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Fabrication and Mechanical Characterization of Jute-Coir Reinforced Unsaturated Polyester Resin Hybrid Composites with Various Fiber Size using Compression Moulding Technique

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Abstract: ***Fiber reinforced composites plays major role in improving the strength of various applications in current trends. Based on these trends the combination of natural jute/coir fiber hybrid composite of different size of fiber length was examined in this study. The hybrid fiber composite was fabricated by compression moulding technique by impregnating jute fiber and coir fiber with unsaturated polyester resin, Cobalt octoate and methyl-ethyl-ketone peroxide as accelerator and catalyst. Then the prepared mould placed into the oven to dry for 4 hrs. at 50°C beneath closely to vacuum condition then convert the cured mould to the hot press initially for 1 hr at 105°C under 84 bar pressure until while squeeze out the excess resin, then it was cooled in cold press under constant pressure of 275 bar pressure for 15 min to prevent the warpage of hybrid composites. The micro hardness, tensile, flexural, impact strength of hybrid composite was carried out and the morphology of the composites was evaluated and compared. The test results of the hybrid composite were analyzed by one way ANOVA analysis technique and it shows significant difference among the groups.***

Keywords: Hybrid Composite, Compression Moulding Technique, Mechanical Properties, Scanning Electron Microscope, Statistical Analysis

I. INTRODUCTION

The uses of composites over straight materials are highly due to their stiffness, fatigue strength and durability which enhance the structure more compact. By statement, composite comprises of two or more elements which combines of both physical and chemical phases.

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The reinforcement materials incorporated in base matrix helps in increasing strength and rigidity. It may be particles, fibres or platelets are economically used to improve the mechanical strength which offers effective load transfer [1, 2]. Among different types of reinforced composites natural fibre reinforced polymer composites were commonly used due to its availability, low density, cost and improved energy recovery [3, 4]. Since natural fibre are classified as jute, banana, coconut, palm fibres, etc. Increased mechanical property simultaneously increases the fibre weight index which reduces the tensile strength [5].

In this work coir and jute fibres are used as raw material for its non-hazardous, lignin ratio and less wear. Kumar et al. [6] states that coir fibre reinforced polymer composites increases the mechanical strength of the composite due to reinforcements and higher addition of coir fibres breaks the interfacial bonding between the fibres and weakens the composite. Fernanda et al. [7] observed that epoxy reinforced composites at different wt. % of 10, 20 and 30 forms an multi-layer protective system which 0.2 % lighter and 34 % cheaper than other composites. Gireesan et al. [8] conclude that the coir epoxy reinforced composite fabricated through hand layup process increases the hardness and tensile where higher addition of fibre debilitates the structure. Sivasaravanan et al. [9] states that nanocomposites prepared by hand layup method has superior mechanical properties where the addition of epoxy/clay reinforcements at 5 wt. % has good mechanical property. Obele and Ishidi [10] reports coir fibre reinforced at 30 wt. % has stable mechanical property with reduced weight. The epoxy reinforced polymer composite exhibit high impact and compressive strength with 30 wt. % of coir fibre where the higher addition of coir fibre reduces the composite strength. Pani and Mishra [11] conclude that coir reinforced with epoxy matrix at 10 wt. % has increased mechanical properties with the effect of mercerization when compared with treated and untreated fibres. Singh et al. [12] states that alkali treated coir fibre reinforced epoxy composite has superior mechanical properties than untreated fibre. It concludes that fibre reinforced at 30 wt. % has better impact, compressive and flexural properties and due to alkali behaviour reduces the moisture content.

Vinayaka and Yohannes [13] relates that increasing the nano clay wt. % decrease the tensile strength due to wettability while matrix content gets reduced. The bonding strength increases from 0 to 1 wt. % and decreases at 5 and 7 wt. % due to discontinuous fibres. Kumar et al.

[14] concludes carbon/epoxy composite has enhanced mechanical strength than the epoxy reinforced with glass and hybrid composite it's due to low bending strength and stiffed reinforcements which reduces the flexural, compressive and impact strength of composites. Adeniyi et al. [15] states that fibre surface modification treatment increase the interfacial adhesion thereby increasing the physical and chemical properties of the coir fibre reinforced polymer composites. Santos et al. [16] observed that due to fibre matrix adhesion the alkali treated composites does not sensitively changes the fibre surface instead it enhance the mechanical strength of the composite when treatment time is increased to 96 or 168 hours. Yan et al. [17] concludes the alkali treated coir fibre with 5 wt. % of NaOH exhibit clear and rougher surface where the untreated reveals the fibre debonding and film breakage. Yan and Chouw [18] states at different ageing conditions composite immersed in NaOH solution which slightly reduce the degradation of fibre/matrix bond which is highly depends on immersion temperature and matrix used. Ali and Chouw [19] results that when compared to soaked treatment the tensile and elongation of the fibre is increased by boiling treatment and decreased by alkali treatment where the bond strength is reduced by 11% and pull out energy decreases by 44% with increased length from 100 to 200 nm. Stephano [20] concludes that coconut coir epoxy and hardener reinforced hybrid composite prepared by hand layup technique were very economical, biodegradable with increased mechanical properties.

Literature survey reveals the advantages of research work in fabrication of coir fiber and jute fiber hybrid reinforced epoxy based composites. The evaluation of mechanical strength of composites like tensile, compressive, flexural, etc. studied by mechanical testing. The statistical analysis of hybrid composites is studied using One-way ANOVA Analysis and the fracture failures are studied using Scanning Electron Microscope (SEM).

II. MATERIALS AND METHODS

A. Materials

Jute fiber mat and coir fiber mat was acquired from Indarsen Shamlal Private Limited, Kolkata, India and D.C. Mills Private Limited Alleppey, India. Unsaturated polyester resin for general purpose manufactured by Kanoria chembond Private Limited was purchased from Mumbai, Cobalt octoate and methyl-ethyl-ketone peroxide as accelerator and catalyst manufactured by Triveni Interchem Private Limited was were purchased from Mumbai. Sodium hydroxide pallets were supplied by Emplura, Merck Life Science Private Limited with molarity of 40.0g/mol. Benzyl alcohol used as diluents and silicone oil used as releasing agent for the fabrication of hybrid composite which supplied by Aldrich Company. [21,22] The physical and mechanical properties of coir and jute fiber are given in Table 1 along with that fiber image was also shown in figure 1

Figure 1 Coir fiber and jute fiber

S.No.	Properties	Coir fiber	Jute fiber
1.	Density (g/cm3)	1.4	1.3
2.	Tensile strength (MPa)	175-240	39-773
3.	Young's modulus (GPa)	30	10-30
4.	Elongation at break (%)	15-17	1.5-1.8
5.	Cellulose content (%)	43.44	58-63
6.	Hemicellulose (%)	0.25	12
7.	Lignin content (%)	45.84	12-14
8.	Microfibril angle (º)	30-48	8
9.	Lumen size (mm)	12	3.40

Table 1 Physical and Mechanical Properties of jute fiber and coir fiber

B. Enrichment Treatment Of Coir Fiber And Jute Fiber

The accumulated coir fiber and jute fiber was first splashed through normal tap water to remove the dust, dirt, mud and other adhered particles on the fiber surface. The coir fiber are then soaked in hot water at 70°C for 2 h, then rinsed with deionized water. Later the fiber were mercerized with 5% NaOH solution for 4 hours at room temperature with complete dissolving of fiber ratio of 20:1. The treated fiber were washed several times with deionized water to remove NaOH sticking on the fiber surface until a final pH of 7 was conquered. To neutralize the alkali dilute acetic acid was used. The fiber were then dried at room temperature for 48 hours followed by oven drying at 100°C for 6 hours. These fibers were preserved in a conditioned room at 25°C and humidity of 50% for future studies.[23] The mercerization of natural fiber occurs according to equation (1)

$$Fiber - OH + NaOH \rightarrow Fiber - O - - Na^{+} + H2O \ldots . \text{Eqn. (1)}$$

C. Fabrication of Hybrid Composite

Initially for preparation of the hybrid composite, a wooden mould with dimensions 304mm X 203mm X 4 mm were prepared and fixed over the cardboard using iron nails. The mould was coated with a thin layer of silicone oil solution, acts as a releasing agent. The preparation of matrix for hybrid composites were unsaturated polyester resin with Cobalt octoate and methyl-ethyl-ketone peroxide as accelerator and catalyst with 100:60 ratio were mixed and benzyl alcohol was added as diluents and the mixture was mixed thoroughly by mechanical stirrer for 20 min.[24] The coir fiber mat and jute fiber mat are cut into 10mm, 20mm, 30mm length for different sizes for hybrid composite component. The processing flow of the compression moulding technique was noticed in figure 2.

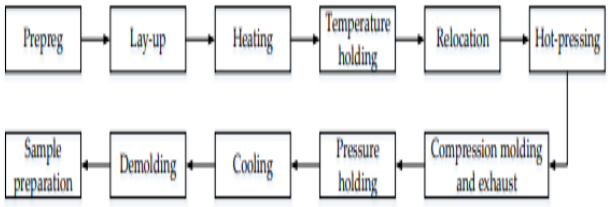

Figure 2 Processing flow chart of compression moulding technique

The different sizes of hybrid composite were developed using compression moulding technique for making the test specimen. Keeping the different weight ratio of reinforcement of total fiber 40% by weight, bilayer hybrid composites were prepared by hybridizing of unsaturated polyester resin and both jute fiber and coir fiber mats were impregnated in mould. The unsaturated polyester resin was poured over the fiber evenly then pressed and pushed down with stainless steel roller to avoid and eliminate the air bubbles until the filling of mould was complete. Then place the prepreg mould into oven to dry for 4 hrs at 50°C beneath closely to vacuum condition then convert the cured mould to the hot press initially for 1 hr at 105°C under 84 bar pressure until while squeeze out the excess resin, then it were cooled in cold press under constant pressure of 275 bar pressure for 15 min to prevent the warpage of hybrid composites.

Figure 3 Compression moulding technique of hybrid composite specimen

D. Characterization of Hybrid Composites

Tensile test

Tensile test of different size of hybrid composite samples in wrap and wrap direction was taken in Instron Universal testing machine (maximum test force: 50 N~10 kN; effective space of tension: 700 mm; effective test width: 300 mm) according to the ASTM D3039 test standard, each tensile test sample was prepared with a width of 25 mm and a total length of 250 mm and subjected to tensile loading at 2 mm/min with the standard strain rate of 0.01 min-1.[25, 33]

Figure 4 Universal Tensile Test Machine

Figure 5 Tensile Test specimens

Flexural Test

Flexural analysis of different size of hybrid composite specimen with rectangular dimensions of ASTM D790 standard using Gotech universal tester-GT-A1-7000L machine shown in figure 6. The rectangular samples of dimension 160 X 20 mm2 were cut using circular saw as shown in figure 7. The speed of the crosshead was 2 mm/min. Two composite specimens were tested for each sample.[26]

Figure 6 3-point Flexural Testing Apparatus

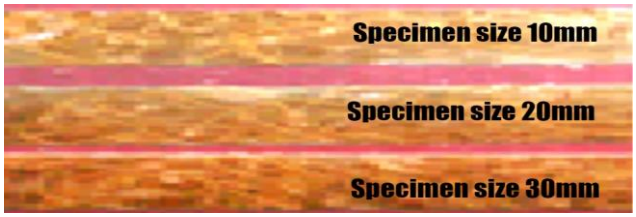

Figure 7 Flexural Test specimens

Micro Hardness Test

The hardness test was carried out using Vickers micro hardness analyser at material testing lab as shown in figure 8 with indenter of pyramid shape at edge 136º and test load utilized for different size hybrid fiber composites specimen were 2.942 {HV 0.3}, in accordance to ASTM E-384 standard. The hardness test was conducted for two specimens, for each specimen three measurements point were recorded then the average value are suggested.[27]

Figure 8 Micro-Hardness testing Apparatus

Impact Test

In this study, Izod notched impact testing was carried out using Go-tech testing machine, Model GT-7045-MDL. The Izod impact test samples with a dimension of 70 X 15mm2 were cut by jig saw. According to ASTM D256 standard their average load at first deformation was noticed and average value are tabulated as impact strength.[28]

Fractography Analysis using SEM

The hybrid fiber composite microstructure was investigated using a scanning electron microscope model FEI Quanta 400 located in material characterization lab at Anna University. Initially the specimen was coated with approximately 20nm of gold to become more conductive and suitable for SE analysis. The SEM was operated using 25 kV of acceleration tension and 30 mm of working distance. The images were attained using the software package ImageJ for measuring fractography of the tensile tested specimens.[29]

Statistical Analysis

Statistical analysis has been taken out using one-way analysis of variance (ANOVA) with two different parameters and the results are discussed. The statistical analysis of difference between the specimen regarding flexural strength and tensile strength are examined respectively.[30]

III. RESULT AND DISCUSSION

A. Tensile Properties

The mechanical properties results exhibited the effect of NaOH treated with different size of 2coir and jute fiber hybrid composites. It is clearly evident that the length of coir and jute fiber of 10,20,30 mm with unsaturated polyester resin significantly affected the tensile strength of hybrid composites. The enriched chemical treatment of fabricating hybrid fiber composite gives more strength along with matrix binding. The tensile strength is perceiving to increase with increasing in size of coir and jute fiber up to 20 mm and fiber weight fraction of 40% beyond which it starts decreasing. Proper reinforcement and matrix bonding of hybrid composites with increasing size might give decreasing strength of tensile properties. The table 2 delivers that tensile test was taken for two specimen of same size and the average value is noticed. It is noticed that 20mm size of hybrid fiber composites has maximum tensile strength of 23 Mpa which shows high improvement of 1% and 23% of 10mm and 30mm than other fiber size hybrid composites as shown in figure 9.

Table 2 Tensile properties of jute/coir fiber hybrid composites

S.NO	FIBER (Length mm) 40% (JF+CF)	SPECIMENS	TENSILE STRENGTH (Mpa)	AVERAGE TENSILE STRENGTH (Mpa)
1	10	T_1	20	22.5
		T_{12}	22	
		T_{13}	25	
2	20	T_{21}	21	23
		T_{22}	23	
		T_{23}	25	
3	30	T_{31}	13	15
		T_{32}	14	
		T_{33}	16	

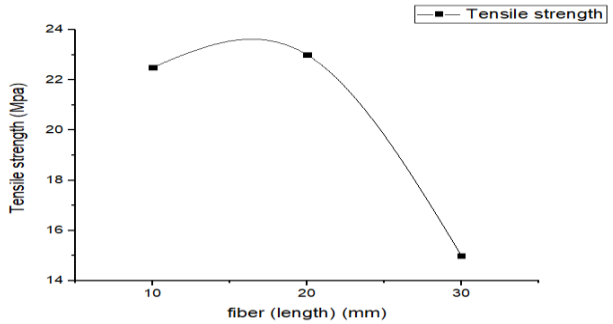

Figure 9 Tensile strength of hybrid composites

B. Flexural Properties

The flexural properties were measured for specimens of each fiber hybrid composites of different size with the help of the flexural stress/strain curves and respective equations. The effect of fiber loading on flexural strength of the hybrid composites having weight fraction and variation of the flexural strength for different size of coir and jute reinforced hybrid composites is shown in table 3. The flexural load was applied in 3-point bending apparatus on the hybrid fiber composites that when bending took place, the coir fiber has higher strength compared to jute fiber which withstand higher stress during flexural testing. It is noticed that 20mm size of hybrid fiber composites has maximum flexural strength of 57.25 Mpa which shows high improvement of 10.6% and 32.41 % of 10mm and 30mm than other fiber size hybrid composites as shown in figure 10.

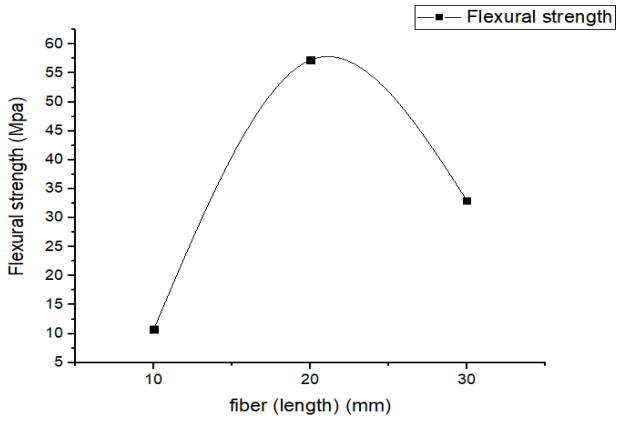

Figure 10 Flexural strength of hybrid composites

Table 3 Flexural properties of jute/coir fiber hybrid composites

S.NO	FIBER (Length mm) 40% (JF+CF)	SPECIMENS	FLEXURAL STRENGTH (Mpa)	AVERAGE FLEXURAL STRENGTH (Mpa)
1	10	F_{11}	9.2	10.8
		F_{12}	10.5	
		F_{13}	12.5	
2	20	F_{21}	52	57.25
		F_{22}	57	
		F_{23}	62.5	
3	30	F_{31}	25	33
		F_{32}	34	
		F_{33}	38	

C. Impact Properties

The impact strength values of different size coir and jute hybrid reinforced unsaturated polyester resin composite are given in the table 4. It delivers that the resistance to impact loading of coir/jute fiber reinforcement which improves strength with increase in fiber length at certain level beyond that the strength will get decreases. Based on this the three different size of fiber length hybrid composites are choosen for impact test analysis. For each size of fiber length three same size specimen taken for test purposes and average value are taken. The average impact strength value of different fiber size are shown in figure 11 Among that the impact strength of 20mm fiber size hybrid composite gives 15.3J of most effective result with 12.8% and 9.6% high improvement than other combination.

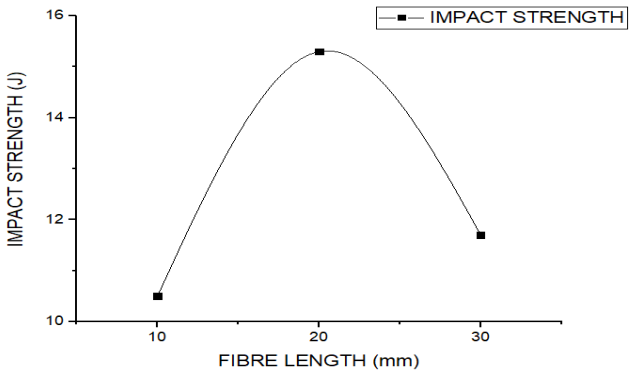

Figure 11 Impact strength of hybrid composites

Table 4 Impact Properties of jute/coir fiber hybrid composites

S.NO	FIBER (Length mm) 40% (JF+CF)	SPECIMENS	IMPACT STRENGTH (J)	AVERAGE IMPACT STRENGTH (J)
1	10	I_{11}	8	10.5
		I_{12}	11	
		I_{13}	13	
2	20	I_{21}	11	15.3
		I_{22}	20	
		I_{23}	15	
3	30	I_{31}	9	11.7
		I_{32}	14	
		I_{33}	12	

D. Hardness Properties

According to the ASTM standard the hardness test was carried out for three specimens of different fiber length of jute/coir reinforced unsaturated polyester resin hybrid composites with five different locations on same specimens[31]. The values of entire specimens is calculated as average hardness value shown in table 5. The result shows that the hardness value of 10mm fiber length hybrid composite at the range of 38 to 44, 20mm fiber length hybrid composite at the range of 42 to 55 and 30 mm fiber length hybrid composite at the range of 35 to 44 as shown in figure 12.

The average hardness value are shown in figure 13 and 10mm fiber length hybrid composite has high improvement of 6.28% and 7.75% than other combinations.

S.NO	FIBER LENGTH (MM)	TRAIL 1 (H_V)	TRAIL 2 (H_V)	TRAIL 3 (H_V)	TRAIL 4 (H_V)	TRAIL 5 (H_V)	AVERAGE (H_V)
1	10	38	41	44	42	40	41
2	20	42	45	50	55	51	49
3	30	39	41	38	35	44	39

Table 5 Micro Hardness Value of jute/coir fiber hybrid composites

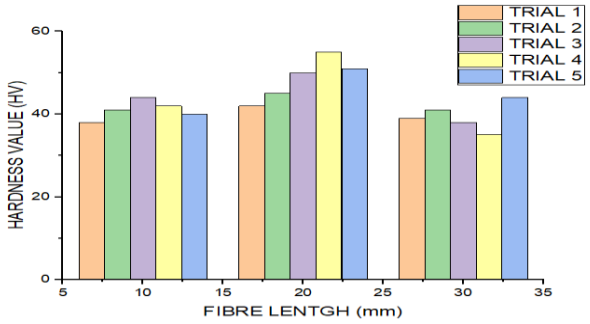

Figure 12 Hardness value of hybrid composites

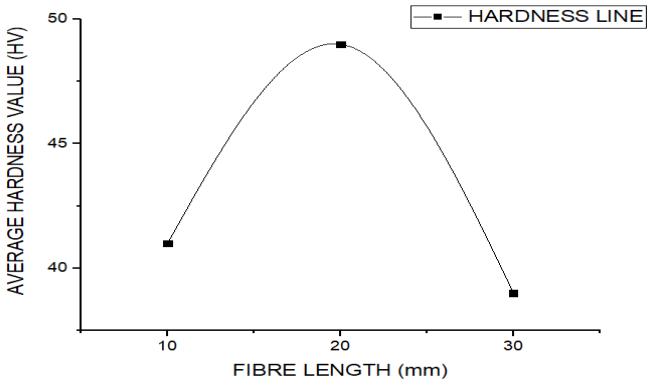

Figure 13 Average hardness values of hybrid composites

E. Morphological Analysis

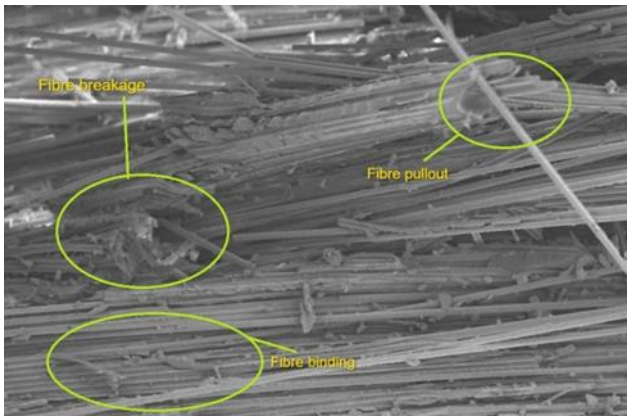

Figure 14 a) SEM image of fiber breakage, fiber pull out and fiber binding of flexural specimen

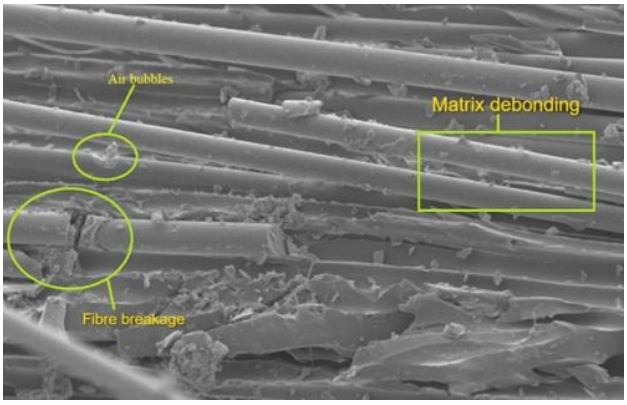

Figure 14. b) SEM image of air bubbles, fiber breakage and matrix debonding of flexural specimen

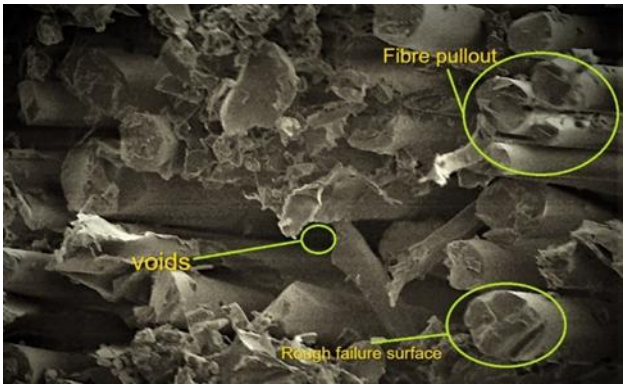

Figure 15 a) SEM image of fiber pull out, voids and rough failure surface of tensile specimen

Figure 15.b) SEM image of air bubbles, fiber breakage and matrix debonding of flexural specimen

The morphological analysis of coir-jute hybrid composites was studied using scanning electron microscope after conducting mechanical testing. The figure 14 clearly explains the fiber-matrix interfacial failure on flexural tested specimen. In figure 14 (a) fiber pull out, fiber binding and fiber breakage was evidently noticed on 50µm which has good physical bonding with fiber and matrix at fiber binding zone and flexural tested fiber breakage zone are also noticed. In figure 14 (b) there are few defects on the flexural testing like air bubbles, fiber breakage and matrix debonding which reduces the strength of the composite slightly.

Even though the fabrication of the jute-coir hybrid composite of different fiber size was done with care, it seen that intra fiber delamination present in the fibers which reduces the strength of the composite. In Figure 15 (a), (b) shows the tensile tested specimen were the loading of the tensile test was done on horizontal direction, so the damage will be more along the same direction. Due to the high strength of the coir fiber it undergoes individual breakage gives it very high strength with all composites. But 20mm fiber size hybrid composite withstands more strength than other composites as shown in figure 14 (b). Along with these the rough failure surface and void of the fiber bonded with matrix undergoing tensile tested specimen are shown in figure 14 (a) respectively.

F. Anova Analysis

The statistical analysis has been carried by the one way analysis of variance (ANOVA) on three different size of fiber length hybrid composites was executed with flexural and tensile strength data.[32] ANOVA analysis was delivered in table 6 and 7 decays the variance of flexural and tensile strength into two apparatuses; a within group (WG) and a between group (BG) respectively. The F-ratio of the tensile strength and flexural strength on the ANOVA analysis was 10.40 and 25.65 obtained. There is a statistically difference between the average value of tensile strength and flexural strength from one level of fiber length hybrid composite to another combination at the 95% confidence level. The test result denotes P-value of the F-test for both the result is less than 5%.

S.NO.	SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARE	F-RATIO
1.	BETWEEN SPECIMENS	SSC=79.83	2	$F_{C=MSC/MSE=10.40}$
2.	WITH IN SPECIMENS	SSE=23.01	6	

Table 6 Anova test for tensile strength of jute/coir reinforced unsaturated polyester resin hybrids and jute composites

ANOVA: analysis of variance; BG: between group; WG: within group; DF: degree of freedom; MS: mean square; and F: F-test for ANOVA.
Number of observations=9.
Number of samples=3.
F_C=10.40
$F_T=F_{2,3}$=9.55
FC>FT
(There is a significant difference at 5% level of significance. The two readings are in differ in its results. So it rejects the null hypothesis)

S.NO	SOURCE OF VARIATION	MEAN SQUARE	DEGREES OF FREEDOM	F-RATIO
1.	BETWEEN SAMPLES	SSC=2172	2	$F_{C=MSC/MSE=25.65}$
2.	WITH IN SAMPLES	SSE=127	6	

Table 7 Anova test for flexural strength of jute/coir reinforced unsaturated polyester resin hybrids and jute composites

ANOVA: analysis of variance; BG: between group; WG: within group; DF: degree of freedom; MS: mean square; and F: F-test for ANOVA.
Number of observations=9.
Number of samples=3.
F_C=25.65
$F_T=F_{2,3}$=9.55
FC>FT
(There is a significant difference at 5% level of significance. The two readings are in differ in its results. So it rejects the null hypothesis)

IV. CONCLUSION

The present study deals with the potential ability of the development of natural fiber hybridization reinforced with matrix delivers improvement in various properties. Due to the hybridization of natural fiber with different fiber size the mechanical properties will increases, at certain stage increasing of fiber size the mechanical properties will get decreases. Based on these aspects the three different size of fiber size are chosen for this study. The fabrication of jute/coir hybrid composite as reinforcement of different fiber size with unsaturated polyester resin as matrix using compression moulding technique various mechanical testing are performed as per ASTM standards.

- The coir-jute hybrid fiber composites of 20mm fiber size have more tensile strength than other fiber size can withstand the tensile strength of 23Mpa followed by the 10mm fiber size and 30mm fiber size composites which holds the value of 22.5Mpa and 15Mpa and which shows high improvement of 1% and 23% than other fiber size hybrid composites.
- The maximum flexural strength of coir-jute hybrid composites are delivered by 20mm fiber size of 57.25Mpa followed by 10mm and 30mm fiber size composites which holds the value of 10.8Mpa and 33Mpa respectively. And it shows much improvement of 32.41% and 10.6 % than other fiber size hybrid composites.
- There is trivial improvement in the impact strength of jute-coir hybrid composites of 20mm fiber size of 15.3J followed by 10mm and 30mm fiber size composites which holds the value of 10.5J and 11.7J respectively. Also, it has high improvement of 12.8% and 9.6% than other combinations.
- The micro hardness analysis obtained in 20mm fiber length of coir-jute hybrid composite of 49H2v as compared with other combinations it has high improvement of 6.28% and 7.75% correspondingly.
- Along with these mechanical studies the failure morphological studies of flexural and tensile tested specimens were examined. Laterally one way ANOVA analysis was also examined the significant differences of test results obtained from different fiber size composites.

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion.

➢ A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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