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Evaluation of Mechanical Properties and Microstructure of Polyester and Epoxy Resin Matrices Reinforced with Jute, E-glass and coconut Fiber

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Abstract

Composite manufacturing is a novel branch of science and often finds numerous applications in several industries. Some of them are sport, automobile, aerospace and marine industries. Some of the properties that can be highlighted are good mechanical properties along with stiffness and comparatively lighter weight. There is a continuous research in this area is as the constant pursuit to achieve greater performance by changing various materials and the combinations of those with various resins are experimented. In the current work, polyester and epoxy resins were reinforced with coconut, E-glass and jute fibers of 5-6mm length and were prepared by hand layup method. The fiber and resin were taken in 18:82 weight percentages. Post production of the composites they were subjected to various physical mechanical and microstructural studies to determine various properties. The morphological features were analyzed through the microstructural study done through scanning electron microscope. In comparison with the composites manufactured, The artificial fiber reinforced composite, E-glass fiber reinforced epoxy composites exhibited superior tensile strength, flexural strength, impact toughness and hardness values. Among the natural fiber reinforced composite, coconut fiber reinforced composites exhibited better tensile, impact and hardness than its counterpart jute reinforced composites. Thus the resins reinforced with E-glass fiber had the highest mechanical properties when compared with jute fiber reinforced composites (JFRC) and coconut fiber reinforced composites (CFRC). The cost effectiveness of the natural fiber reinforced composites is also an added advantage over the artificial fiber reinforced composites.

Selection and/or Peer-review under responsibility of Materials Processing and characterization.

Keywords: aerospace; stiffness; weight percentage; microstructural study; morphological features.

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Nomenclature

σt	Tensile strength.
P	Ultimate load on the specimen.
b	Initial width of the specimen.
h	Initial thickness of the specimen.
E	Young's Modulus.
σf	Flexural strength.
L	span length of the specimen.
b	width of the specimen.
h	thickness of the specimen.
S	measured deflection.
TETA	Triethylene tetra amine.
MEKPO	Methyl Ethyl ketone peroxide.
NFRC	Natural fiber reinforced composites.
GFRC	Glass fiber reinforced comsposites.
JFREC	Jute fiber reinforced epoxy composite.
JFRPC	jute fiber reinforced polyester composite.
EFREC	E-glass fiber reinforced epoxy composite.
EFRPC	E-glass fiber reinforced polyester composite.
CFREC	Coconut fiber reinforced epoxy composite.
CFRPC	Coconut fiber reinforced polyester composite.

1. Introduction

Manufacturing of composite material has been a major area of research for the scientists as it includes vast applications in almost all the recent fields of engineering. From the aerospace to automotive the quest of engineers for the lighter and stronger material has led them to choose composite material as the alternative for the metals. Metals being heavier and difficult to machine is being replaced gradually in all the fields by composite materials manufactured to suit the purpose with necessary strength and flexibility. The main advantage of the composites is that it can be manufactured to suit the exact need of the application. The composites can be manufactured keeping in mind the strength and the workability. The light weight of the composite structures is an added advantage. The immense researches going on this field currently has brought to light different kinds of composites. Fiber reinforced composites being one of the many different types which are invented to enhance the strength of the otherwise weaker polymer matrix composites. The inclusion of the fibers to the polymer matrix not only enhances the mechanical properties but also improves the workability.

The applications of composites are vast and are found to be suitable for marine applications owing to some of the properties like excellent strength, moisture resistance and electrical and fire protection[1]. The applications of fiber reinforced composites even extend to structures in an airplane, which experiences great fluctuations in temperatures upto -60degress during their flight. Even cryogenic temperatures of -150°C use fiber reinforced composites. The higher strength, stiffness and damping properties account to the use of them in these applications [2]. In automobile sector the application of the composites are in multiple areas. It ranges from door panels and interiors to leaf spring of the suspension. The properties of the composites such as less weight and cost effectiveness were the ones that make it the suitable candidate. Hybrid composites can be made to suit the needs and reinforced composites eventually manufactured is relevant to the situation [3]. The composites can be manufactured by stacking different layers of fibers and also in different orientation to improve and build the properties of the composite [4].

One of the important properties of any composite is its stiffness. Researches that were conducted have concluded that if the factors like fiber length and weight concentration are taken into consideration, the stiffness is virtually independent of fiber length; however it showed directly proportional increase with respect to the strand concentration [5].

The fiber weight percentage always seems to to have direct relationship with the flexural and tensile properties. These properties shows considerable improvement from the pure resin composite at the cost of decrease in impact energy due to the rise in brittleness of the composite. [6]. The possible reason for the low impact energy for natural fiber reinforced composites may be; being a natural fiber it contains a considerable amount of greater cellulose content and lower micro fibril angle which results in higher work of fracture during the impact test [7]. Using several methods the energy-absorbing tools are recognized and estimated. Unidirectional composite beams are exposed to impact from which the energy-engrossing tools are considered [8].

Some of the most important aspects of the composites are their interfacial properties like moisture absorption and exterior fiber contact [9]. Glass/epoxy laminated composites can be exposed to low velocity impact at low energy levels to investigate its influence on various factors such as crack length, delamination and elastic energy [10]. The artificial fibers tend to show better mechanical properties than their natural fiber counter parts. Polymer to glass adhesion is one of the main factors that determine the overall strength of the composite. Various efforts such as glass surface modification and polymer matrix modification can be made to improve this by compatibility enhancement. The methods adopted however do not give a satisfactory solution considering the cost to properties relationship [11]. E-Glass fiber reinforced epoxy composites can also be fabricated by adding fillers and reinforcements. Al_2O_3 and $Mg(OH)_2$ being some of the examples of the same. The results can be improved if the fillers are used in the correct proportions however the usage can also cause reduction in the properties [12].

The Natural fibers are easily manufactured and they are also light in weight which allows us to manufacture composites with reduction in density. The composites manufactured are environment friendly and cost effective. Thus the natural fibers can be used as a substitute source to synthetic fibers [13].

The manufacturing of the composites have a number of methods out of which hand layup is one of the most preferred technique. The process can be carried out at different curing temperatures and often with increased curing pressures the elastic tensile stiffness and the ductility was found to converge [14]. The fiber reinforced composites are more suitable for tensile and flexural applications. These properties are greatly influenced by the fiber weight percentage in the polymer matrix. However with the increase in brittleness of the composites the impact energy is found to decrease [15]. The fiber reinforcements at a weight percentage can even be of Nano size which can improve the mechanical properties [16].

The Coir fiber and even the coconut shell can be used as a reinforcement to improve the tensile and flexural properties of the polymer composite [17]. Using SEM, interfusion properties of the natural fiber reinforced composites can be compared to that of E-glass fiber reinforced composites [18]. Jute fiber mats can be used as a natural fiber reinforcement system and using hand layup method resin can be preimpregnated into the jute fiber at vacuum [19]. The imperfections in the composites can be due to many reasons one of which is crimping along with stress concentrations forms one of the main reasons for brittle fracture. Based on experimental and finite element analysis method it is often proved that the fracture behaviour of Composites was found to be tougher along the fiber direction, than across the direction of the fibers [20]. Often the artificial fiber reinforced composites are found to exhibit higher mechanical properties than the natural fiber reinforced composites. However Natural fiber reinforced composites also show excellent mechanical properties and can be actively used in low impact applications [21]. E-glass fiber reinforced composites often show superior mechanical properties than the natural fiber reinforced composites [22].

Various researches for the development of a composite using natural fibers and natural resins which are environmentally friendly and biodegradable and has the properties in par with that of the artificial fiber reinforced composites has been underway for a long time. In the current research we have focused on the synthesis and characterization of the jute, E-glass and coconut fiber reinforced composites, of fiber length 5-6 mm, a fiber-resin weight percentage of 18:82, with thermosetting resin polymers, polyester and epoxy. The research focuses on finding out the mechanical properties of the composites made thereby analyzing the properties. The natural fibers and artificial fibers are used in the process along with the thermosetting polymers. The microstructures of the FRC were perceived in scanning electron microscope thereby analyzing the possible causes of the failures. The prepared composites were subjected to mechanical characterization such as hardness, flexural strength, impact and tensile test. The scope of the work includes study for the improvement in mechanical properties of composites synthesized and identifying an alternate environmentally suitable material for various automotive applications as shown in below Fig 1..

2. Research methodology

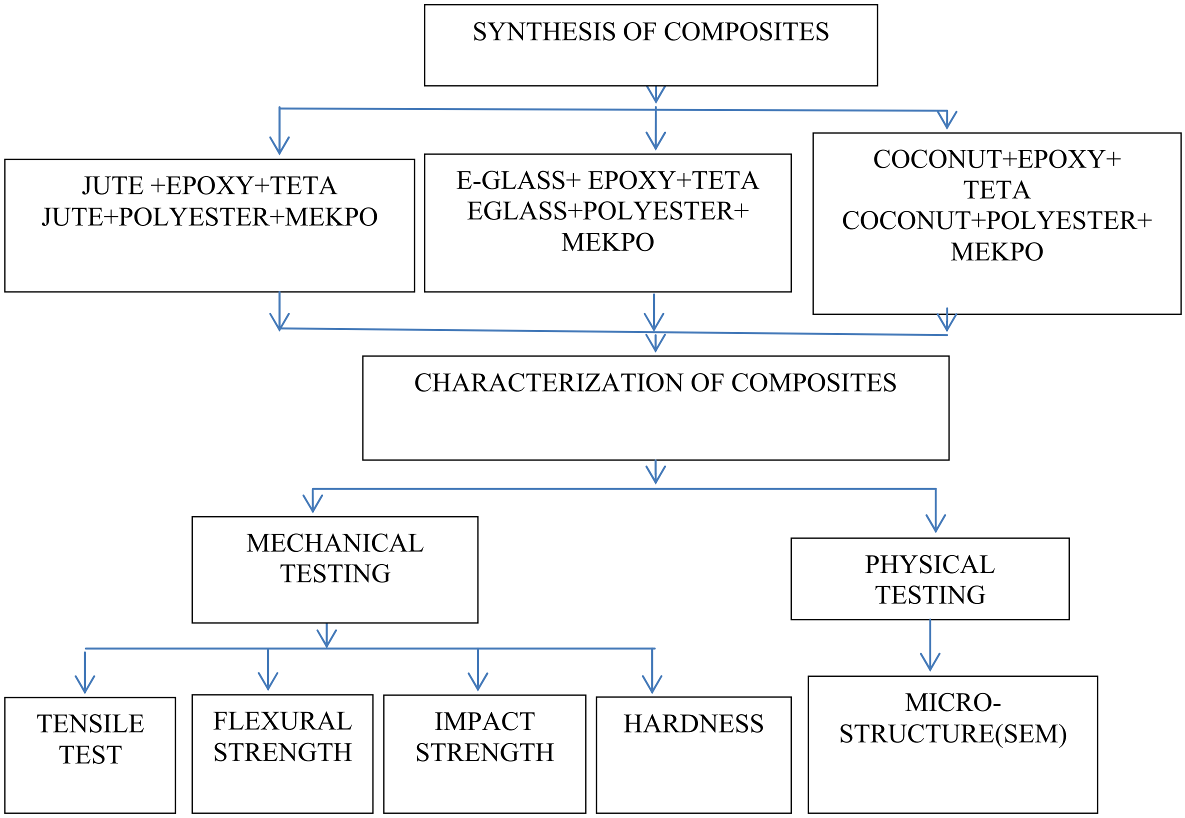


Figure 1. Flow Chart of Research methodology

The polymer resins polyester and epoxy were chosen for making composites in the current research. The natural fibers and artificial fibers were identified to add into the resin matrix as reinforcements. The fibers chosen were coir fiber and jute fiber to manufacture the natural fiber reinforced composites and as the artificial fiber reinforced counterpart E-glass fibers were chosen. These fibers were chosen owing to its easy availability. The natural fibers had to be treated separately with NaOH for improving its surface roughness as its been already proven by the previous researchers that the surface treated fibers tend to make better reinforcements than its counterparts. The fibers were mixed with the resin matrix at a ratio of 18:82 weight percentage. The fiber length taken for the study was 5-6 mm. After pretreatment of the fibers for 24 hours with NaOH they were dried under sunlight and sheets of thickness 8mm were made as per the ASTM standards. The hardeners used are mentioned in the flowchart given above. The setting time for the composites were taken as 24 hours after which the specimens were cut out from the sheet in the dimensions as specified in ASTM standards. The fiber resin hardener mixture was poured in to the mold for making a sheet of dimensions 60 cm x 60 cm from which the specimens were cut out as per ASTM standards. After the preparation of the composites they were subjected to a series of tests to determine its mechanical properties such as tensile strength, flexural strength, impact energy and hardness along with the microstructure by SEM.

Tensile, flexural and hardness tests were done as per ASTM D3039, ASTM 790 and ASTM D785 standard. Rockwell hardness tester was used for measuring the hardness whereas Shimadzu universal testing machine was used for measuring the tensile and flexural properties. Impact energy was measured in joules by cutting the test piece at 55 x 10 x 10 mm dimensions which was notched at 45°, fixed at both the ends and was broken in a single blow by a swinging pendulum. The energy absorbed by the fractured work piece designates the resistance of the fiber reinforced composite to the shocks.

The fiber reinforced composites prepared were very brittle in nature it was hard and strong in the visual examination. The composites fabricated were then subjected to a series of tests as mentioned above to determine its mechanical and microstructural properties. The coconut fibers were comparatively more thicker than the jute fibers whereas E-glass fibers were very smooth and thin to cut and to mix as result of which the E-glass fiber composites seemed to form a better mixture with the resins as the surface area occupied was also lesser as a result the mixing was a little more effective for E-glass composites as shown in below Fig 2 (a-b).

a b

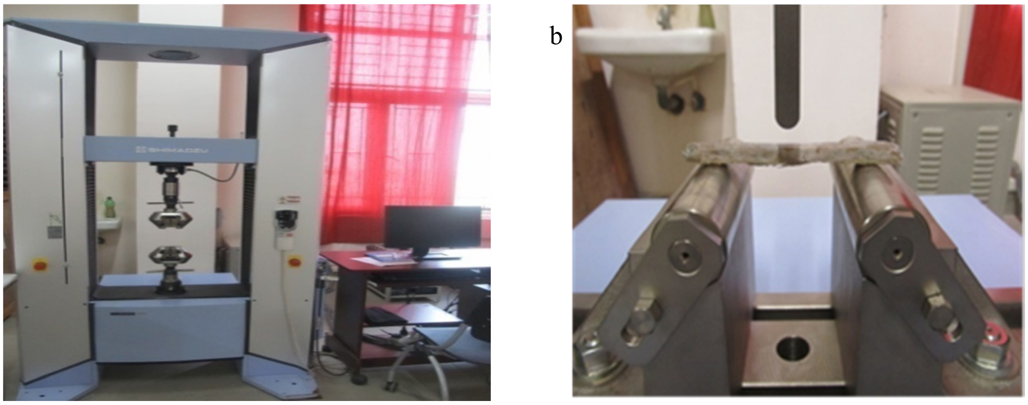


Figure 2. (a)Tensile test setup; (b) Flexural test setup.

The tensile and flexural Shimadzu universal testing machine test setup is shown in figure given above.

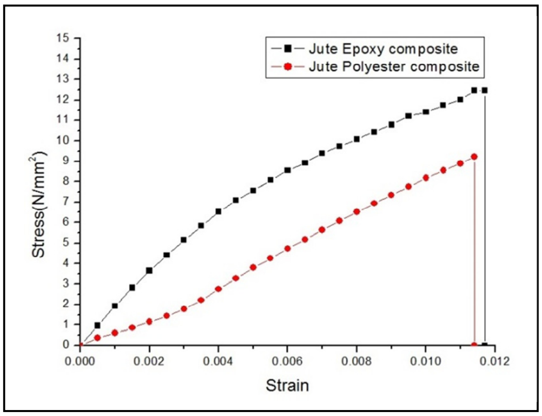
The better mixing has found to pay its dividends later in the research with its improved properties.

3. Results and discussion

The epoxy and polyester polymer resin matrix reinforced with artificial E-glass fiber and natural jute and coconut fiber were tested for mechanical characterization. Various mechanical properties were studied, evaluated and related.

3.1. Tensile test

a



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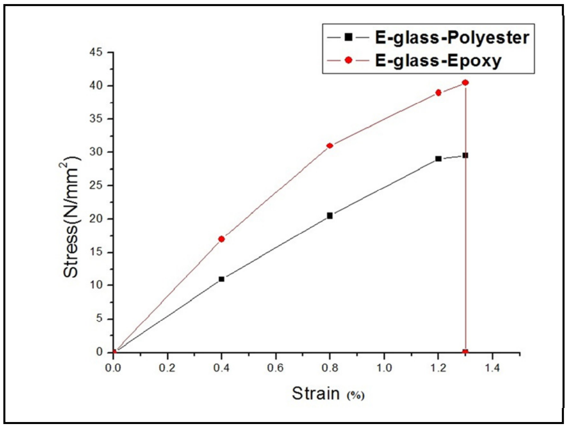

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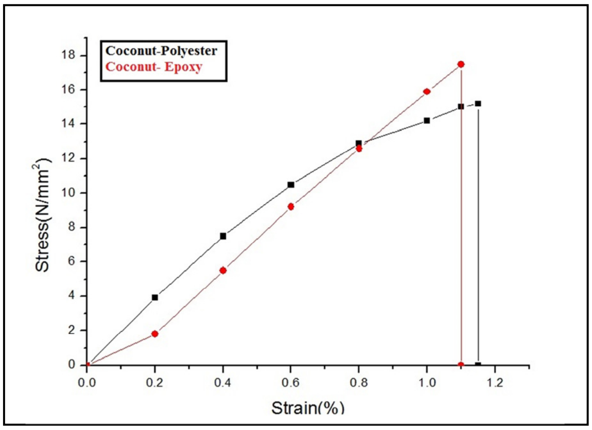


Figure 3. (a)Tensile stress strain plot of E-glass fiber reinforced polymer composites ;(b) Tensile stress strain plot for E-glass Fiber reinforced polymer composites; (c) Tensile stress strain plot for Coconut Fiber reinforced polymer composites.

The tensile strength, flexural strength were calculated theoretically and was experimentally validated. The E-glass fiber reinforced epoxy composites exhibited superior mechanical properties than the other natural fiber reinforced composites. The jute fiber owed its properties to its rigid natural cellulose and other lingo cellulosic fibers. Whereas E-glass fibers seemed to be the perfect choice for the applications as it exhibited superior results from its counterparts.Figure 3(a). indicates the tensile stress strain plot for JFREC and JFRPC. JFREC exhibited better properties than its counterpart. The tensile test was conducted in the UTM as per ASTM D3039 standards. The results indicate that the maximum tensile strength of the jute fiber reinforced epoxy and polyester composites were 12.46 Mpa and 9.24 Mpa respectively. The results showed a maximum tensile strength of 40.53 MPa for E-glass-epoxy fiber composites compared with E-glass-polyester tensile strength 28.87MPa which is plotted in figure 3(b). While coconut fiber epoxy and coconut fiber polyester composites exhibited maximum tensile strength of 17.43 and 14.8 MPa respectively. Ultimate stress and the fracture point is visible from the stress strain plot shown in figure 3(c). Young's modulus of composite specimen calculated shows good value of 3.117 GPa for the E-glass-epoxy composites (Table 1). The tensile strength and young's modulus for composite specimens were estimated from the ultimate load values in load displacement graph. Ultimate load for the E-glass composites was found to be 2431.36 N from the load-displacement graph. The tensile strength and young's modulus for E-glass-epoxy composites were calculated based on the equation.

$\sigma_t = P/bh$ (1)

$\sigma_t = 2431.36/(12 \times 5) = 40.53$ MPa

Young's modulus = Tensile stress / Tensile strain (2)

$E = 40.53/.013 = 3.117$ GPa

The tensile strength for all the fiber reinforced composites calculated is presented in Table 1.

Figure 3 indicates the stress strain plot for E-glass and coconut fiber reinforced composites. It is evident from the curve that the composites showed brittle nature as they reached the rupture point abruptly without any signs of neck formation. The ultimate load applied for E-glass-epoxy, E-glass-polyester, coconut-epoxy and coconut-polyester fiber reinforced polymer matrices was 2431.36 N, 1732 N, 1046 and 888N respectively. Microstructural examination revealed the formation of the air gaps and fiber agglomeration contributed to comparatively lower tensile strength and young's modulus values of the composites. The other factor that contributed to the lower value is random fiber orientation that contributed to the non-uniform stress transfer in the composites. As the natural fiber reinforced composites are also more susceptible to environmental degradation as it absorbs moisture much more than the artificial fibers, hence tensile strength of coconut fiber reinforced composites is low. Better tensile properties are shown by the composites along the direction of orientation of the fiber reinforcement. In the current case since the fibers are oriented in random directions it causes the non-uniform stress transfer in the specimen causing it to break easily.

Table 1.Tensile test results for jute, E-glass and Coconut fiber reinforced polymer matrices.

Fiber reinforcement	Jute		E-glass		Coconut	
Resin(matrix)	Epoxy	Polyester	Epoxy	Polyester	Epoxy	Polyester
Tensile strength (MPa)	12.46	9.24	40.53	28.87	17.43	14.8
Young's Modulus (GPa)	1.064	.811	3.117	2.406	1.584	.986
Maximum Strain	.0117	.0114	.013	.012	.011	.015
Maximum stress (MPa)	12.46	9.24	40.53	28.87	17.43	14.8
Maximum Load (N)	748	554	2431.36	1732.34	1046	888

3.2. Flexural test

Flexural test was carried out in shimadzu UTM as per the ASTM D790 standards. The specimen was prepared according to the required dimensions and the tests were carried out. From the observed results in Table 2, E-glass epoxy specimen resisted a flexural load of 532.65 N before succumbing to it. The ultimate loads for the E-glass-polyester, coconut-epoxy, and coconut polyester fiber reinforced composites were 306.81N, 108.44 N, 108.337 N respectively. Flexural load was always found to be higher than the tensile load due to orientation of fibers. Presence of a small crack in composites subjected to tensile test will also act as a stress concentrating factor. Tensile load being applied will pull the fibers out easily. But in flexural testing the load applied is perpendicular to the cross section of specimen. Hence, the load resisted by the specimen is always higher than the tensile testing. E-glass-epoxy composite was found to show superior flexural strength and flexural modulus (177.37 MPa and 11.09 GPa) as shown in figure 4. Flexural modulus was calculated using by the formula given in the equations 3 and 4.

$$\sigma_f = 3PL/2bh^2 \quad (3)$$

$$\sigma_f = 3 \text{ x } 532.65 \text{ x } 80/ (2 \text{ x } 10 \text{ x } 62) = 177.37 \text{ MPa}$$

$$\text{Flexural modulus} = L^3m/4bh^3 \quad (4)$$

The calculated flexural modulus of E-glass polyester composite was 6.391 GPa, whereas it was 1.291 and 2.777 GPa for coconut-epoxy and coconut-polyester composites. Flexural modulus gives a measure of the stiffness of the material. The materials with higher value of flexural modulus are said to be stiffer and hence will be of brittle nature. The flexural modulus of ductile materials is found to be generally lower than that of brittle materials. The flexural strength of jute epoxy and jute polyester composites computed was found to be 39.08 N/mm2 and 44.71N/mm2.On observation, the jute polyester composite showed better results than the jute epoxy composite.

Table 2.Flexural test results for E-glass and Coconut fiber reinforced polymer matrices.

Flexural properties	jute		E-glass		Coconut	
Resin	epoxy	Polyester	epoxy	Polyester	epoxy	Polyester
Flexural strength(N/mm^2)	39.08	44.94	177.37	102.27	36.15	36.11
Flexural Modulus(GPa)	3.255	1.549	11.09	6.391	1.291	2.777
Maximum Flexural strain	.012	.029	.015	.016	.028	.013
Maximum stress(N/mm^2)	39.08	44.94	177.37	102.27	36.15	36.11
Maximum Load(N)	117.23	134.96	532.65	306.81	108.44	108.337

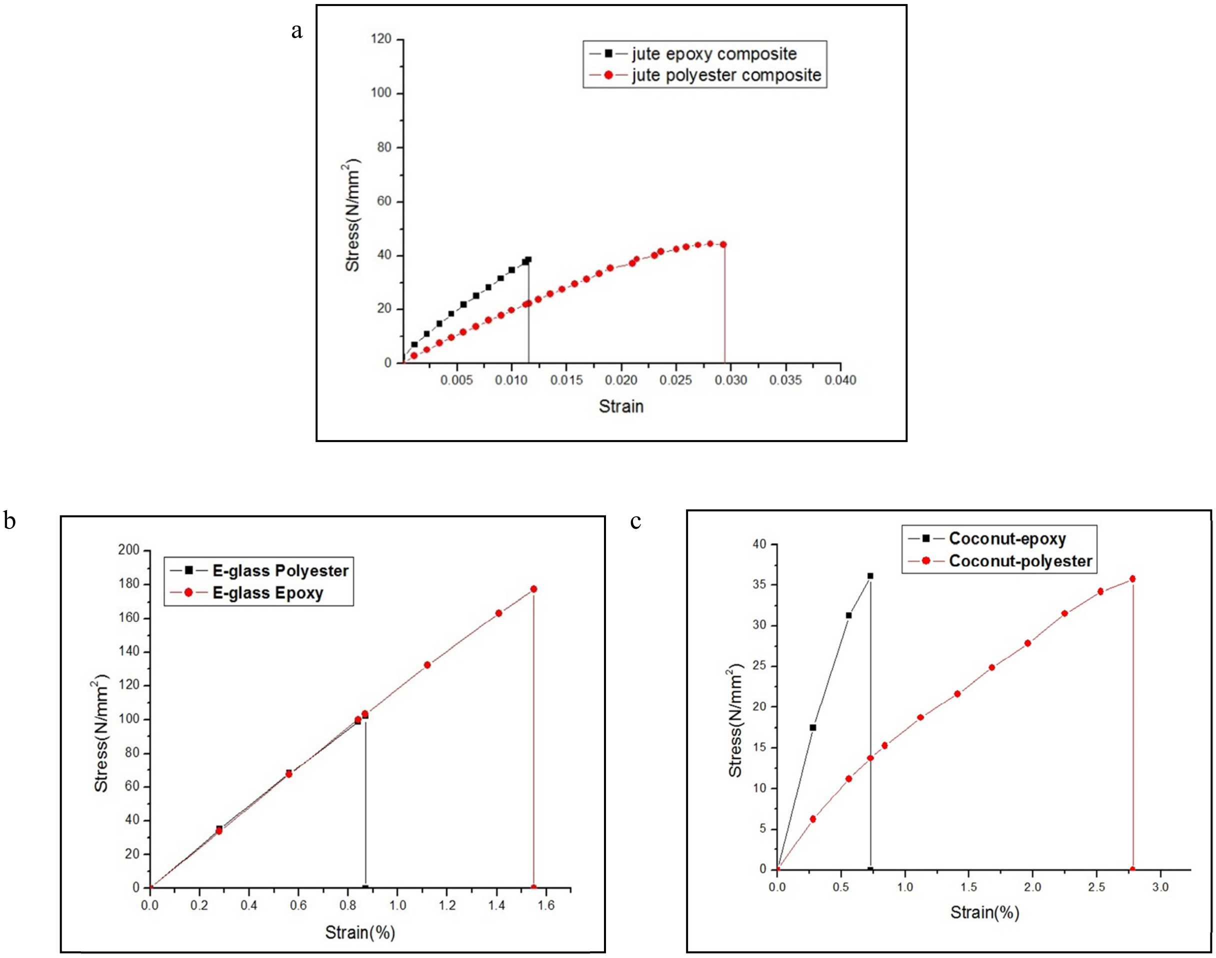


Figure 4. (a) Flexural stress strain plot of E-glass fiber reinforced polymer composites; (b) Flexural stress strain plot of E-glass fiber reinforced polymer composites; (c) Flexural stress strain plot for Coconut Fiber reinforced polymer composites.Flexural test generally helps determine the degree of brittleness of the material. The brittle materials tend to break abruptly without any specific warning, where as in ductile fracture the symptoms of breakage are

visible before the fracture point. The flexural test usually applies more load on the fibers at the extremes. These fibers will be experiencing more stress when compared to the other fibers. Due to which, provided the fibers at the extremes are strong it provides greater strength to the composite during flexural tests as they resist the breakage. During the tensile test though equal load is being applied on all the fibers due to which even the most fragile fiber can initiate the crack which will act as the cause of the rupture of the composite. Due to these reasons flexural strength is mostly found to be greater than the tensile strength. In this experiment E-glass epoxy showed a better flexural strength than the other composites (Table 1). As the resin tends to have better adhesive nature and cross linking capacity than its counterparts.

3.3. Microstructural study

Microstructural study was carried out on the specimens to find out to identify the interior defects and for further understanding of the properties of the material. The specimens subjected to tensile test were subjected to the microstructural study and then the reasons for the failure were reasoned from it. The microstructural study revealed that the pre failure of the specimen occurs due to the fiber agglomeration and the improper fiber resin adhesion inside the material as observed from figure 5(a) and 5(b), which shows the microstructural image of jute reinforced epoxy composite and jute reinforced polyester composite.

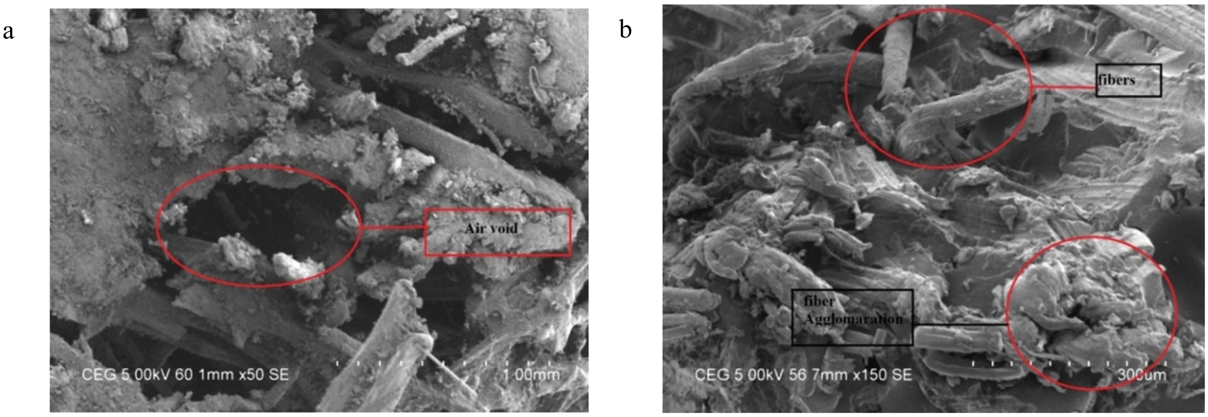


Fig 5. (a) SEM image for jute reinforced epoxy composite; (b) SEM image for jute reinforced polyester composite

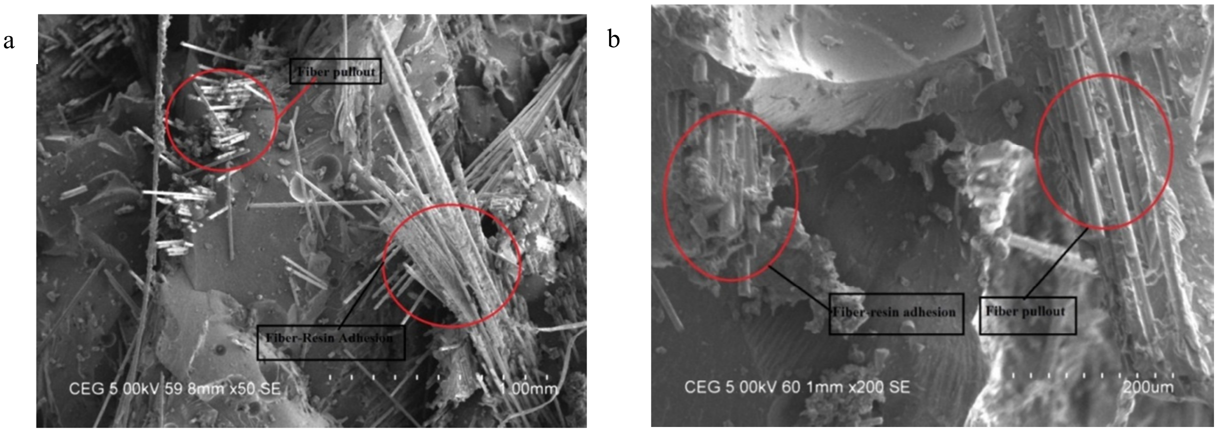
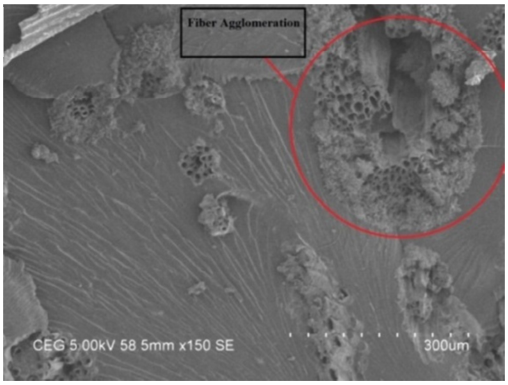


Figure 6. (a) SEM image for E-glass reinforced epoxy composite; (b) SEM image for E-glass reinforced polyester compositeThe air voids visible in the SEM micrographs shows a lack in fiber matrix adhesion and is one of the reasons for the reduced mechanical properties exhibited by the specimen. The fiber pullouts and fiber agglomeration

are visible in the SEM micrographs obtained from E-glass reinforced epoxy composite shown in 6(a) and 6 (b) shows the SEM image for E-glass reinforced polyester composite.

a



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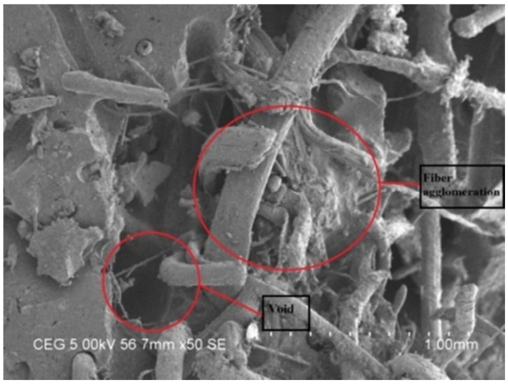

Fig 7. (a)SEM image of coconut fiber reinforced epoxy composite; (b) SEM image of coconut fiber reinforced polyester composite.

In the microscopic images at a magnification of 500µm clearly shows the reasons of the premature failure. The fiber pullout is visible from the figures which clearly indicate the improper fiber-matrix adhesion. This will lead to a considerable reduction in the strength of the composites as shown in figure 6 (a). The matrix is responsible for the uniform stress transfer and the air voids inside the resin is one of the main reasons for reduction in strength of the composite. Hence the evident reduction in the strengths of the composites was due to the very same reasons.

3.4. Impact test

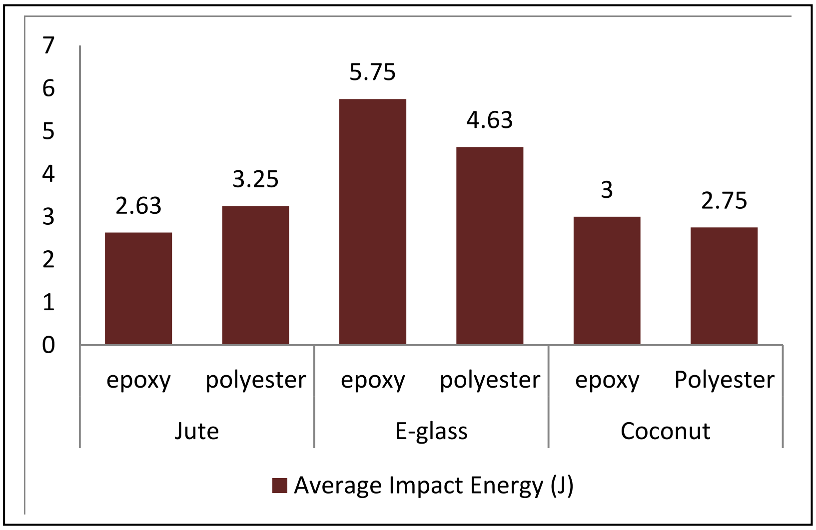

Figure 7. Impact test results for jute, E-glass and Coconut fiber reinforced polymer matrices

Charpy test was conducted on the specimens for determining the impact energy of the composites. The test mainly is done to determine the resistance of the specimen against shocks. The energy absorbed by the specimen to failure was obtained in joules. The obtained energy in joules indicates the resistance of the material to shock loads. The specimens prepared according to the ASTMA370 standards (55 x 10 x 10 mm) were used for this process. From figure 7, the comparatively lower values obtained for the impact test in the fiber reinforced composites was due to the brittle nature of the composites and lower fiber resin weight percentage of 18:82 used in the fabrication of the specimen. The natural fiber reinforced composites showed comparatively lesser values than that of the artificial fiber reinforced composites. Similar to the other results Eglass fiber reinforced epoxy composites exhibited a higher value of impact energy. Though the overall value of the composites seemed to be low, among its counter parts EFREC found to possess higher values of impact energy.

3.5. Hardness test

Hardness is an important property that determines the quality of the composite. The hardness was determined by Rockwell hardness testing setup as per ASTM D785 standards. The hardness test was performed with a ball indenter 1/16'' with an applied load of 100. The scale chosen for the test was M scale. Tests results showed that the E-glass fiber reinforced epoxy composites have the highest hardness value. Hardness of the other composites was almost similar. The hardness values of the coconut fiber reinforced composites seemed to be in close coincidence with each other. The results indicate that more than the fiber the resin plays an important role in determining the hardness of the material. The resistance to scratch on the surface of the specimen is mainly based upon the type of the resin used for the study. As shown in figure 8 the average hardness value of E-glass fiber reinforced composites were found to be 68.2, and 51.4 HRm and 45.6 and 49 HRm for coconut fiber reinforced composites.

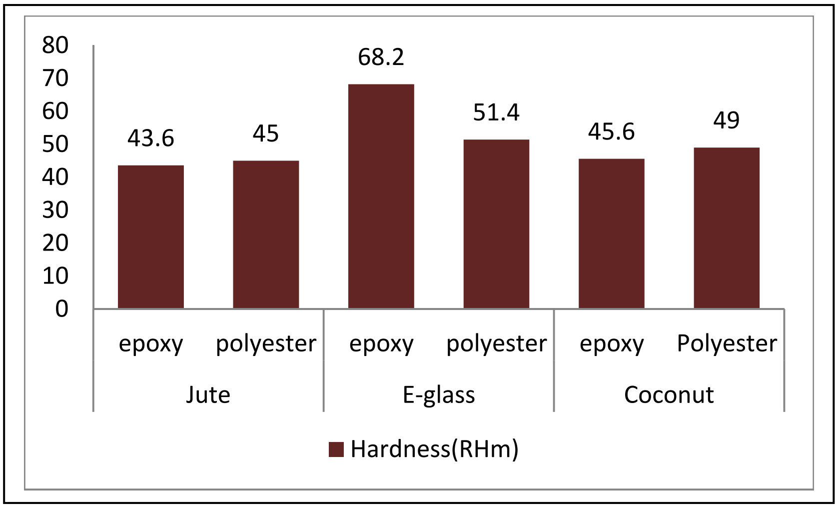

Figure 8. Rockwell hardness test results for E-glass and coconut fiber reinforced polymer matrices

4. Conclusion

The E-glass, jute and coconut fiber reinforced composites were successfully prepared as per the ASTM standards. The prepared specimens were subjected to mechanical and microstructural characterization. Based on the obtained results the research was concluded. E-glass reinforced epoxy resin composites showed superior mechanical properties. The E-glass epoxy composites showed a tensile strength of 40.53 MPa, flexural strength of 177.37 MPa, impact strength of 5.75 J, and hardness value of 68.2 HRm. E-Glass reinforced polyester resin also exhibited better mechanical properties in comparison with jute and coconut fiber reinforced epoxy and polyester composites. The tensile strength of the E glass fiber is 2050 MPa whereas that of jute and coir fiber is 250 MPa and 90 MPa respectively. The enhanced tensile strength of the artificial fiber added further strength to the resin matrix. The jute and coconut fibers having comparatively lesser tensile strength showed good mechanical strength and properties. The cross linking density of the monomers of the epoxy resin and E-glass fiber further enhanced properties of the E glass fiber reinforced composite. From our results it shows that artificial fibers are better suited for automotive applications as it shows much better properties than the natural fiber reinforced composites. The composites were found to have lesser impact energy values but very high flexural values and its use may be found in low impact applications.

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