Effect of dual resin on mechanical properties of juteglass fibre reinforced hybrid composite

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Abstract

The superior properties of the fibres in comparison with the conventional materials have made them as favorite for using as the enhancement material in the polymer composites. Without compromising on the physical and mechanical properties, there is an increasing trend of synthesizing composites. This paper presents the characterization of hybrid composites with the combination of dual resins (epoxy - polyester) prepared by using hand lay-up technique. Hybrid composites are prepared by keeping 50% weight of dual resin and 50% of reinforcement. Dual resin composites are prepared by varying the weight fraction of epoxy—polyester hybrid resins in the percentages of 80E-20P, 70E-30P, 60E-40P, 50E-50P to characterize their mechanical properties. Among the all jute-glass reinforced hybrid composites, jute-glass fibre reinforced 50%E-50%P hybrid composite (50E50PHC) has the highest average tensile strength of 128.047 N mm⁻², 80%E-20%P hybrid composite (80E20PHC) has the highest impact strength of 0.1151 J mm⁻² with energy absorption of 4 J, 60%E-40%P hybrid composite (60E40PHC) has highest average flexural strength of 297.7 N mm⁻² with the deflection of 6.12 mm. SEM morphology under tensile, flexural and impact loading are also presented and images reveal that strength of the composite has increased with the addition of glass fibre.

1. Introduction

In the present technological years most of the researchers are showing attentiveness to use bio-waste as the reinforcing material in the composites because of ecofriendly nature, low density, high specific strength, low cost, renewability etc. In the preparation of composite, the primary aim is the tailoring of the material properties by selecting the appropriate combination of reinforcement, matrix and processing technique. An apt selection of reinforcement, matrix can lead to give better strength to the composite. [1–3]. Jute is the one of the oldest and traditional natural fibre used in South Asia in general and in India in specific. Jute fibre has a high potential to be used as reinforcement in polymer composites for interior applications and it’s insulating characteristics make suitable to use in the field of automotive, aircraft, sea vehicles, electronic devices, electronic circuits and microelectronic packages [4–13]. Plenty of investigations have been carried to evaluate the mechanical properties. Gopinath et al [14] investigated the mechanical properties of jute fibre composites with the epoxy and polyester resin by varying the weight percentages. The results show that the jute epoxy composites have the higher tensile and flexural strength to that of jute polyester composites. The impact energy is found to be maximum with the jute polyester than with the jute epoxy composites.

Mir et al [15] studied the characterization of jute-epoxy composites prepared by the process of infusion. The results of TGA indicate that the dilation coefficient is larger by 48% in weft to that of warp direction. Rana et al [16] studied the effect of impact modifier, compatibilizer, fibre loading on the jute polypropylene composites. The composites were prepared by the injection molding. The results reveal that the addition of impact modifiers increased the impact strength. Munikenche et al [17] evaluated the mechanical properties of untreated jute reinforced polyester composites prepared by the hand lay-up technique. The results conclude that although the mechanical properties of untreated composite are not better those composites can be used for indoor...
applications as a substitute of wood. Huq et al [18] presented the study on thermo-mechanical, degradation and interfacial properties of jute fibre reinforced PET composite prepared by the compression molding. The results demonstrate that there is a significant improvement in the mechanical properties. Dash et al [19] compared the mechanical properties of jute unsaturated polyester composites prepared by the hot curing and solution impregnation methods. Composites were prepared by the both bleached and unbleached jute silver with various fibre loading conditions. Comparison presents 60 wt% of jute fibre has the better mechanical properties. Shah and Lakkad [20] presented the mechanical properties of jute reinforced composites. The results present that jute fibre has improved the mechanical properties and thus can be used as the reinforcement with matrix. Omar et al [21] evaluated the static mechanical properties of unidirectional jute reinforced polypropylene composites. Compression molding was used to prepare the composites. The results present that the static mechanical properties were found to be improved compare to the virgin PP composites. Sudha and Thilagavathi [22] fabricated the jute fibre reinforced vinyl ester composites to study the alkali treatment effect on the mechanical properties of the prepared composites. The composites treated with the alkali treatment has showed the improvement in the mechanical properties. Nguyen et al [23] explored the NaOH treatment effect on the jute fibre reinforced polypropylene and coir fibre reinforced polypropylene composites. For both jute and coir composites the treated composites has showed the high tensile strength, low void content, high tensile modulus than the untreated composites. Tran et al [24] used the compression molding to fabricate the jute fibre reinforced poly-butylene succinate composite to study the alkali and alkali saline treatment effect of the thermal and mechanical properties. The treated composite has enhanced properties. On comparison of the alkali and alkali saline treatment, alkali saline treatment has shown good results on thermal and mechanical properties. Ruhul et al [25] evaluated the mechanical properties of jute fibre reinforced melamine composites. Hot press method was used for the preparation. Further, the prepared composites were treated with gamma-radiation. Their evaluation presents that water absorption was improved. It is interesting to know from the above studies is that epoxy and polyester are most commonly used polymers with jute fibre for better properties. However, it is important to understand that mechanical properties of pure jute reinforced composites are not suitable for high strength structural applications.

In high strength applications, glass fibre is most commonly used reinforcement in polymer composites. But, density of glass fibre is more in comparison to the jute fibre to limit its application in automobile and space sector. Hence, hybridization of glass and jute fibres could overcome disadvantages of high density and poor strength of glass and jute respectively. This opened the further scope for tailor made glass-jute hybrid composites.

Many researchers have been worked on hybrid composites for improvised mechanical properties based the required structural applications. Zamri et al [26] presented the study on the water absorption of pultruded jute/glass fibre reinforced unsaturated polyester hybrid composites. The results indicate that the hybridization increases the mechanical properties and decreases the moisture absorption of the composites. The bilayer hybrid composites enhanced their mechanical properties and thermal stability with the incorporation of the jute fibres. Ramesh et al [27] prepared the hybrid sisal/jute/glass hybrid composites by the compression moulding process to evaluate the mechanical and interfacial properties. The results show that the hybridization of sisal/jute/glass enhanced the tensile, impact, interfacial shear strength and water absorption properties than that of either of the single natural fibres composites like sisal or jute or glass. Pooja et al [28] prepared the jute-glass fibre reinforced epoxy, epoxy poly urethane composites to study the mechanical, electrical properties using hand lay-up methods. The results presented that the prepared composites showed better electrical and mechanical properties. As far as author’s knowledge, mechanical characterization of dual resins in hybrid composites is not attempted.

This paper presents the characterization of hybrid composites with the combination of dual resins (epoxy-polyester) prepared by using hand lay-up technique. Dual resin composites are prepared by varying the weight fraction of epoxy—polyester hybrid resins in the percentages of 80E-20P, 70E-30P, 60E-40P, 50E-50P to characterize their mechanical properties like tensile strength, flexural strength, impact, hardness, weight fraction of reinforcement, matrix, volume fraction. SEM morphology also presented under different loading conditions.

2. Composite materials and method

2.1. Raw materials used

2.1.1. Jute fibre

Among the various natural fibres, jute fibre is the most economical fibre. Because of its adaptability it is recognized as the second plant fibre after the cotton [21]. It is composed of cellulose and lignin. The other names of the jute fibre are brown fibre, golden fibre depending on its usage. Jute fibre is considered predominant due to
its unique properties like low cost, high strength, thermal conductivity, heat insulation, easy processing and complete biodegradability. It is also available abundantly. Jute fibre of 300 GSM is supplied by jute world, Hyderabad and is shown in figure 1.

2.1.2. Glass fibre
Glass fibre is the most widely used of all fibres. It can be in the form of chopped strand mat (CSM) or woven mat. It is available abundantly, cheaper and used as the reinforcement in various applications such as hockey sticks, boat hulls, automobile bodies etc. It has high strength and better insulating properties. Considerably it is used in Fibre reinforced polymeric (FRP) tanks, vessels. Here S-Glass fibre of 600GSM woven mat is preferred and it is supplied by the Allied polymer house, Hyderabad and is shown in figure 2.

2.1.3. Matrix
Resin system constitute the epoxy resin LY556, hardener LY951 supplied by the Allied polymer House, Hyderabad and isothalic polyester resin and its associated MEKP catalyst, cobalt supplied by the Venkat Lakshmi sales and corporation, Hyderabad. Transparent films, grease are used as releasing agents.

Woven mat of S-Glass fibre and Jute fibre was used as reinforcement. Epoxy, Isothalic Polyester resin is used as matrix. Epoxy resin and its associated hardener HT 951 is used in the proportion of 10:1. Polyester resin, MEKP catalyst, Cobalt accelerator is used in the proportion of 1:0.015:0.015. Polythene sheets, grease are used as discharging agents.
2.2. Preparation of dual resin

Dual resin is prepared in two step process. First epoxy resin LY556 and hardener are measured in the proportion of 10:1 and hardener is mixed in the epoxy and mixed with the help of magnetic stirrer. Simultaneously polyester resin, MEKP catalyst and cobalt accelerator are also measured in the proportion of 10:0.15:0.15 and catalyst and accelerator are mixed in the polyester and mixed with the help of magnetic stirrer. Once these two resins are ready then polyester resin is mixed in the epoxy resin with the help of magnetic stirrer.

2.3. Composite laminate fabrication

Hand Lay-up technique is used to fabricate the dual resin reinforced Jute-glass fibre composites laminates. A hardened steel mold of 300 $\times$ 250 mm$^2$ is used for the preparation of composite laminates as shown in figure 3. Polythene sheet placed over the mold for quick and easy removal of the composite laminates. Four laminates of jute-glass fibre reinforced Hybrid composite of dimensions 300 $\times$ 250 $\times$ 3 mm$^3$ are prepared by varying the weight percentage of epoxy-polyester resin with stacking sequence of JJ/G/|J|G/JJ. Weight and weight fractions of constituents are shown in table 1 [29]. Percentage variation of matrix in jute-glass fibre reinforced dual resin composite with the stacking sequence is shown in table 2. Weight percentage of jute and glass are 24 and 16 respectively. The laminates are then allowed for curing about 48 h. Then laminates are cut according to ASTM standards to study the effect of dual resin on the mechanical properties of jute-glass fibre reinforced composite.

![Figure 3. Mould used for preparation of composite laminate.](image-url)

| S.No | Stacking sequence | % Wt of matrix | Name of the composite |
|------|-------------------|----------------|-----------------------|
| 1    | JJ/G/|J|J|G/JJ | 80%E of total wt of matrix + 20%P of total wt of matrix | 80E20PHC |
| 2    | JJ/G/|J|J|G/JJ | 70%E of total wt of matrix + 30%P of total wt of matrix | 70E30PHC |
| 3    | JJ/G/|J|J|G/JJ | 60%E of total wt of matrix + 40%P of total wt of matrix | 60E40PHC |
| 4    | JJ/G/|J|J|G/JJ | 50%E of total wt of matrix + 50%P of total wt of matrix | 50E50PHC |

Table 1. Weight and Weight percentage details of constituents in composites.

|          | Wt% | Wt(g) | Wt% | Wt(g) | Wt% | Wt(g) |
|----------|------|-------|------|-------|------|-------|
| Jute fibre | 24   | 135   | 24   | 135   | 24   | 135   |
| Glass fibre | 16   | 90    | 16   | 90    | 16   | 90    |
| Epoxy resin | 48   | 269.7 | 42   | 236   | 36   | 202.3 |
| Polyester resin | 12   | 67.3  | 18   | 101   | 24   | 134.7 |
| Total     | 100  | 562   | 100  | 562   | 100  | 562   |

Table 2. Laminate stacking sequence with variation in percentage wt of matrix.
3. Composite laminates mechanical testing

All the mechanical tests were carried out according to ASTM standards and in all instances five undistinguishable specimens were tested and average values recorded.

3.1. Tensile test
Most of the materials undergo failure in tensile loading conditions. Thus, it is very important to know the tensile behavior of the material. Tensile test is performed to determine the breaking load, ultimate tensile strength and elongation. Tests were performed using the Computerized universal testing machine of load cell 40 kN on the jute-glass fibre reinforced epoxy-polyester dual resin composites as per ASTM D3039 where the total length of the tensile test specimen is 250 mm in length, 25 mm in width and 3 mm in thickness. A tensile test specimen is loaded in the machine and tensile load is applied gradually until the specimen fractures at strain rate of 1.5 mm min$^{-1}$. Tensile test specimens of jute-glass fibre reinforced with varying wt% combination of hybrid is shown in figure 4.

3.2. Flexural test
Flexural test is used to determine the flexural properties such as flexural strength, flexural modulus and deflection. Test is performed according to ASTM D790 standard where the total length of the specimen is 125 mm in length, 13 mm in width and 3 mm in thickness with the span to depth ratio of 16:1. A 25 kN load cell is used to carry out the test at 5 mm min$^{-1}$ rate of loading. Flexural test specimens of jute-glass fibre reinforced with varying wt% combination of dual resin is shown in figure 5.

3.3. Impact test
In the present study, impact test used is the Charpy impact test method to determine the toughness and impact strength of the prepared composite specimens. The test is performed according to ASTM D256 standard; typically the shape and notch size of the specimen was according to the standard with the length of 55 mm and width of 10 mm. The notched impact test specimens were load into the machine with the span length of 40 mm then the pendulum is raised to known height and set free to impact the specimen and the energy absorbed to crack the specimen was measured from the dial gauge. Impact test specimens of Jute-glass fibre reinforced with varying wt% combination of hybrid resin is shown in figure 6.

3.4. Hardness test
Hardness is resistance to indentation. Hardness method used here is the Barcol hardness. This method is often used for the composites materials to determine how much amount of resin is cured and to check the softness, hardness of the material. The test is performed according to ASTM D2583 where the total length of the specimen is 50 mm in length, 50 mm in width and 3 mm in thickness. It is used to characterize the indentation hardness of the composite material with the indenter penetrated through the depth of the material. Barcol impressor gives
the consistent reading of 0–100 scale on the dial gauge. Hardness test specimens of Jute-glass fibre reinforced with varying wt% combination of dual resin is shown in figure 7.

3.5. Burn off test
Burn off test was used in determining the fiber content in the composite. The test was carried out according to ASTM D3171 for the specimen dimensions are $30 \times 30 \times 3$ mm using muffle furnace. It was expressed finally in terms of volume fraction of constituents. The initial weight of composite ($W_1$) was measured using digital balance. The specimens were loaded in the furnace and then the temperature is set to reach the 600 °C and specimen was burn out. The specimen was cleaned with acetone and then final weight of the specimen residue (glass fiber) ($W_2$) is recorded. The difference between initial weight of composite and final weight of the specimen gives the percentage weight of the resin and jute fiber. From the percentage weight of fibre, percentage weight of matrix, theoretical density of the composite, volume fraction of the composite is calculated. Burn off test specimens of Jute-glass fibre reinforced with varying wt% combination of dual resin is shown in figure 8.
Figure 7. Hardness test specimens of jute-glass reinforced hybrid composites with varying dual resins.

Figure 8. Burn off test specimens of jute-glass reinforced hybrid composites with varying dual resins.

Figure 9. Scanning Electron Microscopy equipment.
3.6. Scanning electron microscopy

Scanning electron microscopy (Model S-3700N) was used to examine the morphological behavior of Jute-glass fibres, matrix at an accelerating voltage of 30 kV. Specimens were spur coated with gold for 50 s to carry out the analysis. Fracture sides of tensile, flexural and impact specimens of dual resin composites were observed using SEM. SEM equipment is shown in figure 9.

4. Results and discussion

In this preliminary study, natural fibre like jute fibre is reinforced with synthetic fibre like glass fibre with epoxy-polyester resin i.e., dual resin as the matrix and the dual resin composites are prepared. The effect of dual resin on mechanical properties of jute-glass fibre reinforced composite was evaluated.

4.1. Tensile test

Tensile strength, breaking load, Young’s modulus, elongation of Jute-glass fibre reinforced with varying wt% combination of dual resin was studied here. Hybridization of jute with glass, dual resin (epoxy-polyester) plays a major role in the tensile strength. Load versus displacement plot of all the combinations of dual resin with Jute-glass fibre reinforced dual resin composite is shown in figure 10. Among the all four dual resin combinations, 50E50PHC had the better performance and has the highest average tensile strength of 128.047 N mm$^{-2}$ with elongation of 6.12% at the average breaking load of 13.58 kN and tensile modulus of 4.08 GPa. This could be because of better interfacial bonding for dual resin combination, 50E50PHC. Other combinations didn’t show well due to poor adhesion between dual resin and fibres. Comparison of the results reveal that mechanical properties are in intermediate range with existing literature of jute-glass fibre reinforced epoxy [30] composite and jute-glass fibre reinforced polyester [31] composite. Tensile strength of all four combinations is shown in figure 11.

4.2. Flexural test

Flexural strength, flexural modulus and deflection of jute-glass fibre reinforced dual resin composite were studied. Load versus deflection plot of jute-glass fibre reinforced dual resin composite is shown in figure 12. Among all the dual resin combinations jute-glass fibre reinforced 60%E-40%P dual resin composite has the highest average flexural strength of 297.7 N mm$^{-2}$ with the flexural modulus of 8.64 GPa at the deflection of 6.12 mm. This could be due to high matrix shear for 60E40PHC. Other combinations may have poor interfacial bonding which leads less stress transfer. Results reveal that there is no improvement in the flexural strength and flexural modulus in comparison with jute-glass fibre reinforced epoxy [30] and jute-glass fibre reinforced polyester composite [31]. Flexural strength of all four combinations is shown in figure 13.

4.3. Impact test

Charpy impact test is used to determine the energy absorbed and the impact strength. Among the all four hybrid resin combinations, jute-glass fibre reinforced 80%E-20%P hybrid resin composite has the highest average
energy absorption of 4 J and impact strength of $0.1151 \text{ J mm}^{-2}$. Energy absorption is in proportion to the more percentage of epoxy. Hence, 80%E-20%P has higher impact strength followed by 70%E-30%P and 60%E-40% P. Results obtained reveal that impact strength is better and is in intermediate range of Jute-glass fibre reinforced epoxy [30] composite and Jute-glass fibre reinforced polyester composite [31]. Impact Strength of all four specimens is shown in figure 14.

4.4. Hardness test analysis

Hardness test is used to determine the softness or hardness of the material. Here the hardness of Jute-glass fibre reinforced with varying wt\% combination of dual resin was studied here. Among the all four dual resin combinations, Jute-glass fibre reinforced 60%E–40%P dual resin composite has the highest average hardness of 35 HN. Better hardness for 60E40PHC may be due to high matrix shear. Other combinations may have poor interfacial bonding which leads less stress transfer. Hardness also depends upon the contact of the indenter. Hardness value may be higher, if the indenter contacts with fibre in comparison to the contact with resin. It means that the prepared dual resin composites are harder and it can withstand the more resistance of indentation effectively. Hardness number versus dual resin proportion of Jute-glass fibre reinforced dual resin composite is shown in figure 15.
Figure 13. Flexural strength of jute-glass reinforced hybrid composites with varying dual resins.

Figure 14. Impact strength of jute-glass reinforced hybrid composites with varying dual resins.

Figure 15. Hardness number versus dual resin proportion plot of jute-glass fibre reinforced dual resin composite.
Table 3. Calculation of composite constituents of jute-glass fibre reinforced dual resin composite.

| Specimen   | Initial weight of composite ($W_1$) | Weight of resin ($W_2$) | Final weight of fibre ($W_3$) | %Weight of matrix ($W_m$) | %Weight of fibre ($W_f$) | Theoretical density of composite ($\rho_c$) (gm/cm$^3$) | Volume fraction of fibre ($V_f$) % |
|------------|-------------------------------------|-------------------------|-------------------------------|---------------------------|-------------------------|------------------------------------------------------|----------------------------------|
| 80E20PHC   | 4                                   | 2.17                    | 1.83                          | 54.17                     | 45.83                   | 3.51                                                 | 48.37                            |
| 70E30PHC   | 4                                   | 2.14                    | 1.86                          | 53.52                     | 46.33                   | 3.45                                                 | 48.10                            |
| 60E40PHC   | 4                                   | 2.13                    | 1.87                          | 52.97                     | 46.03                   | 3.41                                                 | 47.14                            |
| 50E50PHC   | 4                                   | 2.11                    | 1.89                          | 52.75                     | 47.25                   | 3.40                                                 | 46.90                            |
4.5. Burn off test analysis

Burn of test is used to determine the weight fractions of the constituents within the composite. The difference between initial weight of the composite and final weight of the specimen gives the weight of resin and jute fibre. Accordingly, the weight of jute fibre is calculated based on the GSM of jute fibre used, leads to determination of weight of the resin. The weight fractions of fibre (jute and glass) and matrix are used in determining the volume fraction of constituents. Jute-glass fibre reinforced hybrid composites with varying weight percentage combination of dual resin was studied. Average values of volume fraction of the composite constituents are summarized in the table 3.

4.6. Scanning electron microscopy analysis

Morphological behavior of Jute-glass fibres, and interface between the layers was studied here. Figures 16(a)–(d) shows SEM images of four dual resin combinations. Good interfacial bonding is observed in figures 16(a)–(d), where as poor interfacial bonding is observed in figure 16(c). Interestingly, uniform distribution of fibres along with good interfacial bonding is observed in figure 16(b). SEM image of tensile test specimen of jute-glass dual resin composite is shown in figure 17. It is observed that there is a breakage, pull-out in the Jute-glass fibre when the specimen is subjected to tensile loading. Stretching of the glass fibre indicates the increase in strength of the composite with the addition of the glass fibre. Due to the brittle nature of jute fibre there is a breakage with little stretching. SEM image of flexural test specimen of jute-glass dual resin composite is shown in figure 18. It is seen that there is a bending of the fibre due to flexural load. Bending of the fibre indicates it is semi brittle in nature. SEM image of impact test specimen of jute-glass dual resin is shown in figure 19. It indicates there is a pull out of glass fibre, splitting of jute fibre due to impact load. Gaps are observed between layers of fibre due to impact loading.
5. Conclusions

From the work carried out the following conclusions are drawn

1. Jute-glass fibre reinforced 60%E–40%P dual resin composite has the highest average flexural strength of 297.7 N mm$^{-2}$ with the flexural modulus elasticity of 8.64 GPa at the deflection of 6.12 mm.

2. Jute-glass fibre reinforced 60%E–40%P dual resin composite has the highest average hardness Number of 35. It means that the prepared dual resin composite is harder and it can withstand the more resistance of indentation effectively.

3. Burn off tests reveals that in the composite fabrication reinforcement (Jute-glass) constitutes around 50% of weight and matrix (epoxy-polyester) constitute around 50% of weight of total weight of fibre.
4. SEM images reveal that strength of the composite has increased with the addition of glass fibre and there is good adhesion between the fibres.

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Figure 19. SEM image of impact test specimen of jute-glass fibre reinforced hybrid resin composite.

Figure 19.
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