Synthesis and Mechanical Characterization of Synthetic Bio Hybrid FRP Composites

Thyagaraj N R, Aruna B N, T Munikenche Gowda, Rukumangadha P, Ranganatha R

Abstract**:** ***The advantageous characteristics of FRPs over any other caste of composites have provoked many researchers to take up the research on FRPs with different categories of reinforcement which acts majorly as the load carrying and distributing agents. Even though the methodology for synthesis of composites have wide spectrum of choices, it is of greater importance to conclude which method is best suited particularly. Here in this work an attempt is being made to synthesize hybrid FRPs with natural fibers as the reinforcements and the composite generated will be environmental friendly. Always the mechanical characterization of any composite manufactured plays a major role as it leads to deciding on the application area where they can be used without failure. Hence, once the hybrid FRPS are fabricated, the performance analysis on the basis of mechanical characteristics is performed. The comparison of composites with natural fibers as reinforcements along with the hybrid composites is made to obtain the conclusion of better composite. The results obtained reveals that the hybrid composites have better mechanical characteristics as compared to that of jute and glass fiber reinforced composites.***

Key words**:** ***Hybrid composite, FRP, reinforcement, Synthesis***

I. INTRODUCTION

Present technology is focused on design, development and analysis of low cost and high performance hybrid composites, for automobile secondary structural material application. Main purpose of the proposed work is to reduce the weight in automobile structures using nonconventional/conventional fibers such as jute fiber, hemp fiber, glass fiber, carbon fiber etc. Low weight of the auto body structure is economize the fuel consumption however does not solve the problem of pollution. In the present study, environmental friendly natural fiber such as jute fiber and conventional fiber such as glass fiber will be used as reinforcement with epoxy resin as a matrix material. The main purpose is to show that lower specific weight of natural fibers in comparison to synthetic fibers serve the purpose. Also an effort will be made to develop an appropriate methodology to fabricate fiber reinforced hybrid composites. Samples of hybrid composites will be manufactured using hand layup technique where in stacking sequence of layers will be arranged alternatively.

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Weight fraction of fiber and matrix will be determined by the trial basis. Mechanical tests such as tensile, bending and impact performance of composites will be studied as per ASTM standards. Experimentally obtained data will be compared with conventional synthetic fiber based composites. Based on the results obtained, an appropriate secondary automotive body structure will be manufactured and analyzed. Performance evaluation will be carried-out on the developed model.

II. LITERATURE REVIEW

FRP's are most frequently used in aircraft structures and automotive application. Damage tolerance and damage resistance are more important feature under sudden loading, since they are exposed to impact loading specially, low velocity, intermediate velocity and ballistic velocity (Small mass) [1]. Among these impact conditions, the low-velocity impact persuades damages. Delamination is the main failure mode and may leads to major damage to the structural strength when the structure is subjected to a compressive load [2].The debonding between the adjacent layer occurs as soon as the propagation tip of the matrix crack reaches the brittle interface, the high level concentration of stress initiates delamination. Many researchers have carried out the research to study the delamination mechanism and its effect on composite laminates performance [4, 5].

In order to produce an optimized design, it is essential to evaluate finished material for its properties like, tensile strength, flexural strength, and impact resistance etc. The tensile and flexural behavior is determined using UTM and impact test was carried out using Izod/Charpy Impact tester. Layered composites are very sensitive to sudden damage than metallic members of similar kind. Damage due to impact on composite is important phenomenon to consider while designing composite structures [6].To overcome these problems various experimental and numerical methods have been used to study the dynamic response of composite under dynamic loading.

Nowadays composites developed using natural fibres are predominately considered as new class of materials. These composites offer properties like renewable, partially recyclable and biodegradable due to this lot of researchers are showing interest on these composites. Researchers are also developing some secondary structural parts for industrial applications using these FRP's. In most commonly available natural fibres, jute appears to be commercially viable because of its availability and cost.

GFRP is a most commonly used synthetic composites developed using glass fibre of small diameter and polymer matrix with attractive features like robustness, weight to strength ratio. Hybridization of glass and oil palm composite resulted in better mechanical properties. A positive hybrid effect is observed in the elongation property. Thus, glass and OPEFB hybrid fiber reinforcement in Phenol formaldehyde (PF) resin results in a lightweight and cost effective composite was having good performance qualities. These composites can be used as structural materials where strength and cost considerations are important [7].

A positive improvement in mechanical behaviour was observed by the researcher in the pineapple leaf fibre (PALF), sisal fibre and glass fibre reinforced polyester hybrid composite [8]. Improvements in mechanical properties are also observed by the researcher due to the addition of glass fibre to the Palmyra fibre in the matrix and decrease in the moisture absorption was also recorded [9].

Glass/sugar palm hybrid composites are found to have an improvement in tensile, bending, and impact characteristics with increasing fiber substance and the weight ratio of glass/sugar palm fibres [10]. The tensile properties of the flax/glass fiber reinforced hybrid composites were improved with the increasing of glass fiber content. The interlaminar shear strength and the interlaminar fracture toughness of flax/glass fiber reinforced hybrid composites were higher than those of GFRP [11].

Experimental work on woven jute fabric (untreated) polyester composites shows the ability of renewable source of natural fibre for use in various applications [12]. Composites with natural fibres like hemp, kenaf, sisal, banana, jute...etc are creating at most interest in industrial sectors like automotive, aerospace, packaging and sports goods[13]. The enhancement of interfacial characteristics of natural fibres by surface treatments was also studied and reviewed by Mohanty et al., [14].Selection of material is one of the most basic steps in any design procedure. The volume fraction of matrix plays a significant role in a polymer composite due to its numerous functions like it holding the reinforcements together, maintain shape of the component and transferring the load to fibers, protects the reinforcing fibers from degradation and environmental attack. Most of the composites were fabricated using epoxy as matrix material and glass as reinforcement [15].Thermosetting resins such as polyester, epoxy, phenolic and vinyl-ester are most commonly used matrices for polymer composites. Polyester resins are predominantly used resin systems, particularly in the marine industry. By far the majority of yachts and work-boats are built using these resin systems [16].

Pichireddy S et.al [17] has studied the glass/epoxy composite with addition of fly ash and tested for tensile and flexural strength properties and found that 6 grams and 4 grams fly ash composite exhibit better tensile and flexural strength.

Patil Deogonda et al. [18] has mentioned that glass fiber and jute fiber is easily available, most widely used and cheaper in price, so it is important to characterize the impact behavior of fiber reinforced polyester composite. It leads significant contribution to the mechanical behavior of structural FRP's acting to resist delamination between plies of reinforcements and to inhibit fiber buckling during compression

III. EXPERIMENTAL METHOD

A. Fabrication of composite

Hand layup technique was used for fabrication of woven fiber mat (E-glass, Jute. E-glass/Jute) reinforced epoxy laminate. Mould was cleaned using acetone, allowed to dry and a thin layer of releasing agent was applied on the mould because it is easier to remove the laminate after cured. Woven fabric was cut to the required size (300mm×300 mm) and epoxy (LY556) resin was prepared by mixing hardener (HY951) with ratio of 10:1. Once a layer of resin was applied using bristle brush, the weighed quantities (weight fraction) of the fabric is layered one over the other in the mould. The layers are consolidated and air bubbles are removed by squeezing using the hand roller. Finally the weight is placed on top layer of the mould and allowed to cure for 24 hours. The E-glass epoxy laminate is fabricated using 10 layers of glass fabric, Jute laminate is prepared with 8 layers of Jute fabric and hybrid laminate is prepared with 4 layers of jute and 4 layers of E-glass.

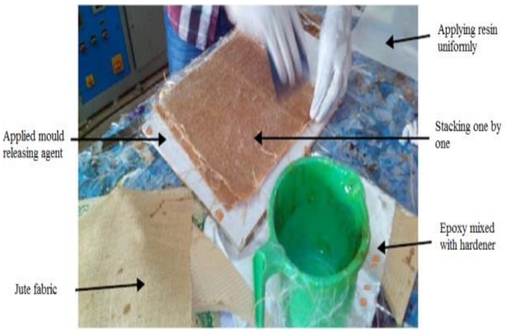

Fig. 1 Laminate preparation (Jute/Epoxy)

B. Specimen preparation

The fabrication process is out lined in the below section; the qualified composite plates were further processed to obtain the final test samples in accordance with different test standards. The composite laminates were cut into pieces with the required dimensions using a cutting machine with a diamond-coated saw. Specimens were finished by abrasive paper (Emery paper) and dimensions were measured by vernier calliper.

Fig.2 Laminates after curing 24 hours

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C. Mechanical Characterization

1. Tensile test

The tensile properties of the bidirectional composite specimens are determined by a series of tensile test in accordance with the ASTM D3039 test standard [19]. The specimen dimension and cross head speeds (1.3mm/min) were chosen according to ASTM standard. A tensile test is done by mounting the specimen in the universal testing machine (UTM) as shown in Fig.3 and tension was continuously applied until specimen fracture. Tensile force and elongation were noted as load increases. The dimensions of the specimens are shown in Fig.4.

Fig. 3 Specimen held between the gripper jaws of UTM

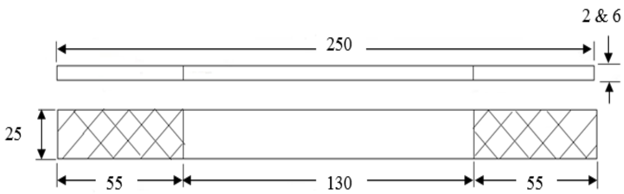
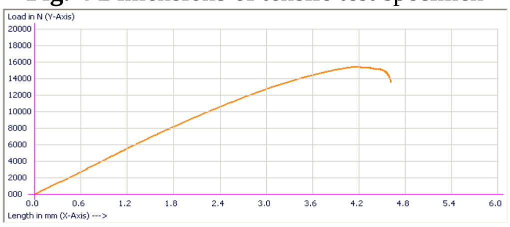


Fig. 4 Dimensions of tensile test specimen



(All dimensions are in mm)

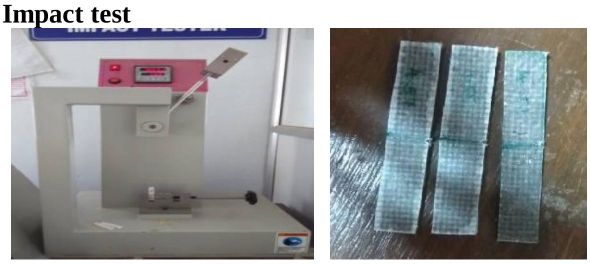
2. Flexural (Bending) Test

(a) (b)

Fig. 5 a) Specimen subjected to bending (3-point load) load b) Specimens for flexural test (E-glass/epoxy Laminate)

The flexural coupons are prepared as per the ASTM D790-02 [20] as shown in Fig. 5(b).The shape of the specimens were rectangular having different dimension according to thickness. Flexural test is performed on Kalpak Universal Testing machine of 10 ton capacity. Flexural test conducted using three point bend fixture and the cross head speed was set to 1.3mm/min. Force and deflection history are obtained by computer controlled UTM. The specimen mounted on UTM for flexural testing is shown in Fig.5 (a). The geometry and dimension of the specimen is shown in Fig.5 (b). The dimensions of the flexural test specimens were measured by using micro meter and vernier caliper (Range 0-20).

3. Impact test



(a) (b)

Fig. 6 a) Izod/Charpy impact testing machine b) Impact test specimens (Jute epoxy laminate)

The impact tests of E-glass, Jute and E-glass/Jute fiber epoxy composite laminate were conducted according to the ASTM –D 256. The test was conducted for 3 specimens having 60 % fibre and 40 % matrix, the results of impact test as follows. Izod impact test is conducted on the specimens using Izod impact tester. The dimensions of the specimens was (64 x 12.7 x 4) mm, The capacity of the impact tester is up to 250 joules and release angle of the pendulum is 150^0 .The specimen was placed in a vertical position. When the impact hammer is released, it strikes the specimen and the corresponding impact strength and angle is displayed digitally.

D. Results and discussions

1. Tensile test

Fig.7(a) Load v/s Length (glass/epoxy)

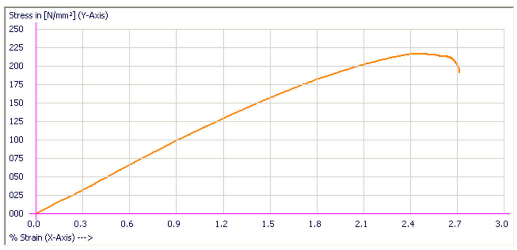


Fig.7(b) Stress v/s Strain(glass/epoxy)

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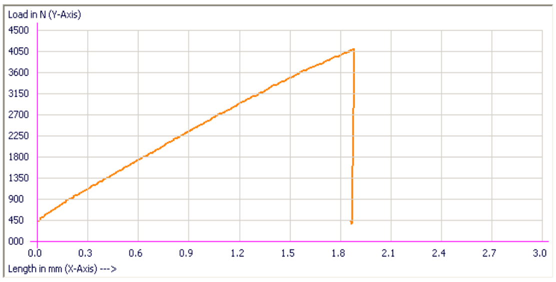

Fig. 8(a) Load v/s Length (jute/epoxy)

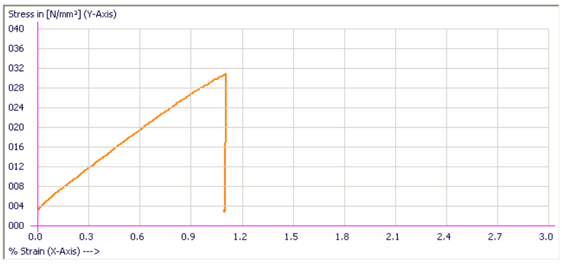

Fig. 8 b) Stress v/s Strain (jute/epoxy)

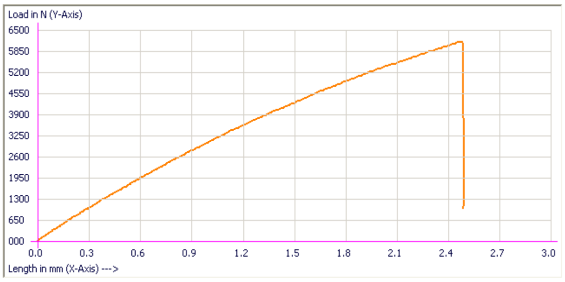

Fig. 9(a) Load v/s Length (Glass/jute/epoxy)

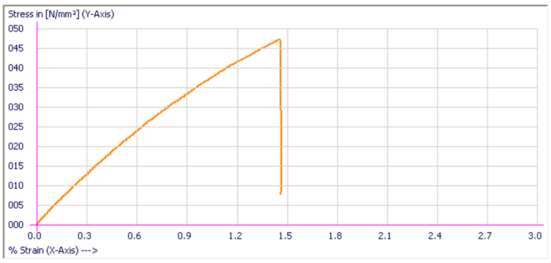

Fig. 9(b) Stress v/s Strain (Glass/jute/epoxy)

All the specimens were failed when they reached to maximum tensile strength, which indicates that the fibres are not able to sustain the load and fibres starts to fail successively and sudden drop in the load due to complete failure of the fibres in the fabric. Table 1 shows that, maximum load carrying capacity was found in glass epoxy composites (load = 15179N) and minimum is in jute epoxy composites (load = 4033N). Few researchers [4, 5] explained that lower strength of natural fiber composites is due to mis-orientation of the fibre in the fabrication process. But in hybrid fiber composites yield strength is much higher than that of natural fiber composites. The experimental values are consistently varied in the plastic region. Addition to this, the failure strain of the hybrid composites is consistently much higher than that of natural fiber composites. It is confirmed that there is a synergistic effect on fracture strain because both natural and synthetic fiber hybridization. In other hand, all three composites specimens showed the gradual failure as load increases, but fracture of fibre initiates at the ultimate stress level. Comparison of the ultimate tensile strength, Young's modulus and elongation of all three types of FRP specimens are noted in Table 1 and characteristics behavior of specimens are shown in Fig. 7-9. As discussed earlier the glass fiber / epoxy showed that highest UTS (213.79 MPa) followed in order of the hybrid composites (71.44 MPa) and lowest in jute /epoxy composites (30.44MPa). The tensile strength and Young's modulus of the laminates are calculated using the Eq.1 and Eq.2.

Tensile strength = Max force/area.................. (1)

Elastic modulus (E) = $\frac{\sigma 2-\sigma 1}{(\varepsilon 2-\varepsilon 1)}$ .... (2)

Table 1: Tensile strength and Elastic modulus of composite specimens

Composite Material	Specimen Code	Max. Load (N)	C/S Area (mm^2)	Ultimate Tensile Strength (MPa)	Modulus of Elasticity (GPa)
Glass/ Epoxy	GF1.1	1650	71	233.10	9.87
	GF1.2	1360	71	191.83	12.8
	GF1.3	1539	71	216.46	7.96
Average		**15179**	**71**	**213.79**	**10.21**
Jute/ Epoxy	JF1.1	4085	1325	30.83	2.78
	JF1.2	4292	1325	32.39	2.42
	JF1.3	3724	1325	28.10	2.23
Average		**4033**	**1325**	**30.44**	**2.47**
Glass/ Jute /Epoxy	GJF1.1	9913	1125	88.11	3.50
	GJF1.2	6129	1125	54.48	3.21
	GJF1.3	8070	1125	71.73	3.32
Average		**8037**	**1125**	**71.44**	**3.34**

2. Flexural test

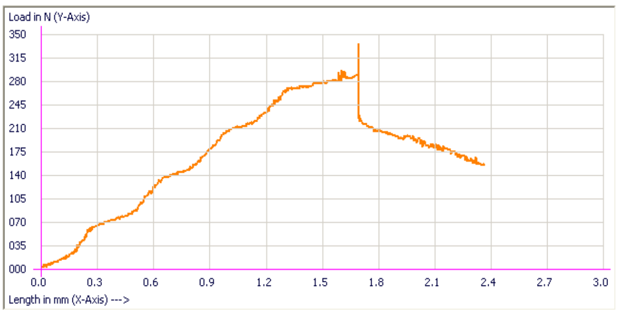

Fig.10(a) Load v/s Length (glass/epoxy)

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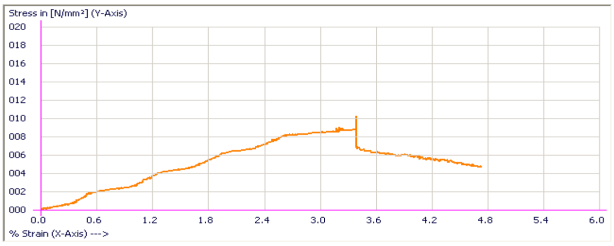


Fig.10(b) Stress v/s strain (glass/epoxy)

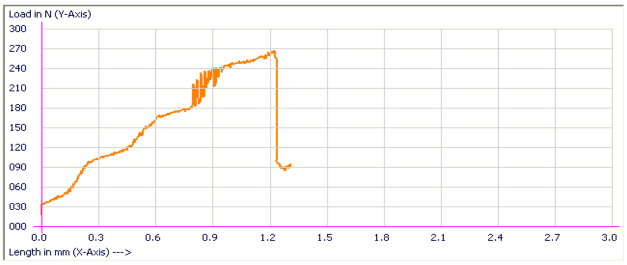


Fig.11(a) Load v/s Length (jute/epoxy)

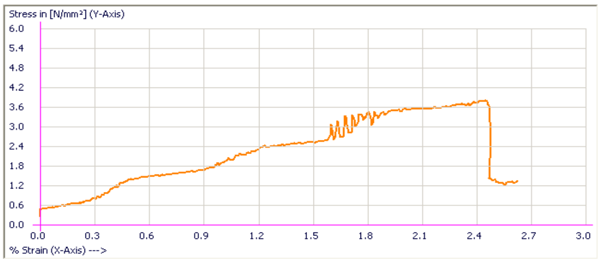


Fig.11(b) Stress v/s strain (jute/epoxy)

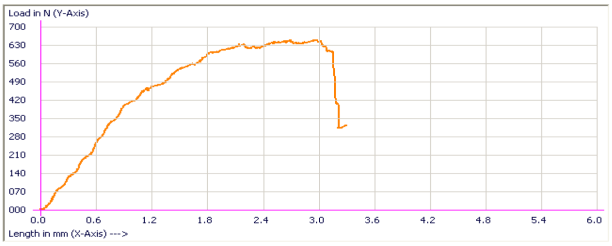


Fig.12(a) Load v/s Length (glass/jute/epoxy)

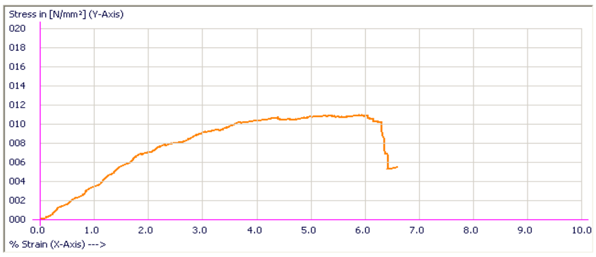


Fig.12(b) Stress v/s strain (glass/jute/epoxy)

From the results it can be observed that the E-glass epoxy composites are better in comparison with jute and hybrid composites. The flexural strength of the laminates is calculated using the Eq.3. The load Carrying capacity of E-glass composites is higher than the jute and hybrid composites. Table 2 shows the flexural properties of the prepared specimens. Also, load v/s elongation and stress v/s strain graphs of samples are plotted and represented in Fig 9-12. All figures demonstrate an approximately linear stress-strain response up to failure of the specimens. After ultimate stress sudden failure occurs can be observed by sharp drop at the end of the loading which indicates catastrophic failure of the specimen. This effect is very less in the case of glass fiber composites and hybrid composites but it is more in the case of jute fiber reinforced composites.

The flexural strength was calculated using,

Flexural stress = $(3PL)/(2bd^2)$ .... (3)

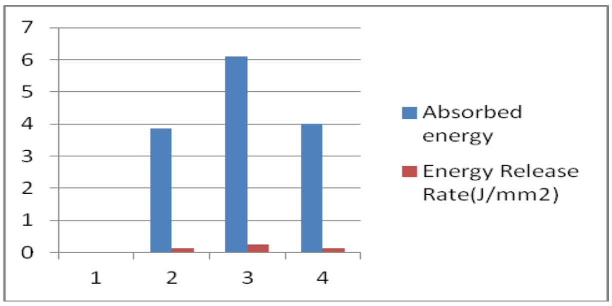
Flexural strain = $(6Dd)/L^2$ .... (4)

Where, D-Mid span deflection in mm,
d- Thickness of beam in mm,
b- Width of beam in mm,
L- Support Span in mm,
P- Load in N

Table 2: Flexural strength and Flexural strain (%) of composite specimens

Composite Material	Specimen Code	Max. Load (N)	Flexural Strain in (%)	Flexural Strength (MPa)
Glass/ Epoxy	GF1.1	335	2.37	269.31
	GF1.2	311	1.78	249.96
	GF1.3	279	2.32	223.69
Average		**308.33**	**2.15**	**247.65**
Jute/ Epoxy	JF1.1	206	1.48	41.57
	JF1.2	266	1.30	53.90
	JF1.3	179	1.10	36.14
Average		**217**	**1.29**	**43.87**
Glass/ Jute /Epoxy	GJF1.1	560	2.31	154.81
	GJF1.2	360	2.70	99.34
	GJF1.3	650	3.15	197.63
Average		**523.33**	**2.72**	**144.59**

3. Impact test



(a)

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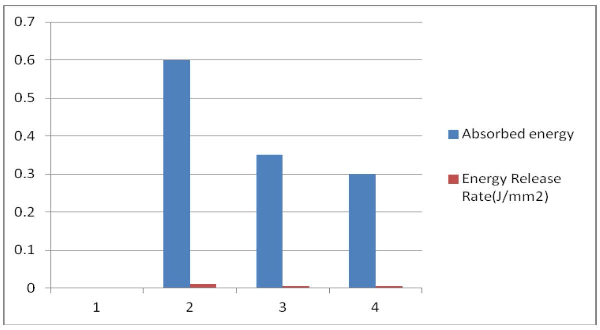
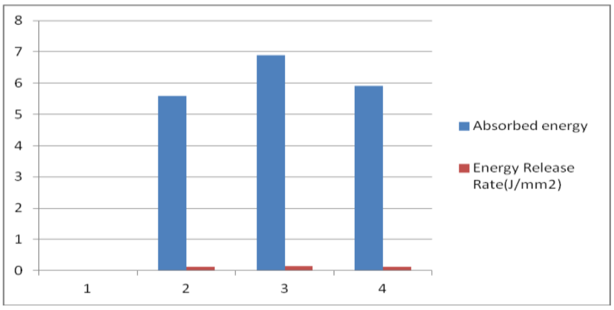


(b)



(c)

Fig. 13(a) Impact strength of glass/epoxy (b) Impact strength of Jute/epoxy (c) Impact strength of glass/jute/epoxy

Table 3: Absorbed energy and energy release rate of impacted specimens

Composite Material	Specimen Code	Absorbed energy (Joules)	Energy Release Rate(J/mm^2)
Glass/Epoxy	GF1.1	3.85	0.124
	GF1.2	6.10	0.257
	GF1.3	4.00	0.135
Average		**4.65**	**0.172**
Jute/Epoxy	JF1.1	0.60	0.010
	JF1.2	0.35	0.006
	JF1.3	0.30	0.005
Average		**0.41**	**0.007**
Glass/Jute /Epoxy	GJF1.1	5.6	0.122
	GJF1.2	6.9	0.148
	GJF1.3	5.9	0.127
Average		**6.13**	**0.132**

The impact strength of the E-glass, Jute and E-glass/Jute fiber epoxy laminates were carried out using the izod impact testing machine according to ASTM D 256 standard. The specimen are prepared with a size was 64 x 12.5 x 4 mm with depth under notch of 1.2mm made by notch cutter. The energy dissipates in composite before and final failure occurs is a measure of it's a impact resistance. The impact strength of an E-glass/jute fiber composite is governed mainly by two factors, the capability of the filler to absorb energy that can stop crack propagation and second, poor interfacial bonding and this induces micro-spaces between the fibre and the matrix, resulting in easy crack propagation. The energy absorbed by the laminates and energy release rate of the samples are tabulated in the table 3.

The energy absorbed by the laminates is 4.65J, 0.41J and 6.13J for E-glass, Jute and E-glass/jute epoxy laminates respectively.

Fig. 14 shows the samples after failure being subjected to tensile, bending and impact test and the results have been tabulated and discussed using the graphs.

(a) (b) (c)

Fig. 14 a) Failed tensile samples b) Failed flexural samples c) Failed impact test samples

IV. CONCLUSION

The synthesis and mechanical characterization of FRP composites have been done in order to obtain a best method for fabrication and comparison between the three categories of composites is carried out to find out the best suitable composite for application in terms of mechanical characterization. The results obtained are tabulated and discussed in section D. With the results obtained the following conclusions are drawn:

- Maximum load carrying capacity was found in glass epoxy composites (load = 15179N) and minimum is in jute epoxy composites (load = 4033N). In hybrid fiber composites yield strength is much higher than that of natural fiber composites. In other hand, all three composites specimens showed the gradual failure as load increases, but fracture of fiber initiates at the ultimate stress level.
- From the results it can be observed that the E-glass epoxy composites are better in comparison with jute and hybrid composites. Hence, the load Carrying capacity of E-glass composites is higher than the jute and hybrid composites.
- The energy absorbed by the laminates is 4.65J, 0.41J and 6.13J for E-glass, Jute and E-glass/Jute epoxy laminates respectively. With the results for impact test it can be conclude on the basis of energy absorbed that the hybrid composite is more superior over the other.

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