FABRICATION AND TESTING OF GLASS FIBRE REINFORCED POLYESTER COMPOSITES FOR AUTOMOBILE APPLICATIONS

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FABRICATION AND TESTING OF GLASS FIBRE REINFORCED POLYESTER COMPOSITES FOR AUTOMOBILE APPLICATIONS

BY

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JANUARY, 2003

DECLARATION

I, **KURAH, Victor,** declare that this thesis is solely the result of my work and has never been submitted anywhere for any degree. All literatures cited have been duly acknowledged in bibliography.

Kurah, Victor	**Date**

CERTIFICATION

This thesis entitled **"Fabrication And Testing of Glass Fibre Reinforced Polyester Composites for Automobile Application"** by Kurah Victor meets the regulations governing the award of the degree of Master of Science (Chemical Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

I dedicate this thesis to God Almighty and to my wife and children, Daye, Jenom and Gyuimen.

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First and foremost, I give Almighty God the Glory, Honour and Adoration for his steadfast love, protection and guidance for seeing me through this programme without hitches.

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ABSTRACT

A polyester matrix was reinforced with chopped glass fibre, randomly arranged using hand-laying method for automobile application.

Tensile properties, flexural strength, impact strength and hardness properties were determined for specimens with glass fibre contents varying between 32 and 45wt%. The maximum tensile strength obtained was 215MPa at 38wt% glass fibre content which was higher than the typical value for aluminium having 80MPa.

The flexural strength was equally superior having the highest value of 420MPa at 40wt% glass fibre content which was better than that of mild steel having the value of 241MPa. The maximum impact strength of 220kJ/m^2 was measured for glass fibre content of 38wt%, which appeared better than the reported value of 170kJ/m^2 for commercial products. The best Brinell hardness value was 289kg/mm^2 equivalent to 3.2 on Mohr scale which was better than the reported of 3.0 for typical commercial materials.

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ABBREVIATIONS, GLOSSARIES AND SYMBOLS

GFRP – Glass Fibre Reinforced Plastics

CFRP – Carbon Fibre Reinforced Plastics

CADD – Centre for Automobile Design and Development

U.K. – United Kingdom

DMC – Dough Molding Compounds

SMC – Sheet Molding Compounds

MgO – Magnesium oxide

PVC – Polyvinyl chloride

ATH – Aluminium trihydrate

MBS – Methylmethacrylate-butadiene-styrene

EVA – Ethylene vinyl acetate

R – Alkyl Group

ASTM – American Society for Testing and Materials

MOE – Modulus of Elasticity

MOR – Modulus of Rupture

σ – Tensile Strength

E – Tensile Modulus

M – Slope of Load Extension Curve

P – Load

L – Sample Gauge Length

d – Impression Diameter

D – Ball Diameter

B – Sample Breadth

H – Sample Thickness

A – Cross Section Area

σ– Tensile Strength

ε – Strain

η – Composite Efficiency

 - Benzene Ring

ϕ– Volume Fraction

W – Weight Fraction

90 91 92 93 94 95 96

90 91 92 93 94 95 96

90 91 92 93 94 95 96

Figure H: Correlation of Brinell Hardness and Mohs Scale

Figure H: Correlation of Brinell Hardness and Mohs Scale

Chapter 1

1.0 INTRODUCTION

The use of metals in automobile body panel constructions has been in existence right from the onset of development of automobile industries just because of the high mechanical properties they exhibit. The metal however, suffers from the disadvantages of high-energy requirement, poor corrosion resistant and high cost of production. As a result of these negative developments alternative material are being sought, which can possess the required mechanical properties without the disadvantages inherent in the metals.

This can be achieved by developing reinforced plastic composite materials. The reinforced plastic is a composite material made by incorporating reinforcement into the resinous matrices and allowed to set. The materials are extremely versatile with relatively high strength-to-weight ratio, easily molded to complex shapes and excellent corrosion resistance. In all these aspects, they out perform many metals. Also the fact that their tooling is less expensive permits more freedom to update an existing model or to replace out dated model with technically advanced and more attractive ones in keeping with the latest market demand.

There are many molding methods that could be employed in the production of plastic composites among them are hand lay-up, compression and injection molding processes.

The hand lay-up process was chosen ahead of others because it has the advantage of controlling the strength and stiffness of the composite by building up the thickness with further layers of mat and resin as desired (Ronald and David, 1997).

1.1 Justification

The technology is not available in the country, therefore it is necessary to develop a local know how in the production of the glass fibre reinforced plastics to replace the imported products so as to conserve the scarce foreign exchange earnings in the country.

The major raw materials required for the production of glass fibre reinforced plastics (GFRP) for automobile use are polyester as the polymer base matrix, the glass fibres and additives such as catalyst, pigments, and fire retardant. All these materials and ingredients are available in Nigerian markets and hopefully polyester will be locally produced in the near future.

The only known development programme in this area in the country is on at the Center for Automotive Design and Development (CADD) [a specialized center of excellence], Zaria and Department of Chemical Engineering, Ahmadu Bello University, Zaria. A glass reinforced plastic (GFRP) body was fabricated for the centre and used in their Mark II prototype car by the Fiat Manufacturing Company, Kano in 1994. More recently, development work at the Department of Chemical Engineering, Ahmadu Bello University,

Zaria on glass fibre reinforced plastics for automobile application has been going on. It was part of this effort that this work was initiated

1.2 Aim

The aim therefore, is to develop glass fibre reinforced plastics as an alternative material to metals for automobile applications.

1.3 Limitations

It was difficult to satisfy all the conditions required to achieve the desired composite through the choice of compatibility. For example, the association of high modulus and low thermal expansion matrix inevitably results in matrix micro damage during cooling after processing.

Additional cost will be incurred if additional treatment before and after processing is done to reduce fibre-matrix interfacial chemical reaction or to control the deformation and fracture mechanism in the vicinity of the fibre- matrix interface.

In addition some equipment that were used for the mechanical test are obsolete and may not give the desire result expected.

1.4 Scope

The work covers the following

a) Construction of the master mold

b) Development of reinforced plastic composites

c) Test on some physical and mechanical properties was done.

In this report, the literature on the glass fibre composites was surveyed. The detail account of the experimental procedure carried out is next reported. The results obtained are presented and discussed. Finally, conclusions drawn from the investigation are given.

Chapter 2

2.0 LITERATURE REVIEW

2.1 Historical Development

Much of the early development work on reinforced plastics bodywork in Europe can be attributed to Auto Union in Germany (Wood, 1980). In 1938 Auto Union, in collaboration with Dynamite AG, experimented with crepe paper reinforced phenolic resin as a body construction material. The results of various tests to determine the behavior of the bodies under impact conditions showed that they were very resilient and tended to crack rather than distort as in the case of a steel body shell (Wood, 1980).

In the U.K. at that time, a number of amateurs were constructing fibre glass/polyester bodies in simple molds using hand lay-up process. This experimental works encouraged a number of companies to commence limited production of GFRP bodies. Among pioneers were Rochdale, Turner, Reliant, Berkley, Lotus and Shamrock to name but a few.

Early work in the 1950s by Pressed Steel B.L. Components Ltd, included the development of a small experimental saloon body incorporating GFRP doors and bonnets. However, the first GFRP bodied car to be produced in quantity was the Corvette built by the Chevrolet Division of General Motors in 1953 (Wood, 1980).

2.2 Composites For Automobile Applications

There is no universally accepted definition of composite materials but in principle composites can be constructed of any combination of two or more materials, whether metallic, organic or inorganic that has deferring physical and mechanical properties. However, the major constituents form used in composite materials are fibres, particles, laminae or layers and flakes in association with matrices.

The use of composite materials for engineering applications have advanced in such a way that it is already influencing the used of reinforced plastics in modern cars which have physical and mechanical properties competing or overcoming the limitations of traditional materials with regards to

a) Tensile strength
b) Tensile modulus
c) Flexural strength
d) Hardness
e) Impact strength

The importance of reinforced plastics has increased since the advent of newer, high temperature engineering plastics, various polyamides, polyether ether ketone, polyesters and epoxies. The mechanical properties compared well with that of aluminium, even at

elevated temperature (200^0c) (Collyer andClegg,1986), resulting in a number of materials been used where traditionally a metal would have been chosen.

The attraction of plastics for engineering applications is influenced by the possibility of property enhancement through fibre reinforcement. The composite produced in this way have enable plastics to become acceptable in the demanding aerospace and automobile industries. In 1990, U.S.A aerospace and automobile industries utilized over 100,000 tones of reinforced plastics out of a total consumption of over 1,000,000 tones (Crawford, 1990).

To meet the economic demands of quantity production these new materials, largely designed to replace metals in some applications, must also be capable of being molded or formed on fast cycles and, as a finished product, to be competitive with metals. Parallel with the development of materials with the required physical properties have been advances in processing techniques, which permit assemblies and output to be economical with respect to speed and labor content.

The excellent properties provided by polymers at low cost without the problems of corrosion control have influenced the use of polymers as a suitable substitute for metals. The choice of polymers for specific applications is based on the following:

a) The end use of the product
b) Physical and chemical characteristic
c) Cost of processing and materials used
d) Weight of the plastic
e) Durability

f) Appearance

g) Ease of fabrication

Several types of engineering polymers are employed in the manufacture of different components of automobile systems. Glass fibre in particular can be combined with various resin systems to form composites with applications in police car door trauma plate, M113 tank personnel carrier, M104 paladin tank and composite armored vehicles (Owen, 1996-2000).

2.2.1 The fibre (Reinforcement)

Most glass fibre are based on silica (SiO_2), with additions of oxides of calcium, boron sodium, iron and aluminium. These glass fibres are usually amorphous although some crystallizations may occur after prolonged heating at high temperatures, leading to a reduction in strength (Hull and Clyne,1996). Typical compositions of three types of glass popular for composites are given in Table 2.1. The most commonly used, E-glass having good strength, stiffness, and electrical properties. S-glass could have been preferred to E-glass but very expensive (Hull and Clyne,1996).

Table 2.1: The Compositions and Properties of Glass Fibre (Hull and Clyne 1996).

	E-glass	C-glass	S-glass
Compositions (%)			
SiO_2	52.4	64.4	64.4
Al_2O_3+FeO_3	14.4	4.1	25.0
CaO	17.2	13.4	-
MgO	4.6	3.3	10.3
Na_2O+K_2O	0.8	9.2	0.3
B_2O_3	10.6	4.7	-
BaO	-	0.9	-
Properties			
Density (ρ),kgm^{-3}	2600	2490	2480
Electrical conductivity (K),$Wm^{-1}k^{-1}$	13	13	13
Tensile strength (σ),GPa	3.45	3.30	4.60
Tensile modulus (E), GPa	76.0	69.0	85.5

Glass fibres are produced by melting the raw materials in a reservoir and feeding into series of platinum bushings, each of which has several hundred holes in its base. The glass flows under gravity and fine filaments are drawn mechanically downwards as the glass extrudes from the holes.

The ultimate strength of the composites lies on the fibre and basically depends on the stress - strain relationship of its components. Any fibre whose strength and modulus of elasticity is greater than the polymer or resin is theoretically providing reinforcement and the

effectiveness of the reinforcement is dependent upon the degree of the adhesion, which can be achieved (Seymour, 1969). Other factors that can influence the properties of a composite are relative volume of reinforcement, their physical and chemical properties, temperature resistance and of very importance the fibre length, which is being used.

The importance of the fibre length has made glass to dominate the reinforcement scene because of the ease with which it can be driven into the fibrous form. Other types of fibre are sisal, wool, nylon, polypropylene, carbon, boron, and ceramic fibres. Fibres are usually materials with cross sectional area to length ratio between 1:10 to 1:100, with minimum cross sectional areas of (5.06×10^{-8} m^2) (Birley and Scout, 1982). Their tensile strength and modulus of elasticity (MOE) are several times higher than those of the same materials in bulk.

The choice of fibre for reinforcement depends on the end use of product. However, the strength to weight ratio attributes largely to the type of reinforcement chosen. The properties of some common fibres used are shown in Table 2.2.

Table 2.2: Properties of some Common Fibres (Birley and Scout, 1982).

Fibre	Specific density	Modulus of elasticity (GPa)	Tensile strength (GPa)
E-glass	2.50	75	5.5
Carbon	2.00	75	0.5-1.0
Boron	2.60	170-200	3.0-3.5
Asbestos	2.5	160	2.0

Silicon carbide	3.15	220-300	4.0-10.0
Kevlar	1.45	130	3.0-3.6

Glass fibre reinforced plastics: The need to replace metals in automobiles has led to techniques for reinforcing plastics with fillers and in particular with glass fibre. It is not possible to make a clear-cut division between reinforcing materials and fillers. Specific application demand variation in the type and quantity of the materials incorporated. In general, properties required are rigidity, lack of heat distortion, hardness, impact strength and tensile strength. Early development involved glass reinforced nylon but more recently there have being advances in incorporating other plastics, notably polypropylene, polyamide, acrylonitrile-butadiene, styrene-acrylonitrile copolymer, polyethylene, poly carbonate and thermoplastic polyester with reinforcing and filler materials. The main reinforcing or filler materials are glass, asbestos, calcium carbonate, silicates and mica. Each imparts special physical properties that affect the processing as well as their subsequent application. The content of reinforcement in the composite can be up to 40% by weight and with fillers up to 70- to 80% by weight (Katz and Milewski, 1978).

Long glass fibre reinforced plastics feature high impact strength, stiffness and dimensional stability while the short glass fibre offers corrosion resistance, cost/weight advantages and ease of processing. Fibre glass reinforced plastics are replacing die cast aluminium, magnesium, zinc and brass with improvement in performance up to five times greater in strength-to-weight ratios (Seymour, 1978). At high fibre loadings, long glass-fibre thermoplastics compete in tensile strength and permit more complex shapes to be molded

than with metal. Additionally, these components can subsequently reduce fabrication costs by eliminating assembly time and secondary finishing operations.

Glass fibre mat reinforced thermoplastics are processed by flow molding using high-speed molding presses. The cut-to-size resins are heated to a forming temperature of 200^{o}C and molded in cooled molds using very short cycles of 20 to 50 seconds. The polypropylene laminate is manufactured continuously. Several layers of glass mat impregnated with a special polypropylene melt are combine to form an endless, completely impregnated sheet material of maximum width 1000 mm, maximum length 240 mm, thickness 3.7 mm and weight approximately 4.5 kg. The standard content is 40% by weight of glass fibres.

Forms of Glass Fibre: Chopped strands are one common form of glass fibre reinforcement. The strand length is from 13 mm to 51 mm (Beadle, 1982). Woven rovings are fabricated by weaving roving into a coarse, heavy-duty, trappable fabric. They find greatest use in making thick laminates and available in a range of weaves and weights.

Reinforcing mats are non woven matting that are generally made from randomly arranged chopped strands. Resinous binders are often used to bind strands together into mat form. Stitching holds other forms together. These forms are available in a wide range of weights. Stitched mats are usually soft while the bonded form is stiffer and are most recommended for those applications that require high mechanical strength (Mark et al, 1981).

Each type of cloth has its particular properties and the choice of any type for reinforcement depends on the nature of finishing required, molding technique, directional strength characteristic of the product and its cost .The properties impacted to polyester resin by different types of glass fibre reinforcement are shown in Table 2.3.

Reinforcing glass fibre have diameters varying from 7μm to 15 μm (Mark et al, 1981). When chopped strands are used, the length diameter ratio (aspect ratio) is dependent on the short fibre composite. The greater the aspect ratio the greater is the strength and stiffness of the composite.

Table 2.3: Physical Properties of Various Types of Glass Fibre in Polyester Resin (Mark et al, 1981).

Type of glass Reinforcement	Tensile modulus, Mpa	Flexural strength, Mpa	Flexural modulus, Mpa	Tensile Strength, Mpa	Density, kg/m^3
Neat Cure resin	54000	88	3900	59	1220
Chopped strand mat	258800	497	9790	217	1500
Roving fabric	395005	550	15000	314	1760
Woven glass fabric	455622	593	17380	331	1880
Unidirectional roving fabric	555510	683	29450	611	1970

Comparison of properties of glass fibre reinforced plastics with metals: Glass fibre reinforced plastics have many attractive qualities that make it adaptable to numerous applications. Below are the lists of some of the general advantages of glass fibre reinforced plastics (GFRP) products.

a) Corrosion resistant
b) High strength-to-weight ratio
c) Low thermal conductivity
d) Adequate optical properties
e) Low transportation costs
f) Low installation costs
g) Low resistance to flow
h) Low electrical conductivity
i) Dimensional stability
j) Ease of installation
k) Good energy requirement
l) Light in weight.

Many of the physical and chemical properties of glass fibre are not unlike those of the bulk glass. The mechanical properties are, however, quite different. High mechanical strengths associated with fibrous glass put GFRP in the class of structural materials. If comparisons are made on equal weight basis, glass fibre is one of the strongest structural materials available. Table 2.4 shows a comparison between GFRP and metals. A close examination of this table reveals that GFRP have properties that are competitive with metals.

Table 2.4 Comparison of Properties of GFRP with Structural Materials (Wood, 1980)

Material	Specific gravity	Modulus of Elasticity, GPa	Tensile strength, GPa	Specific modulus, Gpa	Specific strength, GPa
GFRP	2.0	41	1.3	20.5	0.650
CFRP	1.6	130	1.6	83.9	1.030
Aluminium	2.8	72	0.5	25.7	0.165
Steel	7.8	207	1.0	26.5	0.120
Titanium	4.5	110	0.9	24.4	0.207

2.2.2 The matrix

In reinforced plastics both thermosetting and thermoplastic materials can be used as matrix. The main function of the matrix is to transfer the load from the point of application into the load bearing fibres, which have higher strength and modulus than the matrix. The thermosetting materials are widely used in conjunction with the reinforcement in the production of automobile bodywork (Crawford, 1990). Among the thermosetting materials polyester and epoxy are commonly employed because of the strong 3 – dimensional

network bond they can form, do not liberate volatile compounds during cross linking and can be molded using low pressure at room temperature (Crawford 1990). The only disadvantage they have is that they cannot be re-molded as against thermoplastics, which can.

The thermosetting plastics are hard and relatively brittle, thermally stable and greater resistance to creep than thermoplastics. However, fillers or reinforcements must almost always be added to the resin to make them useful as molding. They are generally more difficult to process than thermoplastics, and require longer molding cycles. But, once molded or formed by heat and polymerized, they remain stable and will not return to their original state.

Thermosetting plastics in the raw-material state are composed of two major components: a resin system and fillers and/or reinforcement. The resin component usually consists of a polymer, curing agents, hardeners, inhibitors, and plasticizers. It has a major influence on the finished plastics dimensional stability, heat and chemical resistance, electrical properties, and flammability. The other component consists of one or more of the following; mineral or organic particles, inorganic or organic fibres, inorganic or organic chopped cloth or paper. This component usually has a major effect on the plastics mechanical properties.

Curing can be achieved at room temperature, but it is usual to use a cure schedule that involves heating at one or more for predetermined times to achieve optimum cross-linking and hence optimum properties. A relatively high temperature final post-cure treatment is

often given to minimize any further cure and change in properties during service (Hull and Clyen, 1996).

Thermo sets have slight different properties from thermoplastics as indicated in Table 2.5. Thermo sets are usually brittle materials while thermoplastics can undergo appreciable plastic deformation. Among the thermo sets epoxies are in general tougher than unsaturated polyesters. Infact, epoxies are superior in most respects to alternative thermosetting systems, but unsaturated polyester is usually chosen among the thermosetting materials as the matrix in conjunction with glass fibre reinforcement in the automobile body panel simply on combined advantages of strength, inexpensiveness and compatibility (Crawford, 1990)

Table 2.5 Selected Properties for Different Types of Matrix (Hull and Clyen,1996)

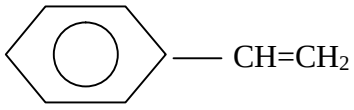
Matrix	Density (ρ) kg/m^3	Young modulus(E) GPa	Tensile strength(σ) Gpa	Thermal expansion(α) $10^{-6}K^{-1}$	Thermal conductivity(K) $Wm^{-1}K^{-1}$
Thermosets					
Epoxy resin	1.1-1.4	3-6	0.035-0.1	60	0.1
Polyesters	1.2-1.5	2.0-4.6	0.04-0.09	100-200	0.2
Thermoplastics					
Nylon 6.6	1.14	1.4-2.8	0.06-.07	90	0.2
Polypropylene	0.90	1.0-1.4	0.02-0.04	110	0.2
PEEK	1.26-1.32	3.6	0.17	47	0.2

Polyester Resins: Polyester resins can be divided into two classes, viz

a) The so called saturated resins such as polyethylene terephthalate (PET) or terylene.
b) The unsaturated resins which can be cross-linked by the addition of suitable catalysts.

Unsaturated polyester resin form the group of all the resins used for laminating applications and without doubt the best known for lamination.

The basic material used to make polyester resin is dibasic organic acid or anhydride and dihydric alcohol (glycol). To obtain a polymer chain that can be cross-linked into a thermosetting resin, a proportion of the dibasic acid most contain an unsaturated group or double bond. This unsaturated group most be non aromatic otherwise cross-linking will not take place. For example, styrene (vinyl benzene) will react through the pendant vinyl group in the presence of the peroxide catalyst



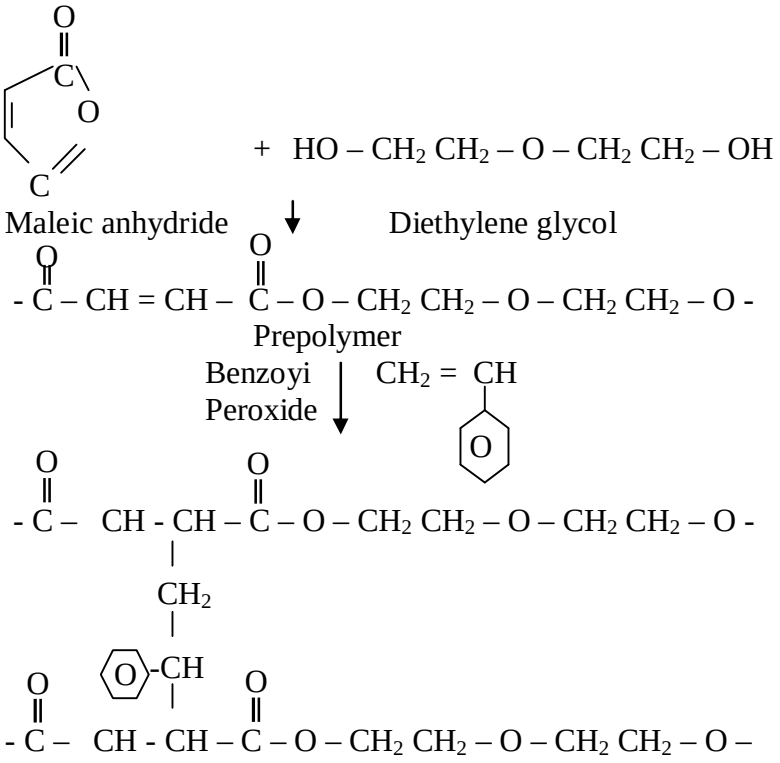
Styrene

A simple polyester resin might be prepared from, maleic anhydride (unsaturated) and orthopthalic anhydride (saturated). By varying the ratio of the anhydride, the cross linking reactivity of the polyester can be varied from high to low. A highly reactive polyester resin contains a high proportion of unsaturation. The polyester formed in this way is a solid or

semi solid thermoplastic material, which could be converted into thermosetting material by the addition of a suitable catalyst.

The styrene serves two purposes: firstly it acts as a solvent for the resin and secondly it enables the resin to be cured from liquid to a solid by cross linking to a polyester chain without the evolution of any by products.

An unsaturated polyester resin, which is used as a matrix component of glass fibre composite, may be obtained by the copolymerisation of maleic anhydride and diethyle glycol. Curing takes place by free radical polymerization through the unsaturated groups (double bond) both in the polyester chain and the styrene or other monomer as seen in Equation 2.1



……..2.1

Equation 2.1 shows the free radical polymerization in which the free radicals are provided by the peroxides as it decomposes and it is the rate at which these free radicals are produced that governs the gel and cure time of the resin.

Polyester begins to cure as soon as the catalyst has been added. However, with heat cure systems and in particular, sheet and dough molding compounds, to all intends and purposes cure does not progress until a certain minimum temperature of $60^{o}C$ has been reached (Mark etal 1981). This is the activation or critical temperature of the organic peroxide. The cure of the polyester can be considered to occur in three stages:

a) Gelation: where the resin changes from a free flows liquid to a soft gel.
b) Hardening: where the resin cures from a soft gel to a hard material capable of being removed from the mold.
c) Final cure or maturing: where resin achieves its full mechanical and chemical properties. This can take several hours at elevated temperature to several weeks at room temperature.

Polyesters are hard, transparent solids with light color. They have good mechanical and electrical properties, and can either be flexible or rigid. They are water and chemical resistant and have good weather ability. They can easily be molded at low pressure and mixed with dyes and pigments (Seymour, 1978).

2.2.3 Fiber-matrix interface

The fibre-matrix interface is the critical factor that determines to what extent the potential properties of the composite will be achieved and maintained during usage. Localized stresses are usually highest at and near the interface, which may be the locus of premature failure of the composite. The interface must have appropriate chemical and physical features in order to provide the necessary load transfer from the matrix to the reinforcement. The interfacial bond must resist stresses due to factors such as the differential thermal expansion of the fibre and matrix, and shrinkage of the resin during cure. Other desirable features of the matrix are resistance to liquid penetration and freedom from void. The interface also assists the matrix in protecting the fibres.

Silanes are used to provide the coupling at the interface so as to obtain the optimum physical properties of the composite, and retaining the properties after environmental exposure or aging. The silanes provide dual functionality in one molecule, such that one part of the molecule form a bond to the glass filament surfaces while another part form a covalent bridge with the matrix molecule (Katz and Milewski, 1978).

In the analysis of theoretical properties of different types of composites, various analytical models and failure theories have been used. There are different considerations involved in the case of randomly oriented discontinuous fibre composite than for a continuous filament unidirectional or angle-ply laminates.

2.3 Theories of Adhesion

Adhesion is the phenomenon in which interfacial forces hold surfaces together. These forces could be mechanical or electrostatic.

2.3.1 Mechanical forces

The molecular interaction between the matrix and the fibres depends on interlocking action between them. Glass fibres, viewed by the eye appear as smooth surfaces. But under microscopic examination they are seen to have rough surfaces into which the matrix interlocks forming strong bonds. This interlocking action can further be enhanced by the use of surface coating agents or coupling agents like saline, which creates the roughness on surface of the glass fibre, allowing the matrix to key in.

2.3.2 Electrostatic forces

This results from the attraction of electrical charges. The theory of electrostatic attractions presumes that the two-bonding materials are the plates of a capacitor that becomes charged through the contact of the two substrates. This creates a force field, which holds the fibre and matrix together forming strong bonds.

2.3.3 Adsorption of molecular alteration

This employs the concept of Van der Waals forces acting across the space between the fibre and the matrix. The matrix, being a liquid at some state in the bonding surface, displaces the gases in between the fibre and the matrix therefore, providing intimate contact with the fibre so that the force can take effect.

It is not certain which of the above accounts for bonding in plastic. But as the composite technology has advanced, it has become virtually imperative that the properties of the composite can be predicted from the knowledge of a constituent matrix, fiber, fiber volume, and fibre orientation. This is required, in the case of advanced composites, where fibre and fabrication cost is high and end product must be extremely reliable in performance, so that the trial and error approach cannot be tolerated.

A first approximation of the physical properties, tensile modulus and strength of a fibre-reinforced composite can be obtained from the rule of mixture.

2.4 Rule of Mixture

The rule of mixture is very important and may be used to determine the density of composite as well as other properties in the fibre direction.

2.4.1 Expressing composite concentration

The concentration of a component in a composite is most frequently expressed in terms of its volume fractions and sometimes, weight fractions.

The volume fractions and weight fractions are defined as

$$\phi_f = \frac{v_f}{v_c}, \phi_m = \frac{v_m}{v_c} \quad \text{..... 2.2}$$

Where $\phi_f \; and \phi_m$ are fibre and matrix volume fraction respectively

But $v_c = v_f + v_m$ 2.3

Where v_f, v_m and v_c are volume of fibre, matrix and composite respectively.

And $W_f = \frac{w_f}{w_c}, W_m = \frac{w_m}{w_c}$ 2.4

Where W_f and W_m are weight fraction for fibre and matrix respectively and w_f, w_m and w_c are the weights of fibre, matrix and composite respectively.

Also $w_c = w_f + w_m$ 2.5

The relationship between volume fraction and the density of the composite, ρ_c, is obtained from Equation 2.5 as

$$\rho_c v_c = \rho_f v_f + \rho_m v_m \quad \text{.....} \quad 2.6$$

Where $\rho_f \; and \rho_m$ are density of the fibre and matrix respectively.

Equation 2.6 becomes

$$\rho_c = \rho_f \frac{v_f}{v_c} + \rho_m \frac{v_m}{v_c} \quad \text{..... 2.7}$$

Therefore,

$$\rho_c = \rho_f \phi_f + \rho_m \phi_m \quad \text{.....} \quad 2.8$$

In general $\rho_c = \sum_{i=1}^{n} \rho_i \phi_i$ …… 2.9

Similarly the density of composite materials can be obtained in terms of weight fraction, W, by use of Equation 2.3 as

$$\frac{w_c}{\rho_c} = \frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} \quad \text{…… 2.10}$$

$$\frac{1}{\rho_c} = \frac{w_f}{\rho_f w_c} + \frac{w_m}{\rho_m w_c} \quad \text{…….. 2.11}$$

$$\rho_c = \frac{W_f}{\rho_f} + \frac{W_m}{\rho_m} \quad \text{…….. 2.12}$$

$$\rho_c = \frac{1}{(\frac{W_f}{\rho_f}) + (\frac{W_m}{\rho_m})} \quad \text{……... 2.13}$$

In general, $\rho_c = \frac{1}{\sum_{i=1}^{n} W_1 / \rho_i}$ …… 2.14

The relationship between weight fraction and volume fraction can be obtain as

$$W_f = \frac{w_f}{w_c} = \frac{\rho_f v_f}{\rho_c v_c} = \frac{\rho_f}{\rho_c} \phi_f \quad \text{…….. 2.15a}$$

Or

$$W_f = \frac{\rho_f}{\rho_c} \phi_f, W_m = \frac{\rho_m}{\rho_c} \phi_m \quad \text{…….. 2.15b}$$

Then, in terms of volume,

$$\phi_f = \frac{\rho_c}{\rho_f} W_f, \phi_m = \frac{\rho_c}{\rho_{f_m}} W_m \quad \text{…… 2.16}$$

In general

$$W_i = \frac{\rho_i}{\rho_c}\phi_i, \phi_i = \frac{\rho_c}{\rho_i}W_i \quad \text{..... 2.17}$$

2.4.2 Prediction of tensile properties

The prediction of mechanical properties of aligned, long fibre is difficult to achieve theoretically and further complications exist in dealing with short fibre reinforcement. This is due to spectrum of fibre lengths and orientations caused by processing into the final part. The predictions for composite tensile modulus can be made easily while that of tensile strength is far more difficult even for long fibre reinforcement.

In obtaining the expression for both long and short fibre tensile properties the following assumptions were made.

a) All filaments are bonded perfectly to the matrix.
b) The composite is linearly elastic.
c) The material response instantaneous with no time lag.
d) The material is homogeneous i.e. equal stress at all points.

Prediction of tensile modulus for continuous fibre reinforcement.: Consider tensile force F acting on the composite containing long fibres as shown in Fig. 2.1.Assumed that both the matrix and the fibres are elastic and that their Poisson's ratios are equal. The

fibres are all aligned along the direction of the tensile stress. The tensile strain in the composite, that in the matrix and that of the fibres are all assumed equal throughout the material and of value ε. In this situation of equal strain, the total force F is shared between the matrix, F_m, and all fibres, F_f, giving the tensile force.

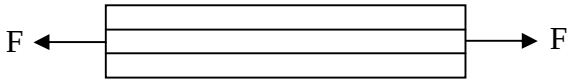


Figure 2.1: A Tensile Force F Acting on a Long Fibre Composite

$$F_c = F_m + F_f \quad \text{..... 2.18}$$

In terms of stresses,

$$\sigma_c A_c = \sigma_m A_m + \sigma_f A_f \quad \text{..... 2.19}$$

Where A_f is the sum of the cross-sectional areas of all the fibres in the composite and A_m is the cross-sectional area of the matrix material.

At constant strain

$$\varepsilon_c = \varepsilon_m = \varepsilon_f = \varepsilon$$

Which means that Equation. (2.19) can be re-written as:

$$E_c A_c = E_m A_m + E_f A_f \quad \text{.....2.20}$$

Where E_c, E_m and E_f are the tensile modulus of the composite, matrix and fibres respectively.

In terms of volume, the total volumes of the composite, v_c, of the matrix, v_m, and of the fibres, v_f, are given by:

$$v_c = lA_c$$

$$v_m = lA_m$$

$$v_f = lA_f$$

Taking ϕ_m and ϕ_f as the volume fractions of the matrix and the fibres in the composite, Equation (2.20) can be re-written as

$$E_c = E_m \phi_m + E_f \phi_f \quad \text{.....2.21}$$

This equation represents simple rule of mixtures, which gives values of E_c for long fibre composites close to actual experimental values. For most thermoplastics matrices Poisson ratio, $\gamma \approx 0.4$ (Rayson and Collyer,1986).

Short fibre reinforcement : In the case of continuous fibre reinforcement all the fibres were working at maximum efficiency, with the average strain in the fibre being equal to that in the matrix. But in aligned short fibre composites the fibre restricts the deformation of the surrounding matrix because it is stiffer than the matrix material. The load is transferred from the matrix to the fibre via the interfacial shear stresses. Cox,1952 shows that the efficiency of stress transfer is never 100%.So the term η_L ,the fibre length correction factor which is less than unity is included in Equations 2.21.

$$E_c = \eta_L E_f \phi_f + E_m \phi_m \quad \text{..... (2.22)}$$

The theory developed by Cox,1952 gives

$$\eta_t = \left[\frac{1 - \tanh(\beta L/2)}{(L/2)} \right] \quad \text{..... 2.23}$$

Where L is the fibre length and

$$\beta = \left[\frac{2\pi G_m}{E_f A_f In(R/r)} \right]^{1/2} \quad \text{.....2.24}$$

Where G_m is the shear modulus of the matrix, r is the radius of the fibre and R is the mean separation of the fibres normal to their length.

Prediction of tensile strength for continuous fibre: Like that for tensile modulus E_c Equation (2.19) gives:

$$\sigma_c = \sigma_m \phi_m + \sigma_f \phi_f \quad \text{..... 2.25}$$

Usually the ultimate tensile strain in the fibre is much less than that of the matrix, and the tensile strength of the fibre,ϕ_{Tf} ,is much greater than that of that of the matrix ϕ_{Tm}

$$\sigma_{Tf} \phi_f >> \sigma_{Tm} \phi_m \quad \text{..... 2.26}$$

There will be a stress in the matrix φ_m at which the ultimate tensile strain is reached in the fibre. From this σ_{Tc}, the tensile strength of the composite is given by Kelly,1980 as

$$\sigma_{Tc} = \sigma_m \phi_m + \sigma_{Tf} \phi_f \quad \text{..... 2.27}$$

This is a simple mixture rule similar to the one for E_c.

<u>Prediction of tensile strength for discontinuous fibre</u>: When the fibres are not continuous, the average tensile stress on the composite will be given by

$$\sigma_{Tc} = \sigma_m \phi_m + \overline{\sigma}_f \phi_f \quad \text{..... 2.28}$$

where $\overline{\sigma}_f$ is the average fibre stress, which is given by:

$$\sigma_f = \frac{1}{L}\int_o^L \sigma_f(x)dx \quad \text{..... 2.29}$$

If the tensile stress builds up from the fibre ends in the non-linear way then

$$\sigma_f = \sigma_{f\infty}\left[1-(1-\beta)\frac{L_c}{L}\right] for L > L_c \quad \text{..... 2.30}$$

Where $\sigma_{f\infty}$ is the tensile stress in a continuous fibre in the same matrix under the same loading conditions and $\beta\sigma_{f\infty}$ is the average stress in the discontinuous fibre within a distance $L_c/2$ of either end.

The fibres can be stressed to their tensile strengths when $L > L_c$. If it is assumed that the fibre failure occurs when $\sigma_f = \sigma_{fx}$, then substituting in Equation (2.28) gives,

$$\sigma_{Tc} = \sigma_{Tf}\left[1-(1-\beta)\frac{L_c}{L}\right]\phi_f + \sigma_m\phi_m \quad \text{..... 2.31}$$

A comparison between Equations (2.27) and (2.31) showed that discontinuous fibres provide composites of less strength than continuous ones. However, 95% of the tensile strength of continuous fibre reinforced composites can be obtained when $L/L_c = 10$ (Rayson and Colley,1986).

The value of L_c represents the shortest fibre length that may be broken in a given matrix. Fibres below this minimum length are not capable of receiving sufficient tensile stress to break them and composite failure occurs because of failure at the fibre-matrix interface.
Values of L_c are generally larger than predicted value because:

1) There is de bonding at the ends of the fibre where the shear stresses are large;

2) The interaction between neighboring fibres constrains the motion of the matrix giving embrittlement; and

3) The fracture process involves matrix fracture between bundles of fibres rather than just individual fibres.

The tensile strength of a short fibre reinforced thermoplastic decreases as the angle between the fibre axis and direction of loading increases.

2.5 Additives for Reinforced Plastics

As a result of the basic feed not having all the required mechanical properties needed or the reaction not fast enough, there is the need to improve on the properties of plastics that are deficient by addition of some ingredients.

2.5.1 Curing agents

Most unsaturated polyester resins are stored in a solution of styrene monomer. The styrene serves two purposes: Firstly it acts as a solvent for the resin and secondly it enables the resin to be cured from a liquid to a solid by cross-linking with the polyester chain without the evolution of any by-products. This curing or cross-linking is achieved at room temperature by adding a catalyst (or initiator) plus an accelerator (or promoter) and at elevated temperatures just by adding a catalyst and heating.

The catalysts used are basically organic peroxides like methyl ethyl ketones (MEK). The safety recommendations of these per oxides should be followed because of their toxic

nature. The quantity of most organic peroxides used is usually between 1 and 4%(Seymour,1978) based on the resin weight.

Cure of unsaturated polyester resins takes place by free radical polymerization through the unsaturated groups (double bonds) both in the polyester chain and the styrene or other monomer. The peroxides provide the free radicals when it decomposed either by redox reaction or in the presents of thermal initiators as in the case of SMC and DMC as seen in Equation 2.32.

$$R\text{-}O\text{-}OH \longrightarrow R\text{-}O^{\cdot} + HO^{\cdot} \quad \text{.....2.32}$$

The free radical so generated attack one of the carbon atoms in the double bond of the substrate. One of the electrons from the double bond pairs up with the free radical electron forming a bond between the initiator fragment and the attacked carbon atom. The remaining electron shifts to the “unattacked” carbon atom of the double bond, which consequently becomes the free radicals. In this way the active center is transferred uniquely to the newly added monomer. This process continues until termination sets in when two free radicals join together.

$$R-(CH_2-CHX)n-CH_2-\underset{\underset{X}{|}}{\overset{\overset{H}{|}}{C}}\cdot + CH_2=\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}} \longrightarrow R-(CH_2-CHX)_{n+1}-CH_2-\underset{\underset{X}{|}}{\overset{\overset{H}{|}}{C}}\cdot \quad \text{.2.33}$$

2.5.2 Flame retardant

Ordinary flames do not readily ignite many plastics such as PVC and polyfluorinated hydrocarbons. However, since these and other plastics are used in many different applications involving extremely high temperature, it is essential that they be compounded to assure the safety of the end users.

The most widely used flame-retardant in plastics is aluminium tri hydrate (ATH). Other flame-retardants include organic phosphates and antimony oxides, which are customarily, used with organic halogen compounds. For structural application using polyester as the resin the amount of ATH and antimony oxide employed are 4 and 7.5%(Seymour,1978) of the weight of the matrix respectively.

2.5.3 Impact modifiers

The addition of impact modifier to unsaturated polyesters and other plastics increase the impact resistance.

These modifiers include polyalkylacrylates, methylmethacrylate-butadiene-styrene copolymers (MBS), chlorinated polyethylene, and ethylene vinylacetate copolymer (EVA). When present the impact resistance could be increased by between 32 to 1060J/m

(Fleck,1931and Seymour,1978) . Elastomers are also being added to unsaturated polyester to improve the impact resistance of SMC.

2.5.4 Colorants

Titanium dioxide is the most commonly use pigment and accounts for about 66%(Birley,1982 andSeymour,1978) of all pigments used in the plastic industry. Carbon black accounts for 19%, and obviously others such as iron oxide, Phthalocyanides and dyes such as nigrosine black, are used in smaller amounts.

The iron oxides that is available as natural and synthetic pigments range in color from yellow, buff, tan or salmon to black. Lead chromates, nickel titanate, and molybdate oranges, which provide yellow and orange colors, can produce other colors when mixed with other pigments. Cadmium pigments yield yellow, orange, red and maroon color. Ultramarine and cobalt aluminate supply blues, while chromium oxide provides green coloration.

2.5.5 Ultraviolet stabilizers

The principal stabilizers for preventing degradation by radiation with wavelengths less than 290 nm are inorganic compounds, such as zinc oxide and nickel complexes and organic compounds such as 2-hydroxyben-zophenes and 2-(2-hydroxyphenyl) benzotriazoles. Carbon black also acts as a screening agent for ultraviolet radiation.

2.6 Types of Molding Techniques

2.6.1 Hand-lay up molding

This method is by far the most widely used processing method for glass fibres reinforced material. In U.K, it takes up about 40% of the FRP market (Ronald and David, 1997). Its major advantage is that it is a very simple process so that very little special equipment is needed and the molds may be made from plaster, wood, sheet metal or even FRP. The first step is to coat the mold with a release agent to prevent the molding sticking to it. This is followed by a thin layer (approximately 0.3-0.4mm) of pure resin (called a gelcoat) which has a number of functions. Firstly, it conceals the irregular mesh pattern of the fibers and this improved the appearance of the product when it is taken from the mold. Secondly, and probably most importantly, it protect the reinforcement from attack by moisture which would tend to break down the fibre -matrix interface (Ronald and David, 1997).

When the gel coat has been given time to partially cure, the main reinforcement is applied. Initially a coat of resin (unsaturated polyester is the most common) is brushed on and this

followed by a layer of tailored glass fibre mat positioned by hand. The advantage of this technique is that building up the thickness with further layers of mat and resin as desired can control the strength and stiffness of the composite. Curing takes place at room temperature but heat is sometimes applied to accelerate this; ideally any trimming should be carried out before the curing is complete because the material will still be sufficiently soft for knives to be used. After curing, special cutting wheel may be needed.

Variation on this basic process is **(i*) vacuum bag molding*** and **(ii) *pressure bag molding*.** In the former process a flexible bag (frequently rubber) is clamped over the lay up in the mold and a vacuum is applied between the molding and the bag. This sucks the bag on to the molding to consolidate the layers of reinforcement and resin. It also squeezes out trapped air and excess resin. The latter process is similar in principle except that pressure is applied above the bag instead of a vacuum below it.

2.6.2 Spray-up

In this process, the preparatory stages are similar to the previous method but instead of using glass fibre mats the reinforcement is applied using spraying gun. Roving is fed to a chopper unit and the chopped strands are sprayed on to the mold simultaneously with the resin. The thickness of the molding (and hence strength) can easily be built up in section likely to be highly stressed. However, the success of the method depends to a large extend on the skill of operator since he controls the overall thickness of the composite and also the glass fibre / resin ratio.

2.6.3 Autoclave molding

For high performance reinforced plastic materials such as in aerospace industries, it is necessary to have strict control over fibre alignment and consolidation of the fibre in the matrix. To achieve this, fabric 'pre-pregs' (i.e fabric consisting of woven fibre yarns pre-impregnated with the matrix material) are carefully arranged in layers in an open mold. The arrangement of the layer will determine the degree of anisotropy in the molded article. The pre-preg is then covered with a series of bleeder and breather sheets, and finally with a flexible vacuum bag. When the air is extracted from between the flexible bag and the pre-preg stack, the latter will be squeezed tightly on to the mold. The whole assembly is then transferred to a very large oven (autoclave) for curing.

2.6.4. Compression Mold

This consists mainly of two molds having close fitting tolerances. The mold is designed to provide sufficient loading space above the cavity so that the un molded thermosetting material can be contained. Closing the mold forces the charge into the cavity. Compression molding is most often done on hydraulic presses operated by water, oil or air pressure.

2.6.5 Cold press molding

The basis of the process is to utilize pressure applied to two unheated halves of a mold to disperse resin through out a prepared fabric stack placed in the mold. Release agent and gel coat are applied to mold surfaces and the fibre fabrics is laid into the lower part of the open mould. The activated resin is then poured on top of the mat and when the mold is closed the resin spread through out the reinforcement. High pressures are not necessary as the process relies on squeezing the resin through out the reinforcement rather than forcing the composite into shape. A typical value of cycle time is about 10-15 minutes (Ronald and David, 1997) compare with several hours for hand lay-up method.

Chapter 3

3.0 EXPERIMENTAL

3.1 Introduction

This chapter gives a vivid account of the instruments and materials used in the work including the step-by-step description of the experimental procedures starting from mold construction, through to sample fabrication and processing up to machines used for the testing.

3.2 Instrumentation and Equipment

The list of instruments with their manufacturers and brief description including the chemicals are listed in Table 3.1.A sketch of the wooden mold, set-up of the molding method, Monsanto testing machine, Brinell hardness tester and impact tester with their working principles are described.

Table 3.1: List of Instrument and Materials Used

Material/Instrument	Manufacturer	Description
Monsanto tensometer W	England	No. 05232
Universal impact tester	Avery, Birmingham, England	Type 6703 Capacity: 120 and 220 ft. lb.
Brinell hardness tester	Avery, Birmingham England	Type: 6406
Electronic weighing balance	Mettler Instrumenten, B.V. Arnhem, Switzerland,	Mettler type P1210
Industrial Microscope	U.S.A	J350
Saturated resin (Polyester)	Open market	SABS 713,Grade G
Glass fibre (Chopped strand mat)	Open market	
Catalyst (Methylethyl ketone)	Open market	
Accelerator (Naphthalene accelerator)	Open market	

(a)

(b1) **(b2)**

Figure 3.1 The Mold (a) Female Part (b1) and (b2) are Top and bottom male part respectively

3.3 Mold Construction

The mold was fabricated from wood with dimension 150mm by 200mm by100mm as shown in Figure 3.1.The mold has two parts: the body of the mold (female part) and two bottom and top covers (male part).

The interior of the female part and the top and bottom internal surfaces of the male part were lined with Formica to prevent water absorption by the wood and also to aid in the release of the fabricated composite. The male parts were made in such a way that they can slipped exactly into the female part (Figure3.1b). The top male part has a handle at the center to provide easy removal at the end of the molding and the bottom male part has a broadened base to support the body of the mold. When the mold has been assembled, a weight is placed on top of the top male part so that, a flat material will be produced at the end of the molding as shown in Figure 3.2.

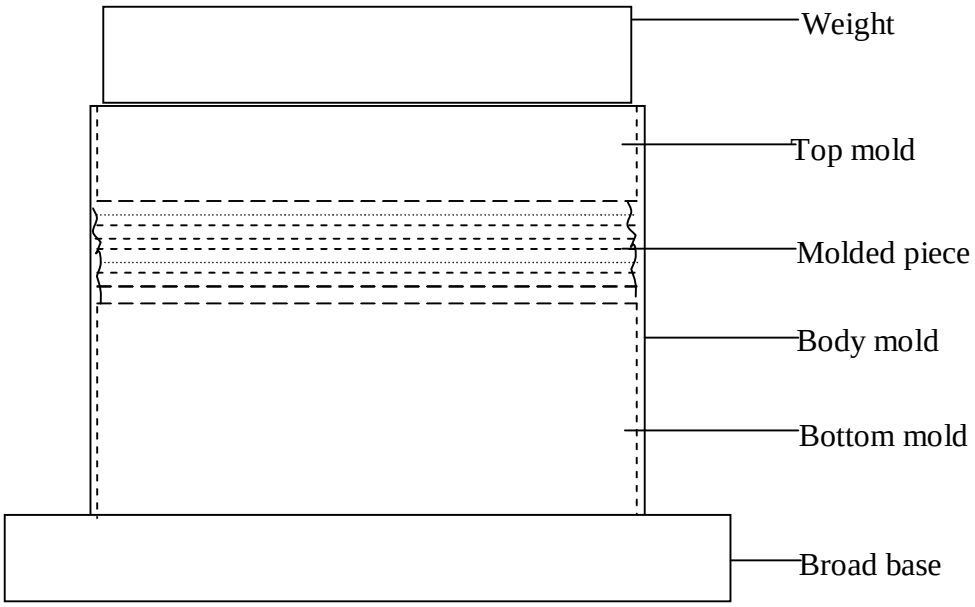


Figure 3.2: The Experimental Set-up for the Hand Lay- up for Glass Fibre Composite Production

3.4 Sample Configurations and Properties Relationship

3.4.1 Sample configuration for tensile properties

The description of the test piece for tensile properties according to ASTM No 638 is shown in Figure 3.3

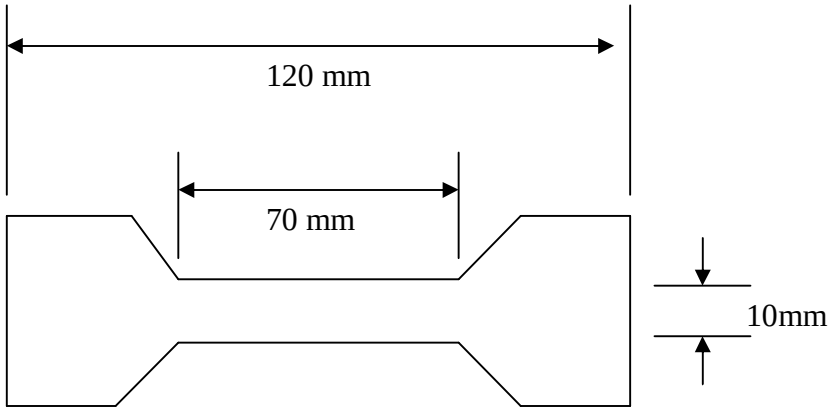


Figure 3.3: The Test Piece for Tensile Properties

The tensile strength is obtained by use of equation 3.1 as

$$\sigma_t = P/A_o(1+\varepsilon) \quad \ldots\ldots 3.1$$

Where σ_t is the true tensile strength, P is the maximum load applied; A_o is the original cross sectional area and ε is the strain

And the stiffness (modulus of elasticity, MOE) is obtained from equation 3.2

$$MOE = ML^3/4BH \quad \ldots\ldots 3.2$$

Where M is the slope of the stress-strain curve taken at 2% strain (Crawford, 1990), L is the gauge length, B is the breath and H is the thickness.

3.4.2 Sample configuration for flexural properties

The dimension of test piece for flexural properties for a three-point loading according to ASTM No D790 is shown in Figure 3.4

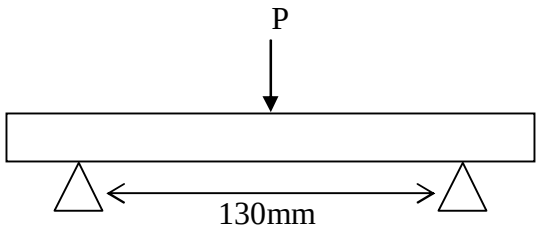


Figure 3.4: The Three Point Loading for Flexural Test.

Usually, flexural strength is measured in terms of modulus of rupture (MOR) and MOE.

$MOR=3PL/2BH^2$ ……3.3

3.4.3 Sample configuration for impact strength

Charpy test piece with a V notch was used for impact test with dimension given in Figure 3.5 according to ASTM No D256

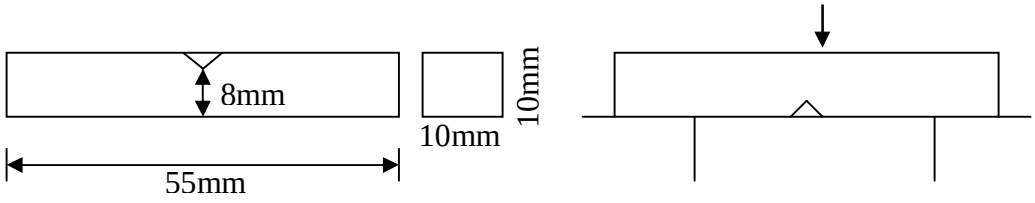


Figure 3.5: (a) Charpy Dimensions (b) Impact Test Piece Arrangement

The impact strength is expressed as

Impact strength = Energy absorbed / Notch cross sectional area……..…….3.4

3.4.4 Brinell hardness determination

The Brinell hardness was performed by using a Brinell hardness tester to make an indentation on a highly polish test piece and the Brinell hardness (HB) of the material was calculated from the relationship

$$HB=P/\pi D[D-\{D^2-d^2\}^{0.5}]\text{……..……..……..3.5}$$

Where D is the ball diameter and d is the indentation diameter.

3.4.5 Density determination

The suspension method was used to determine the density of the composites. Hull and Clyne, 1996 gave the relationship as

$\rho_c = W_a\rho_L - W_L\rho_a / W_a - W_L$ ……3.6

Where W_a and W_L are weight in air and alcohol respectively.

And ρ_L and ρ_a are the density of liquid and air respectively.

3.5 Handling and Safety Precautions

The resin, catalyst, accelerator and other auxiliary materials used were handled with care as many if not all are hazardous to health.

3.5.1 Precautions

The precautions taken during the fabrication process were:

a) The skin was protected from direct contact with the materials by wearing protective hand gloves and laboratory coat.

b) The eyes were also protected by wearing protective glasses.

c) The area where the fabrication was done was ventilated to provide escape way to the atmosphere of possible generation of toxic fumes.

3.5.2 Remedial measures

The remedial measures taken in case of accident were: -

a) The fabrication of the composites was done close to a source of clean water with water showers so that one can wash himself thoroughly well should there be any accident.

b) In case of spillages, absorbents like saw dust was also made available to soak up any possible spillages before shoveled into drum for disposal.

3.6 Experimental Procedure

The step-by-step account of the experimental procedure followed in the investigations is given below. These include preparation of the glass fibre composites and their testing.

3.6.1 Preparation of the glass fibre composites

The hand lay-up method was used in the production of the glass fibre composites, which commenced from the selection of the batch compositions through laying and curing.

3.6.2 Selections of batch composition

The batches of the glass fibre composites were chosen based on the report made by Vernon, 1992 that, the optimum glass fibre content for hand lay-up composites production is between 38-40wt%). Base on this, five batch compositions designated A, B, C, D and E where selected. For each of the batches, six different compositions were made beginning

from 32wt% - 45wt% glass fibre contents as shown in Table 3.2. Twenty-five samples designated as in Table 3.2 were thus prepared.

Table 3.2: Designation of the Composite Batches

No.	Glass fibre Content (wt%)	Batch compositions				
		A	B	C	D	E
1.	32	A1	B1	C1	D1	E1
2.	36	A2	B2	C2	D2	E2
3.	38	A3	B3	C3	D3	E3
4.	40	A4	B4	C4	D4	E4
5.	45	A5	B5	C5	D5	E5

The compositions of the samples were prepared by first weighing eleven layers of chopped glass fibre (Fiqure3.6), which have being cut to size of the mold. The weight percent of the glass fibre composition that is to be produced was therefore used along with the known weight of glass fibre to calculate the weight of polyester that is needed using Equation 3.7.

$w_p=(w_p+w_f)$ x weight % of glass fibre……3.7

And hence the volume of the polyester is obtained with density known. Because there might be some wastage, the volume of the polyester measured was higher than the

calculated so that at the end of fabrication, the proportion of the glass fibre could be close to the expected weight percent. The process was repeated for other samples.



Figure 3.6:A Typical Chopped Glass Fibre Mat

3.6.3 Fabrication of the glass fibre composites

The surfaces of the mold described in Figure 3.1 were cleaned with ethanol to remove all possible adherent materials. A soft piece of cloth was saturated with petroleum jelly (release agent) and rubbed onto the cleaned mold. The mold was placed on a flat and leveled table before applying a thin coat of saturated polyester on the mold interior surfaces to gel for at least five minutes. Based on the composition to be produced, a certain amount of chopped glass fibres cut to the mold size (Figure3.6) was weighed carefully

using an electronic balance. Calculated amount of polyester resin was measured and divided into six different plastic cups in equal quantity.

The first cup of unsaturated polyester was then taken and with the aid of different dropping pipettes, 0.5cm^3 catalysts and 0.7cm^3 of accelerator were added and stirred in turn. As the first cup of prepared saturated polyester was used up, another cup of the resin was prepared. This was done to avoid wastage and caking before the laying was completed.

A thin layer of saturated polyester was then coated on the surface of the bottom male piece of the mold using a brush. The first layer of the chopped glass fibre was laid on and pressed unto the coating of the polyester using the brush. Still using the same brush, polyester was applied onto the surface of the first layer of the chopped glass fibre until the polyester had soaked the chopped glass fibre. The second layer was then placed on top of the first layer and the brush was carefully worked round the second layer to remove air bubbles that might have been trapped. The polyester was applied also on the surface of the second layer as it were on the first layer. The process of laying was continued until it reached the mark inscribed on the mold to signify that the desired thickness has being achieved, then the polyester resin was finally applied on the surface of the top layer before the top male mold was replaced.

A ten-kilogram weight of a solid mild steel block was placed on the top male mold as shown in Figure 3.2 for two hours so that a flat sheet will be produced after curing. The

composite was left over night to cure further before it was removed from the mold and the edges trimmed off.

The whole process was repeated for other samples of different compositions. The composites produced where post treated by steaming for at least 20 minutes and suddenly chilled in cold water at about 4^{o}c to remove stresses. The post treated samples were weighed and cut into standard shapes and sizes and tested for tensile strength, impact strength, flexural strength and hardness strength according to ASTM standard procedures (Katz et al, 1978). Highlights of the test procedures are however, given in the following section.

3.7 Destructive Test

The mechanical test done on the processed specimen were the tensile properties, flexural strength, Brinell hardness and impact strength

3.7.1 Tensile strength test

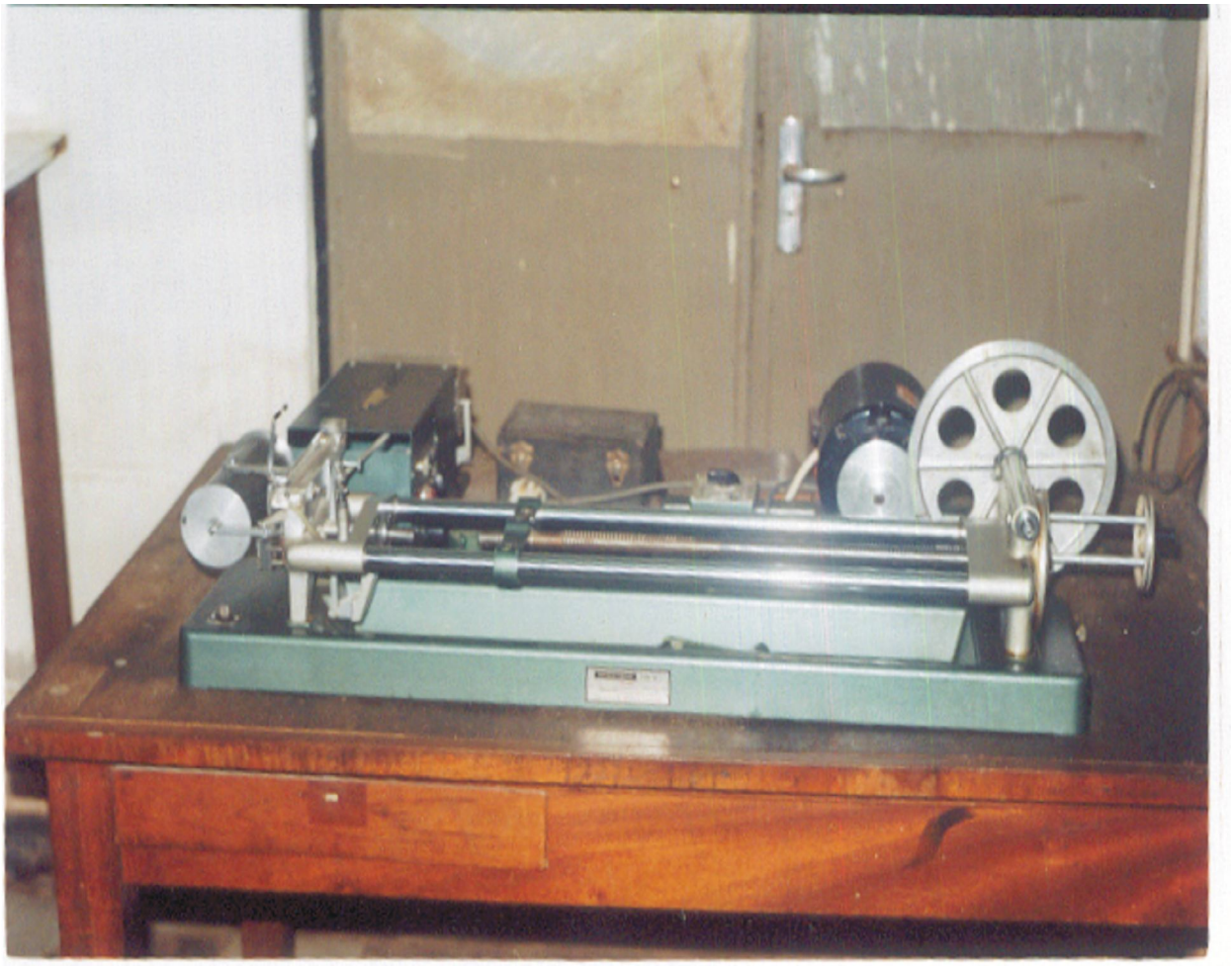


Figure 3.7: The Tensometer Machine

The samples were machined out according to ASTM No 625 as shown in Figure 3.1. A horizontal 'I' shape sample piece was inserted into the grips of the Tensometer W machine (figure 3.7) and held on tightly. A load was applied on the sample by a worm gear box by hand. As the gear box moved to the right the material was extended. The resistive force was simultaneously transmitted to the measuring system, which was indicated by the linear

movement of the machine. The recorder drum had a graph sheet round it. Since the gearbox was linked to the recorder, as the gearbox rotated, the recorder drum rotated proportionally and a prickling device automatically punctured the graph sheet at frequent intervals, thereby recording the corresponding force. The prickling continued as the gearbox rotated until the test piece failed. The process was repeated for the other samples. Tensile strength and modulus were evaluated from the force- strain data and the dimensions of the samples using Equations 3.1 and 3.2 respectively.

3.7.2 Flexural strength test

The fabricated samples were machined out to recommended sizes and dimensions (ASTM No 790) as shown in Figure 3.4.The specimen were mounted between the base and the head of the machine and supported horizontally near its ends by two fulcrum-type support at a known distance apart. A gradual increased in load induced tensile stress on one side of the specimen and compressive stress on the other by a load applied at the center of the test piece until the material failed. The modulus of rupture was calculated using Equation 3.3.

3.7.3 Impact strength (Charpy) test

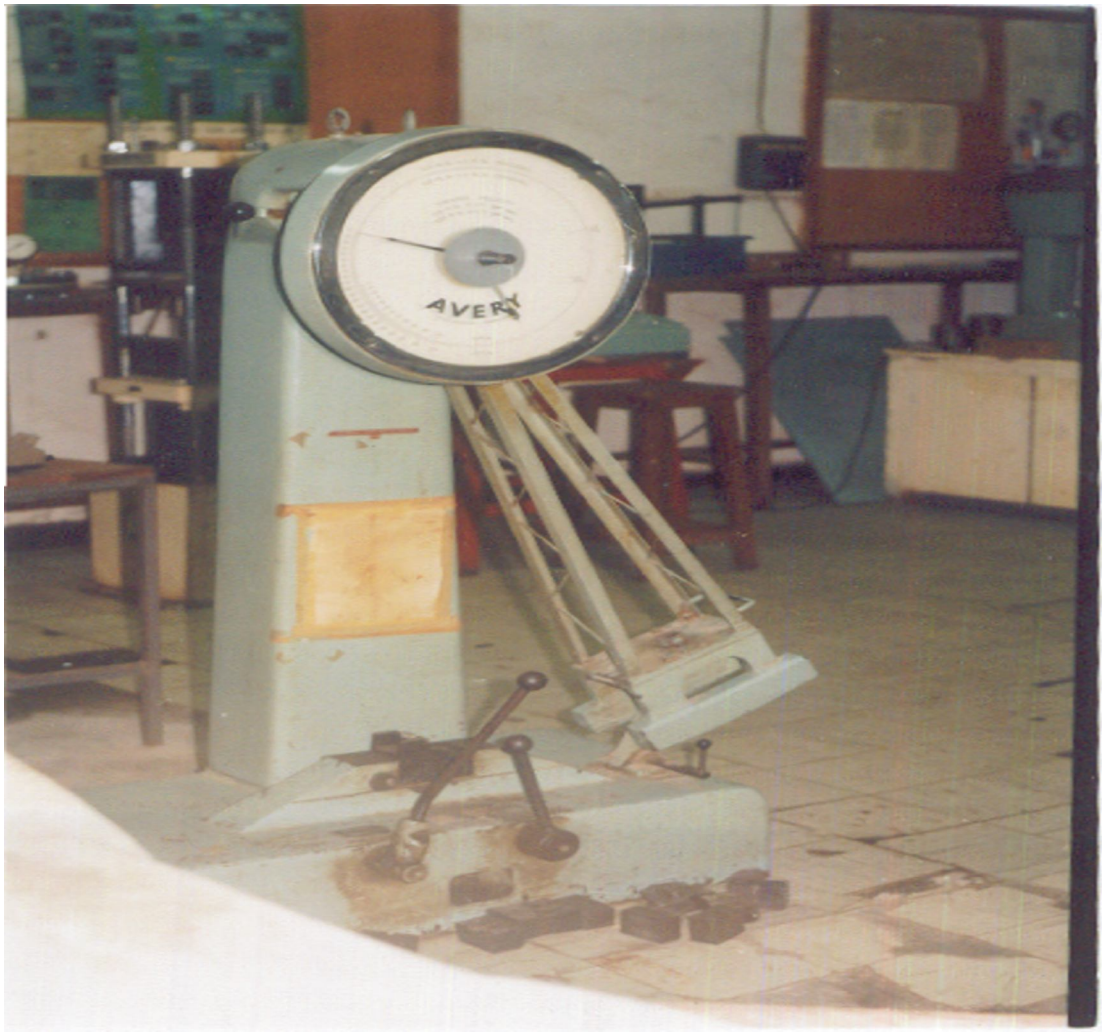


Figure 3.8: The Universal Impact Tester

The test samples were cut to recommended shapes and sizes according to ASTM No 252 with dimensions as presented in Figure 3.5. The arm of the Avery impact machine was allowed to swing freely to ensure freedom of movement and that the pointers were completely freed (Figure 3.8).

Using the position gauge, a sample was inserted in an anvil and rigidly secured by means of the lever. The pendulum was set to a potential energy position of 300 Joules and supported on a release trigger. The specimen was then mounted and the trigger released and energy absorbed by the specimen was noted as indicated by the loose registering pointer. This was repeated for other samples.

3.7.4 Brinell hardness test



Figure 3.9 The Brinell Hardness Tester

The test piece was highly polished and held firmly on the lower bearing block of the Brinell testing machine (Figure 3.9). The jack was screwed up until the polished specimen just touched the ball indenter. The load was carefully applied and allowed for 15 minutes. The specimen was unloaded and removed from the block. The diameter of the indentation was read with the aid of a microscope with inbuilt graduated scale. The indentation was repeated on the same material at different spots and the average values of indentation diameters were calculated and hence Brinell hardness values evaluated by use of Equation 3.5.

3.8 Non-Destructive Test

3.8.1 Density determination

The displacement method was employed to determine the density of the glass fibre composite according to ASTM No792-66 (Katz and Milewski,1981). The samples were first weighed while totally immersed in alcohol. Finally the suspended wire was weighed while immersed in alcohol to the same depth as during samples weighing and the density is obtained by use of Equation 3.6

3.8.2 Water absorption determination

Water absorption was carried out in accordance to ASTM No D570 by measuring the amount of water absorbed when totally immersed in water for 24 hours and then expressed as a percentage of the original weight

Chapter 4

4.0 RESULTS AND DISCUSSION

4.1 Introduction

The results obtained from the investigations carried out are presented in this chapter. These include density and water absorption, tensile properties, flexural strength, impact strength, and Brinell hardness for various glass fibre contents. The comparison between the best composites and some common metals are also presented.

4.2 Density and Water Absorption

The results of density and water absorption measurements are presented in Table 4.1

As can be observed in Table 4.1, the water absorption of the fabricated composites decreased from 0.48% to 0.37% at 35^{o}c for 24 hours as the glass fibre content was increased from 32wt% to45wt%. This was probably due to the limited proportion of polyester, which according to Crawford, 1990 is the major component that could absorbed water. When compared with the reported value of 0.3% water absorption at 20^{o}c by Hull and Clyen, 1996 they were however lower, probably because it was measured at a higher temperature which might promote water absorption.

Table 4.1: Density and Water Absorption of the Composite

Glass fibre Content ,wt%	Water absorption %	Density of composite (ρ_c), kgm^{-3}	
		calculated	determined
32	0.48	1595.46	1980.79
36	0.42	1632.45	2030.00
38	0.40	1651.75	2112.00
40	0.36	1671.43	2149.00
45	0.35	1722.70	2201.00

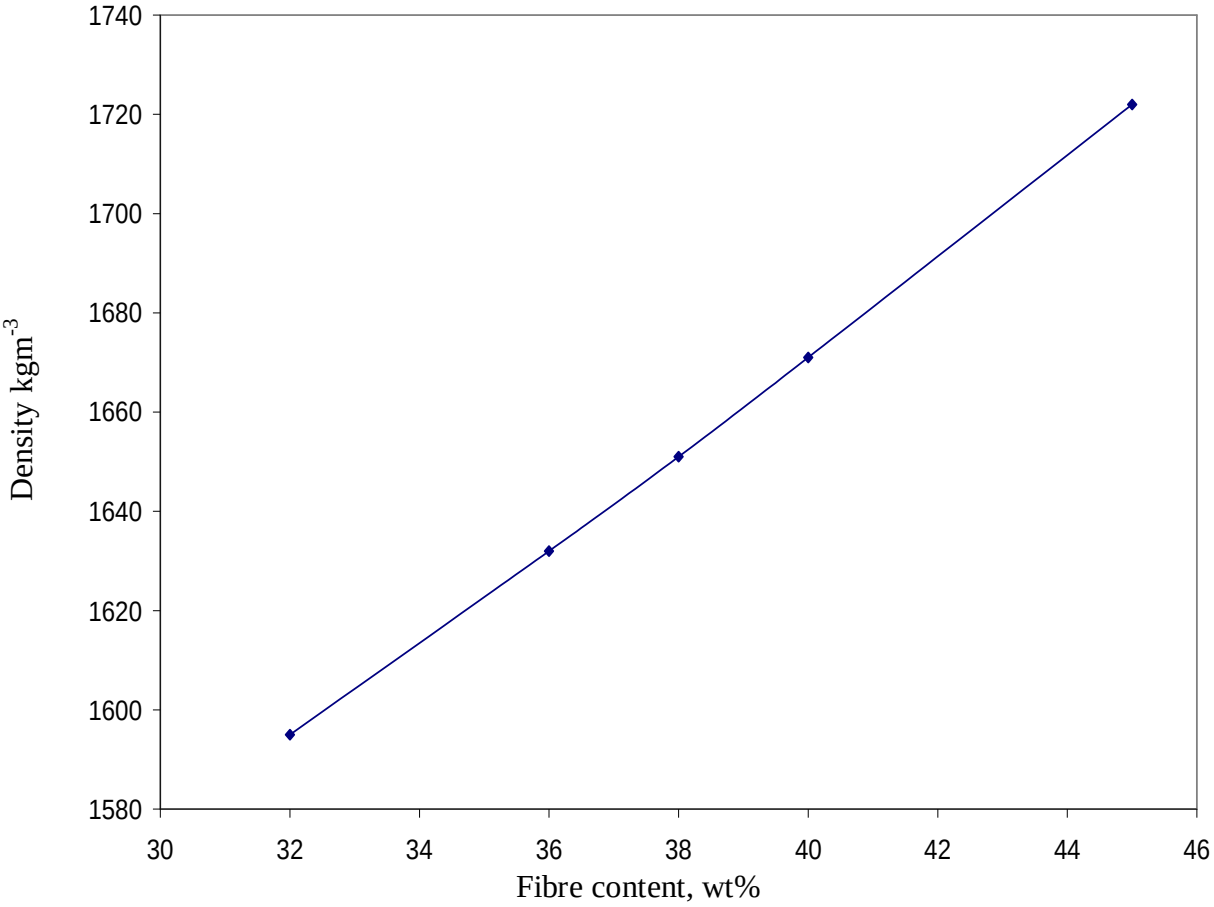


Figure 4.1: Change of Density with Glass Fibre Content

The increased in density of the composites with increased in glass fibre contents as observed in Figure 4.1, was most likely due to the relative increased in pressure applied so as to confine the increased in number of layers of glass fibre content to occupied the same provided space. This reduced the air spaces that might be present and therefore the density increased (Figure 4.2).

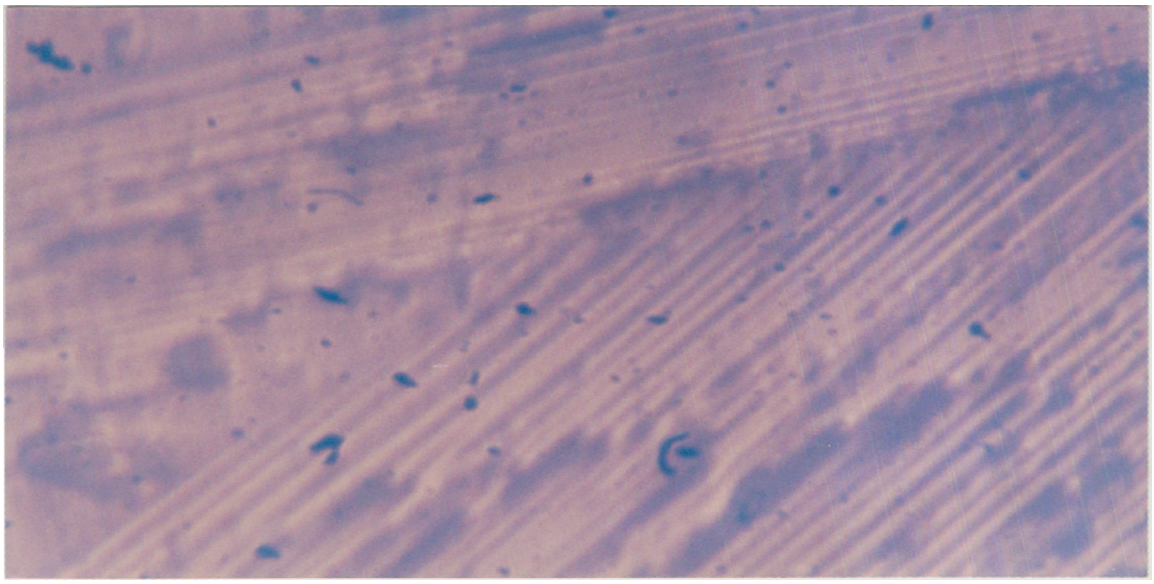


Figure 4.2: The Microstructure of Glass Fibre Composite.

4.3 The Tensile Properties

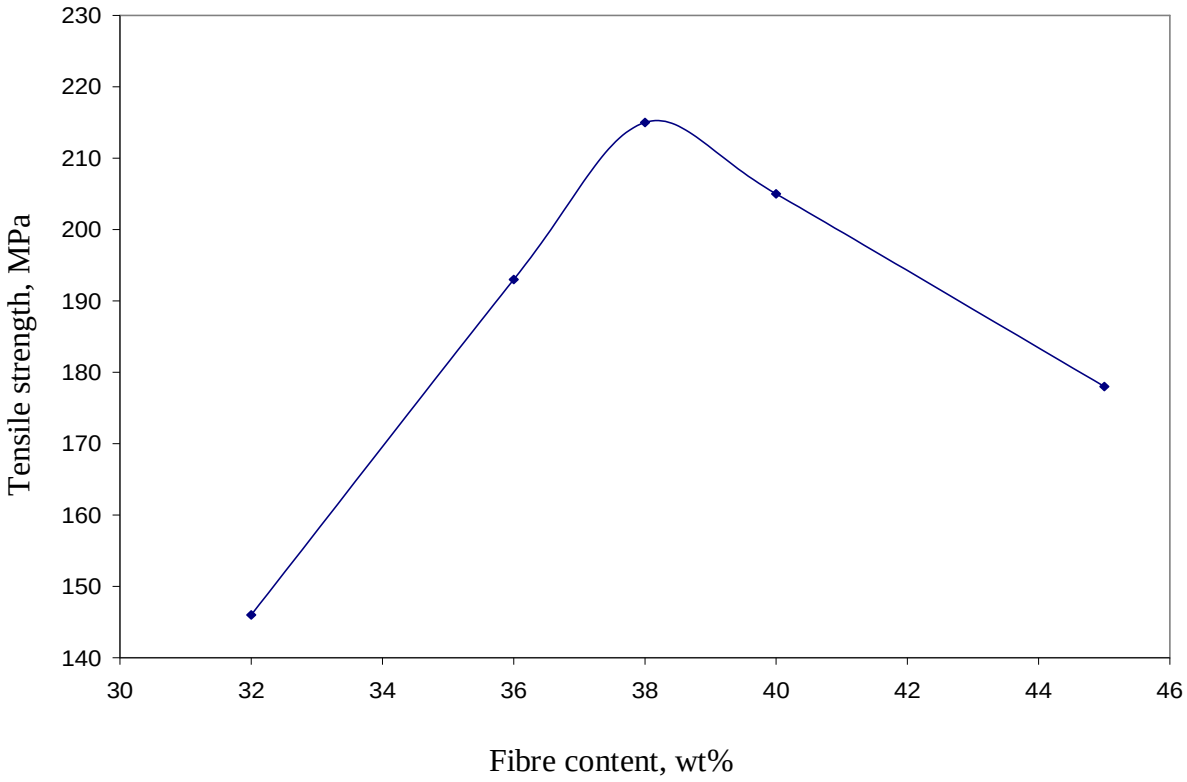


Figure 4.3: Tensile Strength of Polyester-Glass Fibre Composite

Figure 4.3 which was obtained from Table A1in Appendix A shows that, the tensile strength increased from 146.2Mpa to 215.0 MPa with the maximum strength being for the composition with 38wt% fibre content and the tensile modulus showed a maximum value of 253.0 GPa for the same composition (Figure 4.4). The trend in both figures agreed well with the rule of mixture equation up to 38wt% glass fibre content. At higher glass fibre contents a decreasing trend was observed, probably due to diminishing proportion of polyester resin resulting in increasing fibre-fibre contacts that became the weak points liable to initiate fracture.

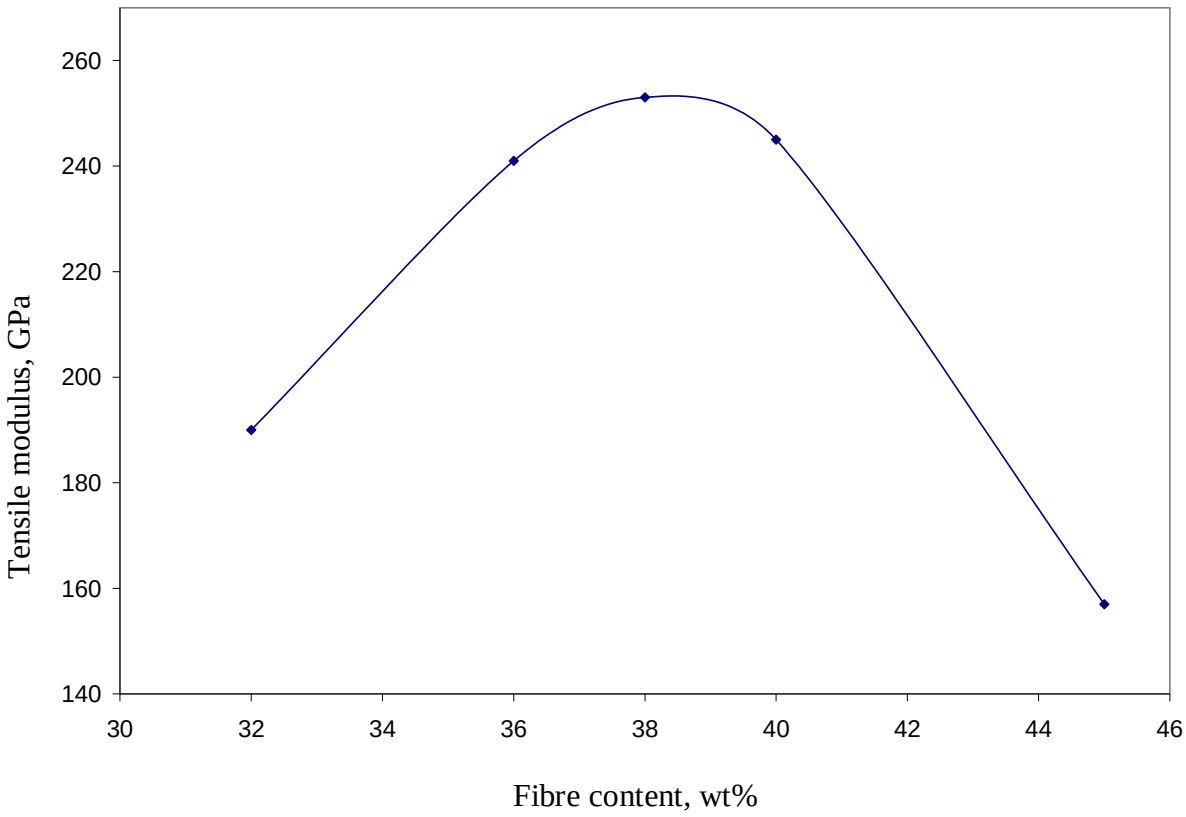


Figure 4.4: Tensile Modulus of Polyester-Glass Fibre Composite

The best tensile strength of 215.0 MPa obtained at 38.wt% fibre content was however lower than the reported value of 288 MPa at 40.0 wt% fibre for hand-lay up molding (Vernom, 1992) owing to the relatively high glass fibre content and probably due to laminate micro damage sustained during processing, thereby inducing some residual stresses making the glass fibre composite susceptible to quick failure.

4.4 The Flexural Strength

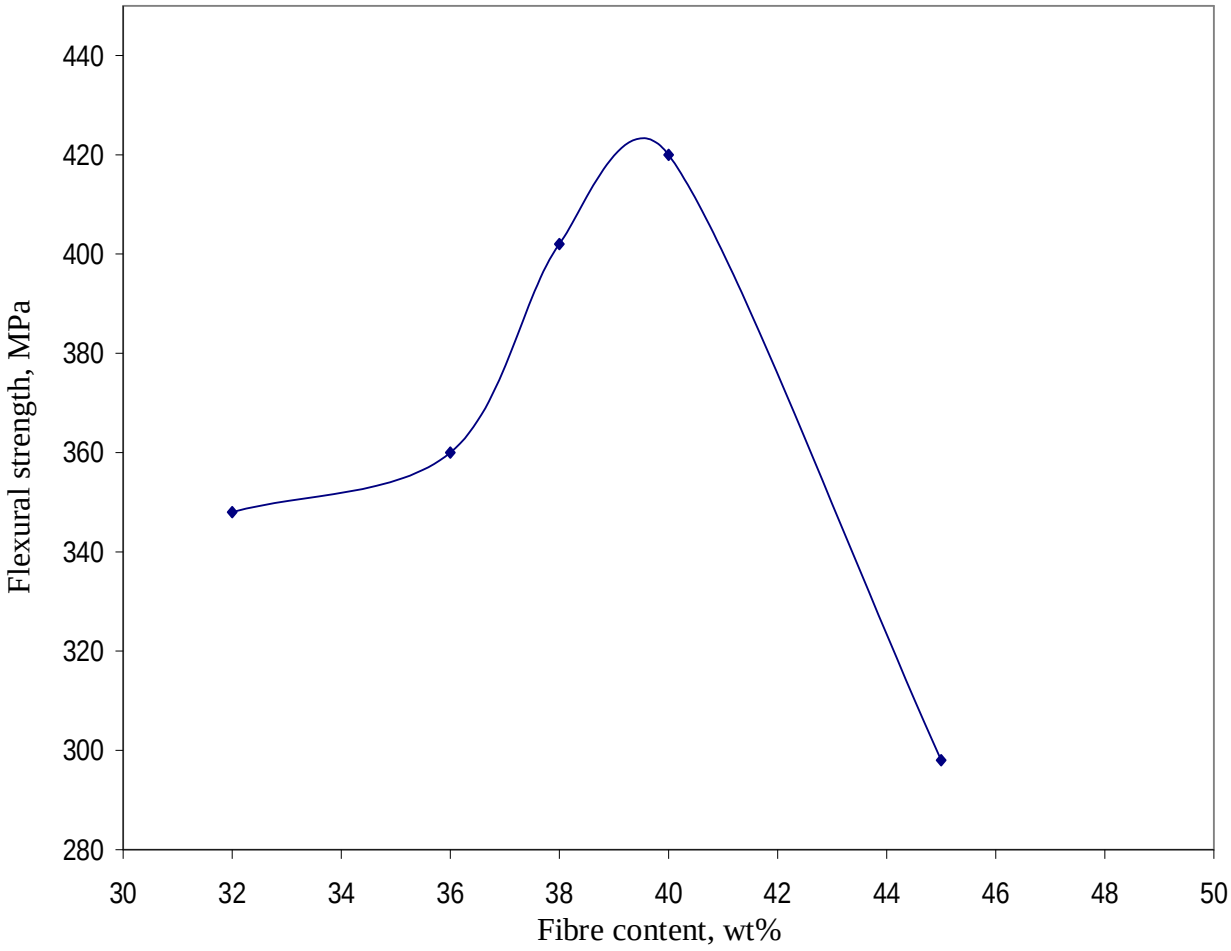


Figure 4.5: Flexural Strength of Polyester-Glass Fibre Composite

Like the tensile properties, the flexural strength profile (Figure 4.5) which was obtained from Table B1 in Appendix B followed a similar trend with the maximum value of 420.6 MPa occurring at 40 wt% glass fibre content.

The way the crack grew from defect was quite different for the two samples ‘a’ and ‘b’ as seen in Figure 4.6. In the case of sample ‘a’, crack originated from the tension face normal to the direction of the fibre alignment before deflecting on reaching the interface. This might be because, the interfacial energy is appreciably lower than that of the reinforcement as reported by (Kendall,1975),while that of spacemen ‘b’ has a radial growth from defect, penetrating into the spacemen because of uniformity in stress distribution since the contribution of fibre fracture energy is insignificant (Hull and Clyne ,1996)

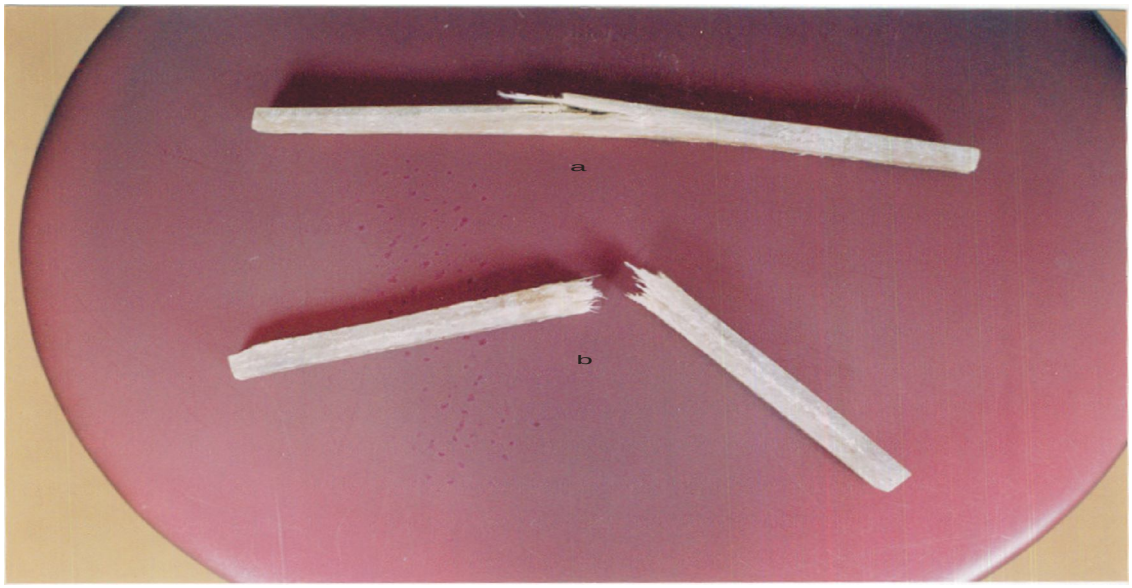


Figure 4.6: The Tested Samples for Flexural Strength ‘a’45wt%Glass Fibre and ‘b’ 38wt%Glass Fibre Content.

4.5 Brinell Hardness

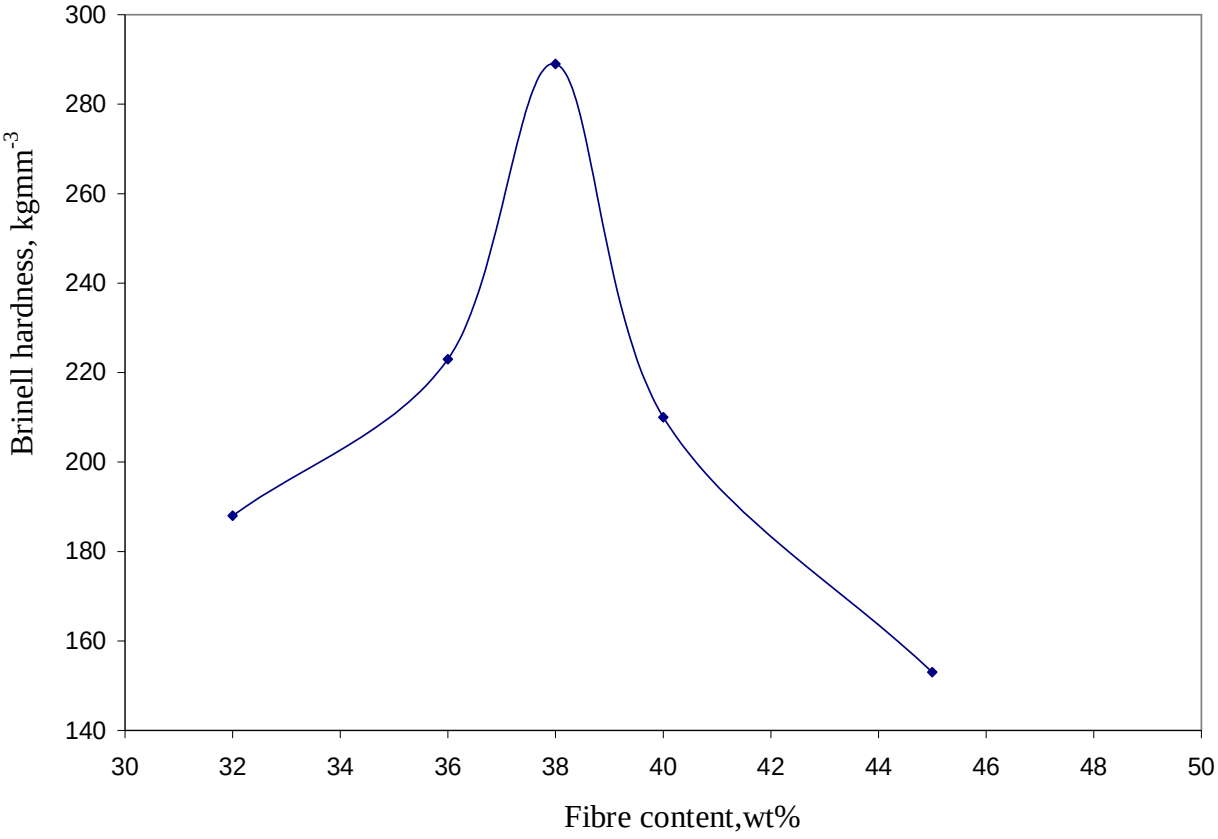


Figure 4.7: The Brinell Hardness of Polyester-Glass Fibre Composite

Figure 4.7 obtained from Table C1 in Appendix C shows that the Brinell hardness increased from185.5 kg/mm^2 to 289.9 kg/mm^2 between 32wt% to 40wt% glass fibre content before it decreased to 153.1 kg/mm^2 at 45wt% fibre content. The maximum Brinell hardness of 289.9kg/mm^2 obtained at 40wt% glass fibre content was equivalent to 3.2 on Mohr Scale (Figure H) which was better than the reported value of 3.0 for typical commercial products (Crawford, 1990).

4.6 Impact Strength

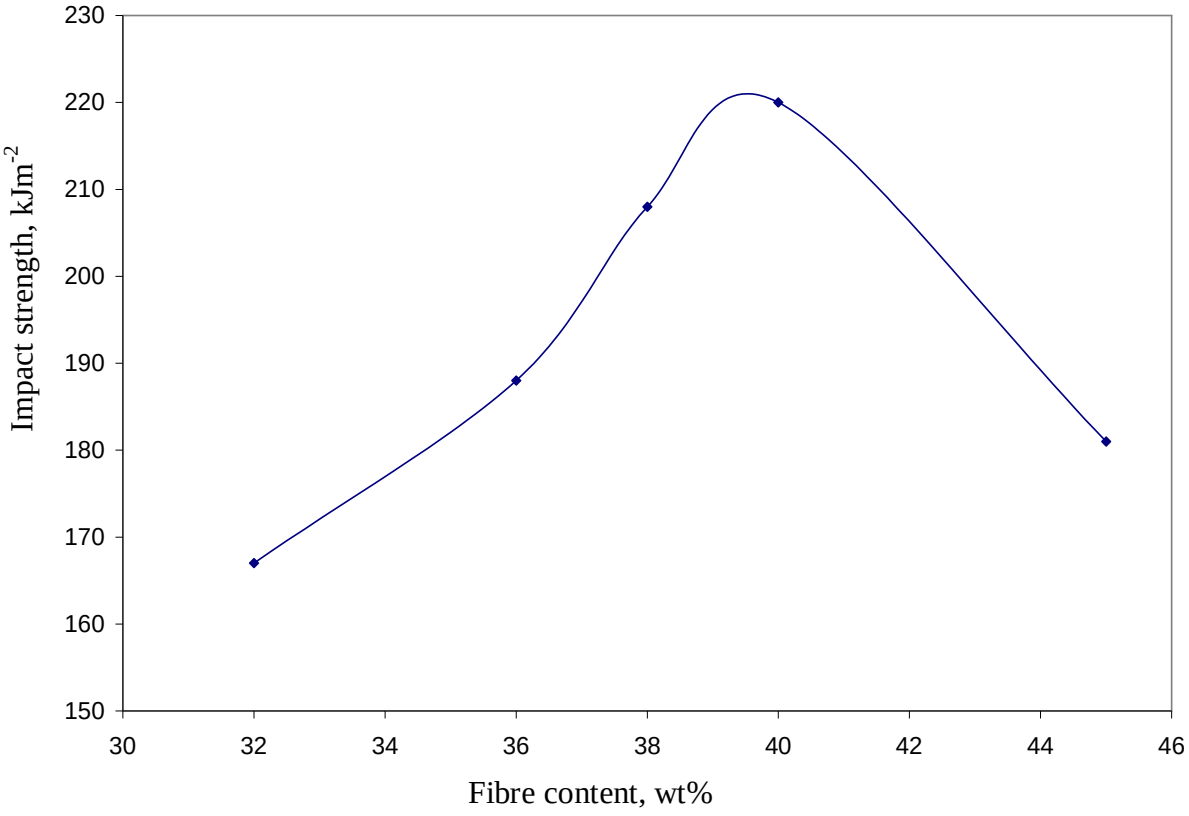


Figure 4.8: Impact Strength of Polyester-Glass Fibre Composite

The impact strength followed the same trend as in the case of tensile properties, and flexural strength as observed in Figure 4.8 obtained from Table D1 in Appendix D. The maximum impact strength obtained was 220 kJ/m^2 for glass fibre composition of 38wt%, which appeared better than the reported value of 170 kJ/m^2 for typical commercial products (Crawford, 1990).

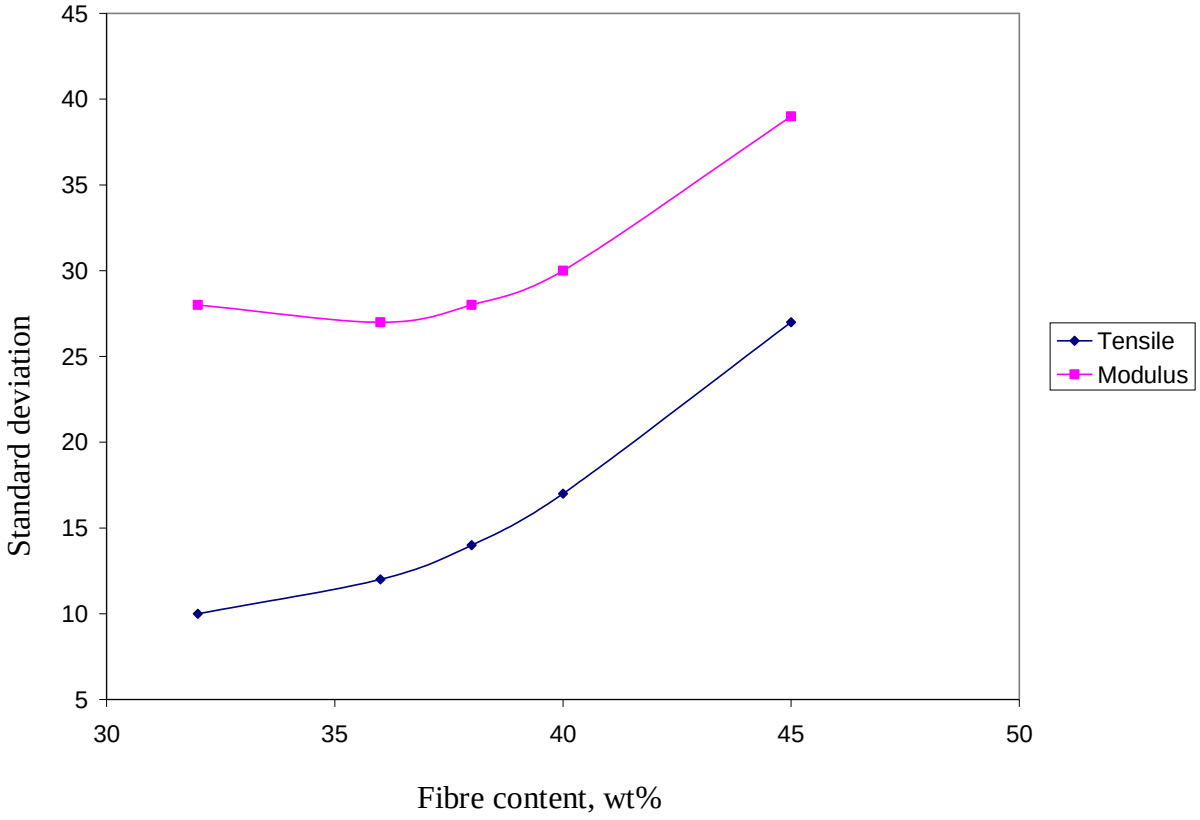


Figure 4.9: Standard Deviation with Change in Glass Fibre Content

From Figure 4.9 obtained from Table A1, the standard deviations became more pronounced beyond 40 wt% fibre content. The reason could probably be due to the fact that, beyond 40 wt% fibre content the difficulty in having a uniform composition was increased which resulted in some locations within the given batch having more matrix concentration than others hence showed greater differences in the properties for the same glass fibre composition.

4.7 Comparison of Glass Fibre Polyester Composites with Some Metals

Table 4.2 compared the properties of glass fibre polyester composites with mild steel and aluminium.

Table 4.2: Comparison of the Properties of the Optimum Glass Fibre Polyester Composites with some Metals (Conrad,1985)

Property	Tensile strength, MPa	Tensile modulus, GPa	Elongation at break, %	Flexural strength, MPa	Specific density	Hardness, Mohr scale	Impact strength, kJ/m^2
Composite (38-40wt%)	215	253	9	420	1.60	3.2	220
Mild steel	460	210	20-30	241	7.86	3.5	2500
Aluminium	80	71	8-11	70	2.0	1.6	125

Table 4.2 shows that the properties of the best glass fibre composites produced compared well to that of mild steel except for impact strength and tensile strength and better than that of aluminium. On strength to weight ratio, the optimum glass fibre (38-40wt% glass fibre content) out performed mild steel and aluminium by 55.8% steel and 77.6% aluminium respectively.

Chapter 5

5.0 CONCLUSIONS

From the investigations carried out, the following conclusions may be drawn.

1. The maximum tensile strength of 215MPa was measured at 38wt% for batch A3 which was superior to that of aluminium having the value of 80MPa
2. The highest flexural strength of 420MPa was recorded at 40wt% glass fibre content which was better than mild steel with typical value of 241MPa
3. The maximum impact strength of 220kJ/m^2 was obtained for glass fibre content of 40wt%, which appeared better than the reported value of 170kJ/m^2 for commercial products.
4. The best Brinell hardness was 289kg/mm^2 at 40wt% glass fibre content equivalent to 3.2 on Mohr scale. This was also better than the reported value of 3.0 for typical commercial materials
5. On strength to weight ratio, the best composition with 38-40wt% glass fibre content out performed mild steel and aluminium by 55.8% and 77.6% respectively.

Chapter 6

6.0 RECOMMENDATIONS

The following recommendations may be made with a view to enhance further development work in the area of glass fibre- polyester composites for automobile industry.

1) Additions of some ingredients like impact modifiers and fire retardant should be carried out to further improve on the quality of the glass fibre-polyester composites.
2) The design and construction of car chassis using glass fibre reinforced polyester should be attempted.
3) Efforts should be made to produce the raw materials like polyester and glass fibre locally.

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Appendices

APPENDIX A

A.1 Calculation of Tensile Strength of the Composites

Tensile strength (σ) $= P/A_o (1+\varepsilon)$

where , P=maximum load, N

A_o =original cross sectional area, m^2

ε =nominal strain

$\varepsilon = (L-L_o)/L_o$

Where, L_o= initial gauge length, m

L= final gauge length, m

For batch A

L_o=0.07m

A_o=0.00004 m^2

Sample I

$(L-L_o)$=0.0047m

P=6800N

:. σ=(6800/0.0004)x(1+0.0047/0.07)

=180.2MPa

Sample II

$(L-L_o)$=0.0039m

P=5600N

σ=(5600/0.00004)x(1+0.0039/0.07)

=147.70 MPa

Sample III

$(L-L_o)$=0.0038m

P=5600N

σ=(5600/0.00004)x(1+0.0038/0.07)

=147.4 MPa

Sample IV

P=4600N

$(L-L_o)$=0.0035m

σ=(4600/0.00004)x(1+0.0035/0.07)

=120.8 MPa

Sample V

$(L-L_o)$=0.0044m

P=6200N

σ=(6200/0.00004)x(1+0.0044/0.07)

=164.3 MPa

Sample VI

$(L-L_o)$=0.0043m

P=4400N

σ= (4400/0.00004)x(1+0.0043/0.07)

=116.6 MPa

Similarly, for others the same calculations were done and the results were recorded A2 A2

A.2 Calculation of Modulus of Elasticity of Glass Fibre Contents

Modulus of elasticity (MOE)=$ML^3/4BH^3$

Where, M=slope

L = sample gauge length, m

H=sample thickness, m

B=sample breath, m

For batch A1

L =0.07 m

H=0.004m

B=0.01m

From Figure G1

Sample I

M=(4-1)/(3.5-1.5)

=$1.5x10^3$ kN/m

:.MOE=$1.5x10^6x0.07^3/4x0.01x0.04^3$

=257.3×10^9 N/m^2

= 257.3 GPa

Sample II

M=(3.6-0.8)/(6-2)

=$1.4x10^3$ kN/m

:.MOE=$1.4x10^6$ $x0.07^3/4 \times 0.010x0.004^3$

=$187.6x10^9$ N/m^2

=187.6 GPa

Sample III

M=(3.8-1.0)/(8.5-6.5)

$=1.4 \times 10^3$ kN/m

$:.MOE=1.4 \times 10^6 \times 0.07^3/4 \times 0.01 \times 0.004^3$

=187.6 GPa

Sample IV

M=(3.2-0.8)/(3.0-1.0)

$=1.2 \times 10^3$ kN/m

$:.MOE=1.2 \times 10^6 \times 0.070^3/4 \times 0.01 \times 0.004^3$

=160.8GPa

Sample V

M=(3.8-1.0)/(6.0-4.0)

$=2.4 \times 10^3$kN/m

$:.MOE=2.4 \times 10^6 \times 0.07^3/4 \times 0.01 \times 0.004^3$

=323.4 GPa

Sample VI

M=(3.8-1.0)/(6.0-4.0)

$=2.4 \times 10^3$ kN/m

$:.MOE=2.4 \times 10^6 \times 0.07^3/4 \times 0.01 \times 0.004^3$

=323.4 GPa

In the same way, other samples were calculated.

Table A1: The Tensile Properties of Glass Fibre-Polyester Composites with Different Glass Fibre Contents.

Original cross sectional area (A_o)=$4x10^{-5}$m

Gauge length = $7.0x\ 10^{-2}$m

Sample thickness =$4x10^{-3}$ m

Sample breath = $1x10^{-2}$m

Batch	Glass fibre content, wt %	Tensile strength (σ), MPa	Elongation at break, %	Tensile modulus (E), Gpa	Standard deviation		Average	
					(σ). MPa	(E). GPa	(σ). MPa	(E). GPa
A1	I 32 II 32 III. 32. IV. 32 V. 32 VI. 32	180.2 147.7 147.4 120.8 164.3 116.6	6.7 5.6 5.4 5.0 6.2 6.0	157.3 187.6 187.6 160.8 223.4 223.4	9.2	27.8	146.2	190.0
A2	I. 36 II. 36 III. 36 IV. 36 V. 36 VI. 36	178.5 168.0 248.8 164.3 188.1 214.0	5.4 5.2 7.5 5.8 6.7 6.8	267.5 267.5 254.6 214.4 201.0 241.1	13.3	26.2	193.6	241.0
A3	I. 38 II. 38 III. 38 IV. 38 V. 38 VI. 38	216.6 211.1 205.2 211.4 238.2 210.3	6.2 6.1 5.8 6.8 7.7 2.8	254.6 247.9 308.2 187.6 235.8 284.1	15.4	28.0	215.0	253.0

Table A1 continue

A4	I. 40 II. 40 III. 40 IV. 40 V. 40 VI. 40	205.4 190.3 211.1 185.1 233.1 206.4	6.1 5.7 6.7 6.7 6.7 6.4	254.6 251.9 282.7 206.3 251.9 227.8	17.0	30.1	205.2	245.9
A5	I. 45 II. 45 III. 45 IV. 45 V. 45 VI. 45	188.2 129.3 206.9 187.5 168.2 192.4	9.0 7.7 9.2 9.2 7.4 8.1	160.8 100.5 182.2 166.1 182.2 151.4	27.3	39.4	178.4	157.0

APPENDIX B

B.1 Calculation of Flexural Properties of Glass Fibre Contents

Modulus of rupture (MOR)=$3PL/2BH^2$

where P=maximum load, N

L=span length, m

B=breath, m

H=thickness, m

For batch B

Sample I

P=702.11N

B=0.01m

L=0.130m

H=0.008m

:.MOR=$3x702.11x0.13/2x0.01x0.008^2$

=342.11MPa

Sample II

P=710.45N

MOR=$3x710.45x0.13/2x0.01x0.008^2$

=346.34MPa

Sample III

P=730.50

MOR=3x730.50x0.13/2x0.01x0.008^2

=356.12MPa

Sample IV

P=725.10N

MOR=3x725.10x0.13/2x0.01x0.008^2

=353.49MPa

Sample V

P=727.11N

MOR=3x727.11x0.13/2x0.01x0.008^2

=354.47MPa

Sample VI

P=698.00N

MOR=3x698.00x0.13/2x0.01x0.008^2

=340.23MPa

Similarly, other batches were calculated and the results obtained were recorded

Table B1: The flexural properties of glass fibre composites with different glass fibre contents.

Original cross sectional area (A_o) = 7.2 x $10^{-5}m^2$

Gauge length (L) = 1.30 x 10^{-1} m

Sample breath (B) = 1.0 x 10^{-2}m

Sample height (H) =8 x 10^{-3}m

Batch	Fibre content, Wt %	Flexural strength, Mpa	Elongation at break, %	Average flexural strength, MPa	Standard deviation, MPa
B1	I. 32 II. 32 III. 32 IV. 32 V. 32 VI. 32	342.28 346.34 356.12 353.49 354.47 340.23	3.64 3.77 3.52 3.37 3.66 3.69	348.82	6.8
B2	I. 36 II . 36 III. 36 IV. 36 V. 36 VI. 36	358.43 361.45 353.73 370.50 360.23 358.81	3.11 3.13 3.29 3.17 3.42 3.14	360.52	5.5
B3	I. 38 II. 38 III. 38 IV. 38 V. 38 VI. 38	389.18 410.09 402.19 414.67 408.53 387.40	2.80 2.80 2.81 2.81 3.05 2.81	402.01	11.4

Table B1 continue

B4	I . 40 II. 40 II. 40 IV 40 V. 40 VI 40	16.16 16.66 17.13 16.01 16.06 16.92	414.44 418.47 426.41 419.25 423.64 421.69	3.11 3.11 3.20 3.01 3.10 3.21	420.65	14.2
B5	I. 45 II. 45 III. 45 IV. 45 V. 45 VI. 45	11.77 12.61 12.48 13.30 11.60 12.92	298.06 276.90 292.93 312.00 316.58 294.50	2.81 2.79 2.81 2.82 2.81 2.83	298.49	14.3

APPENDIX C

C .1 Sample calculation of impact strength of composites

Impact energy=E/A

where , E = energy absorbed, Joules

A= cross sectional area at notch, m^2

Batch C1

Impact energy = $13.43/(8.0 \times 10^{-5})$

= 167875 J/m^2

Batch C2

Impact energy = $15.10/(8.0 \times 10^{-5})$

= 188750 J/m^2

Batch C3

Impact energy = $16.67/(8.0 \times 10^{-5})$

=208375J/m^2

Batch C4

Impact energy =$17.60/(8.0 \times 10^{-5})$

=220000 J/m^2

Batch C5

Impact energy = $14.47/(8.0 \times 10^{-5})$

=181000 J/m^2

Table C1: Energy Absorbed During an Impact (Charpy) Test.

Cross sectional area at notch=$8.0 \times 10^{-5} m^2$

Maximum striking energy =300 J

Batch	Fibre content, wt%	Energy absorbed (Joules)								Impact strength, kJ/m^2
		I	II	III	IV	V	VI	Average	Standard Deviation	
C1	30.12	13.56	14.24	14.92	14.60	12.78	10.45	13.43	0.6	167.80
C2	35.28	15.62	13.50	14.98	15.69	16.01	14.79	15.10	0.9	188.70
C3	38.45	16.68	17.50	15.98	18.31	16.01	15.52	16.67	1.0	208.30
C4	40.10	18.99	17.54	18.51	17.68	15.98	16.90	17.6	1.0	220.01
C5	44.3	17.63	12.88	13.56	15.60	14.50	12.62	14.47	1.9	181.04

APPENDIX D

D.1 Sample Calculation for Brinell Hardness of Composites

Brinell hardness (H_B)=$2P/\pi D\ [D-(D^2-d^2)^{0.5}]$

P=load, kg

D=ball diameter, mm

d=impression diameter, mm

For batch D

Sample I

D=1mm

d=0.75mm

P=100kg

$H_B=2x100/\pi x1[1-\{1^2-0.75^2\}^{0.5}]$

$=188.03kg/mm^2$

Sample II

D=1mm

d=0.74mm

P=100kg

$H_B=2x100/\pi x1[1-\{1^2-0.74^2\}^{0.5}]$

$=194.00kg/mm^2$

Sample III

D=1mm

d=0.80mm

P=100kg

$H_B=2x100/\pi x1[1-\{1^2-0.80^2\}^{0.5}]$

$=164.55kg/mm^2$

Sample IV

d=0.75

$H_B=2x100/\pi x1[1-\{1^2-0.75^2\}^{0.5}]$

$=188.03kg/mm^2$

Sample V

d=0.79mm

$H_B=2x100/\pi x1[1-\{1^2-0.79^2\}^{0.5}]$

$=164.55kg/mm^2$

Sample VI

d=0.75mm

$H_B=2x100/\pi x1[1-\{1^2-0.75^2\}^{0.5}]$

$=188.02kg/mm^2$

Similarly, for other batches the same calculations were carried out and the results recorded

Table D1: The Brinell hardness and Mohr scale equivalent for different glass fibre

Contents

Ball diameter = 1mm Load applied = 100kg

Batch	Fibre content, wt%	1st Mark, Mm	2nd Mark, mm	3rd Mark, Mm	Average Mark, mm	Brinnel hardness $H_{B,}$ kg/mm^2	Average $H_{B,}$ kg/mm^2	Standard Deviation, kg/mm^2	Mohr scale
D1	I. 32 II. 32 III. 32 IV. 32 V. 32 VI. 32	0.78 0.70 0.80 0.80 0.75 0.70	0.72 0.75 0.82 0.78 0.70 0.75	0.75 0.78 0.78 0.80 0.80 0.80	0.75 0.74 0.80 0.79 0.75 0.75	180.3 194.0 159.1 164.6 188.0 188.0	188.0	14.58	2.20
D2	I. 36 II. 36 III. 36 IV. 36 V. 36 VI. 36	0.70 0.75 0.60 0.85 0.70 0.75	0.72 0.60 0.80 0.60 0.75 0.68	0.75 0.68 0.60 0.65 0.80 0.60	0.72 0.68 0.67 0.70 0.75 0.68	208.0 238.0 247.1 222.7 188.0 238.0	223.6	22.25	2.50
D3	I. 38 II. 38 III. 38 IV. 38 V. 38 VI. 38	0.60 0.58 0.60 0.72 0.64 0.59	0.55 0.62 0.65 0.65 0.63 0.58	0.58 0.60 0.58 0.62 0.62 0.61	0.58 0.60 0.61 0.66 0.63 0.66	343.4 318.3 306.7 255.9 284.9 225.9	289.2	42.93	3.20
D4	I. 40 II. 40 III. 40 IV. 40 V. 40 VI. 40	0.75 0.78 0.73 0.79 0.80 0.78	0.68 0.76 0.79 0.81 0.80 0.79	0.79 0.78 0.77 0.79 0.82 0.77	0.78 0.76 0.78 0.80 0.81 0.78	170.1 182.6 170.1 165.4 156.5 170.1	178.5	41.2	2.6
D5	I 45 II 45 II. 45 IV 45 V. 45 VI 45	0.80 0.85 0.90 0.90 0.70 0.80	0.75 0.82 0.85 0.85 0.68 0.90	0.78 0.80 0.88 0.88 0.72 0.85	0.78 0.82 0.88 0.88 0.70 0.85	170.1 148.9 121.3 121.3 222.7 134.5	153.1	38.79	1.70

APPENDIX E

E.1 Calculation of Density by used of rule of mixture and by dermination for Various Glass Fibre Contents

E.II Calculation of density by rule of mixture for various glass fibre contents

$$\rho_c = \frac{1}{\sum_{i=1}^{n} \frac{w_i}{\rho_i}}$$

For 32wt% glass fibre composite

$$\rho_c = \frac{1}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}} = \frac{1}{\frac{0.32}{2600} + \frac{0.68}{1350}} = 1595.46 kg/m^3$$

For 36wt% glass fibre composite

$$\rho_c = \frac{1}{\frac{0.36}{2600} + \frac{0.64}{1350}} = 1632.45 kg/m^3$$

Similarly, for 38wt% glass fibre content $\rho_c = 1651.75 kg/m^3$

For 40wt% glass fibre content $\rho_c = 1671.49 kg/m^3$

And for 45wt% glass fibre content $\rho_c = 1722.70 kg/m^3$

E.III Determination of density for various glass fibre contents

For 32wt% glass fibre content

$\rho_c=(W_a\rho_L-W_L\rho_a)/W_a-W_L$

$=0.4(793)-0.24(1.137)/(0.4-0.24)$

$= 1980.79 kg/m^3$

For 36wt% glass fibre content

$\rho_c=0.41(793)-0.25(1.137)/(0.41-0.25)$

$=2030.01 kg/m^3$

Similarly, for 38wt% glass fibre content, $\rho_c=2112 kg/m^3$

And for 40wt% and 45wt% ρ_c are 2149 and $2201 kg/m^3$ respectively