EFFECT OF VOLUME FRACTION ON THE FLEXURAL STRENGTH AND MODULUS OF WOVEN COMPOSITE

NABILAH IZZATI BT. MOHD. NORDIN

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature

Name of Supervisor :

Position :

Date :

Signature

Name of Panel :

Position :

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature

Name : Nabilah Izzati bt. Mohd. Nordin

ID Number : MF04008

Date :

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ABSTRACT

The project entitled The Effect of Fiber Volume Fraction on The Flexural Properties of Woven Composite generally explained the effect of increasing fiber volume fraction on the behaviour of flexural properties of woven composite. This behaviour can be interpreted into flexural properties versus fiber volume fraction curve which will show how these properties evolve whether increased or decreased when the fiber volume fraction is increased. The woven composite is fabricated with woven glass fiber and polyester resin through hand lay up method with the fiber volume fraction ranging from 0.17 to 0.33. Specimens are made out of the composite with six samples for each fiber volume fraction to be tested through the flexural test based on JIS K 7055, Testing method for flexural properties of glass fiber reinforced plastics. Japanese Standards Association. The specimens were tested under 50kN of flexural load and then a load-displacement curve was obtained to find the flexural strength and flexural modulus of the composite using two specific formulas. From these data, two graphs of flexural strength and flexural modulus versus fiber volume fraction were plotted so that the behaviour of these two properties can be observed. From this test, the graphs produced was almost consistent with the previous studies which is both of the flexural properties were increased linearly due to the increasing of fiber volume fraction until it reached a certain stage where the volume of the resin is no longer enough to cover the entire composite. Thus, the load cannot be distributed effectively by the resin which caused both properties to decreased when it reach $V_f = 0.33$.

ABSTRAK

Projek ini yang bertajuk "Effect of Volume Fraction on Flexural Strength and Modulus of Woven Composite" secara amnya menerangkan kesan peningkatan pecahan isipadu ke atas kelakuan sifat lenturan komposit teranyam. Kelakuan ini boleh di terjemahkan kepada lengkungan sifat lenturan melawan pecahan isipadu gentian yang mana akan menunjukkan bagaimana sifat-sifat ini berkembang sama ada meningkat atau berkurang apabila pecahan isipadu gentian meningkat. Komposit ternyam ini diperbuat dengan gentian kaca teranyam dan resin polyester melalui kaedah "Hand Layup" dengan pecahan isipadu gentian terlingkung di antara 0.17 dengan 0.33. Spesimen-spesimen diterbitkan dari komposit teranyam dengan enam sampel bagi setiap pecahan isipadu gentian untuk diuji melalui ujian lenturan berpandukan "JIS K 7055, Testing method for flexural properties of glass fiber reinforced plastics. Japanese Standards Association". Spesimen-spesimen ini telah diuji dibawah 50kN bebanan lenturan dan kemudian memperolehi lengkungan bebanan-perubahan untuk mencari kekuatan lenturan dan modulus lenturan menggunakan dua formula khusus. Daripada data-data yang diperolehi, dua graf terbentuk iaitu kekuatan lenturan dan modulus lenturan melawan pecahan isipadu gentian supaya perlakuan kedua-dua sifat ini boleh diperhatikan Daripada ujian ini, graf yang diperolehi hampir menyamai graf dari kajian-kajian yang lepas dimana kedua-dua sifat lenturan meningkat dengan peningkatan pecahan isipadu gentian sehingga ia mencapai satu peringkat dimana isipadu resin tidak lagi mencukupi untuk menutupi kesemua bahagian komposit teranyam. Oleh sebab itu, bebanan tidak boleh disebarkan secara berkesan oleh resin yang mana telah menyebabkan kedua-dua sifat lenturan berkurang apabila pecahan isipadu mencapai 0.33.

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LIST OF SYMBOLS

V_f	Fiber volume fraction
E_1	Longitudinal Modulus
δ	Deflection
P	Force
A	Cross section area
L	Length
E_2	Transverse Modulus
ν_{12}	Poisson's Ratio
G_{12}	Shear strength
σ_f	Flexural Strength

LIST OF ABBREVIATIONS

FRP	Fiber reinforced plastic
GFRP	Glass fiber reinforced plastic
GRP	Glass Reinforced Plastic

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

A 'composite' is a heterogeneous combination of two or more materials (reinforcing agents & matrix), differing in form or composition on a macroscale. The combination results in a material that maximizes specific performance properties. The constituents do not dissolve or merge completely and therefore normally exhibit an interface between one another. In this form, both reinforcing agents and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone.

Composites are commonly classified based on the type of matrix used: polymer, metallic and ceramic. In fiber – reinforced composites, fibers are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation. Matrix also acts as a load transfer medium between the fibers, and protects them from environmental damages due to elevated temperatures, humidity and corrosion. The principal fibers in commercial use are various types of glass, carbon and Kevlar. All these fibers can be incorporated into a matrix either in continuous or discontinuous form.

Composite materials have unique, useful and superior performance that can be predicted from the properties, amounts and arrangements of constituents using principles of mechanics. Compared to conventional engineering materials, composites can be designed to produce exceptional strength and stiffness with minimum weight. They are 30-45% lighter than aluminium structures designed for the same functional requirements. They also perform an excellent corrosion resistance and enjoy lower life cycle cost compared to metals. They are also having improved torsional stiffness, impact resistance properties and appearance with smooth surfaces. The composite are flexible in design and are more versatile than metals and can be tailored to meet performance needs and complex design requirements)

The purpose of this project is to fabricate the composite of glass fiber reinforced polyester with the increase of fiber volume fraction for every composite and to prepare the specimen to conduct the flexural test.

In order to start this project, the objectives and scopes of this project will be stated as a guide during the whole process. Then, the problem involves have to be determined to explain why this experiment must be conducted.

1.2 OBJECTIVES OF THE RESEARCH

a) To fabricate the woven composite using hand layup method
b) To investigate the effect of volume fraction on flexural properties and modulus of woven composite

1.3 SCOPES OF THE RESEARCH

The purpose of this project is to observe the effect of different fiber volume fraction on the flexural strength and modulus of woven glass fiber reinforced polyester composite.

i) Fabrication of woven composite plate
ii) Specimens preparation
iii) Flexural test
iv) Data analysis

1.4 PROBLEM STATEMENT

i) The usage of woven composites has increased over the recent years due to it unique and superior performance that can be predicted from mechanical properties.
ii) Studies had discovered that increase of reinforced element addition produced better mechanical properties such as flexural strength which is the ability of a material to bend before it breaks
iii) Investigate the behavior of flexural strength and modulus upon the increasing of fiber content in the composite

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The usage of woven composite has increased over the years due to their lower production costs, lightweight, higher fraction toughness and better control over the thermo-mechanical properties (Bystrom, Jekabsons, Varna, 2000). For instance, these composite materials are being considered for commercial aircraft fuselage structures. Hingeless and bearingless helicopter rotor hubs that are designed using laminated composite materials experience centrifugal loads as well as bending in the flapping flexure region (Murri, O'Brien, Rousseau, 1997).

2.2 COMPOSITE

Composite is a material created from fibers (or reinforcement) embedded in an appropriate matrix material so that the specific performance properties can be enhanced (Nonwovens in Advance Fiber Composites, 1989). It contains at least two constituents that can be physically or visibly differentiated. The constituents do not completely merge together, creating new identity but their properties are remaining the same as they were joined.

Fiber-reinforced composites have very high strength to weight and stiffness to weight ratios which make them lightweight. They also have electrical insulation properties which make them suitable materials in making electrical appliances and tools. That is why most aerospace and high performance sporting goods are made by them. Experienced have proved that the use of composites allows one to obtained weight reduction varying from 10% to 50%, with equal performance, together with a cost reduction of 10% to 20%, compared making the same piece with conventional metallic materials (Gray, Hoa, 2007). Other significant benefits of composites are excellent durability and corrosion resistance, good fatigue behavior and dimensional stability. Commonly used reinforcing fiber materials include metals, ceramics, glasses and carbon. The fiber can be in continuous or discontinuous forms.

There are a lot of traditional ways to make the fiber reinforced composites, such as injection molding, and wetlay process. The idea of wetlay process was proposed by inventor Gregory P. Weeks in his patent (Weeks, 1989). It provides a way to make composite of highly homogeneous distribution of the glass fiber and the thermoplastic resin matrix.

2.2.1 Reinforcement

During the manufacturing process of the composite material, the bonding between fibers reinforcement material and matrix is created which give the fundamental influence on the mechanical properties of the composite material.

Fibers consist of thousands of filaments which the diameter ranges between 5 and 15 micrometers, allowing them to be producible using textile machines. These fibers are manufactured in the form of short fibers with lengths of a few centimeters of fractions of millimeters are felts, mats and short fibers used in injection molding. The other form is long fibers which are cut during time of fabrication of the composite material, are used as is or woven.

In forming fiber reinforcement, the assembly of fibers to make fiber forms for the fabrication of composite material can take the form of unidimensional (unidirectional tows, yarns or tapes), bidimensional (woven or nonwoven fabrics) and tridimensional (fabrics with fiber oriented along many directions)

Fiber reinforcement materials are added to the resin system to provide strength to the finished part. The selection of reinforcement material is based on the properties desired in the finished product which do not react with the resin but are complete part of the composite.

There are three basic types of fiber reinforcement materials that are commonly used which are aramid fibers, carbon/graphite fibers and glass fibers. Four main factors govern the reinforcing fiber's contribution in the composite are:

a) The basic mechanical properties of the fiber
b) The orientation of the fibers in the composite
c) The amount of fiber in the composite (Fiber Volume Fraction)
d) The surface interaction of fiber and resin

Numerous studies have demonstrated the relationship between the quantity of fibers in the polymer matrix and the flexural and impact strength of fiber reinforced construction. (Valittu, 1997, Narva, 1999).

It has been described by increasing the fiber content the flexural strength increases linearly according to the law of mixtures (Behr, Rosentritt, Lang, Handel, 2000). It is preferable to define the fiber quantity in the polymer matrix in volume percentage rather than weight percentage. (Valittu, 1997).

2.2.2 Matrix

The matrix materials include polymeric matrix (thermoplastic resins and thermoset resins), mineral matrix (silicon carbide, carbon which can be used at high temperatures) and metallic matrix (aluminium alloys, titanium alloys, oriented eutectics)

Resin can be thermosetting or thermoplastic resins. Thermoset resin requires addition of curing agent or hardener and impregnation onto a reinforcing material, followed by a curing step to produce a cured or finishing part. Thermoset resins cure into an irreversible state that caused by a cross-linking in the molecule structure. Examples of thermoset resins for composite are unsaturated polyester, vinyl ester, epoxy, urethane and phenolic.

Thermoplastic resin has a linear molecule structure that will soften repeatedly when heated to its melt temperature and harden when cooled. Examples of thermoplastic resins for composite are polypropylene, polyethylene, polystyrene, nylon, polycarbonate and thermoplastic polyester.

Composite are classified according to their matrix phase which are:

a) Polymer Matrix Composites (PMC's)
b) Ceramic Matrix Composites (CMC's)
c) Metal Matrix Composites (MMC's)

Materials of these categories are often called "advanced" of they combined the properties of high strength and high stiffness, low weight, corrosion resistance, and electrical properties in some special cases. The combination of properties make advanced composite very suitable for aircraft and aerospace structural parts (Vaughan. 1998).

A research conducted by Buereau and Denant (Bereau and Denault, 2000) showed that matrix type affects the behavior of glass fiber/polypropylene composites. They found that a composite with a thermoplastic matrix has 2-stage fatigue damage and that with a thermoset matrix has 3-stage fatigue damage. The fatigue behavior is characterized by the spherulitic regions formed within the composite.

2.2.3 Material Orthotropy

Properties of composite layer strongly depend on the form of the reinforcement in the laminate. Those properties, which are the strength, stiffness, thermal and moisture conductivity, wear and environmental resistance, are actually depend on the directional fibers in the fiber-reinforced laminate. Materials whose properties are independent of direction are called isotropic materials while materials with different properties in different direction are called anisotropic. Orthotropic is a materials when two mutually perpendicular planes of symmetry existed in material properties. It is a special case of anisotropy. Some materials that are included as orthotropic are fibrous composites with either short fibers or continuous fibers. In such composite, its properties are defined in the plane of the layer in two directions- the direction along the fibers and the direction perpendicular to the fiber orientation.

2.2.4 Unidirectional Composite Material Coordinates

Unidirectional fibers are the simplest arrangement of fibers to analyse. The basic element of a unidirectional composite is a thin sheet (*ply*). They provide maximum properties in the fiber direction, but minimum properties in the transverse direction. By convention, the principal axes of the ply are labeled '1, 2, 3'. This is used to denote the fact that ply may be aligned differently from the Cartesian axes x, y, z. Material axes are defined as follows:

- Longitudinal direction (1) – parallel to fibers
- Transverse direction (2) – perpendicular to fibers in plane
- Normal direction (3) – out of plane

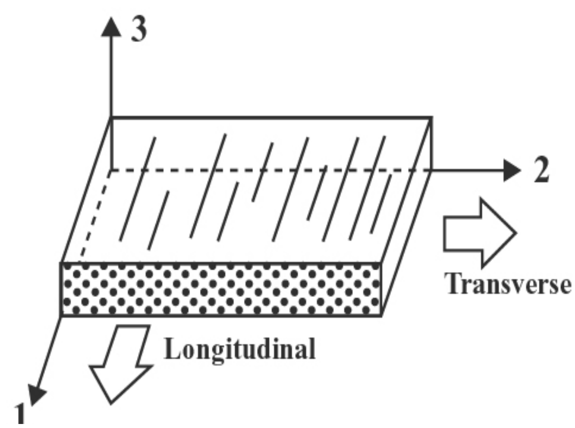


Figure 2.1: The longitudinal and transverse direction in unidirectional composite

2.2.5 Rule of Mixture

Rules of Mixtures are mathematical expressions which give some property of the composite in terms of the properties, quantity and arrangement of its constituents. It is one of the ways to estimate composite material by summarizing the properties of the individual constituents based on their contribution to the overall material volume. It is also employs the volume fraction of the constituents to estimate the properties of the composite.

In the case of a continuous fiber-reinforced composite layer, a fiber volume fraction V_f and a matrix volume fraction V_m, must satisfy

$$V_f + V_m = 1 \tag{2.1}$$

Based on the rule of mixtures, a property p is estimated from the constituent properties, p_f and p_m, as

$$p = p_f V_f + p_m V_m \tag{2.2}$$

$$= p_f V_f + p_m (1 - V_f) \tag{2.2.1}$$

The longitudinal stiffness property, E_1, of the composite maybe calculated from the Young's moduli of the constituents E_f and E_m, using this rule of mixtures as

$$E_1 = E_f V_f + E_m V_m \tag{2.3}$$

The total end-deformation δ of the composite is identical in the fiber and the matrix,

$$\delta_f = \delta_m = \delta \tag{2.4}$$

The total force causing the deformation is carried partly by the fibers and partly by the matrix

$$P = P_m + P_f \tag{2.5}$$

Assuming that each constituent acts as an axial bar with a force displacement relation $\delta = PL/AE$, where A is the cross sectional area, the above equation become

$$\frac{\delta A E_1}{L} = \frac{\delta A_f E_f}{L} + \frac{\delta A_m E_m}{L} \tag{2.6}$$

Since the cross-sectional areas are proportional to fiber fractions ($A_f = V_f A$, $A_m = V_m A$), we obtain Eq. 2.3..

For the elastic modulus in a direction perpendicular to the fibers, the resulting expression for the transverse modulus is

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \tag{2.7}$$

The above equation can be interpreted as the rule of mixtures, Eq. 2.2 applied to the flexibility 1/E. Using similar arguments, Poisson's ratio and the shear modulus for the composite can be obtained in the following form:

$$\nu_{12} = \nu_f V_f + \nu_m V_m \tag{2.8}$$

and

$$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{G_m} \tag{2.9}$$

2.3 GLASS FIBER REINFORCED POLYESTER

Glass fiber reinforced polyester composites are the most popular reinforced plastic materials used in construction industry. Depending on formulation and use, they maybe fabricated into products that are light in weight, transparent, translucent or opaque, colorless or colored, flat or shaped sheets, with no limit to the size of object that can be made.

2.3.1 Polyester

The two components of this composite are the matrix and reinforcing glass. The matrix does not provide strength, but it bonds the reinforcing glass fibers and transfers the load to the reinforcing phase. The matrix is based on cured thermosetting polyester resin which usually supplied in the form of a viscous, syrup liquid comprising a linear unsaturated polyester, a cross linking monomer (curing agent) and an inhibitor to retard cross-linking until the resin is used.

When catalyst (initiator) and glass reinforcement are added, the resulting mixture is ready for production of the GFRP. During fabrication, the monomer reacts with the polyester, resulting in cross-linking of the polyester chain and final cure. The result is a rigid solid material in which the matrix has joined chemically and mechanically with the reinforcing glass fiber to provide a composite structure. The properties of this composite structure are different and significantly superior from those of either material alone.

2.3.2 Glass Fiber

Glass reinforcement provides strength for the glass fiber reinforced polyester composite. It is the most-used fiber in FRPs. It demonstrates excellent thermal and impact resistance, high tensile strength, good chemical resistance and performed the best insulation properties (Neha, 2002) The standard glass fiber used in GRP is borosilicate type; E-glass. It has a tensile strength of 3447 MPa. In general, in reinforced thermoplastics, glass content is between 20-40%.

Table 2.1: The composition and properties of glass fibers

	E-glass	**C-glass**	**S-glass**
Composition (%)			
SiO_2	52.4	64.4	**64.4**
$Al_2O_3 + Fe_2O_3$	14.4	4.1	**25.0**
CaO	17.2	13.4	**-**
MgO	4.6	3.3	**10.3**
$Na_2O + K_2O$	0.8	9.6	**0.3**
B_2O_3	10.6	4.7	**-**
BaO	-	0.9	**-**
Properties			
P (Mgm^{-3})	260	2.49	**2.48**
K ($Wm^{-1}K^{-1}$)	13	13	**13**
A ($10^{-6}K^{-1}$)	4.9	7.2	**5.6**
Σ (GPa)	3.45	3.30	**4.60**
E(GPa)	76.0	69.0	**85.5**
T_{max}(^oC)	**550**	**600**	**650**

Source: Vadya (2002)

Glass reinforcement is used in bundles of fiber combined to form a strand. It can be of several types such as chopped strand mat, rovings (unwoven continuous strands) or cloths (woven fabrics made from glass strands). Chopped strand mat is the most widely used form of glass reinforcement especially in sheet materials. The strands are distributed randomly and the glass content of GFRP generally varies between 25 and 35 percent.

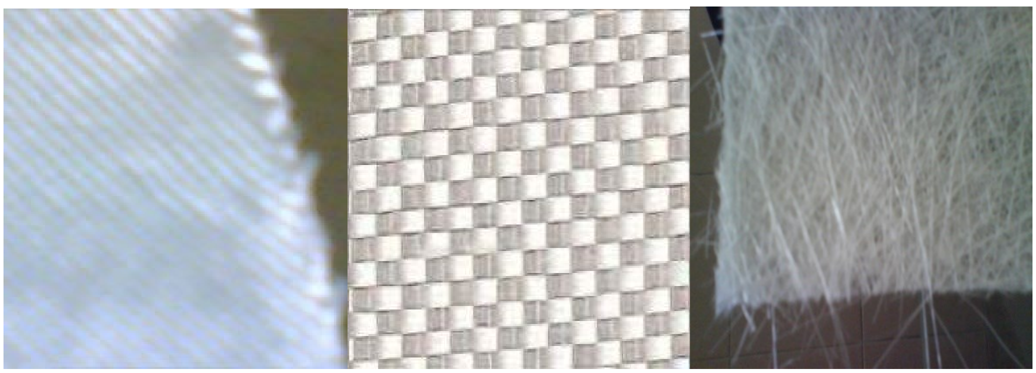


Figure 2.2: Types of glass fiber. From left, cloths (woven fabric), rovings (unwoven continuous strands, chopped-strands mat.

The performance of GFRP material in a given application will depend to the method of manufacture. It maybe made by any of the conventional techniques including hand lay-up, continuous process, spray up, cold or hot press molding and filament winding.

Woven fabrics are made of fibers oriented along two perpendicular directions: one is called the warp and the other is called the fill or weft direction. The fibers are woven together, which means the fill yarns pass over and under the warp yarns, following a fixed pattern.

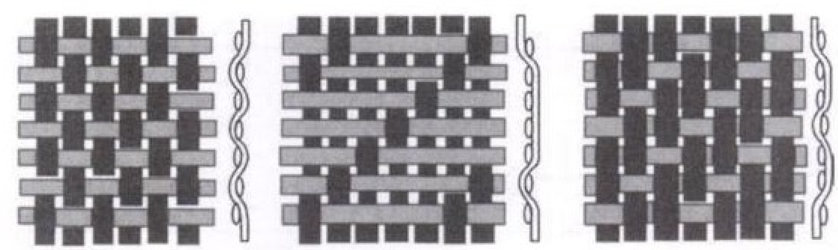


Figure 2.3: From left, plain weave, satin weave, twill weave

Source: Gay, Hoa, 2007

In plain weave fabric, each fill goes over a warp yarn then under a warp yarn and so on. For satin weave, each fill yarn goes over 4 warp yarns before going under the fifth one.

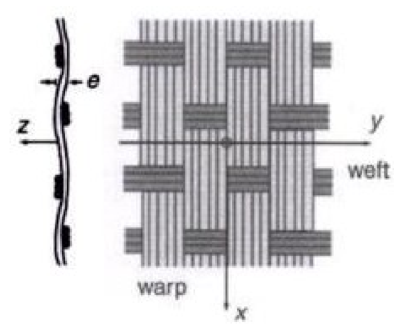


Figure 2.4: Notation for a fabrics layer

Source: Gay, Hoa, 2007

2.3.3 Properties

The properties of finished GRP composite material depend on a great number of compositional and fabrication factors, some of the most important are resin formulation, curing conditions, type and amount of reinforcement, fabrication process and workmanship.

By choice of ingredients, special properties can be achieved. For example, fire retardance can be achieved by incorporating appropriate additives, although it is preferable to modify the basic unsaturated polyester resin to provide built-in fire resistance. GRP reinforced with cloth fabric and roving give a material that is anisotropic in character with properties varying directionally while GRP with chopped strand mat as reinforcement is essentially isotropic.

The range of some physical properties given in Table 2.2 is typical for GRP sheet materials produced with normal care from general purpose polyester resin and reinforced with three types of glass fiber reinforcement.

Table 2.2: Physical Properties of glass fiber reinforced general-purpose polyester sheet (reinforced with various glass fiber construction)

Properties	Chopped-strand Mat	Rovings (Unwoven Continuous Strands)	Cloths (Woven Fabric)
Glass content, weight %	25-45	50-70	**62-67**
Tensile Strength (MPa)	76-160	550-900	**540-600**
Tensile modulus (GPa)	5.6-12	-	**31**
Flexural Strength (MPa)	140-260	690-1400	**590-720**
Flexural modulus (GPa)	**6.9-14**	**34-49**	**31-38**

Source: Blaga (1978)

2.4 HAND LAY UP

Hand lay-up (Khashaba, 2003) is an open contact molding method in one-sided molds with the lowest-cost and most common process for making fiberglass composite products. It is also the most common method of producing composites parts and is used when such parts must be rigid and robust in liquid resin casting.

2.4.1 The Method

A reinforcing fabric or mat, frequently fiberglass, is placed into an open mold or over a form, and the resin is poured over the fabric to wet it thoroughly using a steel roller and to penetrate into a weave, ideally with little or no air entrapment. When plastic hardens, the object is removed from the mold or form, trimmed as necessary and is then ready for use.

Many boats are produced using this process such as bass boats, canoes, sailboats and even military landing craft.

This basic process can be automated as required, with proportioning, mixing and dispensing machines for liquid resin preparation; with matched molds and with conveyors and curing oven.

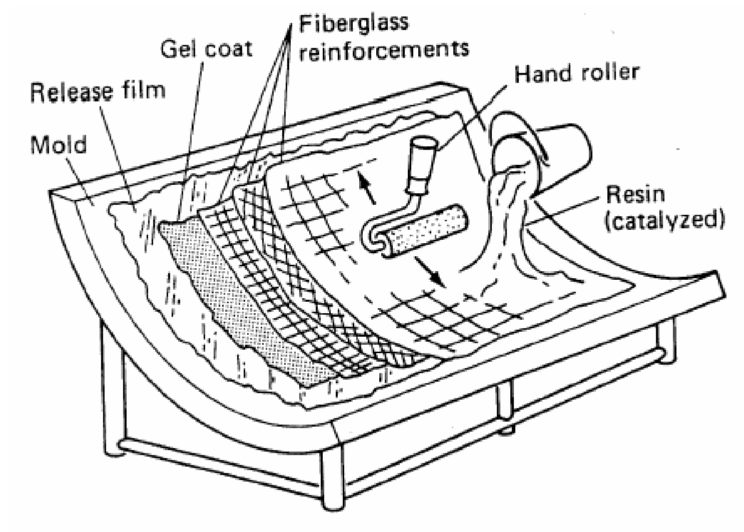


Figure 2.5: Hand lay-up process for producing highly reinforced parts with fiber matting and epoxy.

Source: Modern Plastics Handbook, Charles A. Harper

2.4.2 Reinforcement

Most hand lay-up uses glass fiber chopped strand mats in weight percentages of 30 to 45% of the composite laminate. Other than that, woven roving is also commonly used to achieve higher reinforcement loadings and strength. Woven roving as a weight percent of laminate may range to 65%.

2.4.3 Manufacturing Advantages

Hand lay-up offers a number of benefits although it is among the simplest composite manufacturing process. Hand lay-up process requires a low tooling cost because it does not involve any major machine or any special tools, only the mold and a roller or brush because it is conducted manually by hand. In this process, theoretically, there is no restriction regarding to its' size of part to be fabricated. It can be done on any size or configuration with high surface-are-to-thickness ratios.

The products that use this manufacturing product vary from skateboard deck to yacht and speed boat. Through this method, the parts can be easily fabricated while the molds can be easily modified, cut into part for prefabrication and applied to create various surface textures. It is also easy to control the orientation of the fiber. The designs are also easy to change with variety of colors and decorative finishes.

2.4.4 Process Limitation

The hand lay-up process has several limitations. This process will only result to one finished or “appearance” surface with the quality of the product depends mostly on operator skill. The shape of the product is limited by the ability of reinforcing materials to conform to the mold. The cycle time per part is very long, and only small series can be produced while the rigid properties of final product require that under cuts and straight will be eliminated. In this method, any openings must be machined in post molding operations and all corners must have somewhat large radius. This process also produces emissions of volatile chemicals from the resin system which will slowly be harmful to the operator.

2.5 MECHANICAL TESTING

The complex behavior of fiber-reinforced plastic materials is due to their anisotropic and inhomogeneous properties. These properties cause a variety of failure mechanisms associated with fiber-reinforced composite materials (Lin, Hu, 2002). To investigate how these properties varied with the failure of the composite, a series of mechanical testing can be done.

2.5.1 Flexural Test

Flexural test or bending test can be divided by two; 3-point and 4-point. Figure2.5 below show the diagram of 3point and 4-point flexural tests.

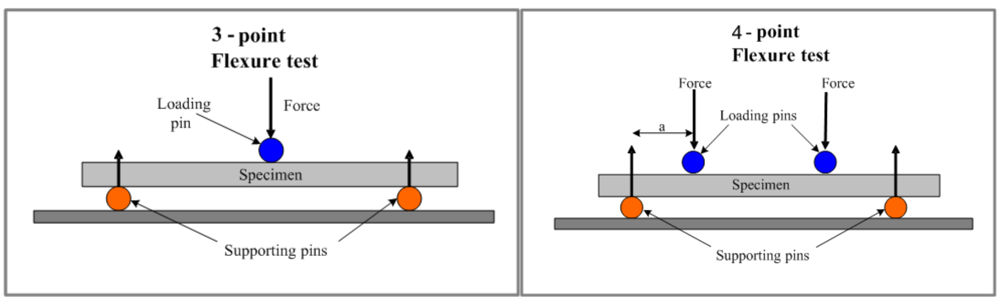


Figure 2.6: 3-point and 4-point flexural tests

The flexural strength of a material is its ability of a material to bend before it breaks. It is obtained when the ultimate flexibility of one material is achieved before its proportional limit. A high flexural strength is desired once the material is under a stress that might induce permanent deformation. Flexural modulus is the ratio, within the elastic limit, of the applied stress on a test specimen in flexure, to the corresponding strain in the outermost fibers of the specimen.

According to Khashaba (Khashaba, 2006), the flexural strength of 4-point specimen is higher than 3-point specimen. This is because the knee (the micro cracking of the matrix) in the 3-point bending test occurs at approximately half of the loading value in the 4-point bending test. He also found that the bending stress is associated with shear stress due to the load concentration at the center of the specimen in the 3-point flexural test which is the main cause of the catastrophic failure of the specimen.

Several researchers found that bending strength was greater than tensile strength in polymeric composite materials (Palmer, Nettles, 1999). Wisnom (Wisnom, 1992) reported in his review that the ratios between 3-point flexural strength and tensilte strength of different composite materials were in the range of 1.3-1.49. The predicted ratios using Weibull strength analysism for a wide variety of brittle materials were found to fully agree with the measured values. Bosia (Bosia, Facchini, Botsis, 2004) investigated the dependency of strains on the thickness of laminated composites plates subjected to 3-point bending loads. They found that using a concentrated load in 3-point bending experiments had enhanced the nonlinearities in the vicinity of the applied load.

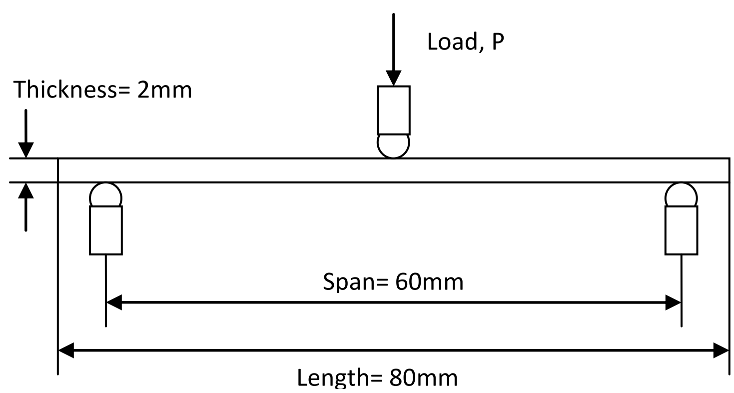


Figure 2.7: 3-point bending test

To evaluate the flexural strength, a test can be done on a specimen with dimension of 80×26×2mm (JIS K7055). Specimens are placed on two supports and a load is applied at the center. This test is known as three-point bending test. The load at yield is the sample material's flexural strength that is calculated by the following formula:

The load at yield is the sample material's flexural strength that is calculated by the following formula:

$$\sigma_f = \frac{3P_{\max}S}{2wt^2} \tag{2.10}$$

Flexural modulus is calculated from the slope of the stress vs. deflection curve. If the curve has no linear region, a secant line is fitted to the curve to determine slope. It can be calculated using the formula below:

$$E_f = \frac{S^3 m}{4wt^3} \tag{2.11}$$

Where P_{max} = is the ultimate load at fracture

S = The specimen's span

w = width

t = Thickness

m = slope of the load-displacement curve

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the entire method and procedures used during the execution of this project will be explain briefly, starting from calculating the fiber volume fraction that will be used to fabricate the composite, fabricate the composite using hand lay-up method, prepare the specimens according to the specific standard, conduct the flexural test and finally plotting the flexural strength vs fiber volume fraction curve to observe the behavior of the flexural strength and modulus of the composite with the increase of the fiber volume fraction. The flow of the whole process is shown in the Figure 3.1 below.

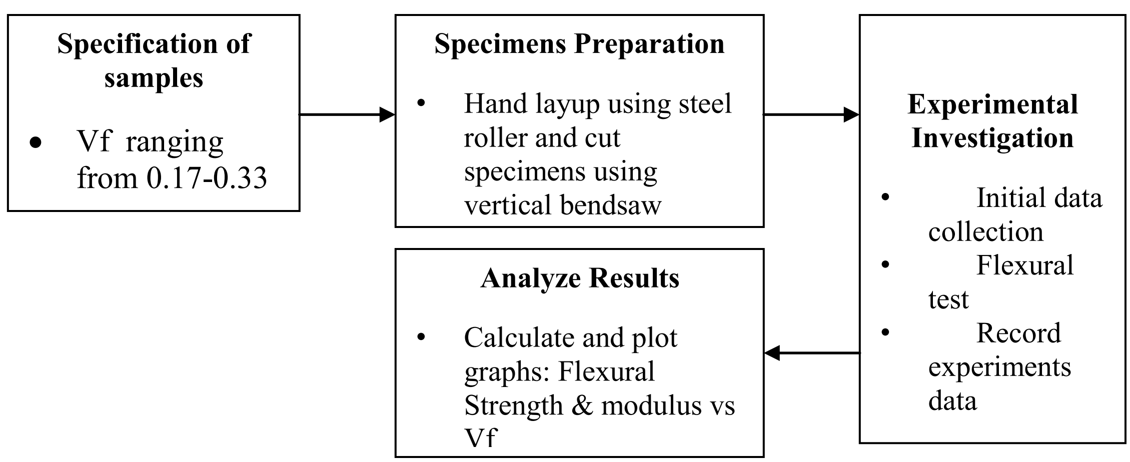


Figure 3.1: Flow Chart of Methodology for the Project

3.2 RAW MATERIAL

In this study, unsaturated polyester resin was selected as a thermosetting resin material and woven roving glass fiber as shown with its mechanical properties in Table 2.3 as a reinforcement material. Woven fabrics are made of fibers oriented along two perpendicular directions: one is called the warp and the other is called the fill or weft direction, held together with a resinous binder. The unsaturated polyester resin cured with Methyl Ethyl Ketone Peroxide (MEKP) as catalyst was used. For this project, the polyester resin and the glass fiber was supplied by the Faculty of Mechanical Engineering Lab. A schematic representation of glass woven is shown in Figure 3.2 below.

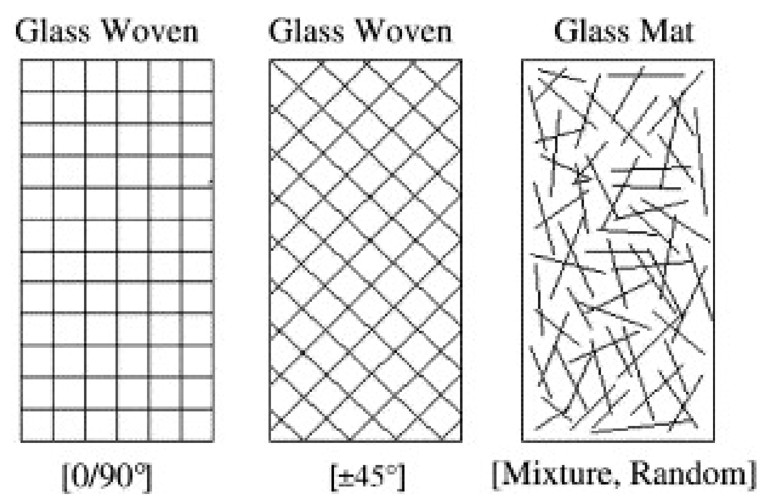


Figure 3.2: Schematic representation of woven glass

Table 2.3: Constituent materials of composite laminates

Material	Type
Reinforcement	Matrix E-woven roving glass fiber Fabric weight: 0.4kg/m^2 Fabric weave: Plain
Matrix	Orthophthalic: polyester resin Catalyst: Methylethyl ketone peroxide

3.3 COMPOSITE FABRICATION

3.3.1 Preparation of Reinforcement

Layers of 33x25cm of woven roving glass fiber were cut and weight to get the exact weight for every layer.

Figure 3.3: The process of cutting the woven roving glass fiber

3.3.2 Preparation of Mould

A mirror with dimension of 50x100cm was used as the mould and was cleaned thoroughly so that it is free from dirt and crack before the application of the release agent. This application is to allow an easy release of the composite from the mould after it is completely cured.

3.3.3 Preparation of Matrix Material

Then, a certain amount of polyester resin is weight into a container and for this project, 250g is used. 0.1% of methylethyl ketone peroxide is then added into the resin and stirred using a spatula slowly to avoid the formation of bubbles. It is then be left for some time so that any bubbles formed during the stirring may die out. The amount of added catalyst should not be high because a high percentage reduces gel time of polyester resin and may adversely affect impregnation.

3.3.4 Preparation of Laminate

The first layer of mat is laid onto the mould and resin is spread onto it uniformly using a steel roller to enhance wetting and impregnation. Laid the second layer and roll over the roller to wet it using the remaining resin from the first layer then if it still did not wet enough, pour the resin and roll over the roller to wet it thoroughly. These processes were repeated until the certain amount of layers needed is achieved. No external pressure should be applied while casting or curing because uncured matrix material squeezes out under high pressure. A symmetry should be maintained in stacking the fiber layers. The casting is cured at room temperature for 24 hours and finally removed from the mould to get a fine finished composite plate.

3.3.5 Preparation of Test Specimens

Test specimens are cut from the composite plate by using a vertical saw in the laboratory. Some precautions should be taken such as wearing proper attire with goggles and mask to avoid the inhalation of the particles from the composite. All the test specimens are finished by abrading the edges on a wood sand paper.

Figure 3.4: The process of cutting the composite into specimens using vertical saw

3.3.6 Specimens Labelling

Each specimen will be prepared in 6 samples labelled with number 1-6 and the value of the content of the fiber as shown in Figure 3.5 below:

Figure 3.5: Specimen of 30wt% of glass fiber numbered from 1-6

3.4 FLEXURAL TEST

Figure 3.6: The Instron machine used to perform the Flexural Test

This test is performed according to JIS K7055, JIS K 7055. Testing method for flexural properties of glass fiber reinforced plastics, Japanese Standards Association. First, the machine is checked suitable to be used for 3-point flexure test as in the figure. Then, start the application of the Instron software and key in all the required input including the dimension of the specimen, cross-head speed and data collection method as followed:

Table 3.1: The Input of the Flexural Test

Properties	Value
Test Span	60mm
Specimen width	26mm
Specimen length	80mm
Specimen thickness	2mm
Cross-head speed	2.54mm/min
Applied force	45kN

The specimens were then loaded into the machine as shown in Figure 3.7 and the test is started. The load-deflection curves were then recorded using PC-computer software (name and model). Data of the flexural properties and the fracture load values were then analyzed using the fiber volume fraction as independent variable and flexural strength and modulus vs fiber volume fraction curves were obtained using Microsoft Excel 2007 software to observe whether these properties are increased or decreased to the increase of fiber volume fraction.

Figure 3.7: Specimen is loaded into the machine before the test is started.

Flexural strength and flexural modulus were calculated from the following formula:

$$\text{Flexural Strength, } \sigma_f = \frac{3P_{max}S}{2wt^2} \qquad (2.12)$$

$$\text{Flexural Modulus, } E_f = \frac{S^3 m}{4wt^3} \qquad (2.12)$$

Where: P_{max} = The applied load at the highest point of load-deflection curve

S = The span length (60mm)

w = Width of the specimen (26mm)

t = Thickness of the specimen

m = the slope of the straight-line portion of the curve

3.5 FIBER VOLUME FRACTION

The quantity of fibers in the specimens was determined by combustion of the polymer matrix of the test specimens for 1 hour at 700^{o}C in a furnace (Material Laboratory, Faculty of Mechanical Engineering Laboratory). The weight of the specimens before and after the combustion was measured with a balance (name and model) with an accuracy of 0.1 mg. The fiber content as percentage by volume (V_f) (vol%) was calculated with the following formula:

$$V_f = \left[\frac{\frac{W_f}{r_f}}{\frac{W_f}{r_f} + \frac{W_r}{r_r}} \right] \times 100\% \tag{2.13}$$

Where:

	W_f	= weight proportion of fiber
	r_f	= density of the fiber
	W_r	= weight proportion of resin
	r_r	= density if the resin

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss the results obtained from the standard based flexural test, JIS K 7055, Testing Method for Flexural Properties of Glass Fiber Reinforced Plastic. The analysis will be made based on the load-deflection curve which was calculated from the data produced by the INSTRON Model 3369 from the test. By the end of this chapter it can be seen how the flexural strength and flexural modulus varied according to the increasing of fiber volume fraction of the composite.

4.2 TYPICAL RESULT

The test was done under 50kN load by using the INSTRON Model 3369 machine The displacement from the crosshead and the force from the load cell were recorded to obtain the load-displacement curve (Figure 4.1). The load versus displacement graph given based on the data produced by the machine was plotted as shown below

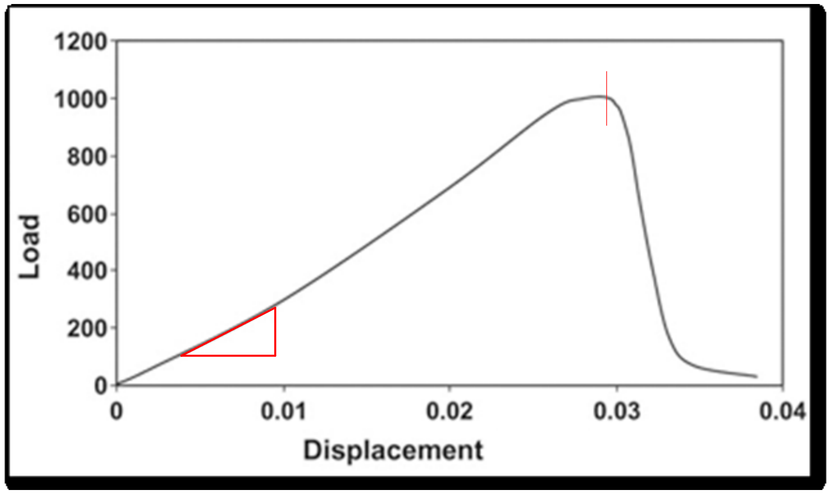


Figure 4.1: Typical load-displacement curve of glass fiber flexural test

The load-displacement curve shows the value of maximum load and displacement to be used to calculate the value of flexural strength and the value of the slope of the initial straight curve will be used to calculate the value of flexural modulus as shown in the Figure 4.1 above.

Then, the value of the flexural strength and modulus of all the specimens will be plotted to obtain the flexural strength vs fiber volume fraction curve and the flexural modulus vs fiber volume fraction curve.

4.3 RESEARCH RESULT

4.3.1 The Calculations

Glass fiber and polyester composites were fabricated with fiber volume fraction ranging from 0.17 to 0.33.

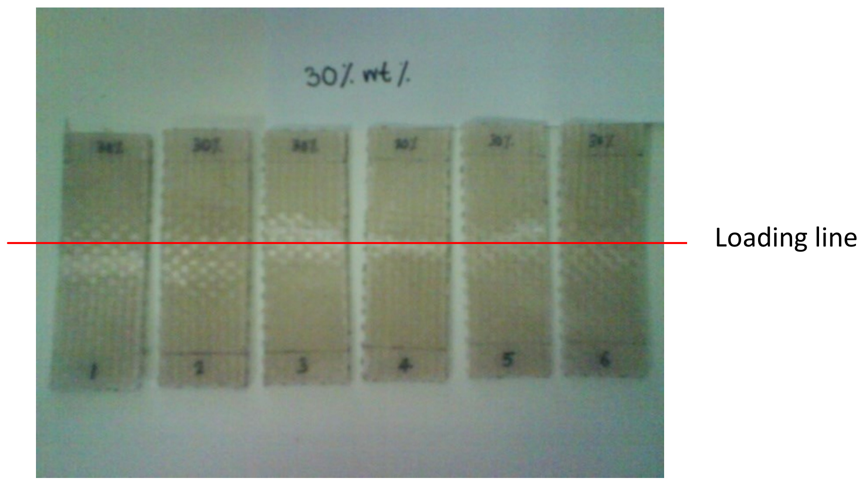


Figure 4.2: Specimens of 17.28% fiber volume fraction with 30wt%

From figure 4.2 above, it can be observed that a white region appeared at the middle of each of the specimen. This white region is recognized as the loading line that caused by the load concentration from the cross-head of the machine applied from the test.

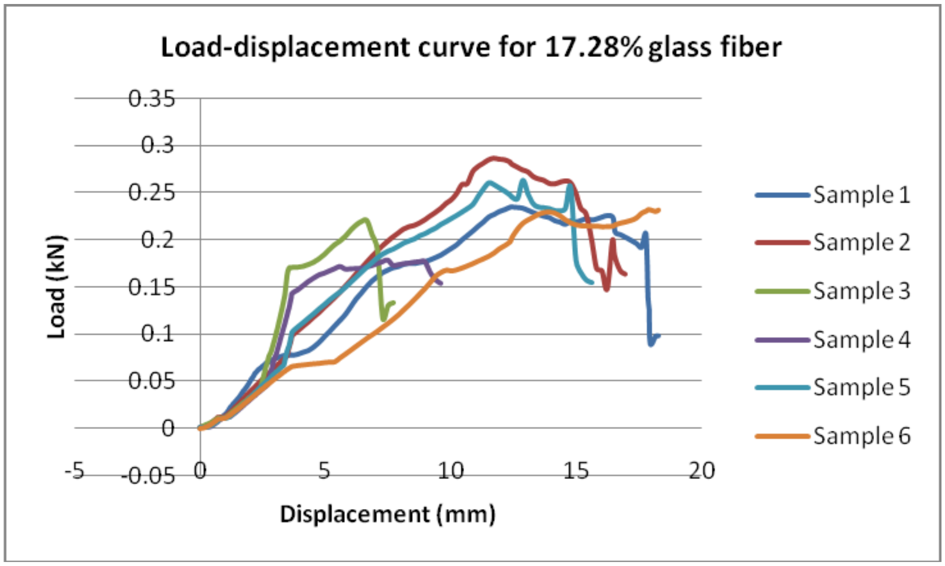


Figure 4.3: Load-displacement curve for 17.28% glass fiber specimen

Figure 4.3 above shows the load-displacement curve for fiber volume fraction of 17.28%. The maximum load that can be held by this specimen is 0.2865kN at the maximum deflection of 12.5308mm. The flexural strength can be calculated from these values using this formula:

Flexural Strength, $\sigma_f = \frac{3P_{max}S}{2w\,t^2}$

$$\sigma_f = \frac{3\times 0.2865\times 10^3\, N\times 0.06m}{2\times 0.026\times 0.002^2}$$

$$\sigma_f = 238.77MPa$$

To calculate the value of flexural modulus, the slop of the curve, m, have to be determined. Select the initial linear portion of the curve and calculate the value of m:

$$m = \frac{0.0033 \times 10^3 - 0.0016 \times 10^3}{0.3386 \times 10^{-3} - 0.2537 \times 10^{-3}}$$

$m = 19.92 \times 10^3$N/m

Then, using the formula below, the value of flexural modulus can be calculated.

Flexural Modulus, $E_f = \frac{S^3 m}{4wt^3}$

$$E_f = \frac{(0.06^3) \times 19.92 \times 10^3}{4 \times 0.026 \times 0.002^3}$$

$E_f = 4.98GPa$

The specimens and load-displacement curves for 36wt%, 41wt% and 46wt% of glass fiber content can be found in Appendix C. Table 4.1 below shows the result of flexural strength and flexural modulus for every fiber volume fraction after the similar calculation were done on the test results.

Table 4.1: The result of flexural strength and modulus for every sample.

Fiber Volume Fraction	σF(Mpa)	EF(Gpa)
0.17	196.7	5.447
0.22	177.97	9.110
0.25	238.93	14.740
0.29	349.11	29.820
0.33	313.67	25.570

4.3.2 The Evaluation of the Results

From the Table 4.1 above, the flexural strength and modulus vs fiber volume fraction curves can be plotted as in Figure 4.4 and Figure 4.5 below:

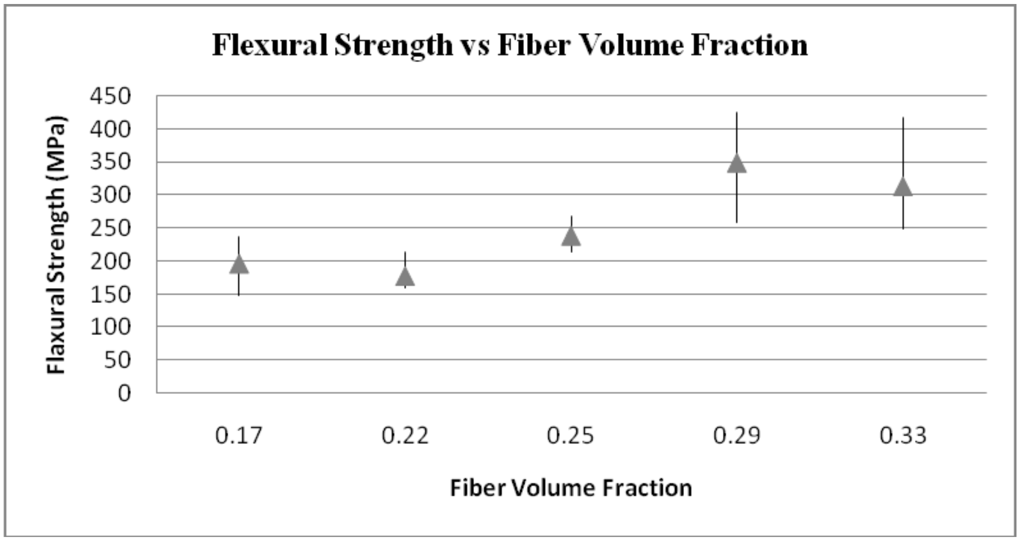


Figure 4.4: Flexural strength vs fiber volume fraction curve

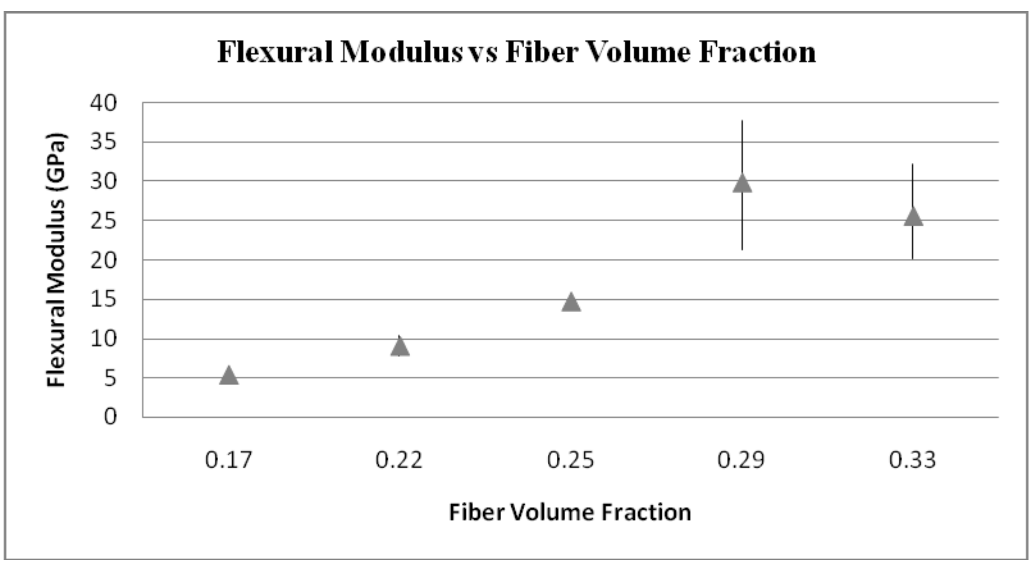


Figure 4.5: Flexural modulus vs fiber volume fraction curve

Figure 4.4 and figure 4.5 above show the flexural test results for glass fiber and polyester composites. For this test, 6 specimens were tested for each fiber volume fraction which was done according to JIS K 7055. All together, 30 specimens were tested to get these results. From the figure, it can be observed that both the flexural strength and modulus increased linearly as the fiber volume fractions increases. It has been described by increasing the fiber content; the flexural properties will increases linearly according to the law of mixtures (Behr, Rosentritt, Lang, Handel, 2000). Then, both properties reach the maximum value at a fiber fraction of 0.29. In other word, for Glass/Polyester composites, 0.29 seems to be an optimal fiber volume fraction for both flexural strength and flexural modulus.

However, when it reaches the fiber volume fraction of 0.33, the flexural strength and modulus were both decrease. The only explanation is the interactions between the fibers and the resin used in the composites. During the manufacturing process of the composite material, the bonding between fibers reinforcement material and matrix is created which give the fundamental influence on the mechanical properties of the composite material. When the fiber volume fraction is low, the resin can cover the entire fiber; act well as the matrix which is to transfer load to the entire composite. This is why be low a certain fiber volume fraction, the flexural strength and flexural modulus increase with the increasing of the fiber volume fraction. However, as the fiber volume fractions become higher, the fixed amount of the resin can no longer be spread throughout the fibers which caused the voids and poor bonding between the fibers and the resin to exist. Hence, the flexural strength and modulus start to decrease as the fiber volume fraction increases above a critical value.

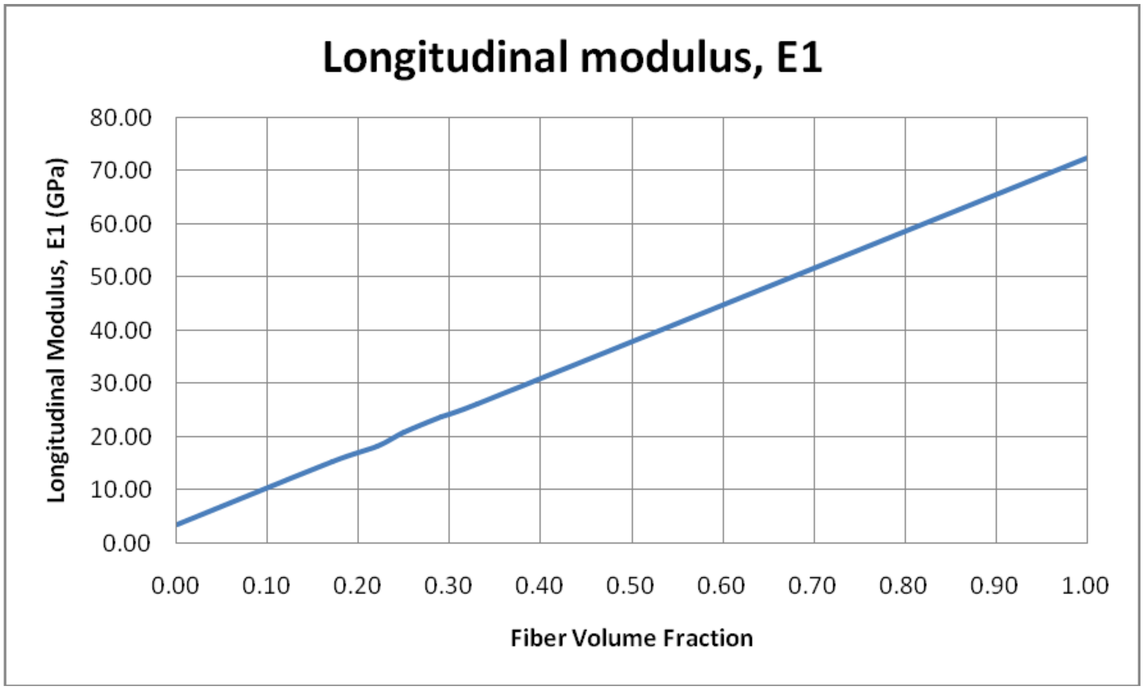


Figure 4.6: Evolution of the longitudinal modulus E_1 with the fiber volume fraction

Figure 4.6 above shows that the evolution of the longitudinal modulus, E_1 of the composite with the fiber volume fraction, V_f is linear and progress from the resin modulus to the fiber's one. This linear evolution is evaluated by Eq. 2.3:

$$E_1 = E_f V_f + E_m V_m \tag{2.3}$$

where E_f is the fiber longitudinal modulus and E_m is the matrix Young modulus.

This linear evolution is described by many researchers where relations between the mechanical parameters of the composite and the fiber volume fraction were presented. (Hashin, 1983, Halpin and Tsai, 1969)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The usage of woven composite has increased over the years due to their lower production costs, lightweight, higher fraction toughness and better control over the thermo-mechanical properties. It has unique, useful and superior performance that can be predicted from the properties, amounts and arrangements of constituents using principles of mechanics. Compared to conventional engineering materials, this composite can be designed to produce exceptional strength and stiffness with minimum weight. However, it is important to understand the mechanical properties of this composite and how its mechanical properties react to a given load from its surrounding.

In this research, the woven glass fiber and polyester resin have been chosen as the material to produce the composite plate. After the composite is fabricated through hand layup method with five different fiber volume fraction ranging from 0.17 to 0.33, test specimens were made out of it and were tested through flexural test to see how the flexural properties of the composite evolve with the increasing of fiber volume fraction. After the test had been made, it can be observed that both flexural strength and modulus were increased with the increasing of fiber volume fraction which had been agreed from the previous study by Vallittu.

From the test, the highest flexural strength of the Glass/Polyester composite is 349.11 MPa at the fiber volume fraction of 0.29 while the highest flexural modulus is 29.820 GPa which also reached by specimen with the same fiber volume fraction. When the test was done on specimen with V_f of 0.33, the flexural properties started to decrease which is caused by the interaction of fiber and resin.

As a conclusion, it can be said that the flexural properties of the composite is gradually evolve with the increasing of the fiber content until it reach a certain stage when the resin can no longer transfer the load applied to the composite through a certain amount of fiber content.

5.2 RECOMMENDATION FOR FUTURE RESEARCH

The flexural tests conducted were successful because the data obtained was considerably relevant to the previous studies of the woven composite. However, in order to make the study on the woven composite better, these are few steps that could be taken to improve the result and data analyzing process:

i. The range of the fiber volume fraction used should be larger so that the behaviour of the flexural properties can be observed more detailed.

ii. The equipment and materials used should be upgraded and the quantity should be added so the fabrication of the composite can be done in a convenient way.

iii. Other test should be conducted as well so that the data can be compared with other mechanical properties of the woven composite.

iv. The used of other type of fiber could be used in the research so that a different behaviour of different fiber can be observed and learnt.

REFERENCE

Behr, M, Rosentritt, M, Lang, R. and Handel, G. 2000. Flexural properties of fiber reinforced composite using a vacuum/pressure or a manual adaptation manufacturing process. *J Dent.* 28: 509-14.

Bereau, M. N. and Denault, J. 2000. Fatigue behavior of continuous glass fiber composites: Effect of the matrix nature. *Polymer composite.,* 21(4): 6360644,

Blaga, A. 1978. GRP Composite Materials in Construction: Properties, Applications and Durability. *Industrialization Forum.* Vol. 9, 27-32.

Bosia, F, Facchini, M. and Botsis, J. 2004. Through-the-thickness distribution of strains in laminated composite plates subjected to bending. *J Comp Sci Technol.* 64:71–82.

Bystrom, J. and Jekabsons, N. and Varna, J. 2000. An evaluation of different models for prediction of elastic properties of woven composites. *J Comp Part B.* **31**, pp. 7–20.

Gay, D. and Hoa, S.V. 2007. Second Edition Composite Materials Design and Applications, 7, 135

Halpin, J.C and Tsai, S.W. 1969. Effects of environmental factors on composite materials. *AFML-TR.* 67-243.

Hashin, Z. 1983. Analysis of composite materials. *J Appl Mech.* 50: 481–505.

Khashaba, U.A. 2003. Fracture behavior of woven composites containing various cracks geometry. *J Comp Mater.* 37(1):5–21.

Khashaba, U.A. and Seif, M.A. 2006 Effect of different loading conditions on the mechanical behavior of [0/±45/90] woven composites. *Composite Structures 74: 440-448.*

Lin, W.P and Hu, H.T. 2002. Parametric study on the failure of fiber reinforced *composite laminates under biaxial tensile load. J Comp Mater.* 36(12):1481–503.

Murri,G.B, O'Brien, T.K. and Rousseau, C.Q. 1997. Fatigue life methodology for tapered composite flex beam laminates. *American Helicopter Society, Inc.*

Murri, G.B, Schaff J.R. and Dobyns, A.L. 2001. Fatigue and damage tolerance analysis of a hybrid composite tapered flexbeam. *American Helicopter Society, Inc.*

Nonwovens in Advance Fiber Composites. 1989. *Philippe Coppin Consulting, Nonwovens An Advance Tutorial, TAPPI: 71-79.*

Palmer, S.O. 1999. An experimental study of a stitched composite with a notch subjected to combined bending and tension loading. *NASA Report No. NASA/TM-1999-209511, National Technical Information Service, 1999.*

Vaidya, N. 2002. The manufacturing of wet-laid hydroentangled glass fiber composites for industrial applications. 12

Vallittu, P.K. and Narva, K. 1997. Impact strength of a modified continuous glass fiber-poly (methyl methacrylate). *Int J Prosthodont.* 10: 142-48.

Vallittu, P.K. 1999. Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers. *J Prosthet Dent.* 81: 318-26.

Vaughan, D.J. 1998. Fiberglass reinforcement. *Handbook of composites.* 131-155, 352-377, 1053-1058

Weeks, G. 1989. Automotive structural composites for nonwoven perform. *E. I. Dupont de Nemours and Co.* INDA-TEC: 197-218.

Wisnom, M.R. 1992. The relationship between tensile and flexural strength of unidirectional composites. *J Comp Mater.* 26(8):1173–80.

APPENDIX A

Table of Specimens Data

Glass/Polyester Data			
Fiber Volume Fraction	**Samples**	**σF(Mpa)**	**EF(Gpa)**
0.17	1	195.42	4.972
	2	237.25	6.010
	3	182.92	4.880
	4	148.35	5.160
	5	219.5	6.400
	6	196.67	5.260
	Average	196.7	5.447
0.22	1	159.81	8.785
	2	166.67	9.335
	3	183.66	8.913
	4	212.93	7.860
	5	186.68	9.443
	6	158.08	10.320
	Average	177.97	9.110
0.25	1	267.83	14.568
	2	244.22	14.225
	3	235.4	15.350
	4	214.67	14.770
	5	236.83	14.740
	6	234.6	14.783
	Average	238.93	14.740
0.29	1	258.53	21.260
	2	296.78	22.510
	3	424.35	34.400
	4	410.71	37.680
	5	382.14	34.030
	6	322.16	29.060
	Average	349.11	29.820

0.33	1	416.9	28.590
	2	334.78	32.280
	3	247.8	20.198
	4	272.83	24.390
	5	320.28	24.060
	6	289.4	23.900
	Average	313.67	25.570

APPENDIX B

JIS K 7055. Testing method for flexural properties
of glass fiber reinforced plastics.
Japanese Standards Association; 1987.

APPENDIX C

Figure of Specimens and Load-displacement Curves

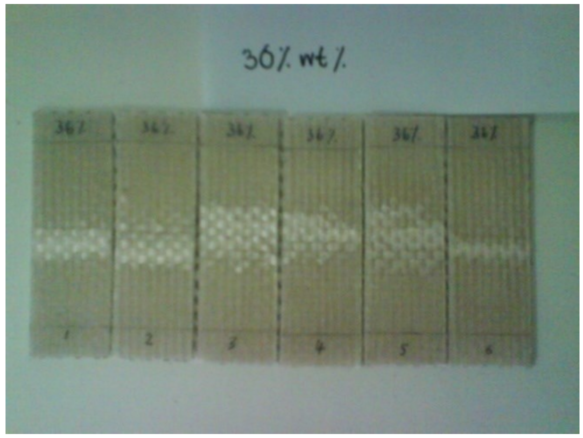


Figure 4.7: The specimens with fiber volume fraction of 21.52%

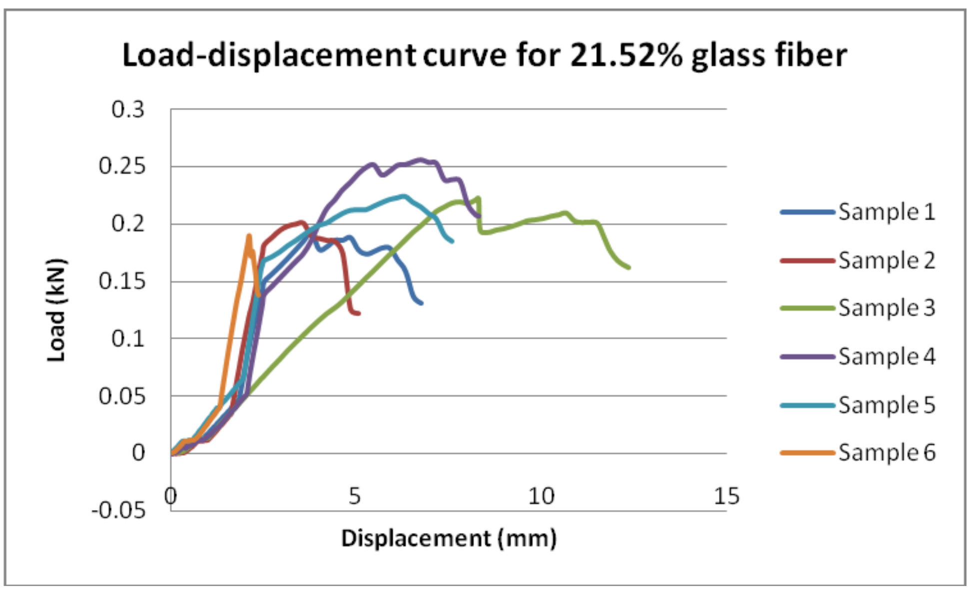


Figure 4.8: The load-displacement curve for fiber volume fraction of 21.52%

Figure 4.9: The specimens with fiber volume fraction of 25.3%

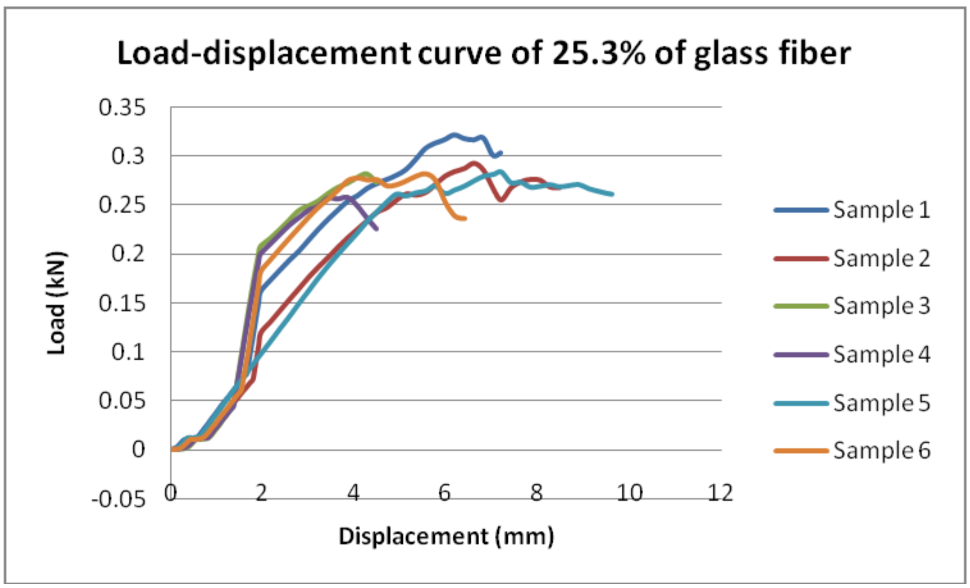


Figure 4.10: The load-displacement curve for fiber volume fraction of 21.52%

Figure 4.11: The specimens with fiber volume fraction of 29.34%

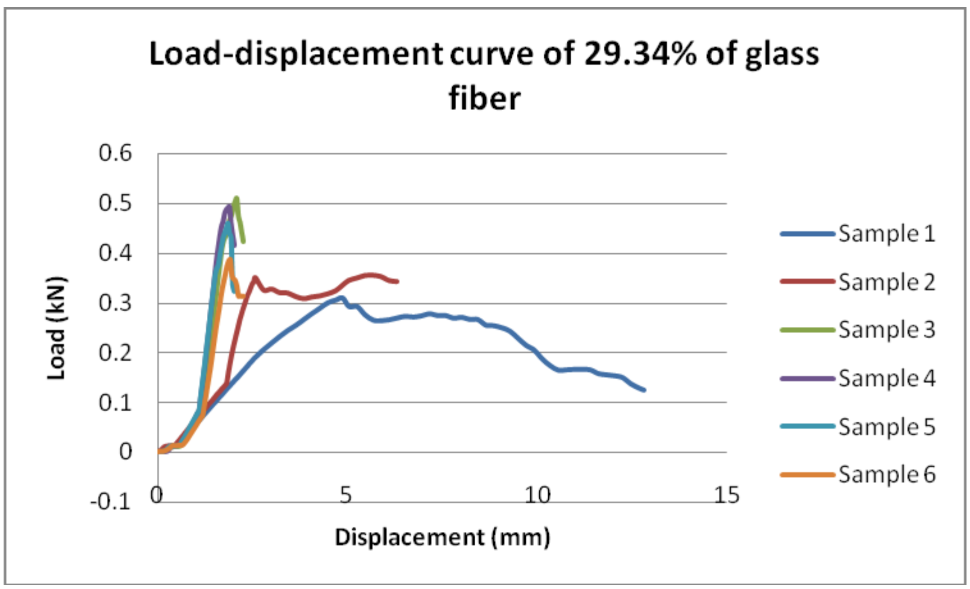


Figure 4.12: The load-displacement curve for fiber volume fraction of 21.52%

Figure 4.13: The specimens with fiber volume fraction of 32.8%

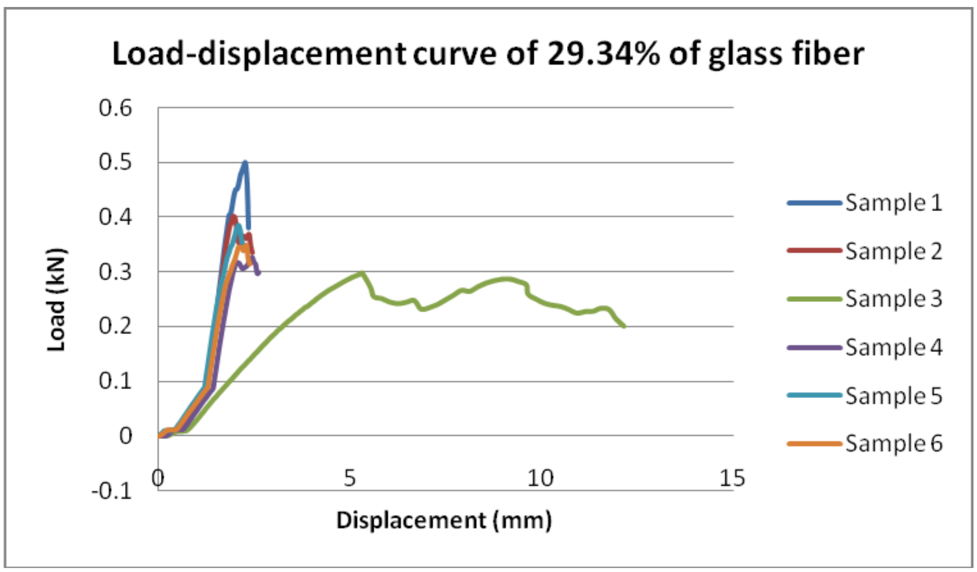


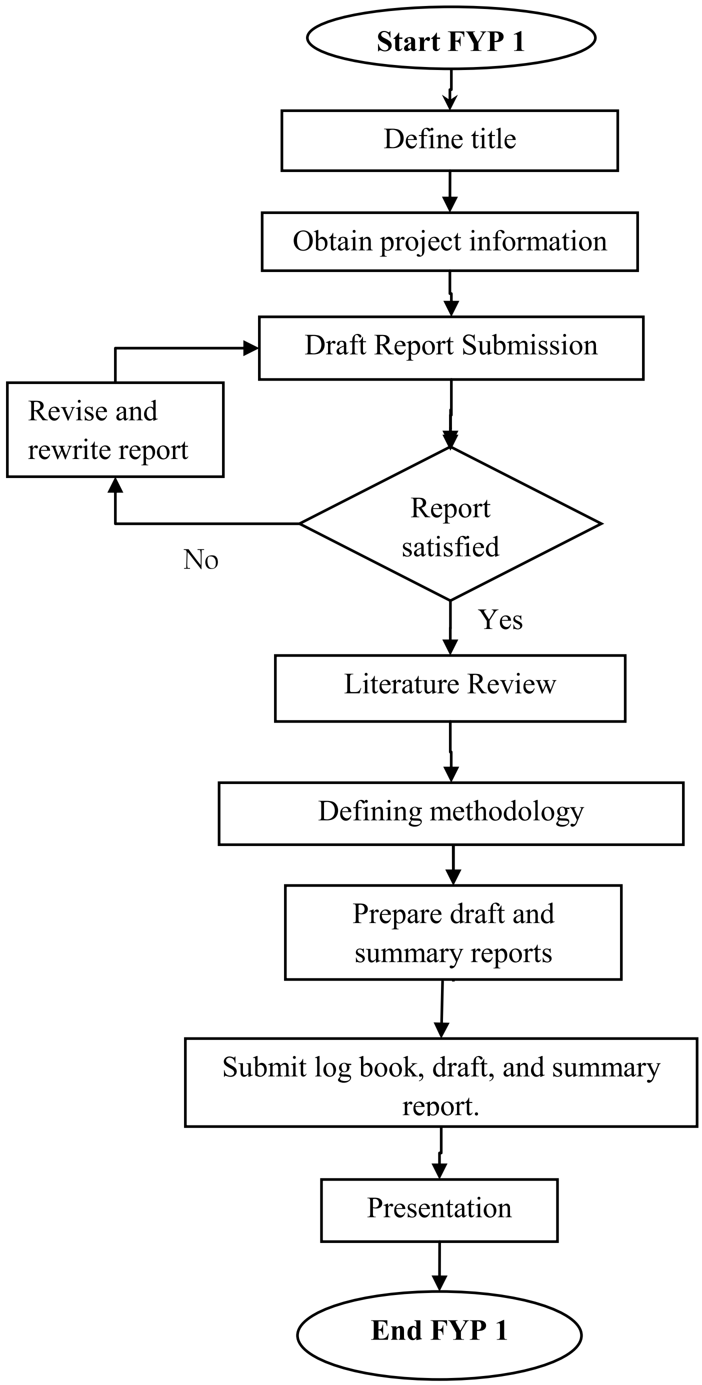
Figure 4.14: The load-displacement curve for fiber volume fraction of 21.52%

Figure 4.15: The Vertical Bendsaw used to cut the specimens

Figure 4.16: The INSTRON machine used to conduct the flexural test

APPENDIX D

Flowchart of Final Year Project 1



Flowchart of Final Year Project 2