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Development and Mechanical Characterization of Low Cost Natural Hybrid Date/Jute Fiber Reinforced Epoxy Composite

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Abstract
The present work focuses on development and mechanical characterization of hybrid epoxy composite consisting of low cost natural date and jute fiber mats. The effect of reinforcement weight percentage (5% and 10%) and the effect of chemical treatment of fibers on mechanical properties were studied. Hand lay-up method was used for the fabrication of composites and was tested as per ASTM standards for tensile and flexural strength. Developed composites showed that date fibers perform better under tensile stresses whereas jute fibers resist bending stresses. On hybridization of fibers, better properties were obtained due to the supportive nature of the fibers. Further chemical treatment of natural fibers improves the properties by improving bonding strength between fibers and matrix. Results revealed that hybridization of fibers improved tensile and flexural strength of composites by 65.01% and 89.56% in comparison to pure epoxy due to the combined effect of jute fiber in terms of better bonding and date leaf in terms of higher strength. The developed hybrid composite allowed a cost saving of 30.43% in comparison to single jute reinforced composites. Overall results supported the effective utilization of low cost hybrid composite for various structural applications including doors, ceilings, walls and furniture.

Keywords
Hybrid Composite, Natural Fibers, Chemical Treatment, Low Cost, Epoxy, Jute Fiber, Date Leaf, Mechanical Properties

Public Interest Statement
Composites are the most advanced and widely used material, which are replacing conventional materials in all areas of engineering and technology. The favored characteristics of the low weight to high strength, anti wear, anti corrosion and better damping properties allowed their applications in all sectors including aerospace and automotive industries. In recent times a lot of work has been carried in the favor of Mother Nature by adopting green composites. Natural composites, though not so strong, were studied by researchers and found that their properties can be altered by processes of chemical treatment, hybridization, processing routes and by adding coupling agents, such that their properties can be brought nearly equals to the synthetic glass fiber reinforced composites. The applications of natural fiber reinforced composites are increasing due to their lower cost, biodegradability, abundance and good strength. In present work low cost natural material in the form of jute fibers mats and date leaf mats were reinforced in epoxy matrix at varying weight percentage and hybridization was carried out to study their interactions. It was found that developed natural composites show good strength on hybridization and chemical treatments and further they can be employed in numerous low cost applications such as low cost structural doors, furniture and wall panels.

I. Introduction
The superior properties and functionally graded attributes allowed composites to be one of the most advanced and widely used materials [1]. The favorable characteristics of composites include low weight, high specific strengths, high stiffness, fatigue and damping characteristics, better resistance to wear and corrosion [2-3]. A lot of work is going in the field of high strength composites made up of glass fibers, carbon fibers, Kevlar fibers and carbon nanotubes (CNT) [4-8]. However, their utilizations are affected by their high cost, recyclability and biodegradability issues. The concern regarding environmental policies leads researchers [9-11] to focus on natural fiber based composites. The works of researchers have shown that the drawbacks of natural fibers such as incompatibility between fibers and matrices and reduced resistance to moisture can be reduced by chemical modifications and treatments such as alkali treatment, benzoylation, acetylation etc. The hybrid composites were studied extensively by researchers [12-15] and they concluded that hybrid composites can offers better resistance to water absorption, cost reduction, weight savings, and increased modulus of materials. The work of Ramesh et al. [16-17] focused on the determination of mechanical properties of glass/sisal/jute fiber-reinforced epoxy hybrid composites and showed experimentally that jute/glass hybrid composites have better flexural properties, whereas sisal/glass fiber-reinforced hybrid composite shows better tensile properties. The experimental work of Kumar and Singh [18] revealed that by adding the proper amount of chemically treated jute fibers in glass fibers, leads to better hybridized composites, which shows higher mechanical properties than glass fiber reinforced plastics (GFRP). Authors revealed that the natural fiber content was effective within the range of 25% to 35 % in hybrid contents and the overall cost was reduced by 22%. The work carried by Trehan et al. [19] focused on optimization of parameters for hybrid laminate containing jute fibers and glass fibers and reported that hybrid fiber content in the composite has the greatest influence on properties. The work on the chemical treatment of natural fibers was shown by many authors [20-24] and they have reported that positive influence was achieved by proper treatments on mechanical properties of natural based composites. The increased properties were reported due to better bonding characteristics between matrix and reinforcements. Further chemical treatments if given for excess periods can lead to weakening effect, due to defibration of fibers and their strength reduces as reported by Symington et al. [25].
Limited literature is available on the mechanical characterization of date fiber reinforced composites [26-28], however, Mohanty et al. [30-31] investigated the abrasive wear of date palm reinforced composites. To the best of author's knowledge very less literature is available on the mechanical characterization of hybrid composites containing date fibers and jute fibers combinations. The present work is based on development of hybrid date leaf/jute fibers reinforced epoxy composites and determination of mechanical properties at varying weight percentages. The effects of alkali treatment of NaOH on mechanical properties were studied and

positive responses were reported.

II. Material and Experimental Details

A. Material

The composite material specimens were prepared by incorporating date leaf mats and jute fiber mats in epoxy polymer resin. The weight percentage of reinforcements in epoxy matrix is shown in Table 1.

Table 1: Weight Percentage of Reinforcements in Epoxy Matrix

Specimen No.	Percentage of reinforcement		Total Reinforcement
	Date Leaf (%)	Jute (%)	
1	0	0	0
2	5	0	5
3	0	5	5
4	2.5	2.5	5% Hybrid
5	10	0	10
6	0	10	10
7	5	5	10% Hybrid

The jute fiber mats (Fig. 1 (a)) were bi-directional woven having average fiber thickness of 0.5 mm and were purchased from a local vendor in Ludhiana, Punjab, India. The date leaf mats are: commercially available in India in the form of hand fans as shown in fig. 1 (b), and were 0.5 mm thickness.

Both the natural reinforcements were given alkali treatment by dipping them in 10% NaOH solution for 5 minutes. After treatment reinforcements were oven dried prior to composite manufacturing.

B. Composite Preparation

Composite samples were produced by manual insertion of reinforcement mats by hand molding technique [32], which were further processed by compression molding in the form of laminates as shown in fig. 2. These hand molded laminate sheets were cured for 48 hours under ambient conditions. Composite specimens were prepared from these sheets as per ASTM D638 and D790 for Tensile and flexural testing as shown in fig. 3.

C. Experimental Details

The tensile tests were performed on the universal testing machine (Autograph Machine). The crosshead speed was maintained constant at 5 mm/min as per ASTM standards, and an extensometer was used to determine the elongation. The flexural testing of composites was carried out on rectangular specimens on Autograph Machine at ambient temperature according to the mentioned procedure in ASTM D790. The test was initiated by applying the load at the center of specimen at 5 mm/min rate. The deflection was measured by a gauge which was placed at center of the support span. All the experiments were carried out at CIPET (Central Institute of Plastic Engineering and Technology, Murthal, Haryana India).

III. Result and Discussion

A. Tensile Strength

Tensile strength is the maximum stress that a material can withstand on the application of tensile loading before breaking. The highest point of the stress-strain curve is the ultimate tensile strength of the specimen. It is an intensive property; therefore its value does not depend on the size of the test specimen, but depends upon other factors, such as the preparation of the specimen, the presence of surface defects, and the temperature of the test environment and material. The characterization of the composites reveals that the jute fibers and glass fibers have a significant effect on the tensile strength of composites in comparison to pure epoxy. The maximum breaking load and maximum tensile strength of various composites are presented in Table 2. The tensile strength of various composites is shown in fig. 4, which shows that maximum strength is of 10% reinforced hybrid composite specimen.

Table 2: Maximum Tensile Strength of Developed Composites

Specimen No.	Percentage of reinforcement		Total Reinforcement	Max Tensile Strength (MPa)
	Date Leaf (%)	Jute (%)		
1	0	0	0	25.78
2	5	0	5	35.78
3	0	5	5	31.57
4	2.5	2.5	5	38.05
5	10	0	10	39.89
6	0	10	10	35.98
7	**5**	**5**	**10**	**42.54**

The effect of reinforcement on tensile strength is shown by fig. 5. The strength of composite increases as reinforcement is increased from 5% to 10%. Further tensile strength of date leaf composite is better than jute due to higher tensile modulus in comparison to low strength jute fibers. However, both the fibers show almost same strength when added in the same proportions. The bonding properties of jute are better than date leaf due to which their hybridization supports each other. On hybridization of 5% date leaf with 5% jute fibers, they produced the best composite with tensile strength of 42.54 MPa. The strength of 10% date leaf reinforced composite is 39.89 which is more than 10% reinforced jute fiber composite by 11%.

In comparison to pure epoxy the tensile strength of hybrid composite with 10% reinforcement is approximately 65.01% higher. The effect of chemical treatment of reinforcements on various composites is shown in Table 3.

Table 3: Effect of Chemical Treatment on Tensile Strength of Composites

Specimen No.	Percentage of reinforcement		Total Reinforcement	Max Tensile Strength (MPa)
	Date Leaf (%)	Jute (%)		
T1	2.5	2.5	5	41.49
T2	10	0	10	49.85
T3	0	10	10	42.06
T4	**5**	**5**	**10**	**56.74**

The fig. 6 shows that after chemical treatment the tensile strength of date leaf composite increases due to better bonding properties in comparison to jute fibers because jute fibers gets defibrate and strength reduces. On hybridization of both the reinforcement, highest strength was obtained.

B. Flexural Strength

Flexural strength is material's ability to resist deformations under bending load. The transverse bending test is employed to calculate the flexural strength of a composite specimen, in which a specimen is bent until fracture, using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress which is given by Eq. (1) [24] for a rectangular sample under a load in a three-point bending:

$$\sigma = \frac{3FL}{2bd^2} \quad (1)$$

Where,
F is the load (force) at the fracture point in N.
L is the length of the support span in mm.
b is width in mm.
d is thickness in mm.
The results of flexural testing of various composites are shown in Table 4, which shows the effect of reinforcements on flexural strength. Results reveal that both types of reinforcements show excellent stiffness and flexural strength.

Table 4: Effect of reinforcements on flexural strength of composites

Specimen No.	Percentage of reinforcement		Total Reinforcement	Max Flexural Strength (MPa)
	Date Leaf (%)	Jute (%)		
1	0	0	0	36.33
2	5	0	5	41.16
3	0	5	5	40.5
4	2.5	2.5	5	47.28
5	10	0	10	65.36
6	0	10	10	65.05
7	**5**	**5**	**10**	**68.87**

The flexural strength of various composites is shown by fig. 7, which shows maximum strength is shown by hybrid composite containing 10% of reinforcement.
Jute fibers and date leaf shows almost same flexural strength due to their better stiffness, however, jute fiber up to 5% shows better strength due to good bonding with matrix. On increasing the reinforcement, the strength increases and date leaf composite being stiffer shows enhanced strength. The effect of reinforcement on flexural strength is shown in Figure 8, which shows higher strength at higher reinforcement percentage. The effect on chemical treatment on various composites is represented in Table 5, which shows considerable amount of strength enhancement due to better bonding between reinforcement and matrix. Both the reinforcement's shows excellent flexural strength after chemical treatment but their combination supports each other in terms of high strength and better bonding characteristics. The flexural strength of treated and untreated reinforcement composites is shown by Figure 9, which clearly indicates rise in strength on treatment with NaOH solution. The strength of 10% hybrid composite increased from 68.87 MPa to 79.5 MPa with percentage increase of 15.43% in flexural strength.

Table 5: Effect of chemical treatment on flexural strength of composites

Specimen No.	Percentage of reinforcement		Total Reinforcement	Max Flexural Strength (MPa)
	Date Leaf (%)	Jute (%)		
F1	2.5	2.5	5	47.66
F2	10	0	10	72.48
F3	0	10	10	71
F4	**5**	**5**	**10**	**79.5**

C. Cost Analysis

The cost of natural fibers is much less than the synthetic fibers due to the manufacturing techniques and processes required to process synthetic fibers. The jute is abundantly available in every part of India and date leaf can be obtained for very low cost. The price of fibers per kilogram as provided by the supplier is shown in Table 6.

Table 6: Price List of Reinforcement Material Per Kilogram

Fibers	Cost in INR (per kg.)
Jute fibers	150
Date leaf	80

The cost analysis of fibers when mixed in equal proportion is shown in Table 7.

Table 7: Cost analysis of fibers when mixed in 1:1 ratio in 10% hybrid composite

Weight of fibers	Cost (INR)
10 gram of Jute fiber	15
10 gram of date leaf fiber	8
Total cost for 10% hybrid composite	23
Total cost for 10% jute composite	30
Cost saving (%)	**30.43**

In comparison to pure jute composite, hybrid composite containing 5% jute and 5% date leaf saves 30.43% of cost and provides better mechanical properties. The cost of 10% jute is more than hybrid composites and produces low strength composites. The hybridization of reinforcement enhances the overall properties of composite and lowers the processing costs.

D. Applications of Developed Composites

The developed natural hybrid epoxy based composites can be used for variety of applications including low cost building material for making temporary houses in flood affected areas, low cost door panels and furniture. The results for tensile strength and flexural strength support these applications and developed composites can be effectively used which in turn will support the cultivation of natural jute and will reduce the wastage of date leaf as garbage. Effective utilization of natural based composites will lead to the economic upliftment of cultivators.

IV. Conclusion

The experimental investigation of mechanical properties different FRP composites fabricated by hand molding process containing date leaf and jute fibers as reinforcement in epoxy resin reveals the following results:

1. The experimental results show that the mechanical properties such as tensile strength and flexural strength of epoxy resin improves by a great extent due to the presence of reinforcement.
2. On increasing the weight fraction of reinforcement the mechanical properties of the FRP composites increases. The effect of date leaf on tensile strength is more than the jute fibers which are better in flexural strength. Date leaf shows higher strength and stiffness whereas jute fiber shows better bonding characteristics with matrix such that their hybridization produced the best composite in terms of mechanical properties.
3. The effect of alkaline chemical treatment favors the tensile and flexural strength. Alkaline treatment causes better bonding which in turn increases the load bearing capacity of composites.
4. The overall cost of hybrid composite reduced by 30.43% in comparison to pure jute fiber reinforced composites. The possible areas of applications were discussed and it was reported that low cost applications in field of construction and furniture can be achieved.

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Fig. 1(a): Jute Bi-directional Woven Mat

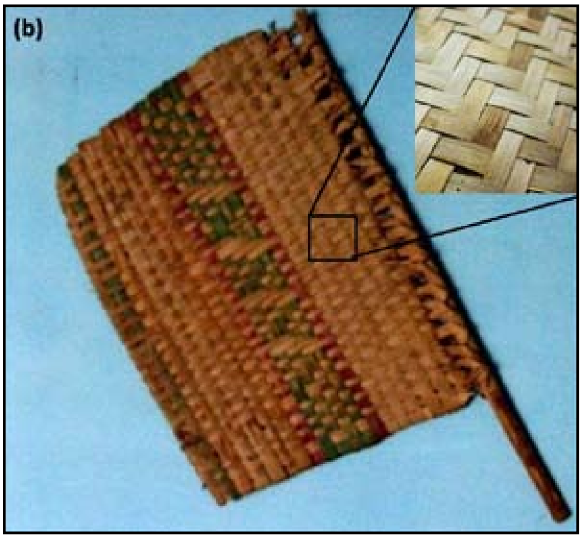

Fig. 1(b): Date Leaf Mat in Hand Fan With Magnified View


Fig. 2: Composite Hand Molded Laminate Sheets


Fig. 3: Composite Specimens as per ASTM Standards for Tensile Strength

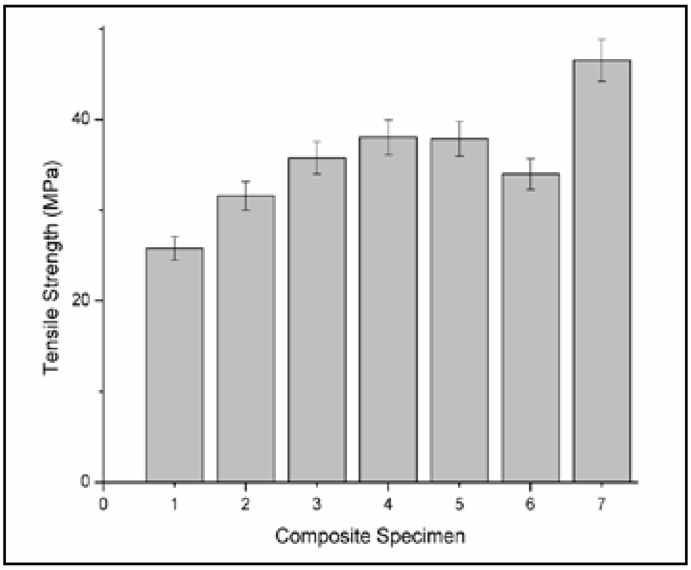

Fig. 4: Maximum Tensile Strength of Developed Composites

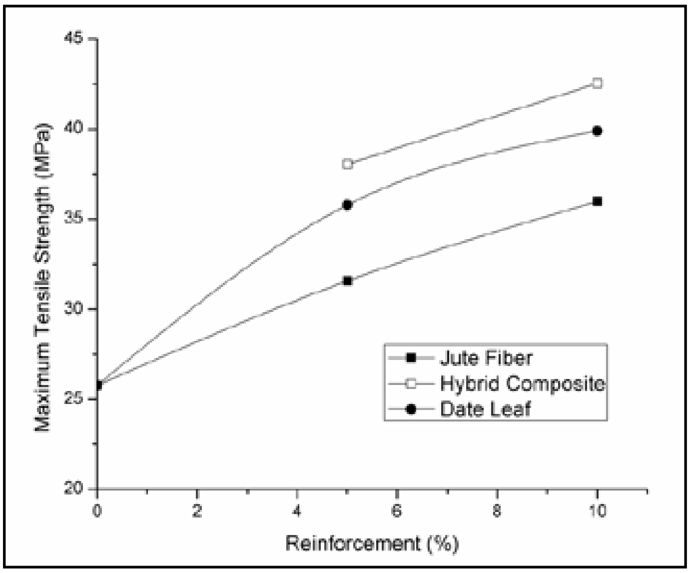

Fig. 5: Effect of Reinforcement Percentage on Tensile Strength

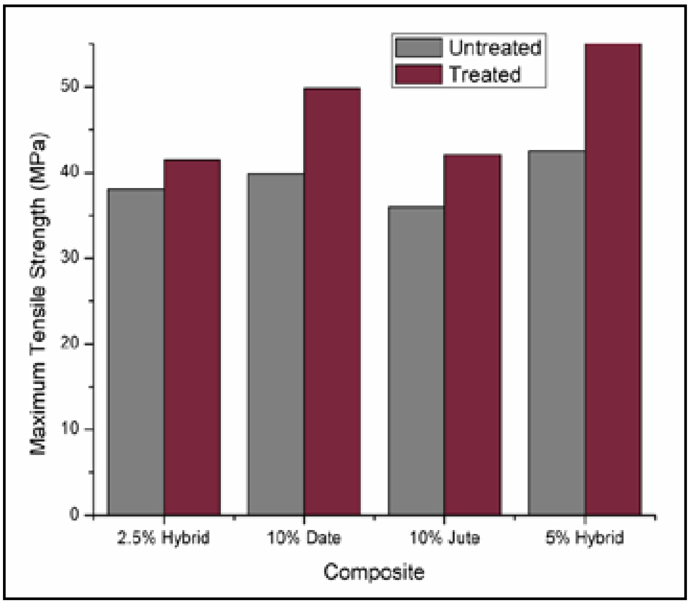

Fig. 6: Effect of Chemical Treatment on Composites Tensile Strength

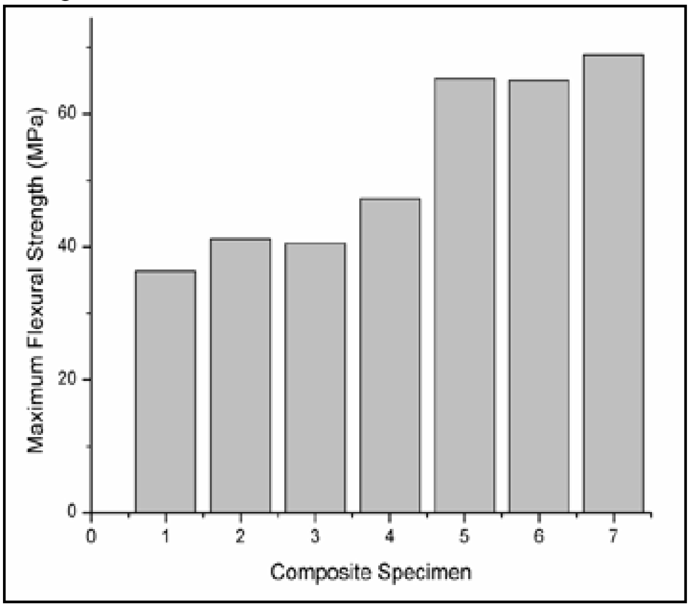

Fig. 7: Flexural Strength of Composites

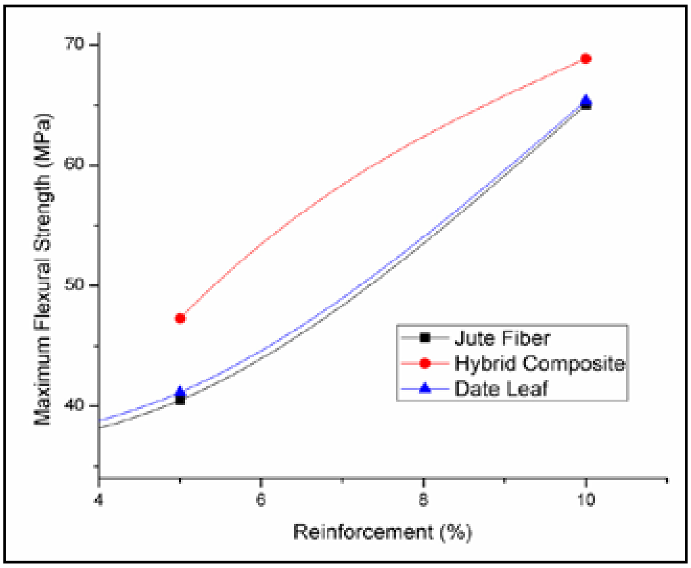

Fig. 8: Effect of Reinforcement Percentage on Flexural Strength

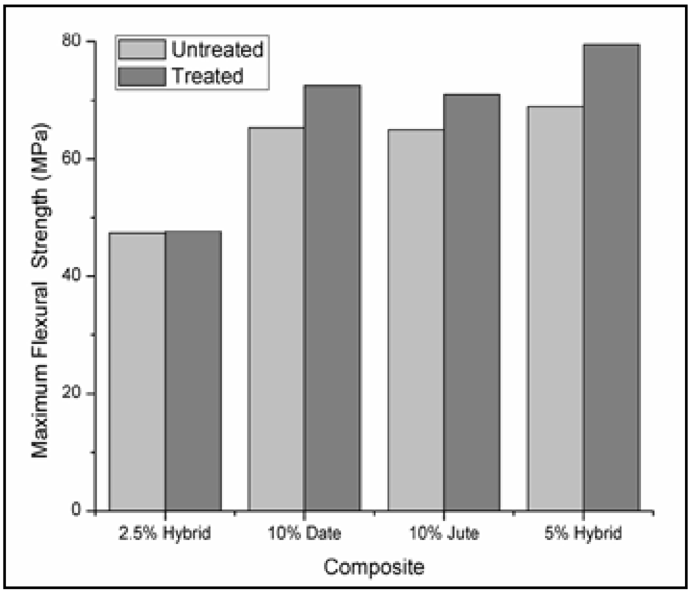

Fig. 9: Effect of Chemical Treatment on Flexural Strength of Composites