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Tribological Behaviour of E-Glass /Epoxy & E-Glass /polyester Composites for Automotive Body Application

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ABSTRACT: *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 and conduct experimental observation using Scanning Electron Microscopy (SEM) to know in homogeneity, 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 moulding process and E-glass/epoxy laminate by hand lay-up vacuum assisted technique. The 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.*

Keywords - *Epoxy, Fiber volume, Polyester, SE Microscope, Tensile test*

I.INTRODUCTION

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. 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. 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].

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, [3, 4].

George C. Jacob et.al. [5] 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 [6]. 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 [7, 8], shear, and flexural properties of glass/epoxy laminate was investigated by Okoli and Smith. 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.

Keshavamurthy Y. C.et.al. [7] 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., [00], [900], and [±450] are generally fabricated. It is observed from the result that Glass/Epoxy with 00 fiber orientation yields high strength when compare to 300 & 450 for the same load, size & shape.

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. Thus, the paper tries to fill the gap which occurs on the composite manufacturer, Dejen Aviation Industry, here in Ethiopia by conducting experimental tests and 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.

II.MATERIALS AND EXPERIMENTAL TEST CONDITIONS

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: woven roving as shown in fig. 1, 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 fibres 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 this 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 roving’s. This fiber type has good mechanical properties as compared to chopped mat and it is used when higher strength part is required.

Fig 1. E-Glass fiber

Epoxy and its hardener: 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 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).

Polyester 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. 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.

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 equations used to determine fiber volume ratio from reference [9], the unknown values (fiber volume fraction) were evaluated and summarized in Table.

Table 1: Fiber and matrix volume contents of the composite laminate

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%

2.1. Composite Sample Fabrication Process

Composite laminates are formed by assembling different plies with different angles and orientations. Generally, in this work 5 plain woven plies are used for Tensile & shear specimens' preparation and 10 plies are used for compression & bending test specimens. The stacking sequence of laminate used with its respected angle is shown in fig. 2.

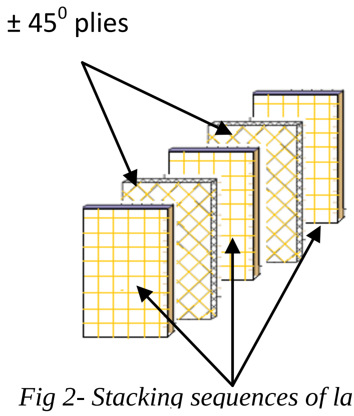
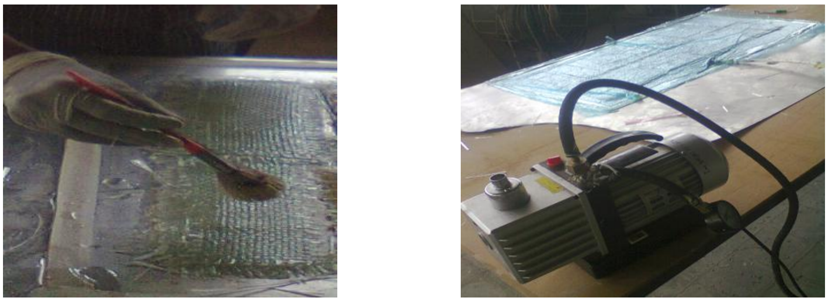


Fig 2- Stacking sequences of laminate

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

1. **Compression Molding** is used for E-glass/Polyester composite samples. 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.
2. **Hand lay-up Vacuum assisted technique (HLVA)** as shown in fig. 3, for E-glass/Epoxy composite samples. 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. The equipment's used are: Rotary vacuum pump, with Model No: 2TW-4C, Capacity: 8cfm, Vacuum: 6.7×10-2Pa, Power: 220-240v/50Hz, Peel Ply (Release Fabric), perforated plastic film, Pressure fabric (breather), Vacuum nylon (vacuum bag), Mastic sealant (Vacuum tape), Vacuum bagging mold, Mold Release, paste wax.

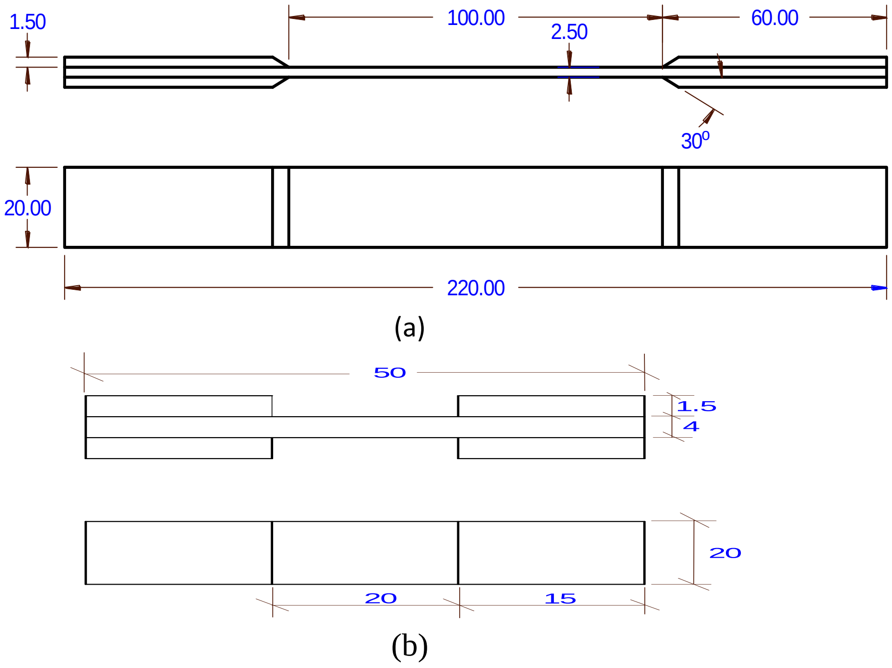


(a) (b)

Fig. 3 Techniques of composite manufacturing used in this paper
(a) Hand lay-up technique (b) HLVA technique

2.2. Specimens Geometry and Dimensions

The geometry of each of loading configuration for E-glass/epoxy & E-glass/Polyester composite material is shown in fig. 4 below and is based on American Society of Testing & Materials (ASTM), [10-14].



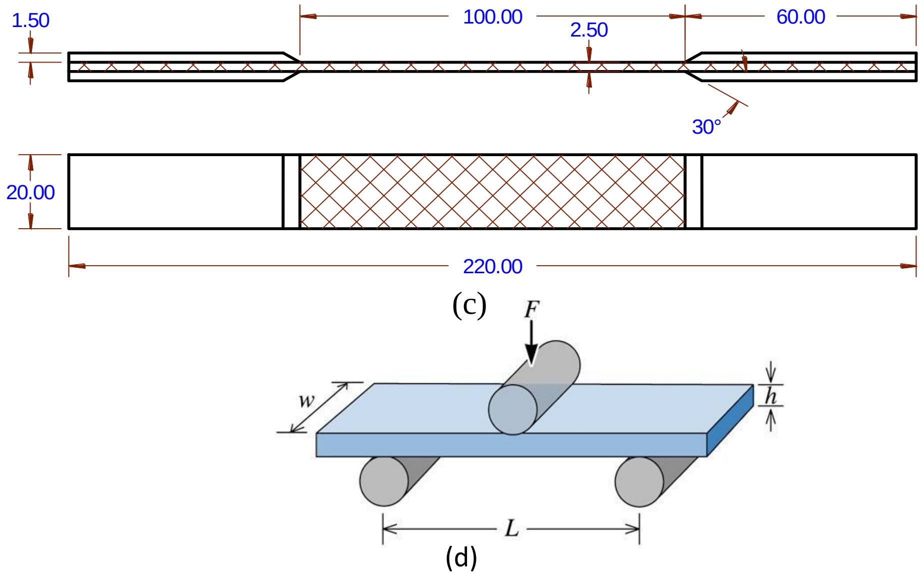


Fig. 4 Test Specimen Dimensions- (a) Tensile Test Specimen (b) Compression Test Specimen (c)In plain Shear Test Specimen (d) 3-point test

2.3. 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 (250C). The strain rate value, crosshead speed and repetition of specimen for these experimental tests are shown in table 2 below.

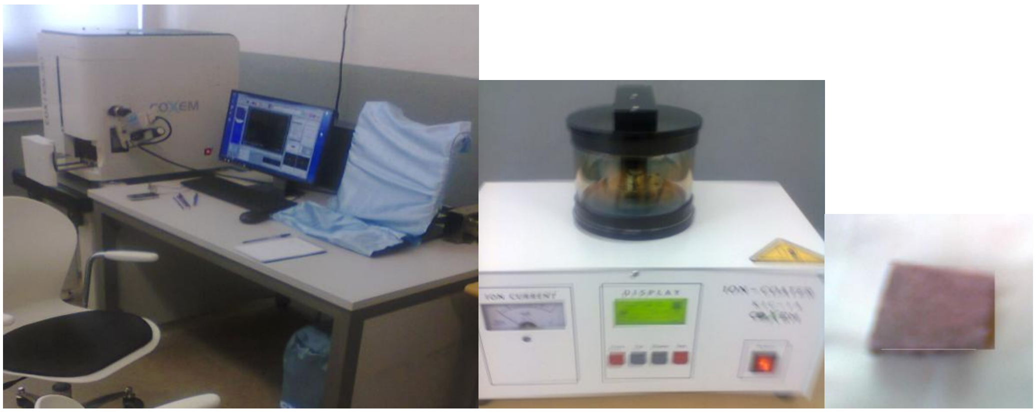
$$\text{Strain Rate} = (\text{Cross Head Speed})/\,(\text{Gauge Length}) \quad = V\,(\text{mm/min})\,/\,(\text{mm})$$

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.

Table 2: Test Condition Parameters

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		

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 fig. 5 below.



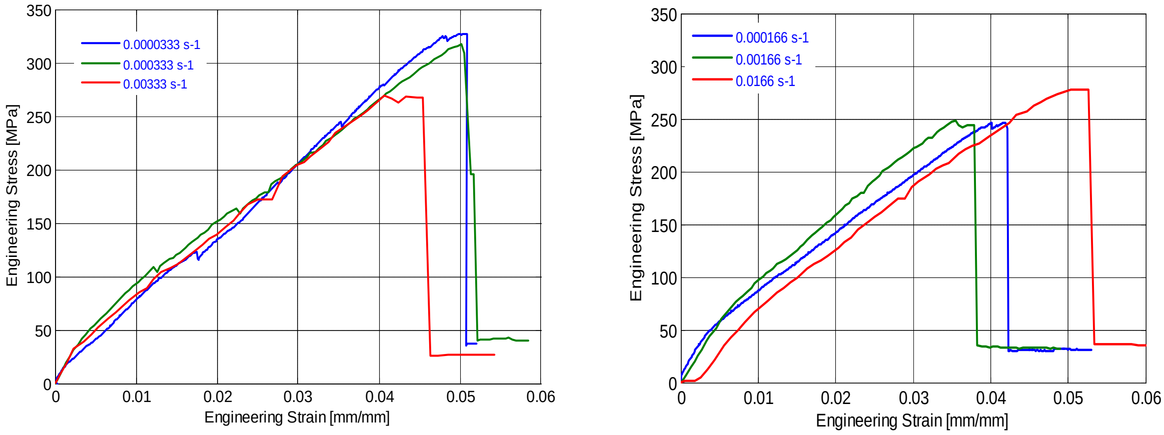
(a) (b) (c)

Fig. 5: (a) Scanning Electron Microscopy (b) Ion Gold Coater (c) Gold Coated Specimen

III. Experimental Results and Discussion

2.4. Tensile test

Fig. 6 (a) 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 6 (b). 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.

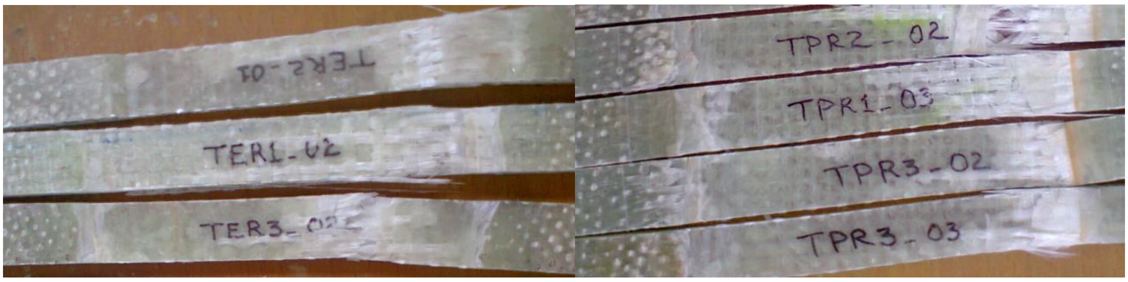


(a) E-glass/Epoxy

(b) E-glass/Polyester

Fig. 6 Effect of Strain Rate on Tensile Strength of E-Glass/Epoxy and E-Glass/Polyester Composites

Regarding tensile failure mode, E-glass/Epoxy composite showed significant failure mode variation with increasing strain rate. As shown in Fig. 7 (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. 7 (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. 7 (b).

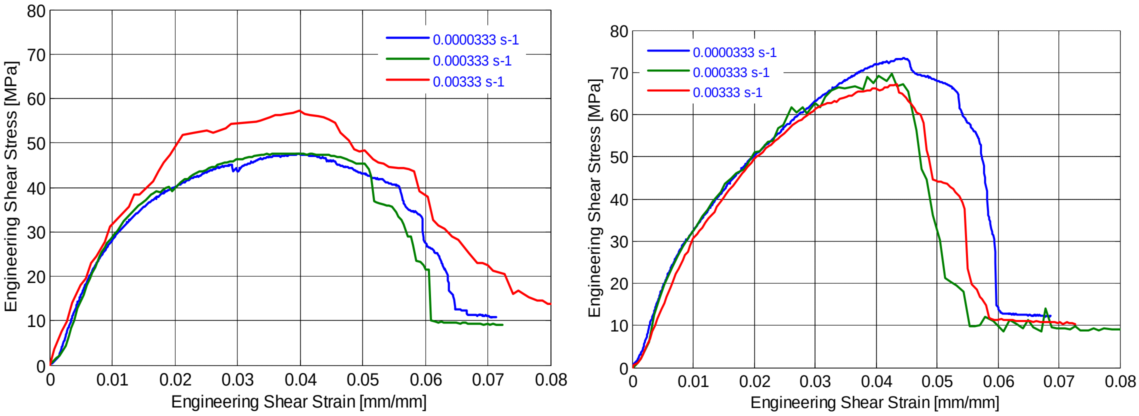


(a) (b)

Fig. 7 Tensile Failure modes (a) E-glass/Epoxy composite (b) E-glass/Polyester Composite

2.5. In-Plane shearing Test

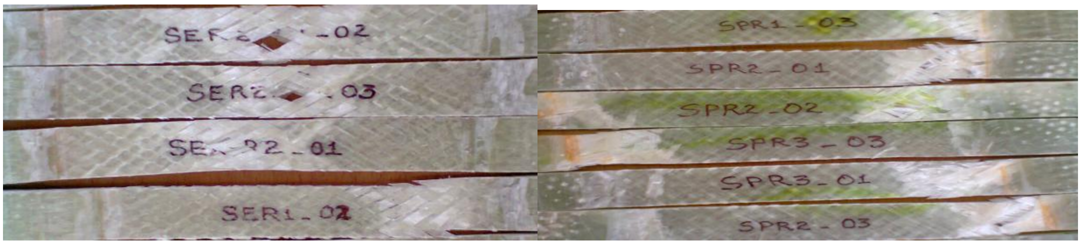
Fig. 8 (a) demonstrates quasi static strain rate effects on shear strength of E-glass/Epoxy composites. The test result shown is based on the average value of three specimens for each strain rate value. It can be clearly seen that the sear strength is increasing with the increase of strain rate. The 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 8 (b) 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 [5].



(a) E-glass/Epoxy *(b) E-glass/Polyester*

Fig. 8 In-plane shear strength of E-glass/Epoxy and E-glass/Polyester composites

Regarding in-plane shear failure mode, E-glass/Epoxy composite showed significant failure mode variation with increasing strain rate. As shown in Fig. 9 (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. 9 (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. 9 (b).

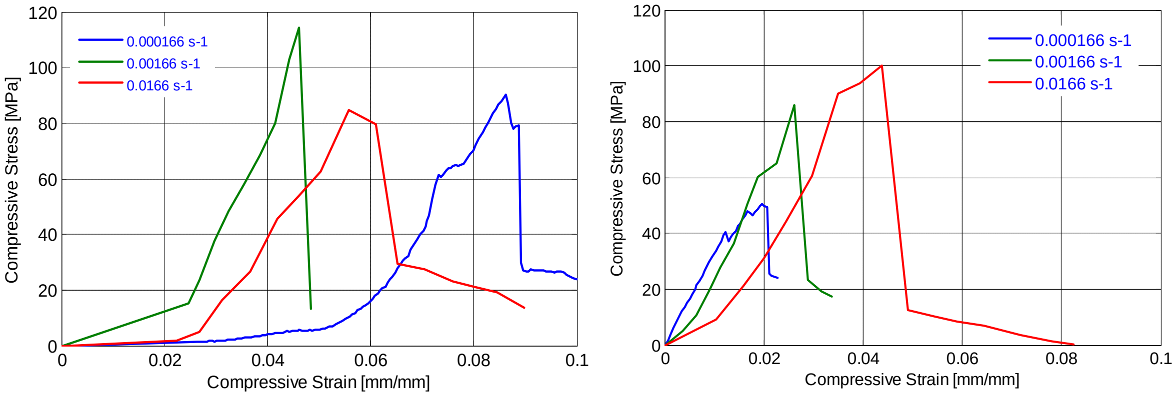


(a) (b)

Fig. 9 In-plane Shear Failure modes (a) E-glass/Epoxy composite (b) E-glass/Polyester Composite

2.6. 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 Addis Ababa Institute of Technology 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.



(a) E-glass/Epoxy *(b) E-glass/Polyester*

Fig. 10 Compressive strength of E-glass/Epoxy E-glass/Polyester composites

Fig. 10 (a) 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 fig. 10 (b). 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. 11 (a and b).

(a) (b)

Fig. 11 Compressive failure modes (a) E-glass/Epoxy and (b) E-glass/Polyester composites

2.7. Flexural Test

Fig. 12 (a) 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 12 (b). 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.

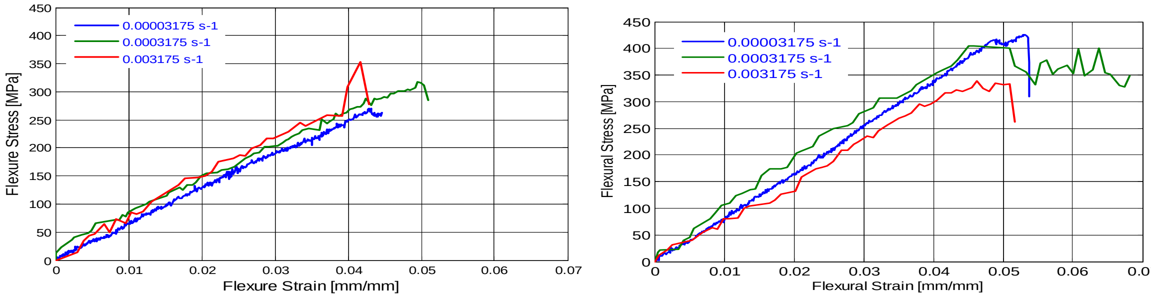
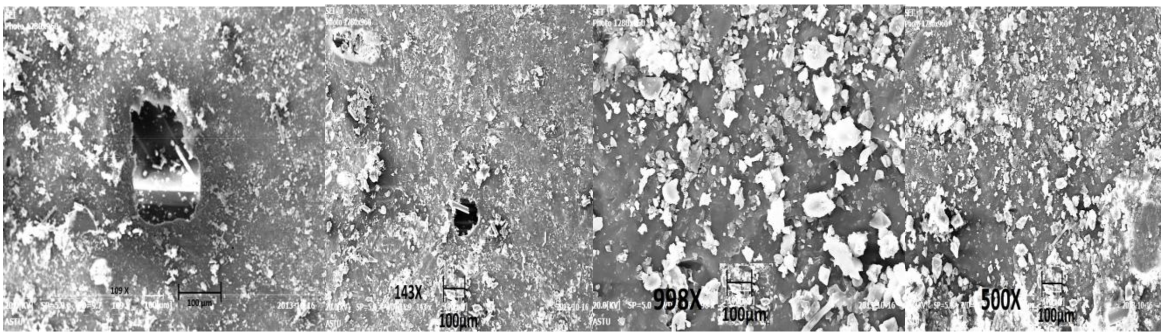


Fig. 12 Flexural strength of E-glass/Epoxy E-glass/Polyester composites

2.8. Scanning Electron Microscopy Observations

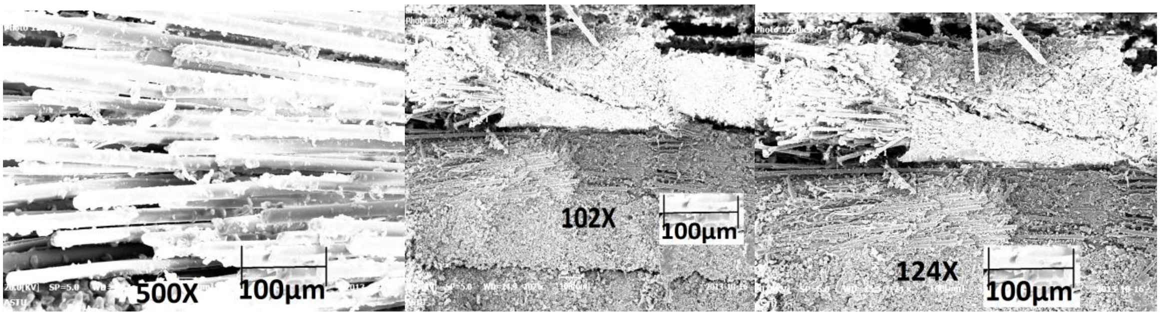
Scanning electron microscope (SEM) pictures of E-glass/epoxy composite surfaces before tensile test were obtained with different magnification scale as shown in Fig. 13a-13d. Fiber bonding and adhesion between the fiber and the matrix are clearly figured out from morphological studies. The interaction between matrix and glass fibers is good as it is seen from scanning electron microscope pictures. Fig. 13a-13b 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 (13c-13e) showed a rough surface and the strongly bonded fiber-matrix interface.



(a)109 X (b) 143 X (c) 998 X (d) 500 X

Fig. 13 SEM picture at different magnification scales before test

Fig. 14(a-c) shows SEM picture when the surface is observed after tensile test was conducted. Fig. 14 (a) indicates that some fibers are pulled out of the matrix as a result of mechanical fracturing done in tensile test. In Figure 14 (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.[5]



(a)500 X (b) *102 X* (c) *124 X*

Fig. 14 SEM pictures after tensile test

IV. 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.

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