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SCHOOL OF GRADUATE STUDIES

Mechanical Characterization of E-Glass Reinforced with Epoxy & polyester Composite for Automotive body Application

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In

Mechanical Engineering (Mechanical Design)

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Abstract

Mechanical Characterization of E-glass Reinforced with epoxy and Polyester Composite for Automotive Body Application
Esmael Adem
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Experimental characterization of the mechanical properties of E-glass/Epoxy & E-glass/Polyester composite was conducted. The objectives of this paper is to present processing techniques of specimen preparation, conducting experiment to obtain mechanical properties of this composite structure and conduct experimental observation using Scanning Electron Microscopy (SEM) to know inhomogeneity, porosity and fracture behavior. The effect of strain rate on E-glass/epoxy and E-glass/polyester has been investigated & experimentation was performed to determine property data for material specifications. E-glass/polyester laminates were obtained by compression molding process and E-glass/epoxy laminate by hand lay-up vacuum assisted technique. The composite laminates were cut to obtain ASTM standards. This investigation deals with the testing of tensile, compression, shear and flexural strength on a universal testing machine. The graphs that are obtained from the tests were documented. This research indicates that the mechanical properties are mainly dependent on the strain rate. It can be conclude from the result that E-glass/Epoxy show better property with the increase of strain rate, so this material is suitable for structural automotive body panel applications.

Key words: Composite, Automotive, strain rate, ASTM, Mechanical tests

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Nomenclature

Wf weight of Fiber (gm)

Wm weight of Matrix (gm)

WC weight of composite specimen (gm)

ρ_f Density of Fiber (gm/cc)

ρ_m Density of Matrix (gm/cc)

V_f Volume of fibers, (cm^3)

V_m Volume of matrix, (cm^3)

VC Volume of Composite specimen (cm^3)

VF Fibers Volume fraction

VM Matrix Volume fraction

D midspan deflection, mm,

L support span for bending and gage length for tensile, shear, compression, mm, and

d thickness of beam, mm

σ_f stress in the outer fibers at midpoint in bending test, MPa

P load at a given point on the load-deflection curve, N

b width of beam tested, mm, and

ε_f strain in the outer surface in bending, mm/mm

E_B modulus of elasticity in bending, MPa,

m slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm of deflection.

F^{ut} Ultimate/Maximum Compressive or tensile Strength, MPa

P^{ut} Maximum load before failure, N

A Average Cross-sectional Area, mm^2

ε tensile strain

δ displacement

E^{chord} tensile chord modulus of elasticity, MPa

$\Delta\sigma$ change in stress between two strain points

$\Delta\varepsilon$ change in strain between two points

τ^m maximum in-plane shear stress, MPa;

P^m maximum force at or below 5 % engineering shear strain, N

List of Abbreviations and Acronyms

ASTM	America Society for Testing and Material
cc	cubic centimeter
DAVI	Dejen Aviation Industry
FG	Fiber Glass
FRP	Fiber Reinforced Plastics
Lay-up	Combination of plies stacked to form a laminate
METEC	Metal and Engineering Corporation
PP	Polypropylene
PAM-CRASH	Commercial explicit finite element code
3-PBT	3 Point Bending Test
4-PBT	4 Point Bending Test
SEM	Scanning Electron Microscopy

CHAPTER 1: INTRODUCTION

1.1. Background

Now a days, the use of composite materials has grown significantly in aeronautic, automotive, naval, and civil construction sectors by substituting conventional materials such as steel, aluminum and other alloy materials. Because laminated Composite materials have of high modulus/weight and strength/weight ratios, excellent fatigue properties, and non-corroding behavior. These advantages encourage the extensive application of composite materials, for example, in sports and aerospace structures, high-speed boats and trains and automotive industries, [1].

Traditionally, the materials used in the construction of vehicle bodies are mainly various grades of steel. Although aluminum-intensive body concepts were used starting from executive class cars, and then later on applied to other car classes. Plastics mainly dominate the vehicle interior, their external application being chiefly limited to non-load bearing components even though recently some innovative plastic materials are being implemented on some vehicle parts such as engine sub-frame and frontal bumpers subsystems to reduce the vehicle weight and improve the occupant and pedestrian safety, [2, 3].

On the other hand, the application of advanced Fiber Reinforced Plastics (FRP) is getting more and more importance because of their lightweight potential and the possibility to manufacture 3D complex parts at relatively low investment costs; however, material cost, availability and compatibility of FRP based component production with the existing automated line production is still a challenging problem in automotive industry, [3, 4].

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes, [2]. Due to rise in demand of lightweight vehicle and better mechanical performance of materials in automotive applications, different material combinations such as composites, plastic and light weight metals are implemented on primary and secondary structural parts of vehicles. Applications of composite materials in automotive industries already include some primary and secondary structures such as dashboard, roof, floor, front & back bumper, passenger safety cell, and rarely, A-pillar and B-pillar, [1, 2].

Even though there are several factors that influence the entire product development process to realize a lightweight vehicle, from the point of view of vehicle structural design, the main governing criteria for material selection are stiffness and strength properties that will determine the overall performance of vehicle during static and dynamic loading conditions, [2].

In order to estimate strength and stiffness, structural materials are subjected to mechanical testing such as tensile, compression, shear and flexural tests. Tests aimed at evaluating the mechanical characteristics of fibrous polymeric composites are the very foundation of technical specification of materials and for design purposes, in order to develop numerical and experimental models. The mechanical testing of composite structures to obtain parameters such as strength and stiffness is a time consuming and often difficult process. It is, however, an essential process, and can be somewhat simplified by the testing of simple structures, such as flat coupons. The data obtained from these tests can then be directly related with varying degrees of simplicity and accuracy to any structural shape, [5].

So to understand the behavior of the composite materials under different loading conditions and because composite materials are produced by different manufacturers, studying the mechanical and physical properties becomes vital. This work presents the effect of strain rate on the mechanical behavior of E-glass/epoxy and E-glass/Polyester composite under quasi-static loading conditions by varying the strain rate in order to get the mechanical properties, this tests includes tensile, compression, flexural and shear tests.

1.2. Problem of the Statement

The automotive industry in Ethiopia is emerging and incorporates assembling of different types of automobile cars. One of the industries which perform these activities is Bishoftu Automotive and Locomotive Industry under Metal and Engineering Corporation (METEC). The parts to be assembled are not manufactured here rather imported from other car manufacturing industry outside Ethiopia among this China. But, some of the fiber composite body parts are manufactured here in Ethiopia by Dejen Aviation Industry (DAVI). The manufacturer doesn’t test the body parts so far rather they take the manufacturing process and give to automotive company. This means the strength and stiffness properties of the composite is not known, which is essential to determine the overall performance of vehicle during static and dynamic loading conditions.

Different researcher studied the mechanical properties of E-glass/Epoxy composite but, studying the mechanical and physical properties becomes vital because the properties of composite materials are different from manufacturers to manufacturer due to manufacturing method used.

Thus, the paper tries to fill the gap which occurs on the composite manufacturer here in Ethiopia by conducting experimental tests and presenting information about tensile, shear, flexural and compressive properties of E-glass/Epoxy & E-glass/Polyester composite.

So, the main aim of the thesis will be to characterize the mechanical properties of E-glass/Epoxy & E-glass/Polyester composite for automotive body application. The paper will focus on presentation of processing techniques of specimen preparation, conducting experiments and recording strength and stiffness data. All the test methods will be presented based on the American Society for Testing and Materials (ASTM). The result we get from this thesis will apply in the design of composite structures under different loading modes.

1.3. Objective of the Study

The general objective of this thesis is mechanical characterization of E-glass/Epoxy and E-glass/Polyester composite for automotive body application. This is achieved by conducting different experimental tests on the above mentioned materials.

The specific objective of the thesis includes:

- Preparation of E-glass/Epoxy & E-glass/Polyester composite.
- To present processing techniques of specimen preparation,
- Conducting experiment on tensile, shear, compression and flexural strength specimens of this composite structure.
- Conduct Experiment observation using Scanning Electron Microscopy (SEM) to know inhomogeneity, porosity and fracture behavior.

1.4. Limitation

Among the many, major obstacles while conducting this work were the followings;

- Financial matter
- Not complete experimental setups

1.5. Organization of the Thesis

This work is organized in five chapters. The first chapter introduces the thesis background; problem of the statement; objectives and research limitations. The second chapter presents literature review on composite materials and the past research activities. The third chapter deals with the experimental methods and conditions which includes topics like materials, sample preparations, methods and test set up for mechanical tests of E-glass/Epoxy &E-glass polyester composite. The fourth chapter addresses experimental test results and discussion. The last chapter presents to give conclusions, recommendations and future works.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction to composite materials

Composite materials in the context of high performance materials for structural applications have been used increasingly since the early 1960's; although materials such as glass fiber reinforced polymers were already being studied 20 years earlier. Initially conventional test methods originally developed for determining the physical and mechanical properties of metals and other homogenous and isotropic construction materials were used [1, 4]. A formal definition of composite materials given by ASM hand book, 2003 [6] is "macroscopic combination of two or more distinct materials, having a recognizable interface between them". According to [3, 7, 8], composite laminate is a combination of fiber and resin mixed in proper form. The reinforcement/fiber is usually much stronger than the matrix/resin, and it gives the composite its good properties, transfer the strength to matrix and load carrying application. The matrix/resin holds the reinforcement in an orderly pattern and also helps to transfer load among the reinforcement.

Classification of Composites

According to [7, 8], generally composite materials are classified based on the type of matrix material, the form of reinforcement. Based on the matrix material we can classify as Polymer, Metal, ceramic matrix composite and based on the form of reinforcement it is depicted in figure 2.1 below:

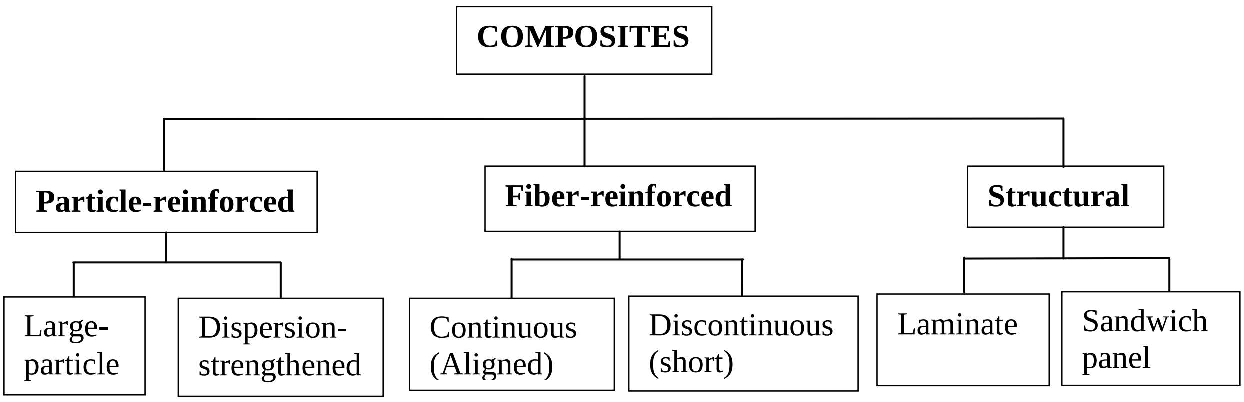


Figure 2.1: Composite materials classification based on the form of reinforcement

Composite Laminate

Laminates are sheet constructions which are made by stacking layers (also called plies or lamina) in a specified sequence. The layers are often in the form of 'prepreg' (fibers pre-impregnated with partly cured resin) which are consolidated in an autoclave. A laminate may have more than 4 layers and the fiber orientation changes from layer to layer in a regular manner through the thickness of the laminate. The figure shown below describes how the laminate is formed from the ply or lamina [7, 8].

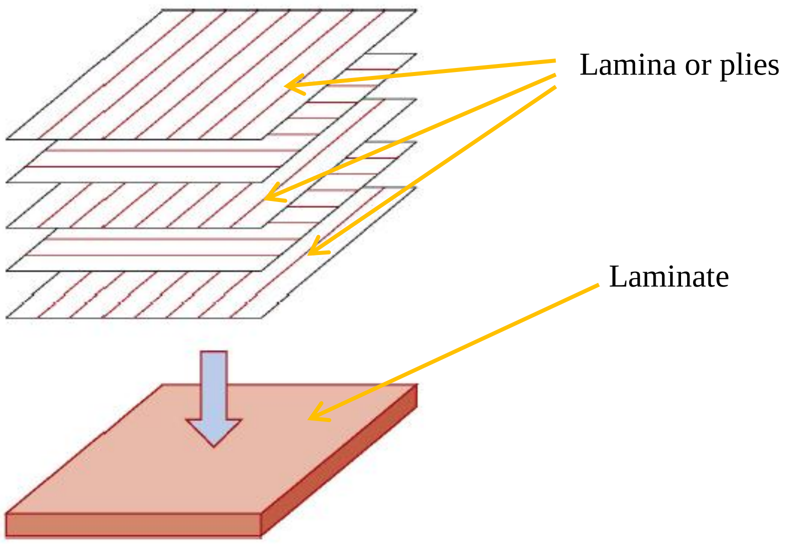


Figure 2.2 composite laminate structures

2.2. Composite Manufacturing

There are two types of manufacturing method for composite materials [7, 8]: Curing and lay up process. There are different types of lay-up process: hand lay-up/wet lay-up, spray lay-up, filament winding. Vacuum Bagging, Resin Transfer Molding (RTM), Autoclave, Pultrusion are grouped under curing process. The choice this Processes depends on many factors as:

- Part size and shape,
- Cost,
- Schedule,
- Familiarity with particular technique, etc.

Here, Hand lay-up and Vacuum Bagging was discussed in detail as follows:

Hand Lay-up Process

Resins are impregnated by hand into fibers which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are left to cure under standard atmospheric conditions. Figure below shows the typical hand lay-up process [8].

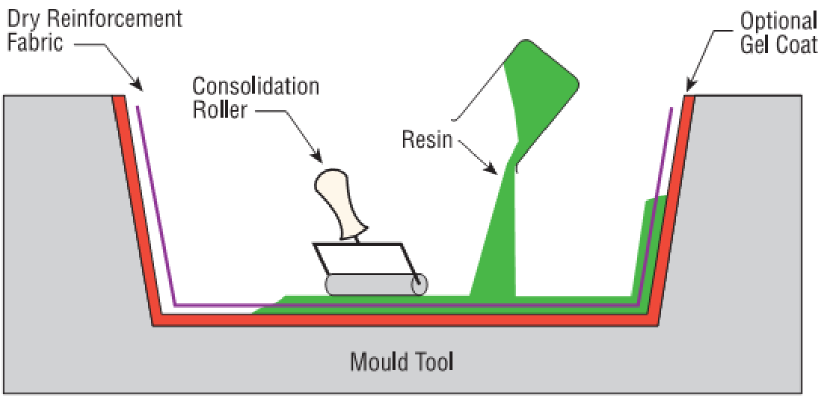


Figure 2.3 hand lay-up techniques

Vacuum Bagging

This is basically an extension of the wet lay-up process described above where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up laminate and on to the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it [8].

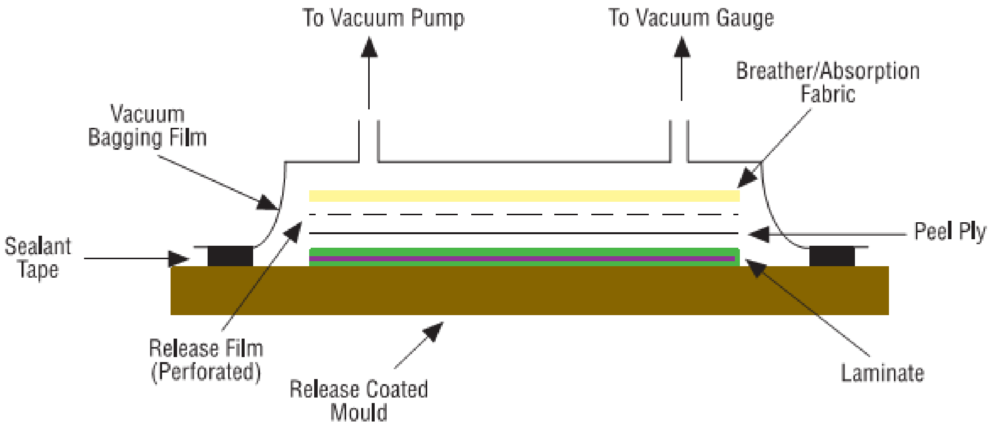


Figure 2.4 Vacuum bagging processes

2.3. Previous Works

Automotive Body Materials in the Past

The design of vehicle body has evolved from a simple, all steel structure that meets the basic requirement of strength and functionality, to the current day complex and efficient structure.

Deep drawing steel sheets with good formability were developed in the 1950s, followed by the development of anti-corrosive steel sheets in the 1960s. In the 1970s and 1980s, low fuel consumption was a keen issue because of the two oil crises. High-strength steel sheets were developed in response to this issue and have contributed to lightening vehicles by reducing sheet thickness. In the 1990s, safety and environmental issues became primary concerns in the automotive industry, and further work was done on developing technologies for weight reductions. Aluminum alloy sheets were developed in this connection and applied to various body panels such as the engine hood, and have contributed to achieving lighter vehicles [3].

According to [3] automobile body panels consist of a double structure with an outer panel and an inner panel. For the outer panels, higher strength materials are especially required to provide sufficient denting resistance. For the inner panels, higher deep drawing capacity materials are especially required to allow the manufacture of more complex shapes. In other words, different properties are required for the outer and inner panels, as shown in Table 2.1.
New materials for the car body have been developed to improve corrosion resistance and to reduce vehicle weight. In the 1950s and 1960s, mass production technologies were developed because of higher vehicle demand, [3].
Material technologies are also expected to contribute to improving crashworthiness. In order to achieve a safe car body in the event of a collision, deformation of the cabin structure should be minimized to protect the occupants, and the collision energy should be absorbed in a short deformation length within the crushable zones. From the viewpoint of materials, both dynamic strength and static strength are important in designing parts for greater crash safety. The average reactive force of a rectangular tube with a hat-shaped cross section is related to the k-value, i.e., the dynamic/static ratio of yield strength. In general, the k-value decreases with increasing strength. To reduce vehicle weight effectively while improving safety, new materials with a higher k-value are needed [3, 29].

Panels	Main Properties
Outer panel	◈ High strength after paint(Yield Strength: 200Mpa at 170^{o}C for 20 min after 2% strain) ◈ Flat hemming property ◈ Surface condition (SS-mark free, anti-orange peel) ◈ Anti-corrosion (anti-filiform corrosion)
Inner Panel	◈ Deep drawing property ◈ Joining Properties (welding, adhesion)

Table 2.1. Important Properties required for body panels

Lightweight composite materials, such as glass-fiber reinforced polymers, have been used to replace traditional steel and aluminum components. This is because composites offer significant opportunities for enhancement of product performance in terms of strength, stiffness and energy absorption, combined with weight reduction and space saving. Today, design procedures of vehicles body that ensures reliability and road worthiness is well established [3].

Mechanical Characterization of E-glass/Epoxy composite

Keshavamurthy Y. C., 2012, [9,] studied tensile properties of fiber reinforced angle ply laminated composites. They conducted experiments on Glass/Epoxy laminate composite specimens with varying fiber orientation to evaluate the tensile properties i.e. three types of specimens with different stacking sequences, i.e., [0^0], [90^0], and [$\pm 45^0$] are generally fabricated. In their work, specimens are prepared in the laboratory using vacuum bag technique with bi-woven epoxy glass as fiber & with epoxy resin as an adhesive. The specimens are prepared for testing as per ASTM standards to estimate the tensile properties. It is observed from the result that Glass/Epoxy with 0^0 fiber orientation yields high strength when compare to 30^0 & 45^0 for the same load, size & shape. In addition, they have conducted failure analysis for glass/epoxy to evaluate different failure modes and recorded. They observe, though glass/epoxy with 0^0 orientation have higher strength, stiffness and load carrying capacity than any other orientation. Hence, they suggested that fiber orientation with 0^0 is preferred for designing of structures like which is more beneficial for sectors like, Aerospace, automotive, marine, space etc.

A. F. Hamed, 2008 [10] conducted a series of tensile tests on the mechanical properties of filament wound glass/epoxy and carbon/epoxy composites under internal pressure loading for different orientation angle [0^0, 45^0, and 90^0] using ASTM standards. The result shows that the load in the tensile test for both composites increases linearly for $\theta = 90°$ and nonlinearly for $\theta = 0°$ to its maximum value then drops suddenly at final fracture load. The maximum tensile loads for both carbon/epoxy and glass/ epoxy composites in case of $\theta = 0°$ are higher than that for $\theta = 90°$. The tensile test for $\theta = 45°$ for both composite materials show nonlinear behavior up to fracture.

Mohd Fitri, 2006 [11] studied the determination of mechanical properties for polypropylene (PP) laminated on fibreglass (FG) composite with epoxy resin under tensile test. The study show that the maximum stress and Young Modulus values for FG/PP is higher compared to

FG. The maximum stress for FG is 93.77 MPa and FG/PP is 126.41 MPa. This proves that the presence of polypropylene in fibre composite had improved the strength of the composite.

An experimental framework to both quasi-static and dynamic material characterization of fiber-glass reinforced composed with additives (montmorillonite nanoclays) has been described by Rafael Celeghini [13], [24-25]. It was found that the material in study has an anisotropic behavior, showing distinct behavior when different load directions are considered. For the quasi-static tension tests it was observed differentiation in the behavior of the material when different configurations of test body are used. The 'Configuration A' made possible a better control of the applied load, generating a failure pattern within the region measured by the strain-gage in all the valid tests; however this configuration showed a less resistant material. Tests with 'Configuration B', following ASTM-D3039 standard, presented a more resistant material however it did not make possible the failure control. One can conclude that the material in study is sensible to strain rate to both tension and compression actions, as proven, respectively, in the quasi-static and dynamic tests. The main differences in the behavior of the material under compression in quasi-static and dynamic regimen are the increase of the maximum tension supported and energy absorbed until the collapse. The maximum tension is about 90% to 120% greater of what the maximum tension in quasi-static regimen.

George C. Jacob, 2004 [14] summarizes a detailed review of strain rate effects on the mechanical properties of polymer composite materials. An attempt was made to present and summarize much of the published work relating to the effect of strain rate studies done in the past on the tensile, shear, compressive, and flexural properties of composite materials to better understand the strain rate effects on these mechanical properties of fiber-reinforced polymer composite materials.

The effect of strain rate on the tensile properties of a glass/epoxy composite was investigated by Okoli and Smith [15]. Tensile tests were performed on a glass epoxy laminate at different rates (1.7 x10-2 -2000 mm/s). The tensile strength of the composite was found to increase with strain rate.

In other studies the effects of strain rate on the tensile [26-28], shear, and flexural properties of glass/epoxy laminate was investigated by Okoli and Smith [16]. Tensile modulus increased by 1.82%, tensile strength increased by 9.3%, shear strength increased by 7.06%, and shear modulus increased by 11.06% per decade increase in log of strain rate. It can be inferred from this detailed review that the effect of varying loading rate on the tensile, compressive, shear, and flexural properties of fiber-reinforced composite materials has been investigated by a number of workers and a variety of contradictory observations and conclusions have resulted. Hence, more work must be done in the pursuit of eliminating all disagreements that currently exist regarding the effect of loading rate on the tensile, compressive, shear, and flexural properties of fiber-reinforced polymer composite material.

Mechanical Characterization of E-glass/Polyester composite

Jovan Radulović, PhD (Eng), 2008 [17] studied the mechanical properties of a composite material - glass fiber/polyester resin, obtained by the filament winding technology. Mechanical characteristics of the filament wound composite material glass fibre/polyester resin produced by the filament winding technology were determined, in accordance with appropriate defined standards.

In the fibre direction, the (longitudinal) tensile strength is 694.7 MPa, the modulus of elasticity 10.949 MPa and the Poisson′s coefficient is 0.296. In the perpendicular direction, the tensile strength is 9.72 MPa, the modulus of elasticity is 3.51 MPa and the Poisson′s coefficient is 0.0013. At compression loading in the fiber direction, the (longitudinal) strength is 409.3 MPa, the modulus of elasticity is 1.171 MPa and the Poisson′s coefficient is 0.312. At compression perpendicular to the fiber direction, the strength is 11.05 MPa, the modulus of elasticity is 767.1 MPa and the Poisson′s coefficient is 0.181. The flexural strength, according to method 3-PBT, is 1.097 MPa. According to method 4-PBT, the flexural strength is 865.5 MP (variety 1), i.e. 674.6 MPa (variety 2). The interlaminar strength is 44.3 MPa (flat specimen method) and 43.5 MPa (ring specimen method). The shear strength is 11.06 MPa and the modulus of elasticity at shear is 6.59 MPa. The investigation results are uniform and acceptable since the standard deviation is up to 10 % of the arithmetic mean.

M. Wilson, 2003 [18, 29] studied the investigation and development of damage modelling techniques for woven long glass fiber reinforced polypropylene matrix composites for automotive part applications. Experiments were conducted to determine the mechanical properties of the aforementioned composite. Two damage modeling methods were investigated. The first, based on ply-level failure criteria and implemented in an implicit finite element code, was developed and validated using a range of coupon tests/experimental tests for a balanced weave 60% weight fraction commingled glass/polypropylene composite. The second method utilized a model previously implemented in the commercial explicit finite element code, PAMCRASH. This model was calibrated and validated using the same coupon tests as the first model. The models were subsequently used to simulate an industrial demonstrator component, during a two-phase design and development programme. The demonstrator, an automotive side intrusion beam, was designed and predictively modeled using the two damage modeling techniques investigated.

Finally, the composite component was compared to a steel side intrusion beam, using a quasi-static vehicle test to a current legislative standard. This test showed comparable performance in terms of strength and stiffness for the two beams. The conclusion is that the implicit finite element damage modeling technique can account for the damage and failure modes observed in a woven glass fiber reinforced polypropylene composite. It was also concluded that the explicit finite element technique was more suited to the simulation of damage development in thermoplastic matrix composite components. Finally it was conclude that aligned glass fiber reinforced polypropylene composite materials are suitable for structural automotive applications, such as side impact protection and perform to a similar standard as steel components. If the weight penalty observed at a component level is overcome by modularization then this technology could potentially be used commercially in crashworthy automotive applications.

CHAPTER 3: MATERIALS, CONDITIONS AND METHODS

3.1. Test Specimen

Mechanical testing of materials is a preliminary condition in the design and fabrication process of structural parts in order to obtain stiffness and strength under varying loading conditions. So to understand the behavior of the composite materials under different loading conditions and because composite materials are produced by different manufacturers and have different properties, studying the mechanical and physical properties becomes vital. The result is used for selection of material for a particular application, before the actual structures are constructed.

3.1.1. Materials

The raw materials used in this work are: E-glass fibers, Epoxy resin with its hardener, Polyester resin with its catalyst; which are obtained from Dejen Aviation Industry (DAVI), Bishoftu, Ethiopia.

E-Glass Fiber

Fiber is the reinforcing phase of a composite material. The present research work, woven E-glass fiber is taken as the reinforcement in the epoxy resin and polyester resin to fabricate composites samples.

E-glass woven roving is a bi-directional fabric made by interweaving direct rovings and is compatible with many resin systems such as polyester, vinyl ester, epoxy and phenolic resins. These fibers are high-performance reinforcement widely used in hand lay-up and robot processes for the production of boats, vessels, plane and automotive parts, furniture and sports facilities. It is relatively low cost, the most common form of reinforcing fiber used in polymer matrix composites. “E” glass produced fibers are considered as predominant reinforcement for polymer matrix composites due to their:

- high electrical insulating properties,
- low susceptibility to moisture,
- high mechanical properties, and
- Low cost

Due to the above promising characteristic and is widely adopted in Dejen Aviation industry, E-glass fiber has been taken as reinforcement for this work. The type of E-glass fiber which is used in this study is woven rovings. This fiber type has good mechanical properties as compared to chopped mat and it is used when higher strength part is required. The typical mechanical properties of woven E-glass is depicted in appendix A. The typical picture of plain woven E-glass fiber is shown below.

(a) (b)

Fig. 3.1 E-glass fibers which is used for this work

(a) Woven Fabrics E-glass fiber (b) Rolled Woven Fabrics

Epoxy Resin and its hardener

Among different types of matrix materials, polymer matrices are the most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and they also have excellent room temperature properties when compared. Polymer matrices can be either thermoplastic or thermoset. The most commonly used thermoset resins are epoxy, vinyl ester, polyester and phenolic. The resin used for this study is Epoxy Resin with brand name of SYSTEM #2000 EPOXY RESINS, which is manufactured by Fiber Glast Development Corporation, which have low viscosity, consistent performance and doesn’t contain any hazardous dilutes or extenders.

In general, the epoxy resins are being widely used for many advanced composites due to their many advantages such as excellent adhesion to wide variety of fibers, good performance at elevated temperatures and superior mechanical and electrical properties. In addition to that they have low shrinkage upon curing and good chemical resistance. It has very low viscosity and long average pot life at 25°C, which are essentials for composite laminate production.

Hardener (catalyst)

Epoxy resin and hardener are complimentary. When epoxy resin and polyamine hardeners are mixed at room temperature, they react and crosslinks are formed between the two chemicals. When some of the crosslinks have formed, the system forms a gel and is said to be “gelled”. When most of the crosslinks have formed, the system forms a solid and is said to be “cured”.

To get better mechanical performance of matrix, appropriate amount of hardener should be chosen [25]. In this work SYSTEM #2060 HARDNER is used; this is manufactured by Fiber Glast Development Corporation, which is characterized by low toxicity, excellent moisture resistance and excellent properties. Here, in #2060, has a one hour working time, and can be used for all sizes of parts using the contact layup method of fabrication. If the vacuum bagging technique is being used, 2060 should only be used for smaller parts. The ratio of net epoxy resin and hardener was specified according to the manufacturer’s manual, (3 part epoxy to 1 part hardener by volume or 100 part epoxy to 27 part hardener by weight). The basic mechanical properties of the epoxy and hardener system, as specified by the supplier, are summarized in appendix A.

According to manufacturer guide lines, stated mechanical properties are attained if & only if the above mentioned ratio is correctly applied irrespective of any environmentally determined conditions. Then mixture is stirred for few minutes using deep stick material.

Polyester Resin and its Catalyst

The resin used for this study is Unsaturated Polyester with brand name of Part # - 83 manufactured by Fiber Glast Development Corporation. It is a low viscosity for fast wet-out, styrene suppressed, high thixotropic index to prevent draining on vertical surfaces. It exhibits good mechanical and electrical properties together with good chemical resistance compared to general purpose resins. Typical properties of the resin are shown in appendix A.

Catalyst

Polyester resin is cured by adding a catalyst, which causes a chemical reaction without changing its own composition. The catalyst initiates the chemical reaction of the unsaturated polyester and monomer ingredient from liquid to a solid state. When used as a curing agent, catalysts are referred to as catalytic hardeners.

The curing agent applied for the liquid resin is Hardener with brand name of #69 MEKP, Manufactured by Fiber Glast Development Corporation.

The ratio of catalyst to resin is 1.25% by weight with #69 MEKP. Most of the time the ratio depends on the weather condition and it is also known that too much catalyst usually result in brittle material so care should be taken. But in this study 1.25% or 1.25g MEKP / 100g Resin was used as the ratio between catalysts to resin.

Fiber and matrix volume content of the composite

The ratio of the resin to the laminate can be determined through experience. It may be based on the volume ratio or weight ratio. But for this study the ratio was made on the base of their weight and then it was converted into volume ratio. The formula used to calculate the weight fraction and volume fraction of fiber and matrix was discussed below according to [7, 8].

i. **Fiber and matrix weight fraction (WF, WM)**

$$\text{Fiber weight fraction} = \frac{\text{Weight of fiber}}{\text{Total Weight}}$$

$$WF = \frac{W_f}{W_f + W_m} \qquad (3.1)$$

$$\text{Matrix weight fraction} = \frac{\text{Weight of matrix}}{\text{Total Weight}}$$

$$WM = \frac{W_m}{W_f + W_m} \qquad (3.2)$$

$$W_f + W_m = W_C \qquad (3.3)$$

$$WF + WM = 1 \qquad (3.4)$$

ii. **Fiber and matrix volume fraction (VF, VM)**

Volume of fibers, matrix and composite is given by

$$V_f = \frac{W_f}{\rho_f}; \quad V_m = \frac{W_m}{\rho_m}$$

$$V_c = V_f + V_m \qquad (3.5)$$

$$\text{Fiber volume fraction} = \frac{\text{volume of fiber}}{\text{Total volume}}$$

$$VF = \frac{V_f}{V_f + V_m} = \frac{V_f}{V_c} \qquad (3.6)$$

$$\text{Matrix volume fraction} = \frac{\text{volume of matrix}}{\text{Total volume}}$$

$$VM = \frac{V_m}{V_f + V_m} = \frac{V_m}{V_c}, \qquad VF + VM = 1 \qquad (3.7)$$

Let ρ_f and ρ_m are density of fiber and matrix respectively. Then we have

$$VF = \frac{W_f \times \rho_m}{W_f \times \rho_m + W_m \times \rho_f} \qquad (3.8)$$

Similarly;

$$VM = \frac{W_m \times \rho_f}{W_f \times \rho_m + W_m \times \rho_f} \qquad (3.9)$$

Where: Wf: weight of Fiber (gm)

Wm: weight of Matrix (gm)

WC: weight of composite specimen (gm)

ρ_f: Density of Fiber (gm/cc)

ρ_m: Density of Matrix (gm/cc)

WF: Weight Fraction of Fiber

Vf: Volume of fibers, (cm3)

Vm: Volume of matrix, (cm3)

VC: Volume of Composite specimen (cm3)

VF: Fibers Volume fraction

VM: Matrix Volume fraction

WM: Weight Fraction of Matrix

By taking technical data about E-glass fiber, epoxy and polyester resin from manufacturer's manual and taking technical measurement on mass of fiber, composite as well as using the above aforementioned equations, the unknown values (fiber volume fraction) were evaluated and summarized in Table 3.1.

Glass fiber density	2.6 gm/cc
Epoxy Matrix density	1.11 gm/cc
Polyester Matrix density	1.2 gm/cc
Glass fiber weight	977 gm
E-glass/Epoxy Composite weight	1347 gm
E-glass/Polyester Composite weight	1666 gm

(a)

Calculated Results	
Parameters	***Value***
Glass fiber volume	375.77 cc
Epoxy Matrix volume	333.33 cc
Polyester Matrix volume	574.16 cc
Fiber volume ratio for E-glass/Epoxy	53%
Fiber volume ratio for E-glass/Polyester	40%
Epoxy Matrix volume ratio	47%
Polyester Matrix volume ratio	60%
Fiber weight ratio for E-glass/Epoxy	72.5%
Epoxy Matrix weight ratio	27.5%

(b)

Table 3.1: Fiber and matrix volume contents (a) Manufacturer's data and measured value (b) Calculated Result

3.1.2. Composite sample fabrication process

Stacking Sequence of Composite Plies

The characteristics of composite materials resulting from the combination of reinforcement and matrix in general depend on

- The proportions of reinforcements and matrix
- The form of the reinforcement
- The fabrication process i.e. the ratio of fiber to resin in the composite (Fiber Volume Fraction), the geometry and orientation of the fibers in the composite.

When designing a laminate it is important to consider the stacking sequence of plies and to be aware of symmetry and balance of the stack. If the stack is symmetric (about the mid plane), it helps to eliminate any tendency to bend or warp, and balanced meaning that there is an equal number of +45° & -45° plies, which reduces shear coupling. [fg] The proportion of reinforcement and matrix, the fabrication process undertaken in this work has been presented in this topic.

Composite laminates are formed by assembling different plies with different angles and orientations. Generally, in this thesis 5 plain woven plies are used for Tensile & shear specimens' preparation and 10 plies are used for compression & bend test specimens. The stacking sequence of laminate used with its respected angle is shown in figure 3.4.

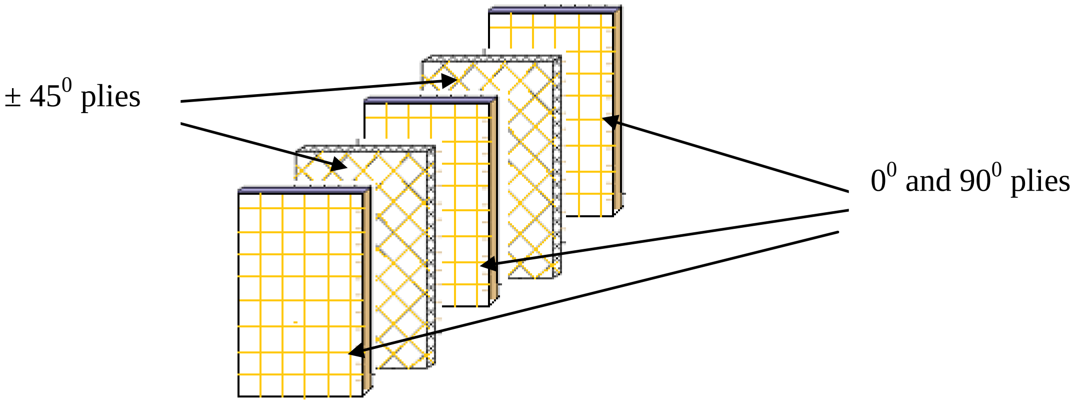


Figure 3.2: Stacking sequences of laminated Composite structure

Here, two types of manufacturing methods are used in order to fabricate the samples:

a) Compression Molding is used for E-glass/Polyester composite samples.
b) Hand lay-up Vacuum assisted technique for E-glass/Epoxy composite samples. The detailed explanation of these methods is summarized below.

3.1.2.1. Compression molding technique

Compression molding is a hand lay-up technique in which the counter mold will close the primary mold after the impregnated reinforcements have been placed on the mold. It is popular in the auto industry because of its high volume capabilities. In compression molding (see Figure 3.3), the whole assembly is placed in a press that can apply a pressure of 1 to 2 bars. The polymerization takes place either at ambient temperature or higher. The process is good for average volume production: one can obtain several dozen parts a day. In this work a pressure of 1 bar is applied for E-glass/Polyester composite sample fabrication.

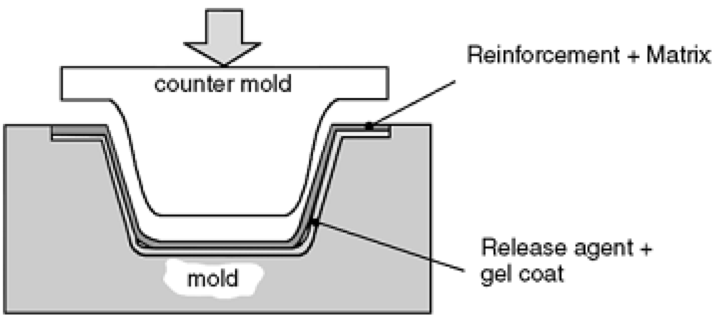


Figure 3.3 Compression molding

This type of manufacturing method is chosen for this work due to:

- ✓ Polyester resin has relatively high viscosity which can damage the vacuum pump when vacuum bagging is used.

- ✓ This method is practiced and used in manufacturing of automotive components at Dejen Aviation Industry.
- ✓ Compression molding uses fewer components than vacuum bagging technique.

Steps used in during compression molding:

- ¤ Preparing the mold: Remove any dust and dirt from mold then apply soft wax.
- ¤ Lay-up the reinforcement and resin: Brush catalyzed resin over mold, then apply the woven E-glass. Work with Brushes adding more resin where necessary until all white areas in fibers have disappeared and all air bubbles have escaped.
- ¤ Apply the counter mold and allow the part to cure for 24 hours.
- ¤ Remove part from mold
- ¤ Finally, cut the unnecessary parts at the end of part.

3.1.2.2. Hand Lay-up Vacuum assisted technique (HLVAT)

This is basically an extension of the hand lay-up process where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the hand laid-up laminate and on to the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it.

Hand Lay-up Vacuum assisted technique (HLVAT) equipment's

1. Rotary vacuum pump

The pump used for this work is taken from Dejen Aviation Industry, Unmanned Air Vehicle department. The specifications and the photograph of the vacuum pump are illustrated below:

Specification:

Model No: 2TW-4C

Capacity: 8cfm

Vacuum: 6.7×10^{-2}Pa

Power: 220-240v/50Hz

Figure 3.4: Rotary vacuum pump

2. Peel Ply (Release Fabric)

Release fabric, which shown as in figure 3.5 (a), is a smooth woven fabric that will not bond to epoxy. Its main purpose is to make rough composite surface after curing process. It also used to separate the breather and the laminate or the vacuum bag and the laminate. Excess epoxy can wick through the release fabric and be peeled off the laminate after the laminate cures. It sticks with the composite laminate but it can be pulled without problems.

(a) (b)

Figure 3.5: Materials used for vacuum bagging system (a) released fabric (peel ply) (b)Perforated nylon

3. Perforated nylon

A perforated plastic film, which shown as in figure 3.5 (b) above, may be used in conjunction with the release fabric. This film helps hold the resin in the laminate when high vacuum pressure is used with slow curing resin systems or thin laminates. Perforated films are available in a variety of holes size and patterns depending on the clamping pressure, and the resin's open time and viscosity.

4. Pressure fabric (breather)

A breather (or bleeder) cloth allows air from all parts of the envelope to be drawn to a port or manifold by providing a slight air space between the bag and the laminate. Typical breather use for this study is shown in Figure 3.6 (a) below.

5. Vacuum nylon (vacuum bag)

The vacuum bag, in most cases, forms half of the airtight envelope around the edge of the mold. The vacuum bag is always larger than the mold and allow for the depth of the mold. The vacuum nylon as it is depicted in figure 3.6 (b) below, is clear and transparent plastic material which enables to allow easy inspection of the laminate as it cures begins.

6. Mastic sealant (Vacuum tape)

Vacuum tape is used to provide a continuous airtight seal between the bag and the mold around the perimeter of the mold. The Vacuum tape may also be used to seal the point where the manifold enters the bag and to repair leaks in the bag or plumbing. The photograph of vacuum tape is indicated in figure 3.6 (c) below.

(a) *(b)* *(c)*

Figure 3.6: Materials used for vacuum bagging (a) Pressure Fabric or Breather
(b) Vacuum nylon or Vacuum Bag
(c) Mastic sealant (Vacuum tape)

7. Vacuum bagging mold

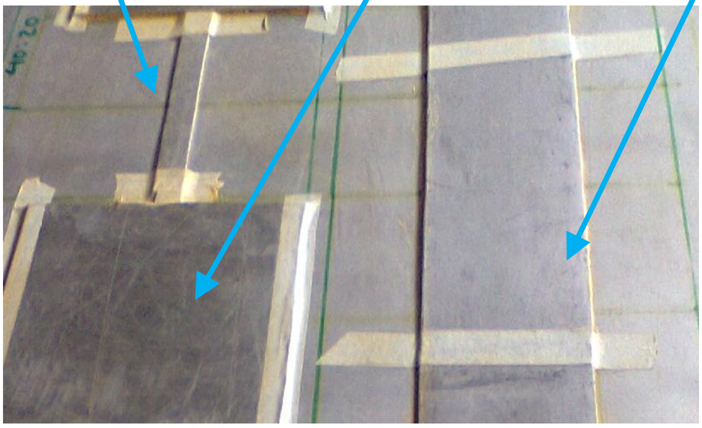
The mold structure must be too strong in order to support the mold itself in its proper shape during the impregnating process as well as in order to carry the composite laminates after the impregnating process.

Vacuum bagging molds should take advantage of the fact that atmospheric pressure is equal everywhere on the outside of the envelope. The mold surface must be airtight and smooth enough to prevent bonding to the laminate.

Care should be taken while selecting mold materials; in this work aluminum sheet is used as a mold since the composite laminate must be flat. This mold is shown in the figure 3.6.

8. Mold Release

Mold release is essential for preventing the epoxy from sticking to the mold when laminating a part. Even though, there are several types of mold release used depending on the mold material and desired characteristics of the finished part, the most common type and used for this work is paste wax, which shown as in figure 3.6. This is usually put on in up to 5 layers for new molds and at least one layer before each new part is molded. Fine detail and gloss level are obtained with the use of paste wax, but it can be difficult to buff anything with a textured surface. Usually this release agent is quick, cheap and widely available.



(a) (b)

Figure 3.7: Materials used for vacuum bagging (a) Vacuum Bag Mold
(b) Mold Release/Wax

Usually, Vacuum bagging technique is suitable for composite laminate manufacturing. So, in this work sample specimen for tensile, compression, flexural and shear tests of E-glass/Epoxy composite is done by this technique and this process is done with a series of steps summarized below:

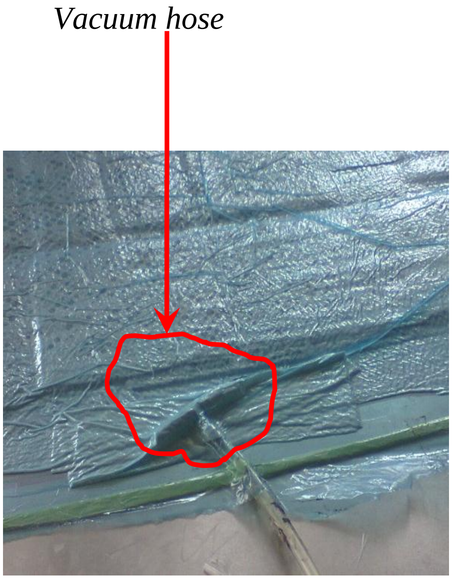
- The mold is cleaned and prepared for use and then apply release agent (wax) to the mold.
- Apply the mastic sealant around the perimeter of the mold.
- Prepare the materials to be laminated, mix resin and hardener and feed to the system using hand lay-up technique.
- Cut peel ply, release fabric, perforated nylon and the vacuum bag with appropriate size then attach the peel ply, release fabric and perforated nylon over the impregnated laminate respectively.
- Attach the vacuum bag with the mastic sealant.
- Cut the vacuum bag around the port to attach the fixed hose to the vacuum pump.
- Operate the vacuum pump and check leaks throughout the system.
- Remove the vacuum pump from the system after 2 hours.
- Finally, remove the vacuum bag, the perforated nylon and release fabric from the laminate and then the composite laminate from the mold after 24 hours.

Generally, figure 3.7 illustrated the techniques of composite fabrication process used for this work. The hand lay-up, which is processed manually using brushes and HLVAT process as shown in figure 3.7 (a) and (b) respectively.

(a) (b)

Figure 3.8 techniques of composite manufacturing used in this thesis (a) hand lay-up technique (b) HLVA technique

The air from laminate, which is done using hand lay-up technique, is removed by using T shaped ports/fixed hose inserted in the mold, which is used to eliminate any voids or impurities of laminates after curing process as shown in figure 3.8 (a). Part (b) illustrates excess amount of epoxy is collected somewhere and transported elsewhere where deficiency of epoxy is occurred. This process is assisted by vacuum pump. If there is excess epoxy in the entire mold, the pump sucks this epoxy via release film holes into the breather.



(a) (b)

Figure 3.9: Composite fabrication by vacuum bagging system

a) Vacuume hose
b) Collecting of excess resin for removal

3.1.3. Specimens Geometry and Dimensions

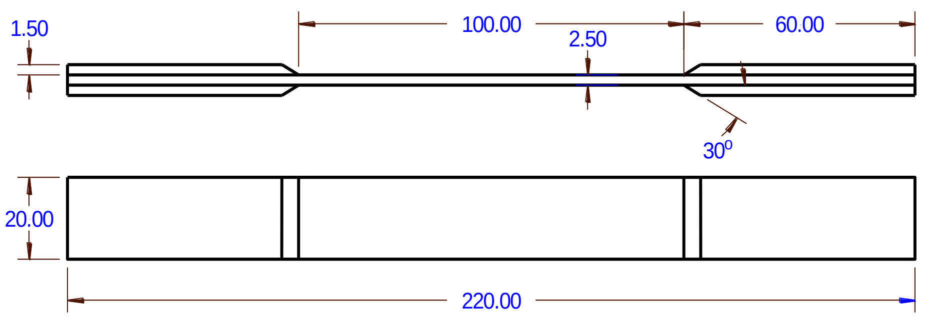
The geometry of each of loading configuration for E-glass/epoxy & E-glass/Polyester composite material is based on American Society of Testing & Materials (ASTM).

As per American Society for Testing & Materials (ASTM) test method D3039-00 [19] the constant rectangular cross section specimen was used. As it is shown in figure 3.9 (a), 20 mm wide, 220 mm long and 2.5 mm thick by 100 mm gage length woven E-glass/ epoxy and E-glass/Polyester doubling tabs bonded to the grip ends is prepared.

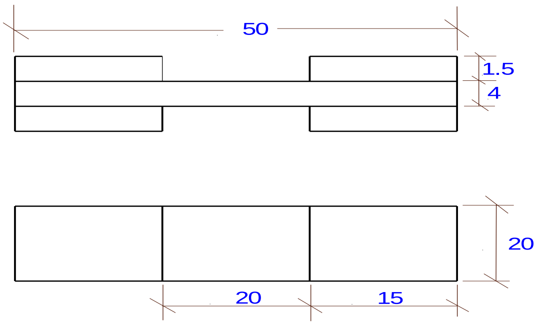
Flexural testing was conducted in accordance with ASTM test method D790-03, [20] using Method I, three-point loading. The flexural specimens were 150 mm by 20 mm and 4mm thickness. The loading fixture was adjusted to a 105 mm span which resulted in a span-to-thickness ratio of about 27:1which is shown in figure 3.12.

The compressive test was conducted along the longitudinal direction of the fibers on universal testing machine according to ASTM standard [21]. According to ASTM 3410-03 the specimen dimensions are 20 mm gage length, thickness of 4 mm and 20mm width with composite tab is prepared which is depicted below in figure 3.9 (b).

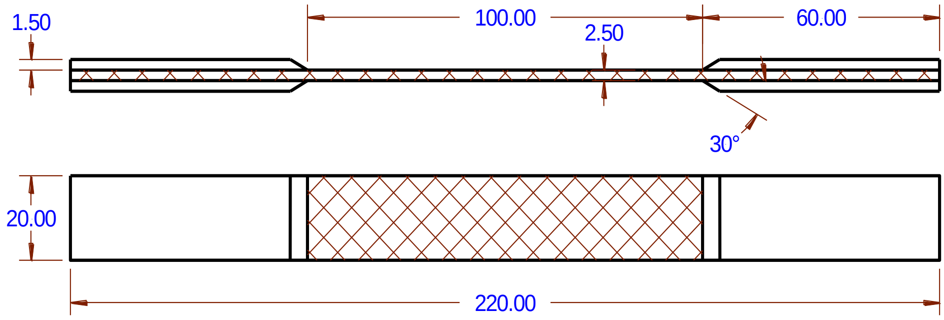
Similarly, the In-Plane Shear Response by off-axis tensile tests of a ±45° was conducted on universal testing machine according to ASTM D 3518-94 [22]. Even though there are different shear testing methods, $\pm 45^0$ Tension Shear is easy to perform. And also it prevail a combined stress state (not pure shear). When a $\pm 45^0$ laminate is loaded in unidirectional tension, a biaxial state of stress is induced within each of the $+45^0$ and -45^0 lamina. In laminated composites, a 123 Cartesian Coordinate System describing the principle material coordinate system for a laminated material, where the 1-axis is aligned with the ply principal axis, as illustrated in figure 3.10, in which a coordinate system in $\pm 45^0$ off axis tensile load . Similar to tensile test specimen the dimension is shown in in figure 3.9 (c).



(a)



(b)



(c)

Figure 3.10: Test Specimen Dimensions

a) Tensile Test Specimen
b) Compression Test Specimen
c) In plain Shear Test Specimen

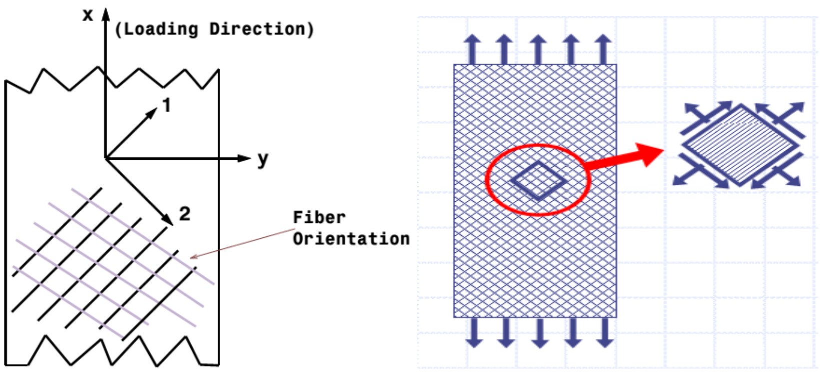
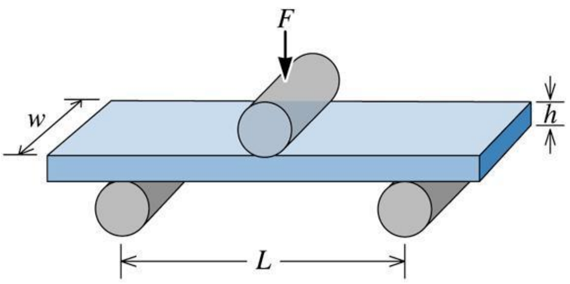


Figure 3.11: Material Coordinate System, x and y represent the specimen or reference axes, while 1 and 2 represent the material or local axes



Tickness, h= 4 mm
Span, L= 105 mm
Width, W= 20 mm

(a)

Figure 3.12: Flexural strength/3-point test/ dimensions and set up in 3D drawing

3.2. Testing Conditions

Three specimens for each test configuration were tested, in order to show the repeatability of the results through which minimizing the experimental errors, under tensile, compression, flexural and in plain shear loading with a Computer electro-hydraulic universal testing machine (model: WAW-600) with a capacity of 600 kN, precision grade is 0.5 with 0.01 - 500 mm /min test speed and manufactured in Shanghai Hualong Testing Instruments Co.LTD, China. Test world data acquisition software is used to acquire data from the machine during testing. Each specimen was clamped by means of hydraulic wedge grips. The machine was equipped with a standard load cell and a crosshead displacement measuring device. The experiment was conducted with varying strain rate values in quasi-static condition at room temperature (25^0C). The strain rate value, crosshead speed and repetition of specimen for these experimental tests are shown in table 3.2 below.

Strain rate is the rate of change in strain (deformation) of a material with respect to time. The strain rate at some point within the material measures the rate at which the distances of adjacent parcels of the material change with time in the neighborhood of that point. It comprises both the rate at which the material is expanding or shrinking (expansion rate), and also the rate at which it is being deformed by progressive shearing without changing its volume (shear rate). Strain rates at or below 10^{-2} s-1 are considered to represent quasi-static deformations. Quasi static experiments are typically accomplished through a variety of servo hydraulic machines, and ASTM standards exist for most of these experiments. Generally, strain rate is determined using the following formula.

Strain Rate = (Cross head speed)/ (Gage Length)
= V (mm/min) / (mm) *(3.10)*

Therefore, the total amount of specimen used for this study was 9 specimens for tensile, 9 specimens for shear, 9 specimens for compression and 9 specimens for flexural tests a total of 9x4 = 36 specimens were used for E-glass/Epoxy composite and the same amount was used for E-glass/Polyester composite. In general, 36x2 = 72 specimens were used for this study.

Strain Rate	Tensile and shear Test		Compression Test		Flexural Test		Repetition for all tests
	Value (S-1)	Crosshead speed (mm/min)	Crosshead speed (mm/min)	Value (S-1)	Crosshead speed (mm/min)	Value (S-1)	
Strain rate 1	3.33E-5	0.2	0.2	1.66E-4	0.2	3.175E-5	3
Strain rate 2	3.33E-4	2	2	1.66E-3	2	3.175E-4	3
Strain rate 3	3.33E-3	20	20	1.66E-2	20	3.175E-3	3
Required Specimen	2x3x3=18 specimen		3x3=9specimen		3x3=9specimen		

Table 3.2: Test Condition Parameters

3.3. Test Methods

3.3.1. Experimental Setup

Experimental investigation of mechanical property of the E-glass/Epoxy & E-glass/Polyester composite was conducted using Universal testing machine but, before that the specimen was cut in to the required size using band saw which was described later.

1. **Band Saw**

Band Saw is used for cutting of specimens after fabrication process in to the required dimension. The machine has a cutting speed of 500-1000m/min, with blade length 2560mm and maximum work piece height of 230mm which is shown in figure 3.13.

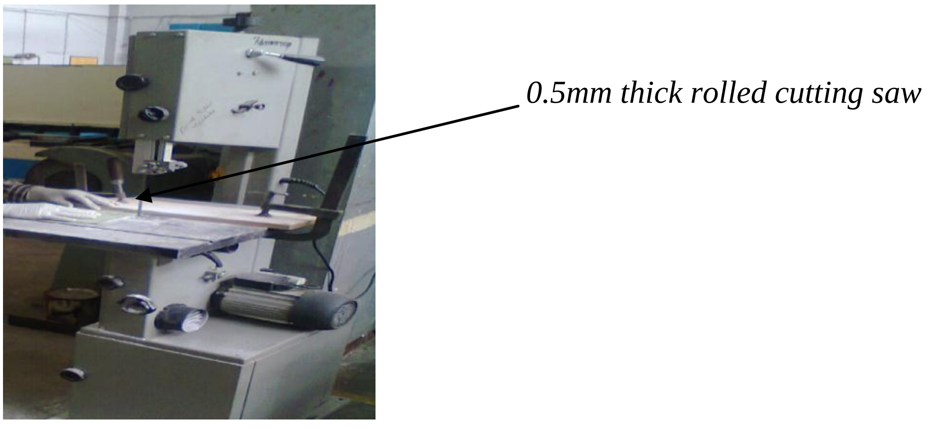


Figure 3.13: Band Saw

2. **Universal Testing Machine**

Mechanical testing of tensile, compressive, flexural and shear strength of E-glass/Epoxy & E-glass/Polyester composites are tested using Computer Controlled Electro-Hydraulic Servo Universal Testing Machine. Three specimens were fabricated for each strain rate value from the proposed material in order to show the repeatability of the results.

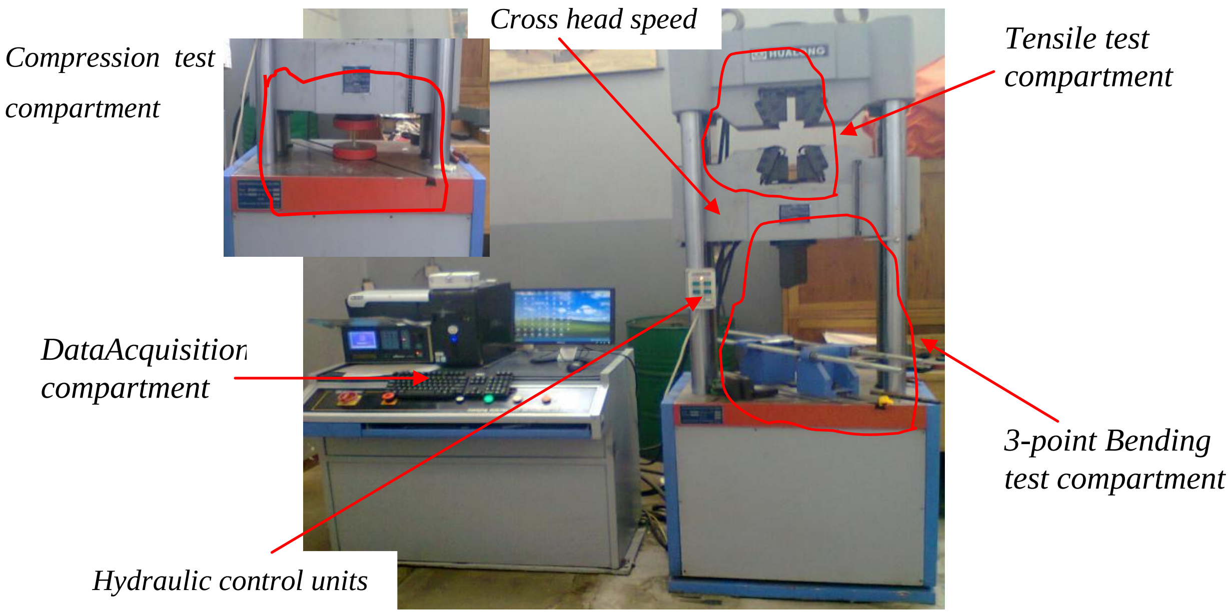


Figure 3.14: Computer-Electrohydraulic Universal Testing Machine

3.3.2. Scanning Electron Microscopy (SEM)

Morphology of E-glass/Epoxy before test and the interfacial adhesion between fiber–matrix and tensile fracture after test was examined by scanning electron microscopy (SEM), Model: EM-30, serial number: CXS-3TAH-113031 with mark COXEM, which is shown in figure 3.15 below.

The first step obviously is to cut the specimen to appropriate size in order to fit with the scanning electron microscope specimen chamber, grind and polish the surface to expose the feature(s) of interest. These steps are commonly referred to as metallography even though they are applicable to all materials. For scanning electron microscopy of non-conducting/electrically insulating specimens can absorb electrons and accumulate a net negative charge that repels the following electron beam, this leads to charge buildup on the specimens that makes imaging or other analysis difficult. To a certain extent, lowering the accelerating voltage or reducing the spot size can reduce this artifact, but that would limit the instrument capability considerably. The best way to counter this is to coat the specimen with a thin conducting film. In the past, organic antistatic agents have been tried, but the best method is to deposit a thin film (tens of nanometers) of a metal or carbon [29].

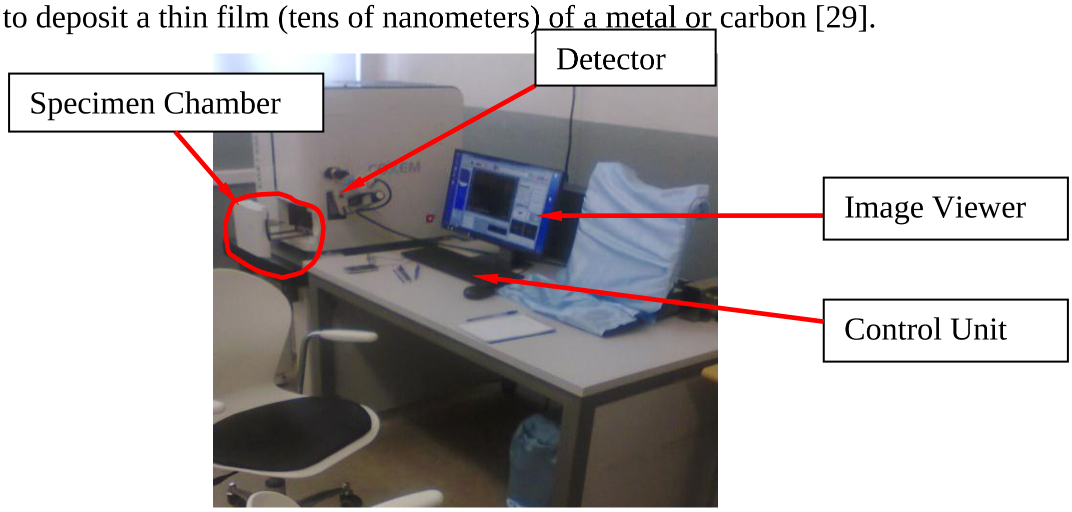


Figure 3.15: Scanning Electron microscopy

Metal coatings such as gold will give their characteristic signal and the investigator needs to check in advance whether this will interfere with any peaks from the specimen. In this work, specimens before test and after test were coated with a thin layer of gold with COXEM Sputter ion coater, which uses plasma voltage of 800ev, current 20mA, coating rate 2.2nm/min and plating thickness of 15nm. Figure 3.16 (a) shows typical ion coater and (a) coated specimen.

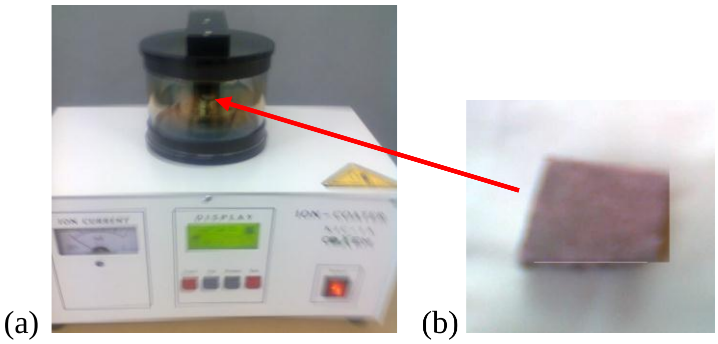


Figure 3.16: (a) Ion Gold Coater (b) gold coated specimen

After the specimen preparation, the coated specimen is inserted to SEM in order to observe the surface morphology. The surface is magnified with different magnification scale which was discussed in the fourth chapter.

CHAPTER 4: RESULT AND DISCUSSION

4.1. Experimental Results

4.1.1. Tensile Test

Tensile tests_of the fabricated composite were conducted and the result is summarized and presented below.

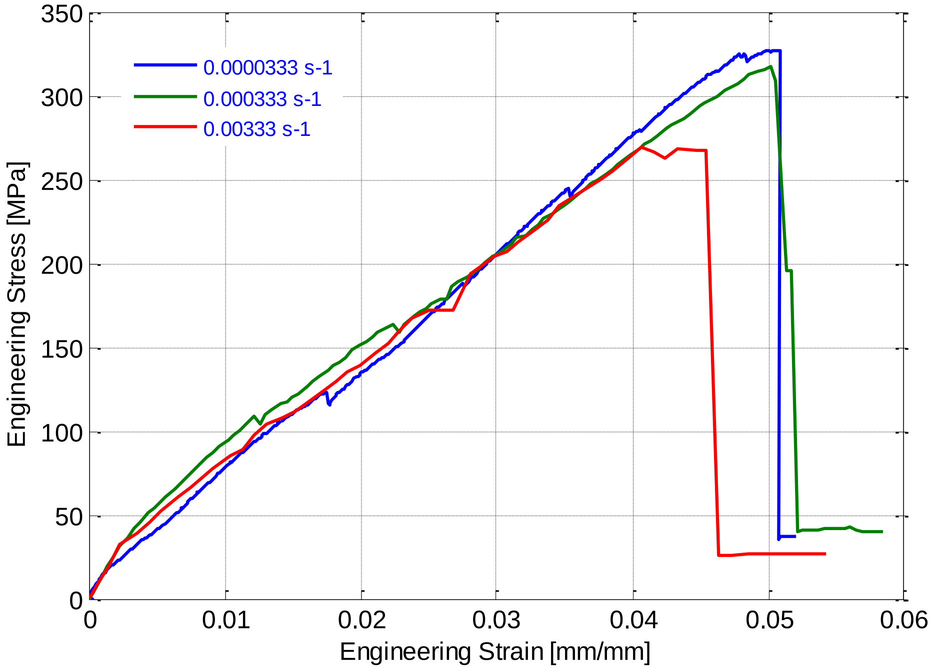


Figure 4.1 effect of strain rate on tensile strength of E-glass/Epoxy composite

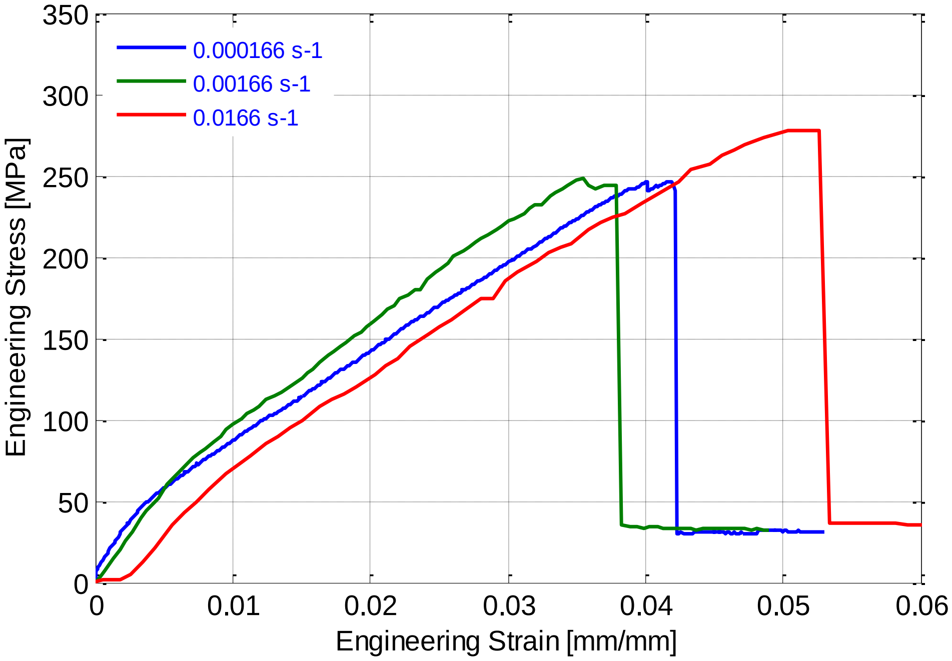


Figure 4.2 effect of strain rate on tensile strength of E-glass/Polyester composite

From behavior of the above two graph indicates there are a rapid increase in engineering stress when the engineering strain is increased up to the maximum or ultimate tensile stress is obtained and the there is a rapid drop from ultimate value to the minimum. At this point the sample doesn't resist any load.

Figure 4.1 above shows tensile strength of E-glass/Epoxy composite as a function of strain with different quasi-static strain rate. The test result shown is based on the average value of three specimens for each strain rate value. The result clearly shows when the strain rate is increased the tensile strength of the material was decreased. The percentage decrement of tensile stress is 3.06% and 15.24% for the first and second speed respectively.

The effect of strain rate on tensile strength of E-glass/Polyester composite is shown in figure 4.2. The given graph indicates the tensile strength of E-glass/Polyester composite was increased with the increase of strain rate. The percentage increment in tensile strength of the given composite is 0.514% and 11.98% for the first and second speed respectively.

Regarding tensile failure mode, E-glass/Epoxy composite showed significant failure mode variation with increasing strain rate. As shown in Fig. 4.3 (a) limited damage within the gage length near grip area at the first speed and further strain rate increment changed the failure mode by extending the damage area to the center gage length and create fiber pullout. For example, as shown in Fig. 4.3 (a), at 0.000333 s-1 strain rate (TER3-02), excessive deboning between the fiber and matrix was exhibited. On the other hand, E-glass/Polyester composite showed grip area failure, as shown in Fig. 4.3 (b).

(a)

(b)

Figure 4.3 Tensile Failure modes (a) E-glass/Epoxy composite (b) E-glass/Polyester Composite

4.1.2. In-Plane shearing Test

Figure 4.4 demonstrates quasi static strain rate effects on shear strength of E-glass/Epoxy composites. The test result shown is based on the average value of three specimens for each strain rate value. It can be clearly seen that the sear strength is increasing with the increase of strain rate. The percentage increment for the first two speeds are 0.44% and 19.93%.

The effect of strain rate on shear strength of E-glass/Polyester is displayed in figure 4.5 below. The result shows that the shear strength shows a decreasing trend with an increasing strain rate but, the effect of insignificant. The percentage decrement in shear strength of the given composite is 5.09% and 3.59% for the first and second speed respectively.

The application of composite materials in mechanical engineering is limited by poor transverse and shear properties of unidirectional composites, which raise concern about their impact behavior [31]. But, the result obtained on this thesis is better than from the previous work done by [17, 29].

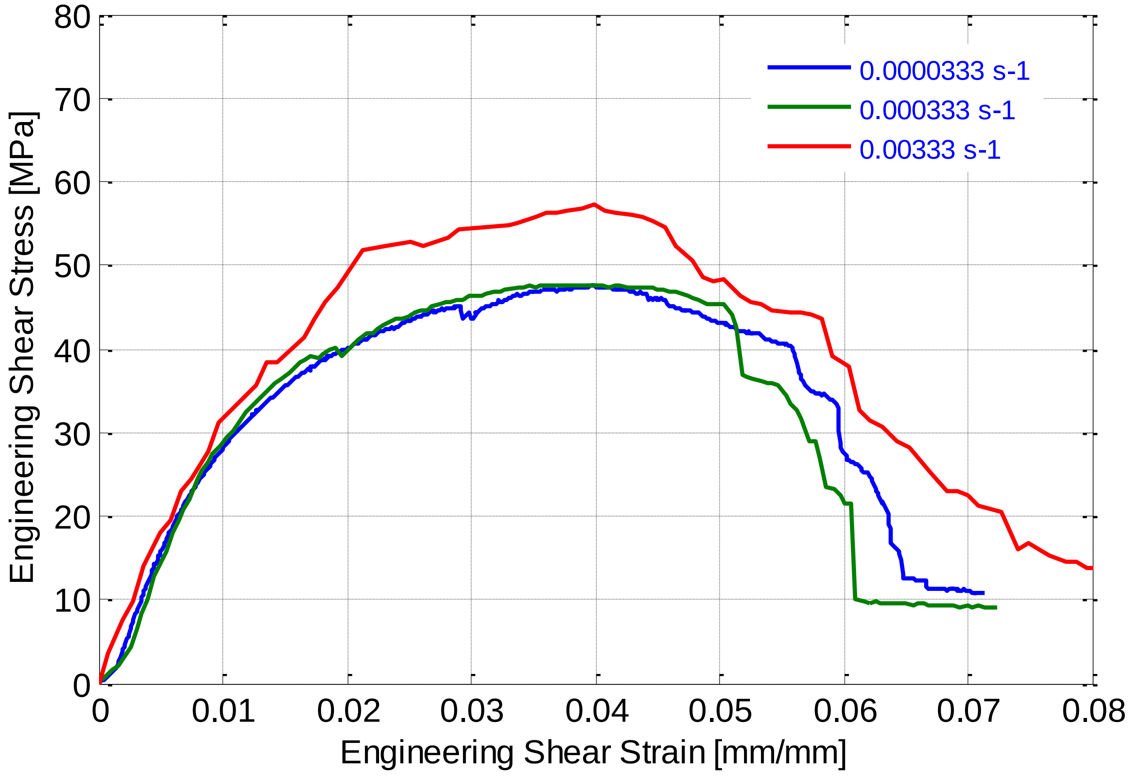


Figure 4.4. In-plane shear strength of E-glass/Epoxy composite

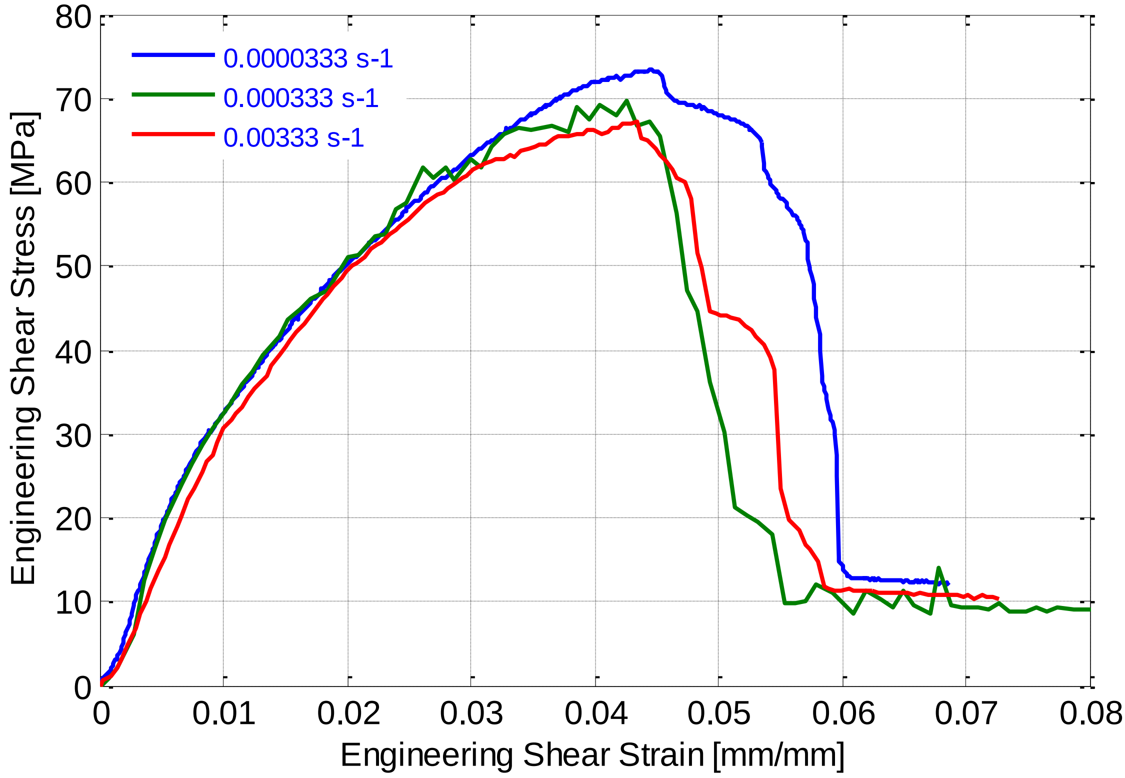


Figure 4.5. In-plane shear strength of E-glass/Polyester composite

Regarding in-plane shear failure mode, E-glass/Epoxy composite showed significant failure mode variation with increasing strain rate. As shown in Fig. 4.6 (a) limited damage within the gage length near grip area in the first strain rate and further strain rate increment changed the failure mode by extending the damage area to the center of gage length and create fiber pullout. For example, as shown in Fig. 4.6 (a), at 0.000333 s-1 strain rate, excessive deboning between the fiber and matrix was exhibited. On the other hand, E-glass/Polyester composite showed grip area failure, as shown in Fig. 4.6 (b).

(a)

(b)

Figure 4.6 In-plane Shear Failure modes (a) E-glass/Epoxy composite (b) E-glass/Polyester Composite

4.1.3. Compression Test

The compression test results obtained from this work are not much satisfactory because the universal testing machine available in Mechanical and Industrial engineering school of AAiT material testing laboratory is not complete especially for this tests. For example there is no grip for compression tests. Due to this the shape of compressive stress-strain curve is unusual and the maximum value of compressive strength is lower.

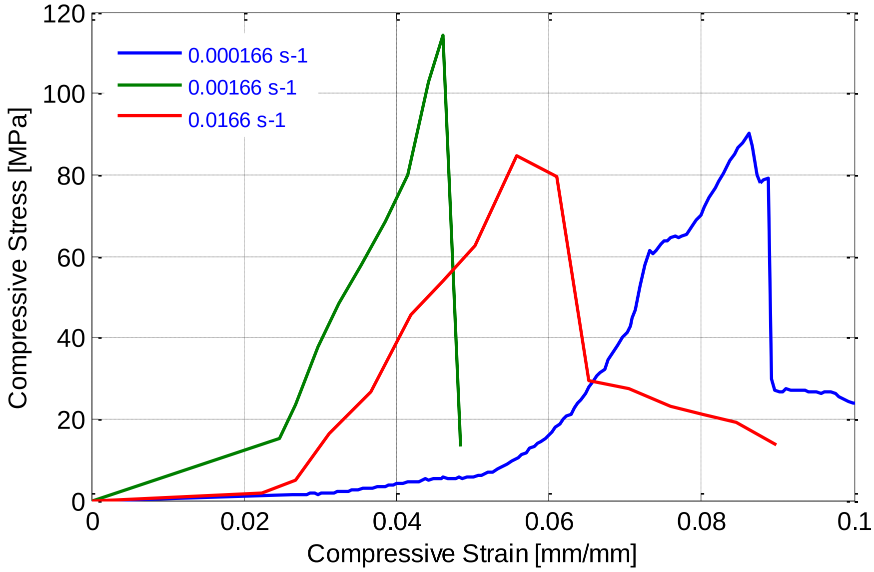


Figure 4.7 Compressive strength of E-glass/Epoxy composite

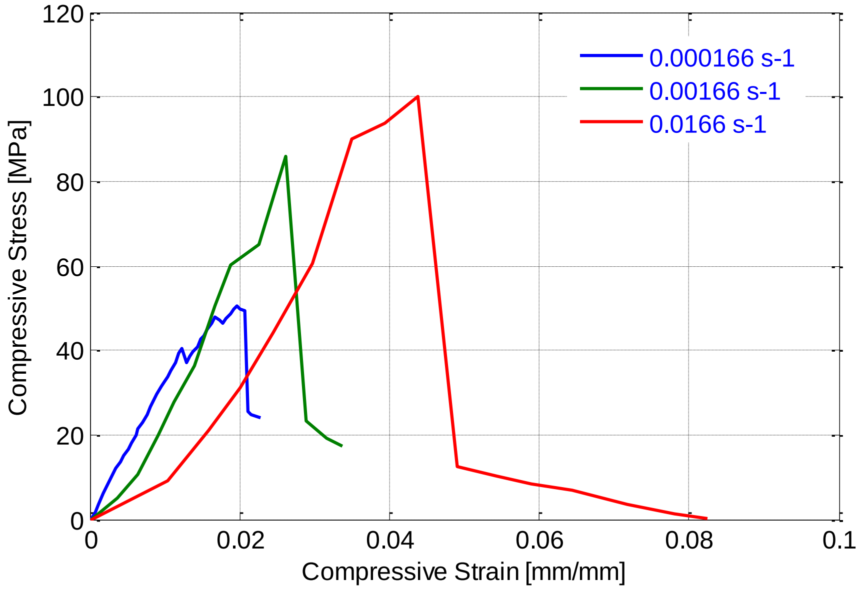


Figure 4.8 Compressive strength of E-glass/Polyester composite

Fig. 4.7 presents quasi-static strain rate effect on compressive strength for E-glass/epoxy composite as a function of strain rate. The test results presented are based on average values of three specimens for each strain rate value. It can be clearly seen that the compressive strength follows an increasing trend with the increase of strain rate for the first two speeds and decreases. The percentage increment and decrement for the first two strain rate values are 26.42%and. 6.53% respectively.

The effect of strain rate on compressive strength of E-glass/Polyester composite is shown in figure 4.8. The given graph indicates the compressive strength of E-glass/Polyester composite was increased with the increase of strain rate. The percentage increment in compressive strength of the given composite is 77.68% and 11.32% for the first and second strain rate values respectively.

The failure mode of compression, both E-glass/Epoxy composite and E-glass/Polyester composite shows the micro-buckling of fibers along the shear plane due to global shearing of laminate as shown in Fig. 4.9 (a and b).

(a) (b)

Figure 4.9 Compressive failure modes (a) E-glass/Epoxy and (b) E-glass/Polyester composites

4.1.4. Flexural Test

Fig. 4.10 presents quasi-static strain rate effects on flexural strength for E-glass/epoxy composite as a function of strain rate. The test results presented are based on average values of three specimens. It can be clearly seen that the flexural strength was increasing trend with the increase of strain rate. The percentage increment for the first two strain rate values are 20.24% and 12.21%.

The effect of strain rate on flexural strength of E-glass/Polyester composite is shown in figure 4.11. The given graph indicates the flexural strength of E-glass/Polyester composite was decreased with the increase of strain rate. The percentage decrement in flexural strength of the given composite is 18.5% and 5.61% for the first and second strain rate values respectively.

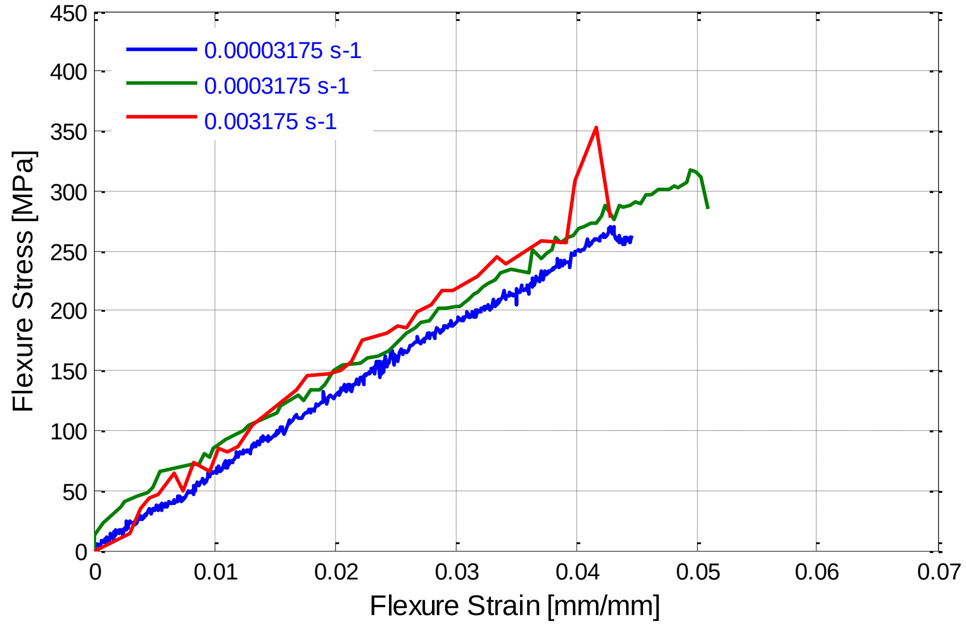


Figure 4.10 Flexural strength of E-glass/Epoxy composite

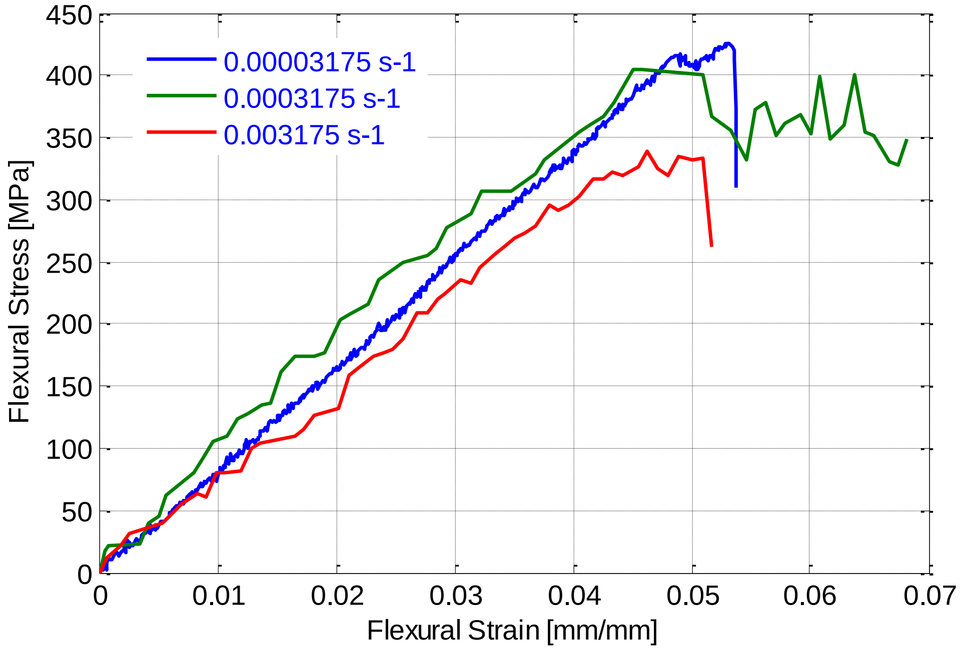


Figure 4.11Flexural strength of E-glass/Polyester composite

4.1.5. Scanning Electron Microscopy Observations

Scanning electron microscope (SEM) pictures of E-glass/epoxy composite surfaces before tensile test were obtained with different magnification scale as shown in Fig. 4.10a-4.10d. Fiber bonding and adhesion between the fiber and the matrix are clearly figured out from morphological studies. The interaction between matrix and glass fibers is good as it is seen from scanning electron microscope pictures. Figure (10a-10b) shows a small pores area. This is due to imperfect pump suction during manufacturing process. This area is a crack initiation during the application of load on tests leads pre-mature failure. The other area on this picture shows good, which clearly reveals strong adhesion and good interface attraction between glass fibers and matrix material. Figure (10c-10e) showed a rough surface and the strongly bonded fiber-matrix interface.

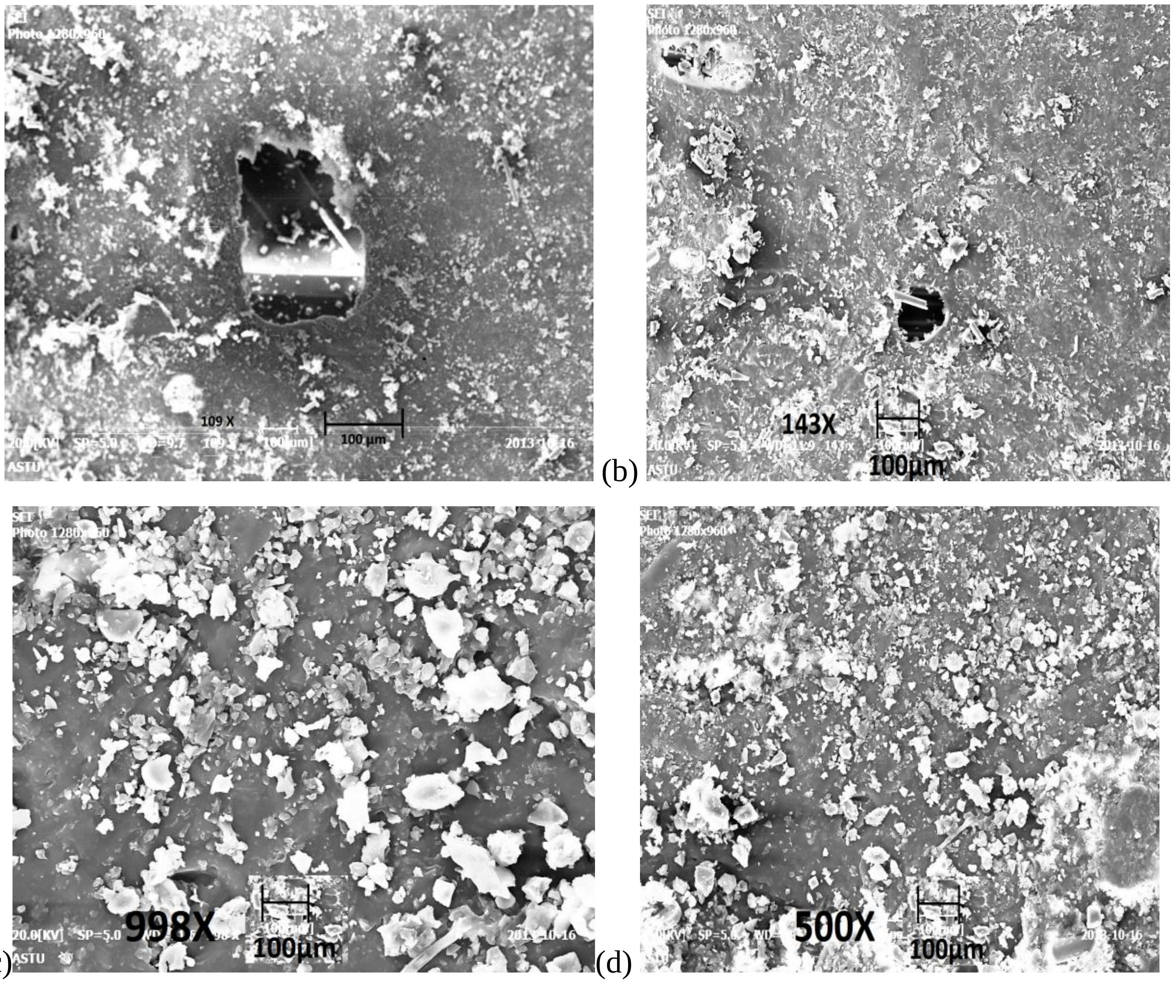
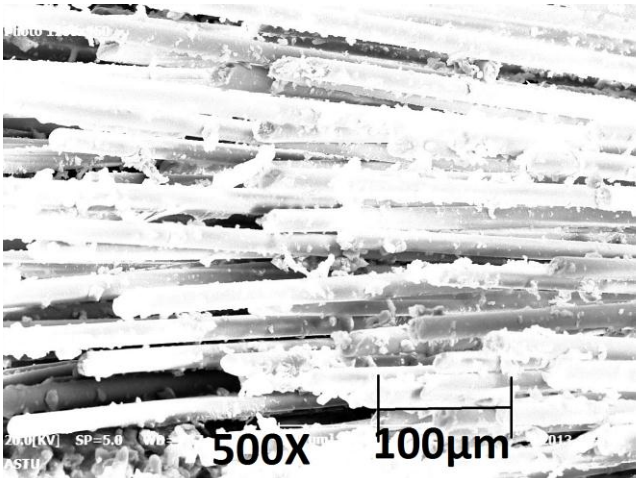
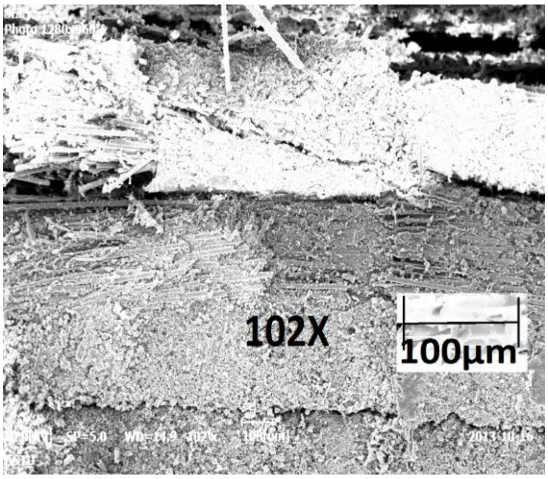


Figure 4.12 SEM picture at different magnification scales before test
(a) 109 X (b) 143 X (c) 998 X (e) 500 X

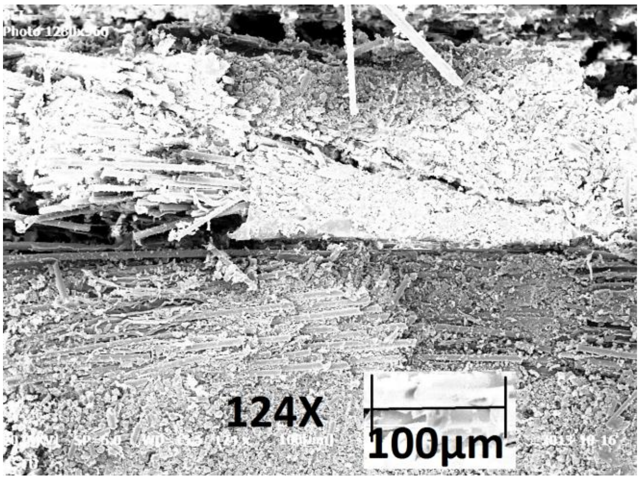
Figure 11(a-c) shows SEM picture when the surface is observed after tensile test was conducted. Figure 11 (a) indicates that some fibers are pulled out of the matrix as a result of mechanical fracturing done in tensile test. In Figure 11 (b-c), some glass fiber experience fiber pull out and delamination, which are the key features that are associated with the composites but very little fiber pull out was observed in the case of the thermoplastic modified epoxy matrix and GFRP composites, which reveals the efficiency of the modified matrix to hold the fibers. Strong interaction between thermoplastic and epoxy resin in matrix material leads to efficient stress transfer from the matrix to reinforcing glass fibers that reduce the crack growth rate, leading to good mechanical strength of the composites.[28]



(a)



(b)



(c)

Figure 4.13 SEM pictures after tensile test (a) 500 X (b) 102 X (c) 124 X

4.2. Discussion

4.2.1. Effect of Strain Rate on Tensile Properties

According to ASTM standard [19], the ultimate tensile stress, tensile strain and modulus of elasticity can obtained using the following formula:

$$F^{ut} = P^{ut}/A$$

$$\varepsilon = \delta/L$$

$$E^{chord} = \Delta\sigma/\Delta\varepsilon \qquad (4.1)$$

Where:

F^{ut}= Ultimate Tensile Strength, MPa

P^{ut}= Maximum load before failure, N

A= Average Cross-sectional Area, mm^2

ε= tensile strain

L= gage length

δ= displacement

E^{chord}= tensile chord modulus of elasticity, MPa

Δσ = change in stress between two strain points

Δε = change in strain between two points

Figure 4.14 presents the effect of strain rate on ultimate tensile stress and tensile modulus of elasticity. From the graph it can be understood that the tensile stress and as well as the modulus of elasticity of E-glass/Epoxy composite decreases as the strain rate increases. The percentage of decrement on modulus is 7.692% and 64% for the first and the second strain rates respectively.

In case of E-glass/Polyester composite, both the ultimate tensile and tensile modulus of elasticity increases with strain rate. As it is shown in figure 4.15 below, the percentage of enhancement in modulus is 5.179% and 6.822% for the first and the second strain rate values respectively. Typical tensile properties for E-glass/epoxy and E-glass/polyester composites when the strain rate is 0.000333 s-1 is shown in the appendix B.

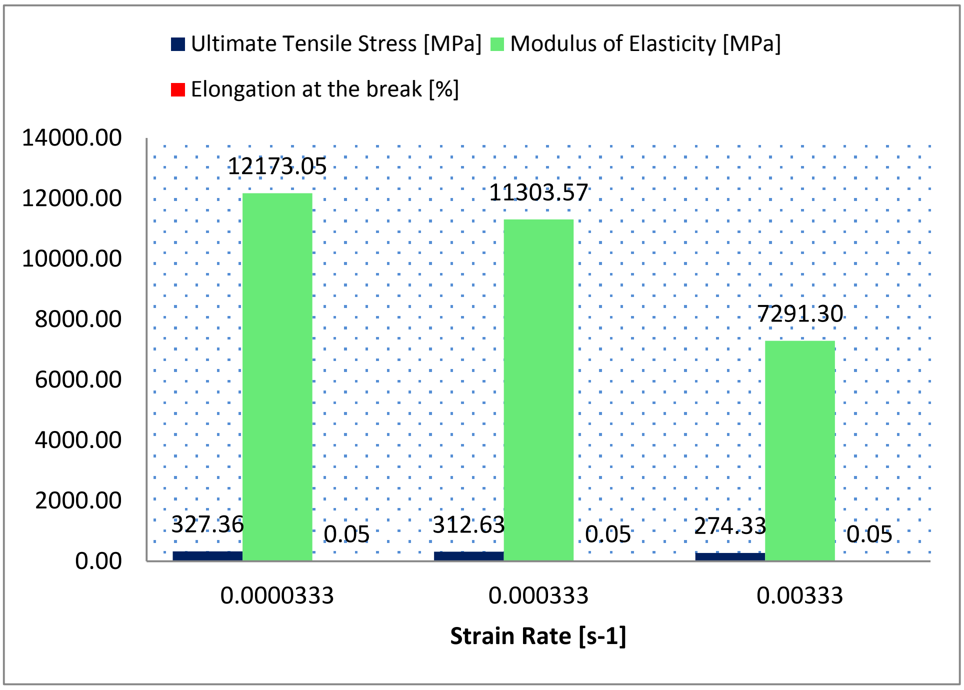


Figure 4.14 Strain Rate Effect on Tensile Stress and Tensile Modulus of Elasticity for E-glass/Epoxy Composite

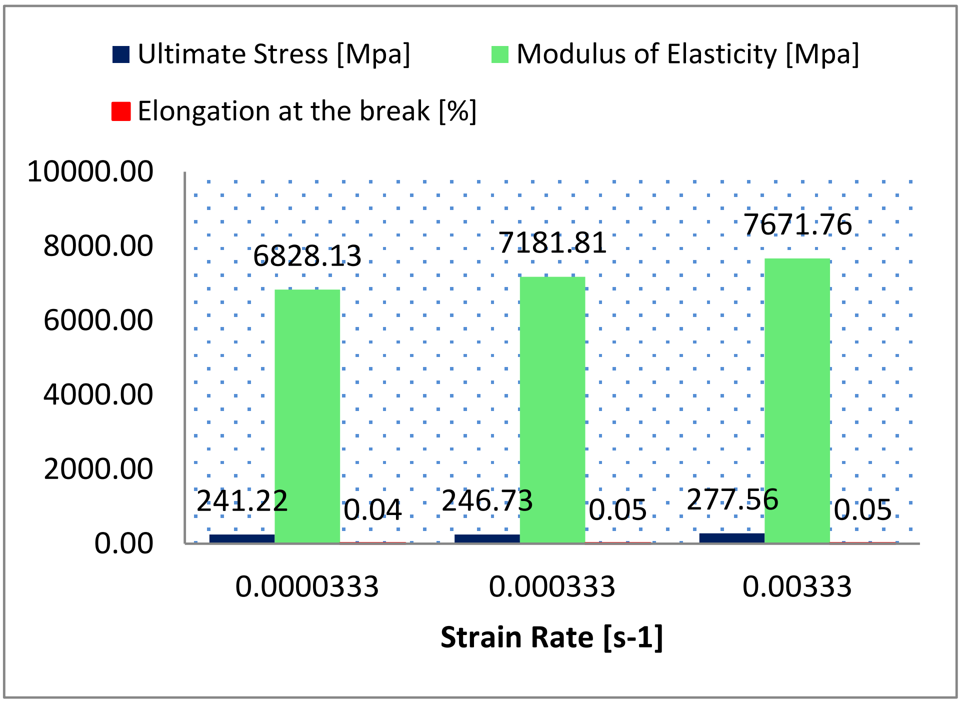


Figure 4.15 Effect of Strain rate on Tensile Stress and Tensile Modulus of elasticity for E-glass/Polyester Composite

4.2.2. Effect of Strain rate on Shear Properties

According to ASTM standard [20], the maximum shear stress can obtained using the following formula:

$$\tau^m = P^m/2A \quad (4.2)$$

Where τ^m = maximum in-plane shear stress, MPa;

P^m= maximum force at or below 5 % engineering shear strain, N

A= Cross-sectional Area, mm^2

Figure 4.16 shows the effect of strain rate on maximum shear stress and modulus of elasticity. From the graph it can be understand that the tensile stress and as well as the modulus of elasticity of E-glass/Epoxy composite increases with the strain rate. The percentage of increment on modulus is 21.41% and 16.21% for the first and the second strain rates respectively.

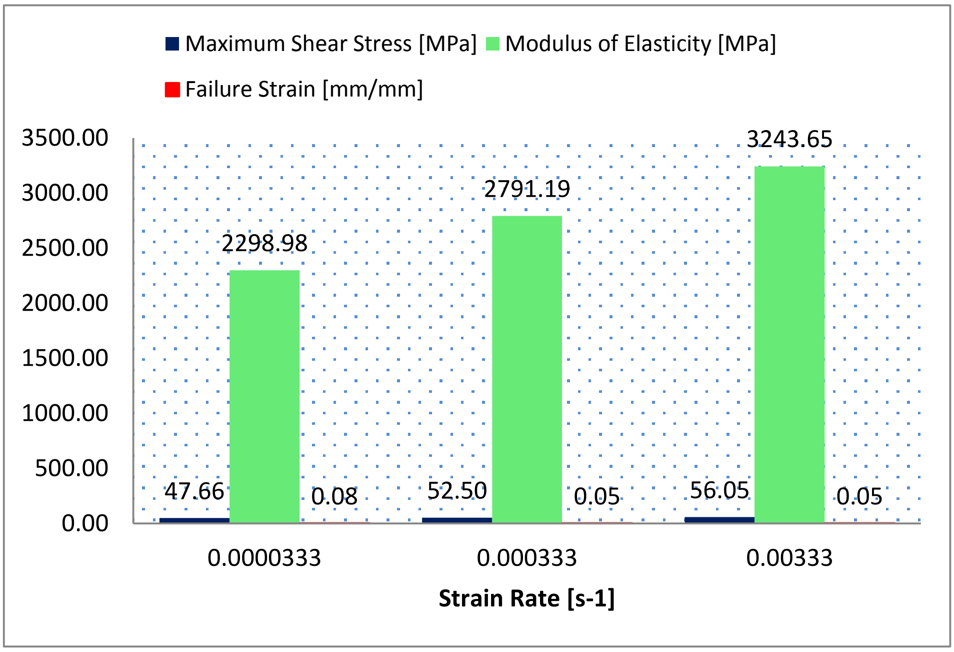


Figure 4.16 Effect of Strain rate on Shear Stress and Shear Modulus of elasticity for E-glass/Epoxy Composite

In case of E-glass/Polyester composite, both the ultimate tensile and tensile modulus of elasticity decreases when the strain rate increases. As it is shown in figure 4.17 below, the percentage of decrement in modulus is 13.55% and 7.98% for the first and the second strain rate values respectively.

Typical shear properties for E-glass/epoxy and E-glass/polyester composites when the strain rate is 0.000333 s-1 is shown in the appendix B.

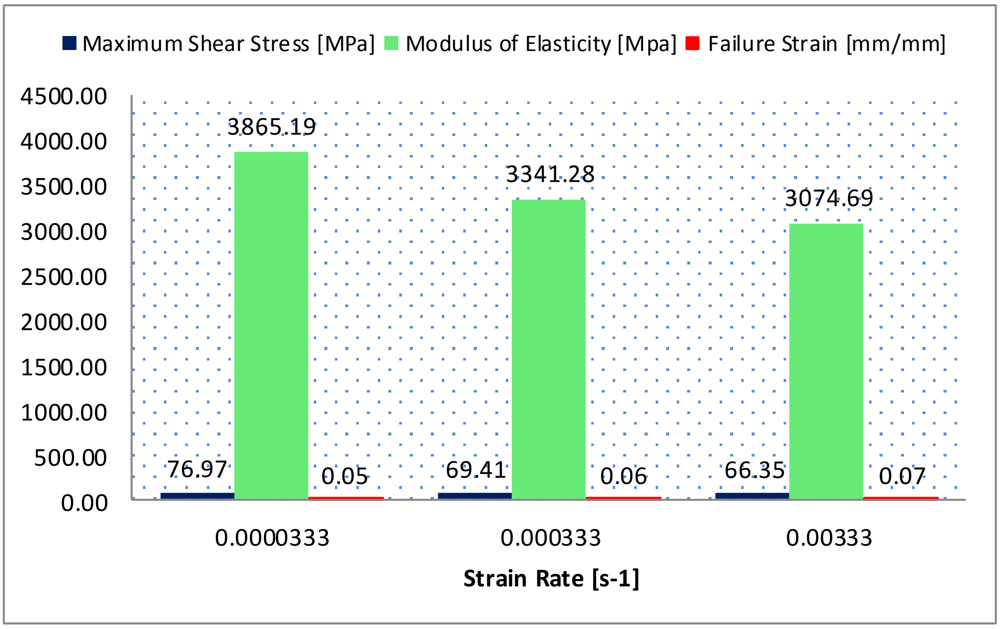


Figure 4.17Effect of Strain rate on Shear Stress and Shear Modulus of elasticity for E-glass/Polyester Composite

4.2.3. Effect of Strain rate on Compressive Properties

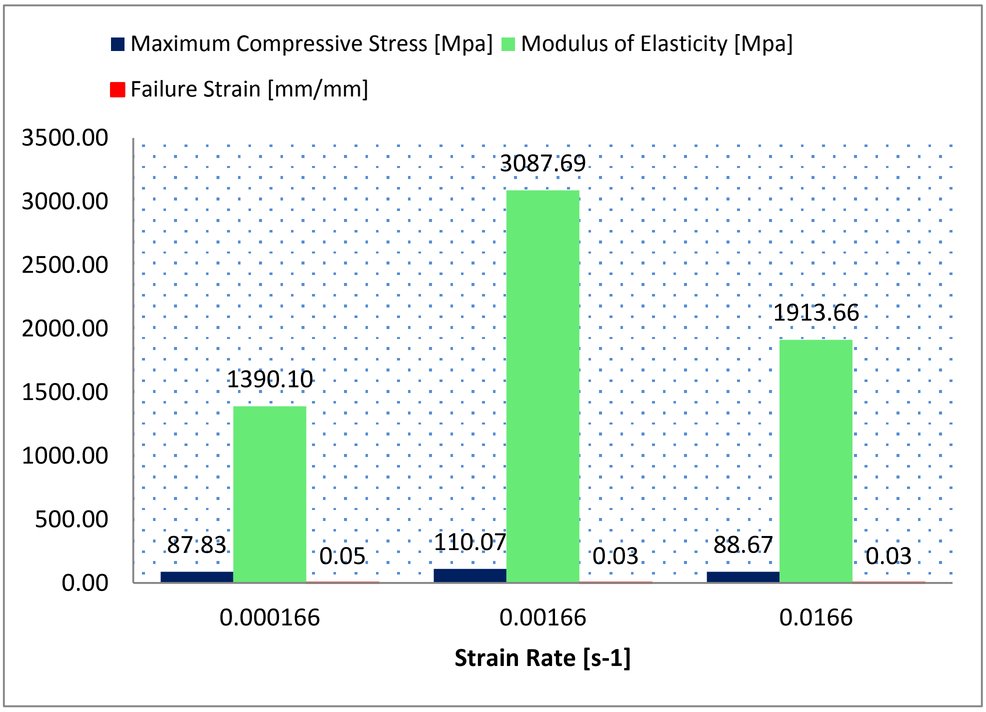


Figure 4.18 Effect of Strain rate on Compressive Stress and compressive Modulus of elasticity for E-glass/Epoxy Composite

According to ASTM standard [21], the maximum compressive stress can calculated using the following formula:

$$F^{ut} = P^{ut}/A \quad (4.3)$$

Where: F^{ut}= Ultimate/Maximum Compressive Strength, MPa

P^{ut}= Maximum load before failure, N

A= Average Cross-sectional Area, mm2

Figure 4.18 presents the effect of strain rate on maximum compressive stress and modulus of elasticity. From the graph it can be understood that the compressive stress and as well as the modulus of elasticity of E-glass/Epoxy composite increases with the strain rate for the first two speeds and decreases for the last speed when the strain rate increases. The percentage of increment and decrement on modulus is 122.22% and 38.02% respectively.

In case of E-glass/Polyester composite, both the maximum compressive stress and modulus of elasticity increases with strain rate. As it is shown in figure 4.19 below, the percentage of enhancement in modulus is 24.29% and 22.41% for the first and the second strain rate values respectively. Typical compressive properties for E-glass/epoxy and E-glass/polyester composites when the strain rate is 0.00166 s-1 is shown in the appendix B.

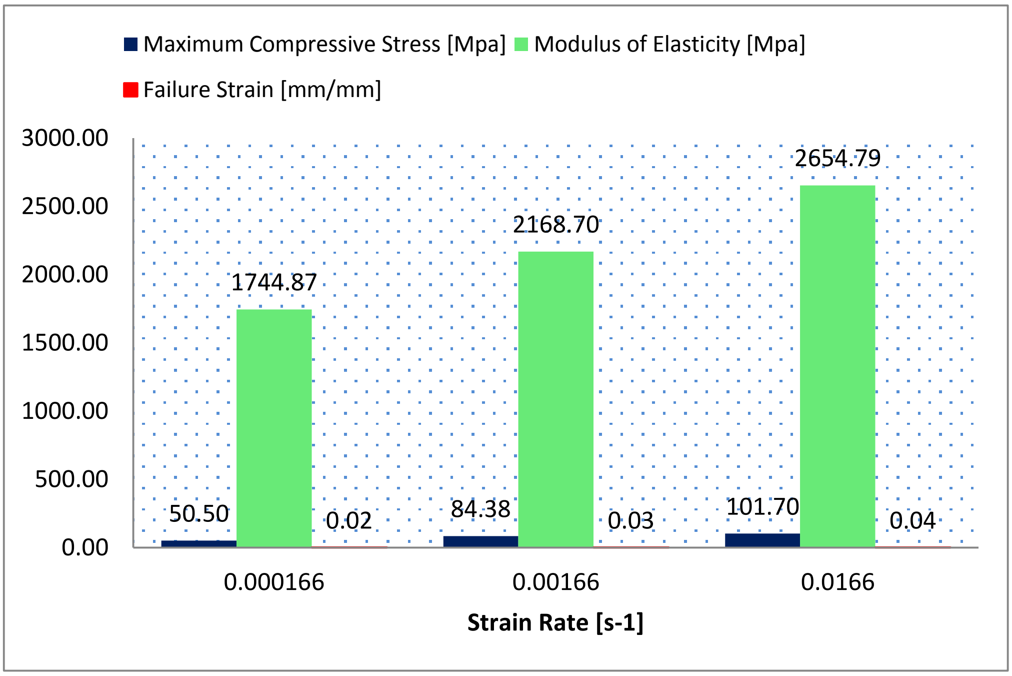


Figure 4.19 Effect of Strain rate on Compressive Stress and compressive Modulus of elasticity for E-glass/Polyester Composite

4.2.4. Effect of Strain rate on Flexural Properties

According to ASTM standard [22, 30], the deflection, flexural stress, flexural strain and modulus of elasticity at bending can obtained using the following formulas:

$D = rL^2/6d$

$\sigma_f = 3PL/2bd^2$

$\varepsilon_f = 6Dd/L2$

$E_B = L^3m/4bd^3$ (4.4)

Where: D= midspan deflection, mm,

r = strain, mm/mm,

L = support span, mm, and

d = thickness of beam, mm

σ_f = stress in the outer fibers at midpoint, MPa

P = load at a given point on the load-deflection curve, N

b = width of beam tested, mm, and

ε_f = strain in the outer surface, mm/mm [in./in.],

E_B= modulus of elasticity in bending, MPa,

m = slope of the tangent to the initial straight-line portion of the load-deflection curve, N/mm of deflection.

Figure 4.20 presents the effect of strain rate on flexural stress and bending modulus of elasticity. From the graph it can be seen that the flexural stress and as well as the modulus of elasticity at bending of E-glass/Epoxy composite increases with the strain rate. The percentage of increment on modulus is 18.08% and 10.34% for the first and the second strain rates respectively.

In case of E-glass/Polyester composite, both the maximum flexural stress and modulus of elasticity at bending decreases when the strain rate increases. As it is shown in figure 4.21 below, the percentage of decrement in modulus is 27.997% and 6.124% for the first and the second strain rate values respectively. Typical Flexural properties for E-glass/epoxy and E-glass/polyester composites when the strain rate is 0.0003175 s-1 is shown in the appendix B.

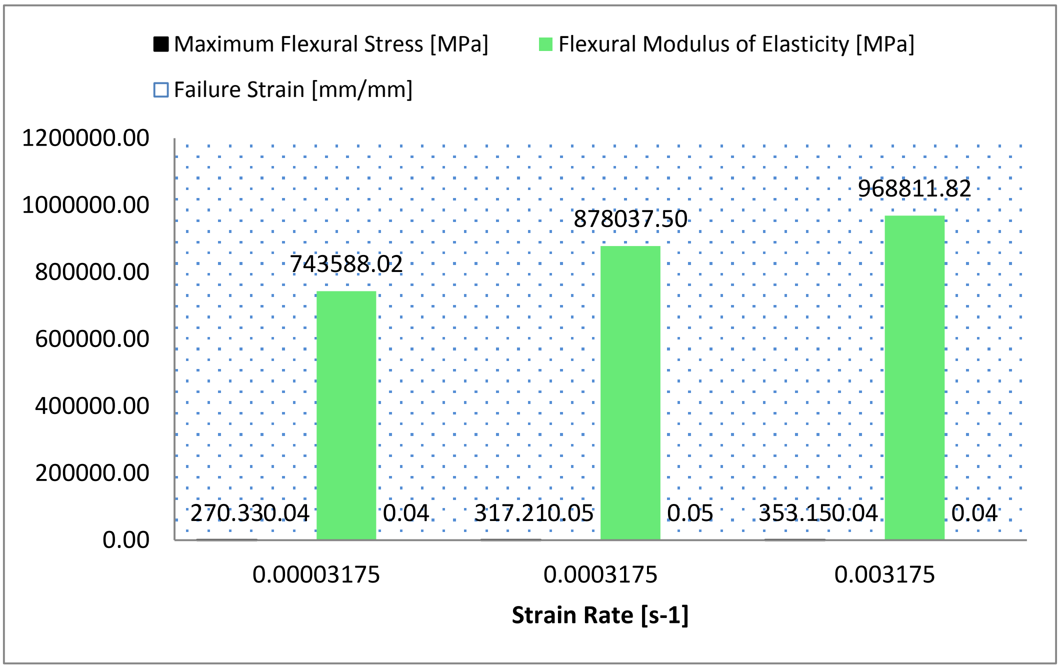


Figure 4.20 Effect of Strain rate on Flexural Stress and Flexural Modulus of elasticity for E-glass/Epoxy Composite

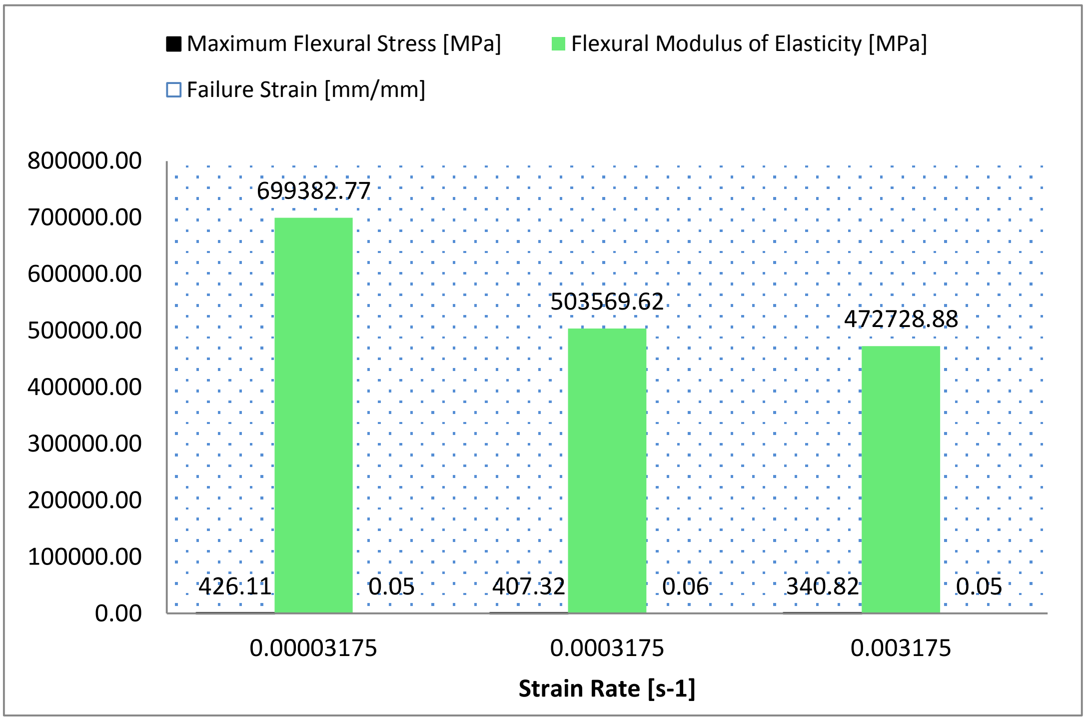


Figure 4.21 Effect of Strain rate on Flexural Stress and Flexural Modulus of elasticity for E-glass/Polyester Composite

CHAPTER 5: CONCLUSSION AND RECOMMENDATION

5.1. Conclusion

The tensile, compression, flexural and in-plane shear properties of plain woven E-glass/Epoxy &E-glass/Polyester composite are presented under quasi-static strain rate and the following conclusions are obtained.

- The compressive, shear and flexural properties of E-glass/Epoxy composite have an increasing trend when the strain rate is increasing; whereas the tensile strength decreases as the strain rate increases.
- In case of E-glass/Polyester composite, the tensile strength and compressive strength increases as the strain rate increases and the in-plane shear and flexural strength show a decreasing trend as the strain rate increases.
- SEM observation indicates the main problem of E-glass reinforced with epoxy and polyester is that fiber pull-out and delamination.
- On the other hand, the properties obtained from this test result shows better than the one that was used for automotive panel manufacturing in the past [3, 17].

5.2. Recommendation

From the SEM observations it can be concluded that care must be done during the manufacturing of composite material in order to avoid micro-voids/porosity and delamination of fibers. This defect can be eliminated by using controlled vacuum pump in vacuum bagging techniques.

Different auto makers specify different strength requirements to achieve dent resistance. Auto makers in the U.S.A. typically require higher strength outer panel alloys (yield strength >207 MPa) to achieve dent resistance while Japanese manufacturers sometimes specify lower strength alloys (138 MPa < yield strength < 172 MPa, for example). Outer panels must also be formable. In addition to stretch ability and draw ability, certain parts require stringent flat hem capabilities for joining. Inner hang-on panels include such components as inner hoods, deck lids, and doors. Formability is typically the limiting requirement for these types of parts, and surface requirements are less stringent, [3, 32]. From this point of view composites satisfy the properties listed above.

Finally, it is recommended that woven glass fiber reinforced with epoxy composite materials are suitable for structural automotive applications, such as interior and exterior body panels and perform to a similar standard as steel components.

5.3. Future Works

The area that must be done in continuous with this work is presented in this sub topic. The following area is suggested for further study:

1. Impact behavior of E-glass/Epoxy or E-glass/Polyester composite
2. Modification of the mechanical properties of E-glass/Epoxy or E-glass/Polyester composite by adding Nano clays.
3. Effect of fiber orientation on the mechanical properties of E-glass/Epoxy or E-glass/Polyester composite
4. Modeling of E-glass reinforced with epoxy composite using Finite Element Softwares
5. Studying the fracture properties of composite material

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Appendix

A. Mechanical Properties of Materials

Mechanical properties of plain woven fabric E-glass fiber, epoxy and hardener

Woven Fabric E-Glass fiber

Technical Data

Color	white
Normal thickness	0.55mm
Weave type	Plain woven (0, 90)

Typical properties of Woven fabric E-glass fiber

Mechanical Properties	**Value**
Density (gm./cc)	2.6
Tensile strength (MPa)	2500
Tensile modulus(MPa)	74,000
Shear modulus (MPa)	30,000
Elongation	3.5%

Table A.1: Typical properties of woven E-glass fiber

System 2000 Epoxy Resin and System 2060 hardener

Product Specifications of 2060 hardener

	2000	2020	2060	2120	ASTM Method
Color	Lt. Amber	Amber	Amber	Amber	Visual
Viscosity, @ 77° F, centipoise	1,650 cps	150-175 cps	190-200 cps	200-250 cps	D2393
Specific Gravity, gms./cc	1.15	0.96	0.96	0.95	D1475
Mix Ratio, By Wt		100 : 23 By Weight, or 4 to 1 By Volume	100 : 27 By Weight, or 3 to 1 By Volume		D2471
Pot Life, 4 fl. Oz. Mass @ 77° F		20 minutes	1 hour	2 hour	PTM&W

[Source: Fiber Glast Development Corporation, 385 Carr Drive-Brookville, Ohio 45309, USA]

Typical Mechanical Properties of system 200 Epoxy Resin with its hardener

	2000 w/ 2020	2000 with 2060				2000 w/ 2120	ASTM Method
		Neat Resin (Unreinforced)	With Fiberglass	With Carbon	With Kevlar		
Mix Ratio	100 : 27 By Weight, or 3 to 1 By Volume						PTM&W
Pot Life, @ 77° F	20 minutes	1 hour				2 hours	D2471
Color	Lt. Amber	Light Amber				Lt. Amber	Visual
Mixed Viscosity, @ 77° F, cps	950-975 cps	900 - 950 cps				925 – 975 cps	D2393
Cured Hardness, Shore D	86-88 Shore D	88 Shore D				87 Shore D	D2240
Specific Gravity, grams, cc	1.12-1.13	1.11				1.12	D1475
Density, lb./cu Inch	.0410	.0401				.0410	D792
Specific Volume, cu. in./lb.	24.4	25.0				24.4	D792
Tensile Strength, psi (1)	45,326 psi	9828 psi	45,170 psi	75,640 psi	45,400 psi	45,870 psi	D638
Elongation at Break, % (1)	1.93%	1.90%	1.96%	0.91%	1.31%	1.98%	D638
Tensile modulus, psi (1)	2,.53 x 10^6 psi	418,525 psi	2,620,000 psi	8,170,000 psi	3,770,000 psi	2,520,000 psi	D638
Flexual Strength	65,308 psi	16,827 psi	62,285 psi	96,541 psi	34,524 psi	66,667 psi	D790
Glass Transition Temp. Tg	180° F	196° F				194° F	TMA
Thermal Coef. Of Expansion Range:	3.73 x 10^{-5} in./in./° F	4.3 x 10^{-5} in./in./° F				4.15 x 10^{-5} in./in./° F	D696
Fiberglass Properties Derived with A 10 Ply Laminate, Hand Lay-up, Style 181 Glass Fabric, 55% Glass Content; Carbon Properties with a 10 Ply Laminate of 5.6 oz. 3K Fabric; and Kevlar Properties with a 10 Ply Laminate of 5 oz. Kevlar							

Table A.2: Typical Mechanical Properties of system 2000 Epoxy Resin with its hardener
[Source: Fiber Glast Development Corporation, 385 Carr Drive-Brookville, Ohio 45309, USA]

Properties of polyester hardener

Typical* Liquid Properties	
Viscosity @ 25°C, #2 @ 30 RPM, cps	475
Thixotropic Index	3
%NV	56
Catalyst	1.25g MEKP / 100g Resin
RT Gel Test @ 25°C	
RTG	15
GPE	13
PEF	312.5

*Typical Values: Based on materials tested, but varies from sample to sample. Typical values should not be construed as guaranteed analysis of any specific lot or as specific items.

Typical Cure Schedule	
Pot Life at 77°F	15 min*
Total Time at 77°F	28 min*

*Catalyzed at 1.25% by weight with MEKP

Typical Mechanical Properties of polyester Resin

Resins	Density ρ (kg/m^3)	Elastic Modulus E(Mpa)	Shear Modulus G(Mpa)	Poisson Ratio ν	Tensile Strength σ_{Ult} (Mpa)	Elongation E%	Coefficient of Thermal Expansion α ($°C^{-1}$)	Coefficient of Thermal Conductivity λ(W/m°C)	Heat Capacity C(J/kg°C)	Useful Temperature Limit T_{max} (°C)	Price 1993 ($/kg)
Polyester	1200	4000	1400	0.4	80	2.5	8×10^{-5}	0.2	1400	60 to 200	2.4

B. Mechanical Properties of selected strain rate

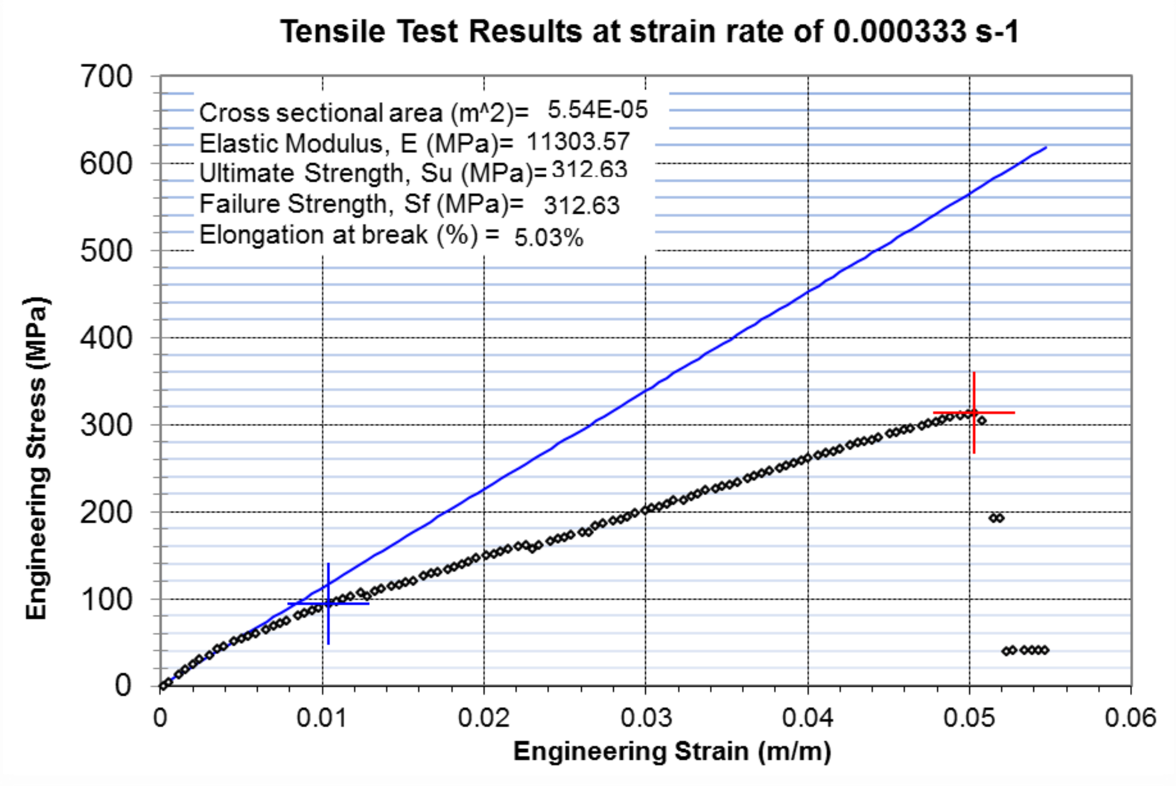

Figure B1 Tensile Properties of E-glass/Epoxy Composite

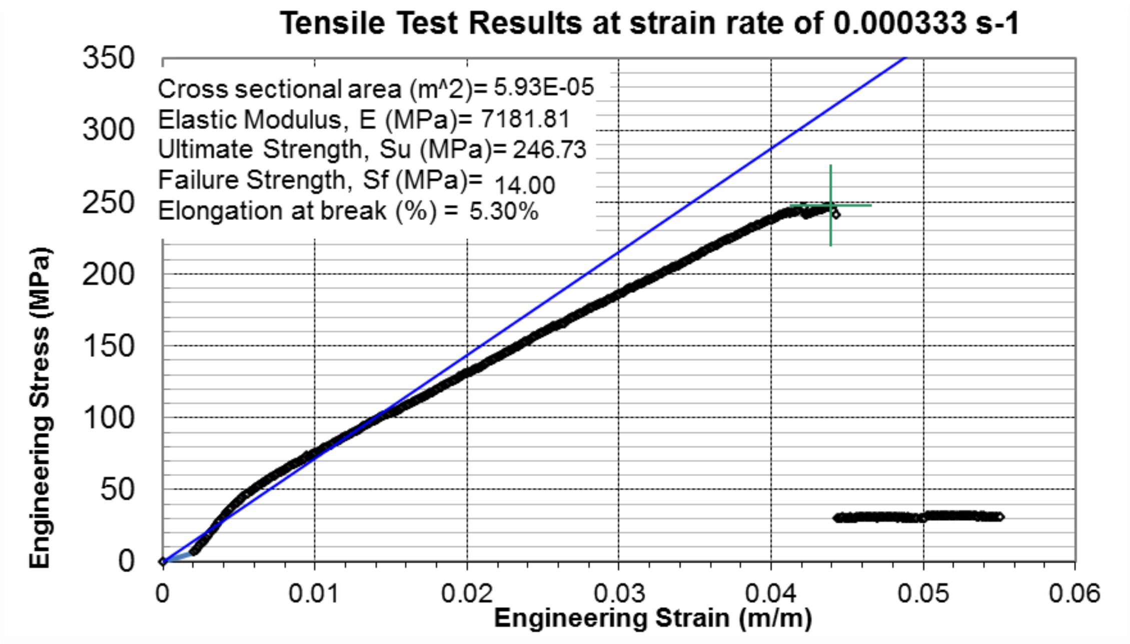

Figure B2 Tensile Properties of E-glass/Polyester Composite

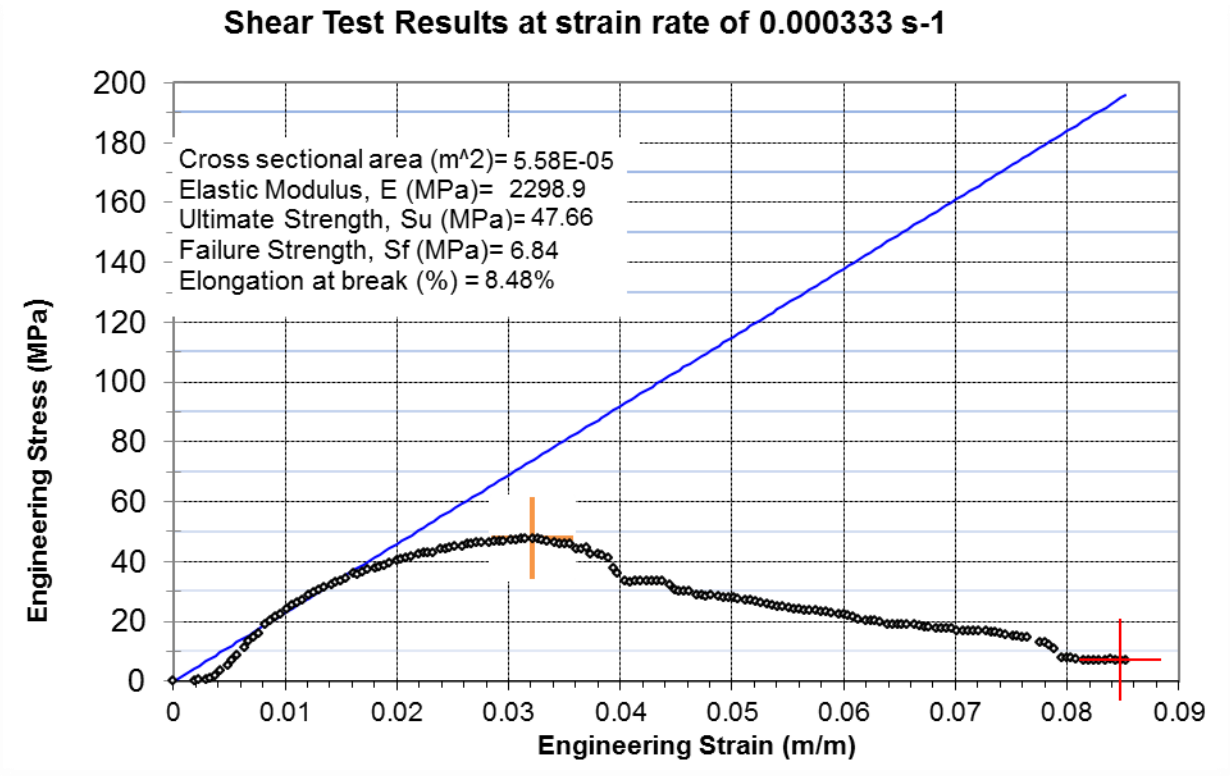

Figure B3 Shear Properties of E-glass/Epoxy Composite

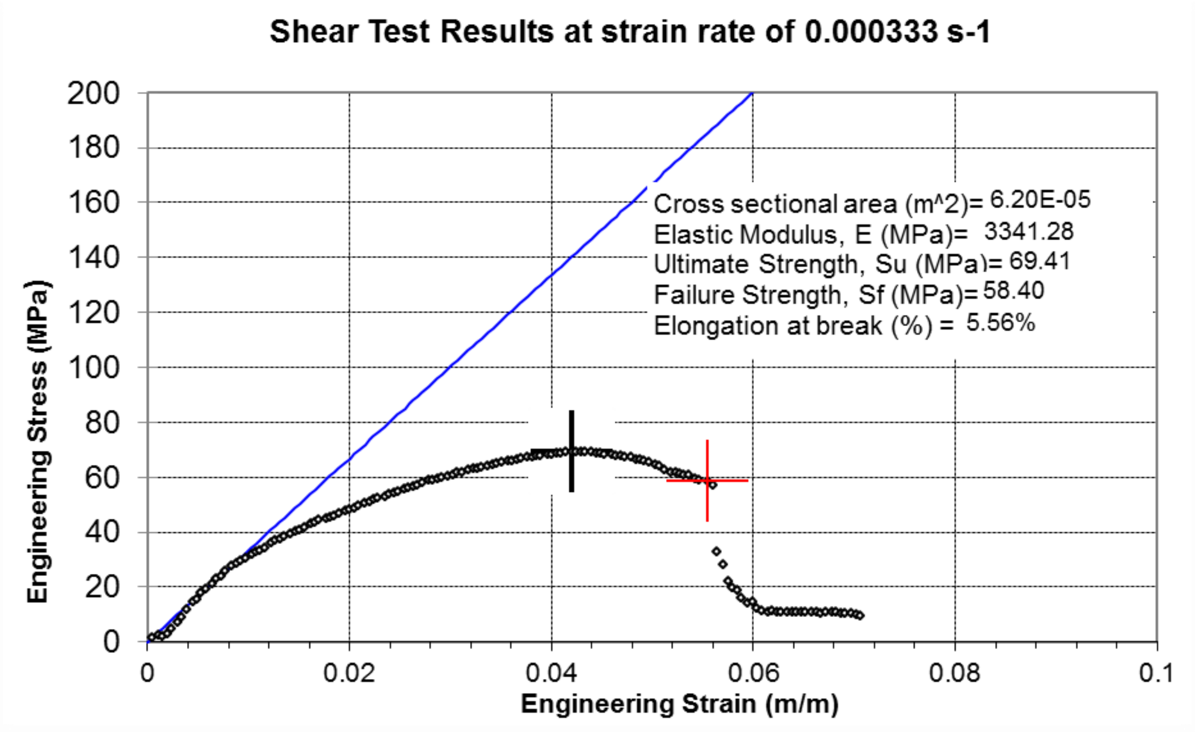

Figure B4 Shear Properties of E-glass/Polyester Composite

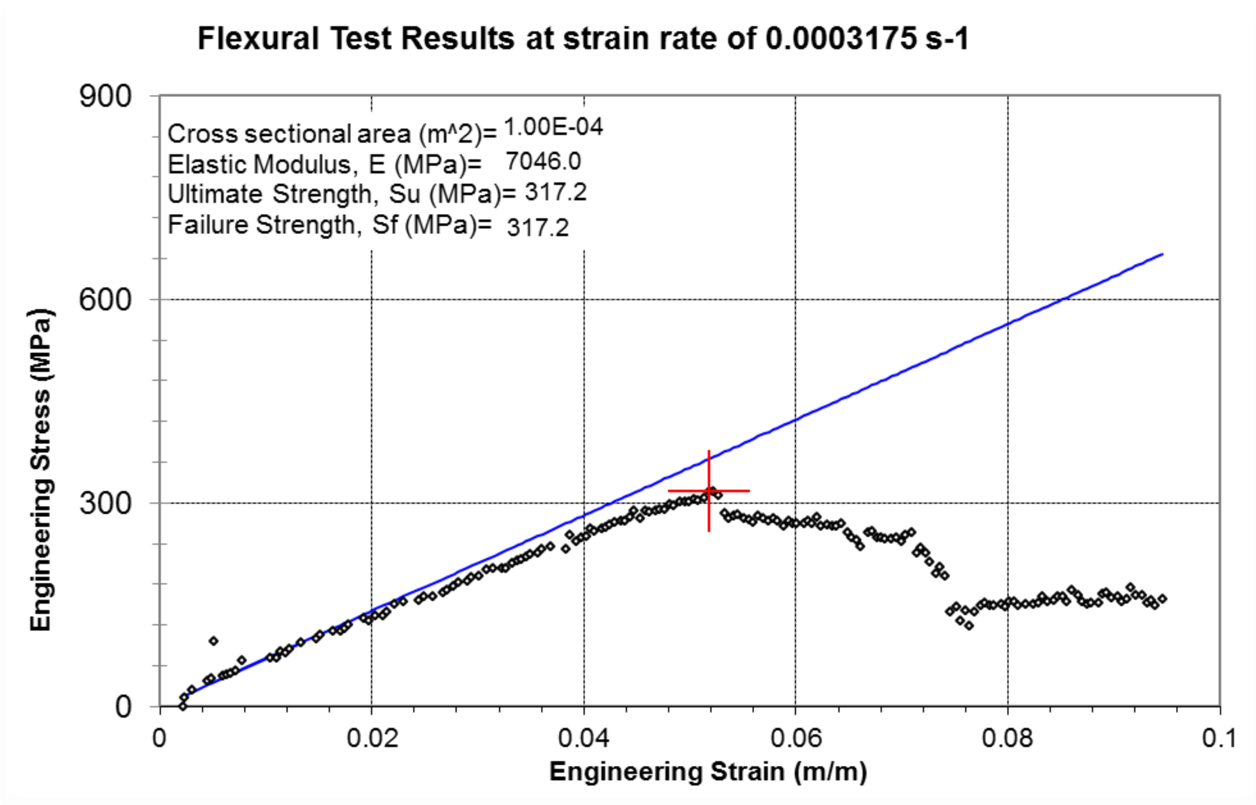

Figure B7 Flexural Properties of E-glass/Epoxy Composite

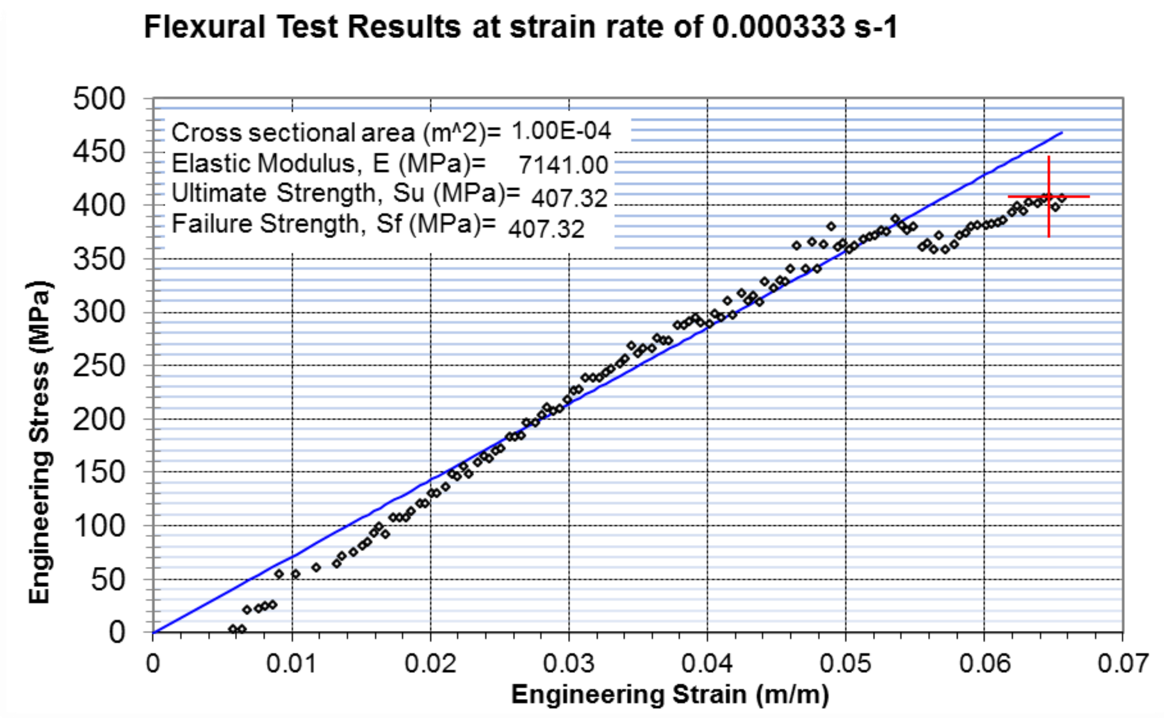

Figure B8 Flexural Properties of E-glass/Epoxy Composite

Addis Ababa University

School of Graduate Studies

This is to certify that the thesis prepared by **Esmael Adem**, entitled: **Mechanical Characterization of E-glass/Epoxy & E-glass/Polyester composite for automotive body application**, do here by declare this thesis is my original work and that it has not been submitted in full for a degree in any university/institution, which compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

Signature ___________________

Date ________________________

Signed by the Examining Committee:

Advisor	___________________	Signature	______________	Date	__________
Internal Examiner	___________________	Signature	______________	Date	__________
External Examiner	___________________	Signature	______________	Date	__________

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