Average per column	3.9% *12.7%*	12.9% *21.8%*	42.3% *44.3%*	40.9% *21.3%*

Table 4.3 Summary of comparison results

In terms of the gain in knowledge regarding specifications, web page and the possible use of these materials in the future, the results were as follows for the three questions:

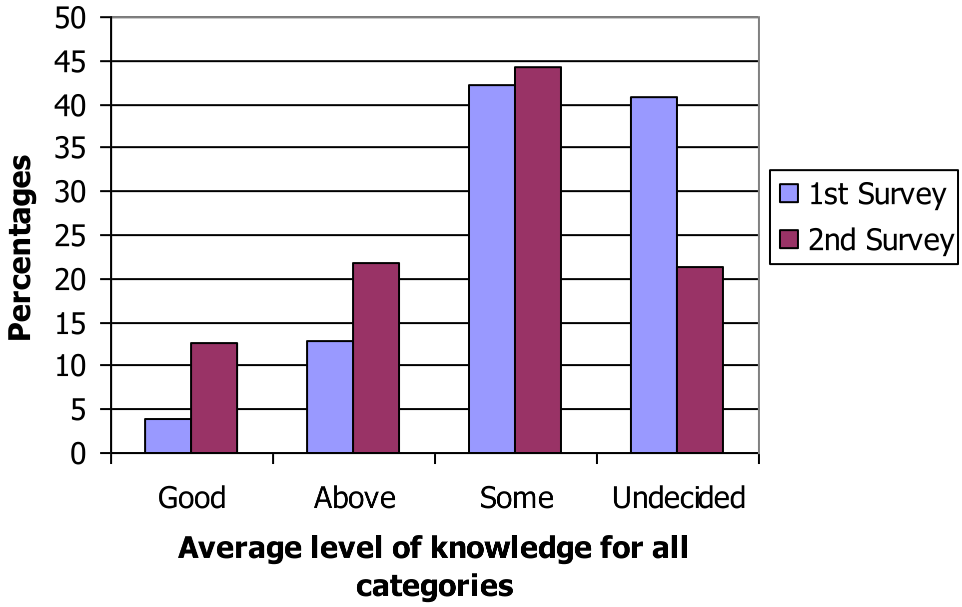
(i) 'Are you aware that twenty-two Sasol Non-metallic Specifications exist?' (Question 1). The awareness increased from the initial 22.9% to 95.8%.

(ii) 'Are you aware of the Sasol Non-metallic Intranet?' (Question 2). The awareness increased from the initial 42.8% to 97.6%.

(iii) 'Would you consider using non-metallics for future, new and replacement projects/maintenance?' (Question 3). Confirmation increased from the initial 92.6% to 98.5%.

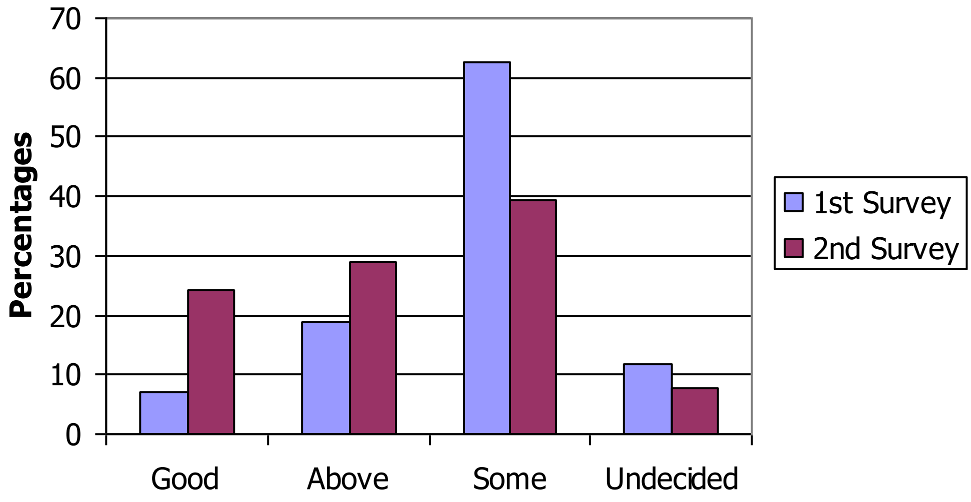
4.2.1 Summary of results of the initial and final survey

The last row of Table 4.3 indicates the change in knowledge and awareness for the period, and summarized in Graph 4.1.



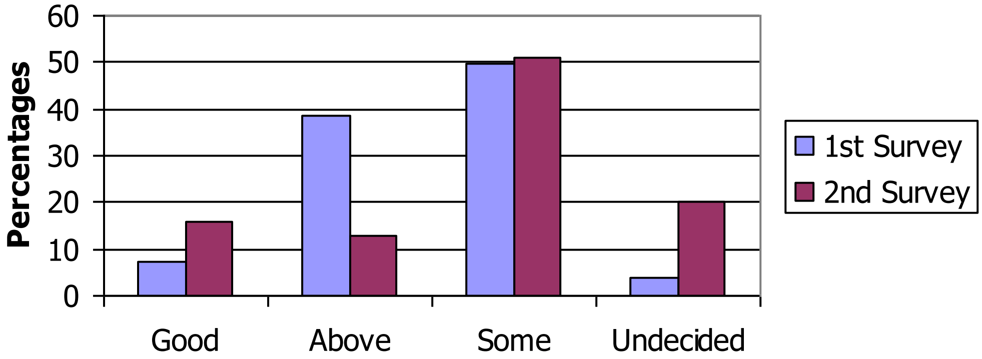
Graph 4.1 Survey 1 & 2 – Average level of knowledge

Shapes, sizes and forms of non-metallic products. Educating and informing in terms of the wide selection of possible non-metallic products was one of the most specific focus areas during the Awareness Campaign. The main reason for this drive was to ensure that the engineering personnel of Sasol would have the knowledge and awareness of products shapes and forms (e.g. beams, sheets, rods, etc) that are available. Graph 4.2 shows the significant progress made in this regard.



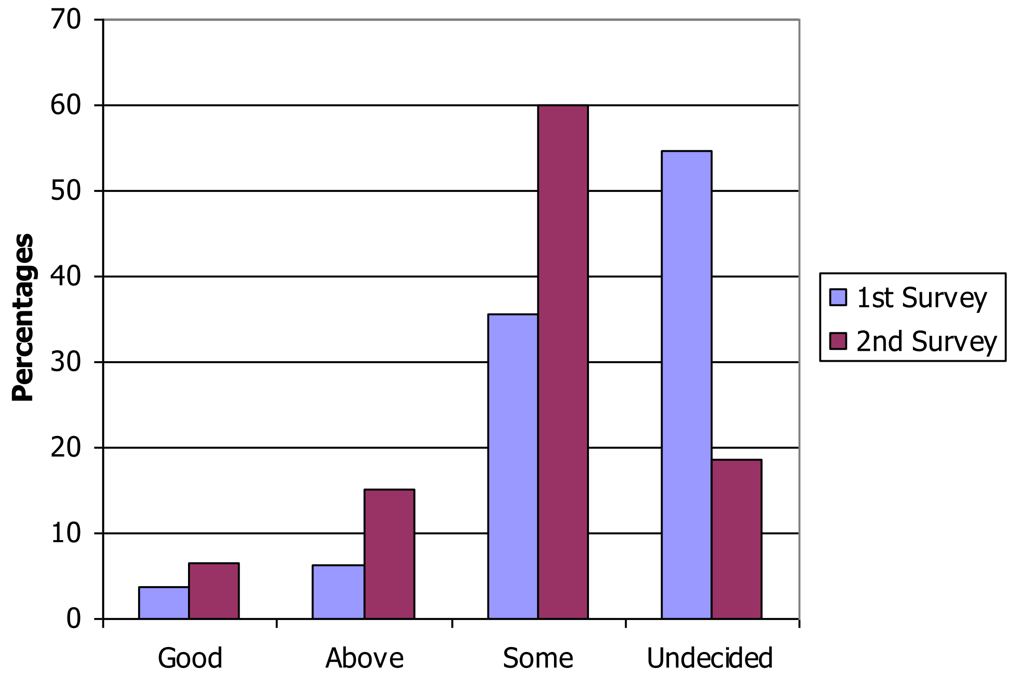
Graph 4.2 Survey 1 & 2- Level of knowledge regarding products

Specifications. Although significant improvement was made in terms of awareness regarding the existence of the Non-Metallic Specifications, the actual level of knowledge regarding the content of the specifications showed little improvement. As mentioned before, one possible reason for this could be the technical level of the specifications may have been perceived as difficult.



Graph 4.3 Survey 1&2- Level of knowledge regarding specifications

Fabricator's required technical capabilities. As the result of the varying degrees of technical capabilities at the various manufacturers, specific emphasis was placed in informing the target groups about the requirements from Sasol's side in terms of expected competencies of manufacturers and suppliers. Graph 4.4 indicates the change in knowledge gained during the process.



Graph 4.4 Survey 1 & 2 - Level of knowledge regarding fabricators technical capabilities

Knowledge gained by level 5 & 6 personnel. In Sasol, technical personnel on levels 5 and 6 are involved in the majority of day-to-day decisions regarding replacement, extensions and capital expenditure of maintenance programs and projects. Although in some cases higher levels in management take the final decision, most of these technical managers will rely on the recommendations of the engineering personnel who are actively involved in the implementation of decisions. Therefore, reaching these individuals in the different management and technical levels to raise their awareness of the use of non-metallic products was of importance to this process. Table 4.3 shows the knowledge gained by these individuals.

	Good Knowledge	**Above Average Knowledge**	**Some Knowledge**	**Undecided Don't Know**
Various shapes, sizes and forms of non-metallic products	6.8% *24.2%*	22.0% *31.7%*	64.2% *38.0%*	7.0% *6.0%*
Application possibilities of the different types of non-metallic materials	5.1% *8.1%*	23.5% *29.5%*	57.2% *56.4%*	14.2% *6.0%*
Procurement instructions	1.6% *15.1%*	6.8% *18.6%*	36.0% *45.8%*	55.6% *20.4%*
Specifications	3.9% *17.1%*	8.6% *14.4%*	43.4% *49.1%*	44.0% *19.4%*
Design	4.3% *16.9%*	10.7% *16.9%*	42.2% *42.3%*	42.8% *23.9%*
Roles/Responsibilities of the Inspection Authority	5.8% *28.0%*	13.4% 21.4%	38.5% *28.5%*	42.4% *22.2%*
Roles/Responsibilities of Consultants/Engineering Contractors for non-metallic equipment	3.9% *12.3%*	10.9% *30.5%*	39.9% *28.2%*	45.3% *29.0%*
Fabricator's required Technical Capabilities & Resources	3.7% *7.6%*	8.4% *17.4%*	37.0% *57.7%*	50.8% *17.4%*
Fabrication Techniques	3.3% *4.8%*	12.6% *23.2%*	44.4% *64.0%*	39.7% *8.1%*
Transportation; Erection and Installation	2.7% *6.0%*	9.7% *37.0%*	48.8% *39.8%*	38.9% *17.1%*
Maintenance Requirements/Techniques	2.3% *3.8%*	4.9% *28.0%*	42.6% *35.3%*	50.2% *33.0%*
Statutory Inspection requirements	4.5% *12.6%*	6.6% *20.4%*	33.5% *32.2%*	55.3% *34.8%*
Average per column	3.99% *13.04%*	11.50% *24.08%*	43.97% *43.10%*	40.51% *19.77%*

Table 4.4 Summary of results for knowledge gained by level 5 & 6.

The results of Table 4.4 closely correspond to those of the whole target group as indicated in Table 4.3.

Knowledge gained by SSF and Sasol Technology. Table 4.5 compares the results of the first survey (carries out in January 2001) with those of the second survey (in italics).

	Good Knowledge	**Above Average Knowledge**	**Some Knowledge**	**Undecided Don't Know**
Various shapes, sizes and forms of non-metallic products	8.8% *34.3%*	18.6% *21.2%*	59.6% *43.7%*	13.1% *0.8%*
Application possibilities of the different types of non-metallic materials	4.6% *10.2%*	18.0% *26.9%*	61.9% *60.6%*	15.5% *2.3%*
Procurement instructions	1.3% *17.1%*	8.0% *13.8%*	29.4% *50.1%*	61.3% *18.9%*
Specifications	4.1% *16.9%*	6.7% *13.6%*	37.6% *53.7%*	51.5% *15.9%*
Design	4.1% *24.6%*	10.1% *15.9%*	31.7% *44.8%*	54.1% *14.8%*
Roles/Responsibilities of the Inspection Authority	5.9% *32.7%*	18.6% *20.5%*	35.8% *28.6%*	39.7% *18.2%*
Roles/Responsibilities of Consultants/Engineering Contractors for non-metallic equipment	3.1% *16.1%*	13.1% *26.1%*	38.1% *28.1%*	45.6% *29.7%*
Fabricator's required Technical Capabilities & Resources	4.9% *2.3%*	6.4% *16.6%*	30.7% *70.1%*	58.0% *11.0%*
Fabrication Techniques	3.9% *1.5%*	11.3% *23.8%*	43.3% *73.4%*	41.5% *1.3%*
Transportation; Erection and Installation	2.3% *1.8%*	8.2% *48.8%*	50.8% *39.9%*	38.7% *9.5%*
Maintenance Requirements/Techniques	1.8% *1.5%*	5.9% *28.1%*	39.4% *34.0%*	52.8% *36.3%*
Statutory Inspection requirements	3.4% *6.6%*	9.5% *18.4%*	28.4% *32.0%*	58.8% *43.0%*
Average per column	4.01% *13.8%*	11.2% *22.8%*	40.55% *46.58%*	44.21% *16.80%*

Table 4.5 Summary of results for knowledge gained by SSF and Sasol Technology.

The results indicate a higher level of awareness and knowledge compared with the results obtained for the whole target group (see Table 4.3). The expected higher awareness can be attributed to more attention paid by the author to these companies in terms of awareness days, presentations, etc. Specific focus was placed on these two companies, because SSF is the larger user of process equipment while Sasol Technology is responsible for the implementation of capital projects in the wider Sasol group of companies.

4.3 Growth in capital expenditure on non-metallics in Sasol

Before the awareness campaign started (and Sasol bought Polifin), Sasol had no recorded capital expenditure on non-metallic equipment. As the awareness campaign gained momentum (and the idea of using alternative materials to steel), the use of these materials increased. Specific milestones that were reached over the last 5 years were:

(i) non-metallic fire-mains on all new plants. Total of 8 local systems were installed (value R58 Million), as well as 3 new systems abroad (Sasol Arya, Quatar) of value R25 Million.

(ii) all cooling water pipe systems for abovementioned overseas plants are now non-metallics, value R18 Million.

(iii) Secunda, the EDR Plant storage facility constructed in 2003 now uses non-metallics instead off metallic storage tanks and interconnecting pipes, value R 5 Million.

(iv) extension of Chlorine facility in Sasolburg in 2004 with Project Lara, project in non-metallics of value of R12 million.

(v) refurbishment of Natref Refinery underground storm water system in GRP, value R5,8 Million.

(vi) Waste water lines from Sasol Chemcity to Sasol main site in PE, value R1,3 million.

(vii) New Chrlorine Drying tower instead of Titanium on Project Aquarius, Value R5,4 million.

(viii) Several Scrubber units made of GRV for several maintenance units instead off existing 316 SS, value R6,8 Million.

As most of the application of new technologies (e.g. non-metallics, etc) is driven via Sasol Technology, inroads have been made. On existing plants, growth is much slower as they can only apply new technologies once Sasol Technology has developed the relevant specifications (see Chapter 3).

Chapter 5

Conclusion and recommendations

This thesis details a case study that was carried out by the author. The aim was to ultimately ensure expanded use of composite materials within the Sasol group of companies in order to benefit by their advantages and thus long term cost savings. In order to achieve this aim, the levels of awareness of composite materials and their uses within the group had to be raised. Also (and perhaps more importantly), the technical resources to enable their use had to be developed and put into place. Thus, the study mostly concerns itself with this aim.

A study of the literature shows that the uses of composite materials are generally well understood, *but no similar case studies could be found*. The Sasol group is a vast multinational and thus ensuring expanded and ongoing use of these materials when their uses prior to this study were extremely limited is no short term project. In a nutshell, the most important tasks included identifying potential users within the group together with suitable strategies to facilitate learning and knowledge of the use of these materials, as well as developing appropriate technical resources (like design standards and codes) to enable their use within the group.

The South Africa Coal, Oil and Gas Corporation Limited (Sasol) was established on 26 September 1950. From a very humble beginning, the company has grown to be a world leader in the commercial production of liquid fuels and chemicals from coal and crude oil. Sasol manufactures more than 200 fuel and chemical products at its main plants in Sasolburg and Secunda in South Africa as well as at several other plants abroad.

While most of the Sasol plants use conventional materials as the material of construction; modern composites offer a wide range of advantages compared to conventional structural materials, e.g. steels and aluminum alloys. Although composites were originally defined for aerospace applications, they are now used in many varied applications to ensure low costs and improved safety. Replacing existing steel components like storage tanks, pressure vessels, piping, etc with composite versions results in stronger but lighter constructions, excellent chemical and environmental resistance, comparable initial capital costs for the user, design flexibility and lower maintenance costs.

The benefits of using composites in chemical plant environments is very well known in certain quarters, but not widespread. For this reason, the use of composites traditionally within Sasol has been extremely limited. As a company, Sasol could be considered, until recently, to be very conservative particularly with respect to engineering activities, and this has, in the past, impacted on the education and training of those involved in such activities. Thus, conventional materials dominate in Sasol. To start a conversion process, an awareness programme had to be initiated within the company. This case study details the programme, which was designed and initiated by the author, who also monitored its success. In parallel, the technical resources (like design standards and codes) to enable the use of these materials within the group were also developed by teams that were lead by the author.

In order to raise the awareness of the use of composite materials in Sasol, enormous efforts would be needed to change the conventional thinking of the Sasol mechanical and chemical engineering personnel. A decision was made by the author that target groups would be identified and several methods selected and used to increase knowledge and awareness over a time period of approximately three years. Furthermore, in the initial phase, more attention would be given to the role-players outside the company, e.g. manufacturers, technical committees, etc, while the latter half of the period would be more focused on the target groups in the company. Raising the awareness of composite materials was the first step aimed towards the target groups inside the company. It was also envisaged that most of the awareness and technical actions would be parallel activities.

The objective of raising the awareness and increasing the use of non-metallic materials in the Sasol Group of companies has been achieved through the development and implementation of specific focused strategies. The gains in awareness as well as the use of these materials have been realised predominantly through the implementation of the following two strategies: (1) cross-pollination between Sasol and the non-metallic industry in the formation of supporting structures and systems and, (2) the use of methodologies for permeating a culture of non-metallics within the target groups.

As Sasol (and specifically Sasol Polymers) is a supplier and user of these non-metallic materials, cross-pollination has taken place on a national basis. Sasol aided the industry in assisting with the formation of these systems and structures in terms of approved legislation (e.g. Vessels under Pressure, etc) as well as training of approved qualified inspectors/designers/design verifiers. The specific inclusion of reference to polymeric and composites materials in the new proposed Pressure Equipment Systems Regulation would be a first in the world. Further, supporting legislation is found in the new SABS 10349 and SABS 1748-2 standards, ensuring uniformity as well as minimum compliance in the conveyance of hazardous chemical substances. Another milestone that was reached is the effective operation of PCISA on a national as well as regional basis (in Gauteng), providing a voice by and to the fragmented industry, giving input as well as directing the industry to future challenges. Supporting legislation, the finalizing and implementation of the long-awaited Competent Persons Inspector scheme has, and will, set the standards in the industry giving end-users like Sasol the assurance that statutory inspections are conducted by certified personnel.

As mentioned in Chapter One, an effective awareness campaign in Sasol to increase the uses of these materials had to focus on the inherent benefits derived from these types of materials. Cost effectiveness, ease of maintainability, corrosion resistance, product forms, etc were therefore only a few of the long list of important communication messages to the different target groups. The awareness campaign used various techniques e.g. e-mails, training days, the internet/intranet, and specifications, to reach the target groups in the various divisions of Sasol. Based on research, the most effective methodology used to reach these individuals proved to be e-mail. Although e-mail served as a communication medium, one should not under-estimate the contribution of the non-metallic web page (intranet), courses and other media that actually were the main tools in the teaching and learning process.

Comparing the initial survey done in Sasol with the last one, it became clear that a significant growth has taken place regarding the awareness as well as use of these materials. Specifically, about 20% of the respondents have moved from a stage of no knowledge to higher levels of confidence. Increased activity on the web page, requests for more information regarding the capabilities and use of these materials as well as more requests for training days and/or presentations confirms that the level of awareness has improved significantly. In terms of use of these materials, significant growth has also taken place in terms of the number of plant requests, activity on major capital projects and so on. In fact, from almost nothing in 1999, over the last 5 years in excess of R137 Million has been spent on capital equipment manufactured from composite materials, with the majority in the last 2 years.

The main objective in the future in terms of the industry is to maintain the momentum gained during this process. In order to ensure that the industry is perceived as professional, the industry will have to come together and face the challenges of the future. The finalisation of the Learnerships for various levels in the industry will have to be completed, accepted and implemented to allow industry to face and react to the shortage of competent workers already experienced by the sector. Furthermore, the wind of change blowing across Europe and America in terms of environmental issues will also come to South Africa and therefore the industry will have to be pro-active in the issues of re-use and disposal of non-metallic materials as well as unacceptable high styrene emissions during manufacturing. Ultimately, an effective PCISA representing the wider industry on a truly national basis organising events like Composites Africa should be an industry and end-user goal.

In terms of Sasol, future drivers should be the raising of awareness and use of these materials more effectively across all Sasol divisions internationally with even more effective day-to-day support from a larger specialist group. Ultimately, the establishment of a *hub of excellence* inside Sasol with testing capabilities, responsible for the development of cutting–edge specifications with the aid of international alliance partners should also be considered. Using such a facility also as a training centre for the development of human capital would open new opportunities in skills development as well as fulfil certain social responsibilities.

There is no question that composites are a material of the future. One only has to look at the different modes of transport today to realise the potential. If we are willing to trust these materials to drive and fly us around and for use in domestic applications then they really should be considered more seriously for problems experienced in the industrial field as well, such as for corrosion, erosion and fatigue. Composite materials are becoming more and more affordable and their application is leaning more and more towards the man in the street. If a composite material is applied in the correct way, solving the correct problem, it will bring down a client's total cost of ownership substantially. The industry and Sasol are now moving into the next phase in which the use of composite materials is growing rapidly, and for it to be taken further, there is a need for sharing of information and the supporting of initiatives which are beneficial, not just for individual companies, but for the industry as a whole.

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Appendix A

E-mail sent to all the level 3 managers of target companies

One of the main drives is to educate as well as show the engineering personnel of the Sasol group the endless possibilities where these materials can solve engineering problems, extend lifespan of equipment, decrease total life cycle cost (TCOs), etc.

In order to reach the correct engineering personnel of the Sasol group, we are looking for the names of personnel involved in design, manufacture, maintenance and testing of equipment in the group (e.g. the decision makers on various levels, functions).

The following will serve as a guideline; indicating the requirements:

- Level in the company - 4, 5, 6 or 7.
- Function - Mechanical/Process/Inspection/Maintenance/Procurement.

After we have received their names they will be contacted via e-mail to determine their level of knowledge, what they would like to know about non-metallics/Composite engineering; notify them about training events, etc.

Awaiting your favorable response.

Appendix B

E-mail to Respondents

Attached you will find a questionnaire in order to ascertain the level of knowledge of Sasol Mechanical / Chemical Engineering personal regarding the use and application of composite/non-metallic materials.

I can give you the assurance that the questionnaire is 100% anonymous.

Note: You are welcome to forward this e-mail to other interested parties!!

To what extent would you agree or disagree in terms of your level of knowledge with each of the following statements regarding non-metallic equipment - Please tick:

1	*Various shapes, sizes and forms of non-metallic products*
2	*Application possibilities of the different types of non-metallic materials*
3.	*Procurement instructions*
4.	*Specifications*
5.	*Design*
6.	*Roles/Responsibilities of the Inspection Authority*
7.	*Roles/Responsibilities of Consultants/Engineering Contractors for non-metallic equipment*
8.	*Fabricator's required Technical Capabilities & Resources*
9.	*Fabrication Techniques*
10.	*Transportation; Erection and Installation*
11.	*Maintenance Requirements/Techniques*
12.	*Statutory Inspection requirements*

The following questions need only to be answered by a <u>Yes</u> or <u>No</u> !

1. *Are you aware that twenty-two Sasol Non-metallic Specifications exist?*
2. *Are you aware of the Sasol Non-metallic Intranet on web-site address - [http://intwww.sasol.com/Sastech/Functions/Non-Metallics/Index htm]*
3. *Would you consider to use non-metallics for future, new and replacement projects/maintenance?*
4. *If your answer to Q3 above is No, please state why?*

Appendix C

Abstract of Press Release

SASOL POLYMERS ANNOUNCES COMPOSITES AFRICA 2002

EXTENDING HORIZONS CONFERENCE

Sasol Polymers will hold in conjunction with the Polymeric Composites Institute of South Africa (PCISA) the annual Composites Africa 2002 Conference at Caesars Palace, Johannesburg, South Africa, on August 21, 2002.

This local hallmark features one day of programming for composites professionals from the chemical, corrosion, advanced composites, marine, automotive, building, swimming pool, academic and mining sectors.

This annual event attracts composites professionals and interested individuals from across South Africa and featured programming includes educational sessions covering training issues, technical and regulatory updates, as well as live demonstrations and exhibits from more than 45 national and international suppliers and distributors to the composites industry.

"The Composites Africa 2002 Conference promises to be an exciting opportunity for those in the composites industry to increase their professional network," said Jacques Mouton, Sasol Technology Non-Metallic Specialist and portfolio holder for Training, Education and Conferences. "We have a one packed day of specific programming for different industry segments, including sessions on training requirements, quality assurance, design and inspection techniques for the composites industry."

Appendix D

E-mail on design of non-metallic equipment

Dear All,

End-users are seeking a long-term, cost-effective corrosion resistant product. The result is that many previously metallic (steel) constructed vessels under pressure are now been converted to composite materials.

However, this conversion process is being carried out without re-engineering for the non-metallic construction, resulting in detrimental effects to the end-user's plant, and non-compliance with the relevant code of practice and specifications.

Not only is it mandatory that these vessels are designed and manufactured to recognized standards and specifications, but these specifications also indicate the correct non-metallic methods of construction. The design specifications for GRP pressure vessels are BS 4994:1987, AD Merkblatt N1 and RTP-1. For GRP process piping the design specifications are BS 6464:1984 and BS 7159:1989.

It must be highlighted that unlike steel, where the manufacturer purchases a certified sheet of steel, with known properties, and forms it to construct the product, the GRP material and it's properties are created at the same time as the composite product is fabricated.