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Mechanical Properties as a Flexural Strength of Entada Rheedii Fibre and Banana Fibre Hybrid Reinforced Polymer Composites

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ABSTRACT: Investigations were carried out for determining the flexural properties such as flexural (bending) strength, flexural modulus, percentage elongation of an epoxy resin matrix reinforced with a novel variety of hybrid fibre viz. a combination of naturally occurring Entada Rheedii (African dream herb or Sea bean fibre) and banana fibre. Biodegradability, low density, low cost and improved energy recovery make banana fibre and Entada Rheedii fibre desirable candidates for effective reinforcement of the polymer. The polymer reinforced with the hybrid fibre combination of Entada Rheedii fibre and banana fibre exhibited superior flexural and tensile strengths compared with those reinforced with other natural and synthetic fibre combinations such as banana fibre, jute, sisal, hemp, Kenaf polypropylene, Molybdenum fibre etc. Natural fibre reinforced polymer composites are finding wider applications in the manufacture of sports goods, crash guards, woven or braided composites are used for wide variety of cross sectional forms such as stiffeners, truss members, rotor blade, spars, packing materials, etc. The combinations of Entada Rheedii fibre and banana fibre hybrid polymer reinforced composites has investigated excellent flexural properties, to be used for manufacturing of automobile body parts and aircraft structures owing to reduced costs and lower weights without reduction in desired strength.
Further experiments are suggested by the authors for investigation of the mechanical properties viz. tensile and impact strengths of Entada Rheedii and banana fibre reinforced hybrid composites.

Keywords: Automobile body parts, Banana fibre, Entada Rheedii fibre, Flexural strength, Hybrid composite.

Abbreviations: GABGRP, Glass-Aluminium Foil/Wire Mesh- Banana Fibre-Glass Hybrid Reinforced Plastic; MPa, Mega Pascal; GPa, Giga Pascal; HFREC, Hybridization of Fibre Reinforced Epoxy Composite; GFREC, Glass Fibre Reinforced Epoxy Composite; in 3F1- 3 means 24% hardeners added to the composite; F1, first flexural test; in F1 5BP - 5 means 40% hardeners added to the composite; B, banana fibre, P, Entada Rheedii fibre or paranda valli fibre; in F1 8BPBP- 8 means 64% hardeners added to the composite.

I. INTRODUCTION

This work attempts to evaluate the flexural strength, flexural modulus and percentage elongation of a polymer with an epoxy resin reinforced by a novel hybrid combination of Entada Rheedii fibre [1] and banana fibre [2]. Aluminium silicate [3] was used as the hardener. Dicyandiamide, Diethylenetriamine were the accelerator and catalyst [4] respectively.

Generally, either natural or synthetic fibres are used for reinforcing various kinds of polymer matrices. Synthetic fibres are manmade while the natural fibres are extracted from plants. Natural fibres by themselves have not exhibited superior properties (Table 4) while the hybrid composites have. Apart from acceptable specific properties, the natural fibres possess desirable qualities such as lower cost and weight, ease of separation, eco-friendliness, enhanced energy recovery and biodegradability. Moreover, recyclability and CO_2 neutrality make the natural fibres desirable candidates for polymer reinforcements.

Present day use of synthetic polymer materials leads to contamination and environmental issues associated with disposal of waste and its treatment techniques demanding immediate solutions. The increased application of bio-fibres in polymer reinforcement is believed to pave the way for mitigating such issues. The present research evaluates the use of banana fibre-Entada Rheedii fibre hybrid [5] reinforcement of the polymer composite. The Entada Rheedii (African dream herb or sea bean) fibre is a new natural fibre in field of natural polymer composite material category. The Entada Rheedii and banana fibre hybrid reinforced polymer composite has better flexural strength than other natural fibre combinations. The importance of this research can be attributed to the significant aspects of Entada Rheedii and banana fibre hybrid composites which are found to predominantly affected by factors. The factors include based on fibre volume fractions/ weight fractions, variations in arranging sequence of layer of fibres, fibre reinforcement or fibre treatment. Hybrid composites are fabricated by combinations of two or more fibre layer in a single matrix composites.

The flexural strength of the resulting polymer increases with increasing percentage volume fraction [6] of the banana and Entada Rheedii fibre combinations [7].

Devrukhkar *et al.,* (2019) [1] investigated the mechanical properties such as flexural, tensile and compressive strength of Polyacrylonitrilenano-fibres (PAN) and banana fibre reinforced epoxy nano-composites. The flexural strength was determined by three point bending attachment in a universal testing machine. The nano-fibre reinforced composite was found to possess a higher flexural strength (95 MPa) while compared with that of non-reinforced composite (59 MPa). PAN nano-fibres reinforced banana epoxy nano-composite exhibited a tensile strength 57 MPa while that of non-reinforced composite was only 44 MPa. An average tensile strength increase of 22% in banana fibre was noticed with nano-fibres addition. The higher compression strength of 91 MPa resulted with addition of nano-fibre while the compression strength of the composite without nano-fibre addition was only 67 MPa. When nano- fibre addition to the composite was increased from 0.5 to 3% the tensile strength of the composite increased by 22%, compressive strength by 26% and flexural strength by 38%.

VijayaKumar *et al*., (2019) [2] experimental research to determine the tensile and flexural properties of Palmyra fibres impregnated in polymer resin matrix with different volume fractions. Large quantities of Palmyra trees were available in India and 60 percentages grows in Tamil Nadu, belongs to the grass scientifically called as Borassus Flabellifera. The maximum tensile and flexural strength at varying volume fractions was 8 MPa and 41 MPa respectively.

Thiruchitrambalam *et al*., (2018) [3] investigated the mechanical properties of woven mat of banana/kenaf fibre polyester based reinforced hybrid composite. The fibres were treated with a solution of 10% alkaline and 10% sodium laurel sulphate. The maximum tensile and flexural strengths were recorded by 40% volume fraction of woven hybrid fibre composites. Hybrid natural fibre reinforced polymer composites have beneficial properties such as low density, low cost and reduced solidity when compared to synthetic composite products, thus providing advantages for utilization in automotive, construction and medical applications.

The main objective of a work carried out by Chaitanya *et al.,* (2016) [4] was to investigate the effect of NaOH solution on the mechanical properties of banana fibre impregnated polyester composites. Hand lay-up method was adopted to fill the prepared mould with general purpose polyester resin of ECMALON 4413 grade as the matrix with fibres as reinforcement. Mechanical properties such as tensile, impact and bending strengths were evaluated by carrying out tests on composite samples with varying weights of fibre content viz. 0.5, 1, 1.5 and 2 g. The tensile strength was found to be 77MPa and the impact strength 0.34 J/mm^2 for 23% volume fraction of NaOH. The mean bending strength of banana fibre polyester composites treated with NaOH solution increased to 266 MPa at 24% volume fraction of fibre while that of non-treated 17 % vol. fraction fibre was only 153 MPa.

Thirumurugan *et al.,* (2016) [5] studied the bending properties of banana fibre reinforced epoxy composite for treated and untreated fibres. Surface treatment was done on the fibres by applying a thin layer of coating with acetate. Fibres were also treated with sodium hydroxide (NaOH) and potassium permanganate ($KMnO_4$) was added as reinforcement to the epoxy composite. Tests revealed that the resin has less load carrying capacity as compared to the fibre reinforced material. The load carrying capacity of the composite increased with increase in the number of fibres .

Kharat & Sidhu (2016) [6] observed that banana pseudo-stem with epoxy resin (BPE) had higher strength and elasticity than glass fibre and polyester combination (GFPC). The higher flexural values induced by BPE composite over GFPC were attributed to the use of chemical surface treatment of banana pseudo-stem. Alkali treatment has been reported to enhance the flexural properties of composites. The tensile strength of banana pseudo stem epoxy composite was 49 MPa, the Young's modulus 5.22 GPa and flexural strength 55 MPa. On 30% of fibre ratio the flexural strength of banana pseudo-stem epoxy composite was 72 MPa. On the same 30 % fibre ratio the glass fibre polyester composite exhibited a tensile strength of 65 MPa with a Young's Modulus of 7.33 GPa and a flexural strength of 66 MPa. Flexural property is of great significance in prosthetic sockets as the materials involved must be able to resist deformation under loads. Ability to withstand dynamic loads, light weight, elasticity and strength are some of the desirable properties of materials used in making prosthetic sockets.

Udaya Vaidya *et al.,* (2015) [7] that banana fibre /eco-polyester composites had higher flexural strength and modulus due to improved fibre /matrix interaction. The resulting banana fibre/epoxy composites were found to exhibit a flexural strength of 35 MPa and compressive strength of 122 MPa when alkaline pre-treated, while the non-alkaline pre-treated banana fibre/polyester composites were found to possess a flexural strength of 40 MPa and a compressive strength of 123 MPa. In flexural testing, banana fibre/eco-polyester composites presented a flexural modulus of 2419 ± 129 MPa whereas, banana fibre/ epoxy composites showed a modulus 4.19% smaller than the banana fibre/eco-polyester composite. Accordingly, the elongation of the banana fibre/eco-polyester composite is higher than that of the banana fibre/epoxy composite.

Sakthivel *et al*., (2014) [8] In their work on hybrid composite laminates of banana-glass-banana (BGB) and glass-banana-glass (GBG), found the maximum tensile, flexural and impact strengths to be 54 MPa, 163 MPa and 10 J/sq.mm respectively. Chemical treatment of the natural fibres with NaOH, leading to moisture removal, increased the flexural strength to 163 MPa.

Sanjay *et al.,* (2014) [9] in his work evaluated the mechanical properties such as tensile, flexural and impact strength of jute/ glass fibre reinforced polyester composites with various fibres weight fractions. Jute fibre-glass fibres of 50/50, 40/60 and 30/70 weight fraction ratios were used with isophthalic polyester resin as the accelerator. Results indicated that the flexural strength of 40% jute-60% glass fibre composition was better than that of the other two compositions and the tensile strength and impact strength of 50% jute-50% glass fibre composition was also better than those of the other two compositions. The highest tensile strength of 84 MPa was recorded in 50% GFRP - 50% jute composition. The highest flexural strength recorded was 113 MPa in 60% GFRP - 40% jute composition and the highest impact energy of 7.12 Joules was registered in 50% GFRP - 50% jute composition during the impact.

Santhosh *et al.,* (2014) [10] In their study**,** performed flexural test by the three point bending method as per the ASTM D 790 standards at a cross head speed of 1 mm/min. The flexural properties of untreated/alkali treated banana fibre/epoxy composites at 30% fibre loading were evaluated. Flexural strength which is a combination of the tensile and compressive strengths varied with the interfacial shear strength between the fibre and matrix. The maximum flexural, tensile and impact strengths of the composite were found to be 51 MPa, 22 MPa and 8.11 KJ/M^2 respectively.

Kumar & Choudhary (2013) [11] in their investigation showed that banana fibre in combination with glass fibre could yield excellent cost effective polymer composites. The hybridization of fibre reinforced plastic (FRP) at 20% wt. fraction of reinforcement resulted in an increase in the tensile strength of hybrid fibre reinforced epoxy composite (HFREC) by an amount of 1.24% than that of glass fibre reinforced epoxy composite (GFREC) and by 71% than that of banana fibre reinforced epoxy composite (BFREC). The hybridization of FRP at 30% wt. fraction of reinforcement resulted in 2.5% increase in the tensile strength of HFREC compared with that of GFREC and an increase by 63% when compared with that of BFREC. The tensile strength was the highest when a 10% banana fibre and 20% glass fibre mix was used with an interleaving arrangement. The hybridization of FRP at 20% wt. fraction of reinforcement resulted in an increase of flexural strength of HFREC by an amount of 7% than that of GFREC and by 27% than that of BFREC. The hybridization of FRP at 30% wt. fraction of led to an increase in the flexural strength of HFREC by an amount of 6% than that of GFREC and by 23% when compared with that of BFREC.

Sathishkumar *et al.,* (2013) [12] worked on the tri-layered snake grass (SG) reinforced polyester composites with banana and coir fibres. Experiments indicated that the volume fraction of fibres played a major role in the mechanical properties of the composites. Results showed that 20% volume fraction of SG/banana fibre and 25% volume fraction of SG/coir fibre composites exhibited maximum tensile and flexural strengths. The tensile strength of the SG/banana was higher than that of the SG/coir fibre reinforced composites.

Madhukiran *et al.,* (2013) [13] conducted investigations on pure pineapple and pure banana composites. The flexural strengths of pure pine apple and pure banana composites were observed to vary between 212 MPa and 137 MPa respectively. The flexural strengths of the hybrid composites with % weight fractions of 15/25 and 20/20 (pineapple and banana) were found to be 192 MPa and 223 MPa respectively. The effect of hybridization was noted to be negligible for these composites. However, the flexural strength of the hybrid composite with 25/15 weight fraction was 277 MPa which was higher than the rest. Such phenomenon was attributed to the hybridization effect as both fibres contributed to the higher flexural strength of the composite.

Kumar *et al.,* (2013) [14] in a work, banana fibre was incorporated in polypropylene resin matrix hybridized with glass fibre. Composite specimens at various fibre weight percentages viz. 0, 5, 7.5, 10, 12.5 and 15%. Glass fibre added was 2.5% of fibre weight. To obtain homogeneous mixture polypropylene pellets were mixed. Three - point bend tests were performed as per the ASTM D 790 M standards to measure the flexural properties. Impact test specimens were prepared in accordance with ASTM D256-97 to measure the impact strength. It was seen that 7.5% fibre weight fraction composites exhibited maximum tensile strength and the maximum flexural strength observed was for 10% fibre weight fraction composites. Tensile and flexural modulus increased with increase in fibre weight fraction and higher values were observed in 15% fibre weight fraction composites.

Shah *et al.,* (2012) [15] in their experiments found the maximum and minimum flexural strengths of silane treated and woven banana fabric (WBF) reinforced unsaturated polyester resin (UPR) composites to be 58 MPa and 70 MPa respectively. The corresponding tensile strengths were 39 MPa and 45 MPa. The organo-functional groups of the silanes in turn form an interpenetrating polymer network with the polyester. The higher flexural strength was due to good bonding between fibre and matrix. Fourier transforms infrared spectroscopy (FT-IR) was utilized to characterize the chemically modified fibres. Reduction in flexural strength was noticed in water absorption of silane treated and untreated woven banana fibre / unsaturated polyester resin composite. The improved fibre–matrix interaction after silane treatment enhanced tensile and flexural properties.

Hoyur & Cetinkaya (2012) [16] in their study produced bio-composites using banana fibres and glass ropes with polyester resin as the filling material. The specimen surface was coated with glass fibres by hand lay-up method. The test results showed the highest and lowest flexural bending strengths for a single layer specimen to be 13 MPa and 8 MPa, respectively, while the highest and lowest bending strengths for the double layer specimens were 18 MPa and 16 MPa respectively.

Sapuan *et al.,* (2006) [17] carried out experiments on banana fibre reinforced epoxy polymer to determine tensile and flexural strength. Maximum stress values in x and y directions were evaluated to be 14 MN/m^2 and 3 MN/m^2 respectively. Young's modulus of 0.976 GN/m^2 in x-direction and 0.863 GN/m^2 in y-direction were obtained. As for the case of three-point bending (flexural), with a maximum applied load of 36.25N a deflection of 0.5 mm in the banana fibre reinforced polymer composite specimen was noted. Statistical analysis using ANOVA-one way showed that the differences of results obtained from three samples were not significant confirming a stable mechanical behaviour of the composites under different tests.

II. BIO FIBRE USED IN THE PRESENT INVESTIGATION

A. Natural Fibre Reinforcements

In the present study, polymer matrix reinforcement was done with two naturally occurring fibres viz. Entada Rheedii- African dream herb (or Sea bean) fibre and banana fibre.

B. Entada Rheedii Fibre

The Entada Rheedii fibres are extracted from a herbal climber, Entada Rheedii, largely available in small forests in Kerala, South India. The Entada Rheedii plant is mostly fibrous with the rest being fleshy. The fibres are extracted manually or mechanically from the plant stem whose length varies from 2 m to 20 m and diameter between 2 cm and 15 cm. The fibres of Entada Rheedii are shown in Fig. 1 (a, b, c) and its stem in Fig. 1 (d, e).

Entada Rheedii herbal climber is shown in Fig. 2.

Fig. 1. Entada Rheedi (a),(b), (c), (d), (e).

Fig. 2. Entada Rheedii herbal climber.

C. Banana Fibre

The banana fibres are extracted [10] from the banana plant which is abundantly available in the Indian states of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh Maharashtra and Gujarat.

(a) manually.

(b) mechanically extracted banana fibres.

Fig. 3.

III. EXPERIMENTAL PROCEDURE

In this research work, epoxy resin polymer matrix was reinforced with a novel variety of hybrid fibre viz. a combination of naturally occurring Entada Rheedii – African dream herb (or Sea bean) fibre. Varying percentage of hardener, accelerator and catalyst viz. Aluminium silicate, Dicyandiamide and Diethylene-triamine respectively, were added in the epoxy resin for making the composite solution. Both a mono-fibre composite with Entada Rheedii fibre and a hybrid composite with Entada Rheedii and banana fibres were moulded as sandwich layers by hand lay-up method. These composites were kept in the oven at 50°C for 16 hours continuously followed by atmospheric cooling for a period of two weeks for proper curing [11]. From these specimen planks samples for flexural test cut as per ASTM D790 standard. The specimen planks [12] and test samples are shown in Fig. 4 (a, b). Samples after the flexural test are shown in Fig. 5.

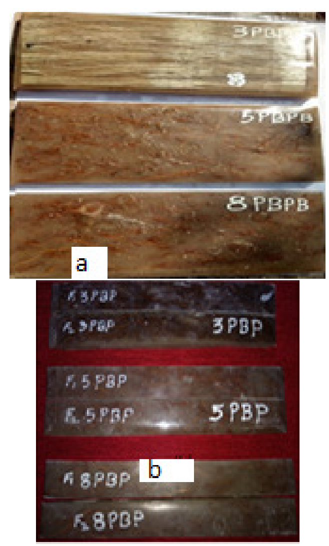


Fig. 4 (a) Specimen planks. (b) Test samples.

Fig. 5. Samples after flexural testing.

IV. FLEXURAL TEST

Entada Rheedii fibre / banana fibre reinforced polymer composite samples were subjected to three point [13] bending test on a Universal Testing Machine [Fig. 6 (a)] in accordance with ASTM D 790 standard. The samples were prepared in different volume fractions of Entada Rheedii fibre (Fig. 1 a, b, c, d, e) or reinforced banana fibre (Fig. 3 (a,b) by hand lay-up method [14] with varying hardener compositions viz. 24%, 40% and 64%. The volume fractions of Entada Rheedii fibre and banana fibre were varied from 7.13 % to 14.26% and 15.36% to 30.72 % (Table-3) respectively. The thickness of banana fibres and Entada Rheedii fibres before reinforcement varied from 0.2 mm to 0.6 mm and 0.6 to 1.2 mm respectively. The span of the lower points was maintained to be 70 mm in the three point test. Results of the flexural tests [15] are given in Tables 1 and 2.

The specimens are identified by notations [16] such as F13P, F15B, F18 PBPB etc. 'F' for flexural test, second digit referring to the sample number, third digit referring to the percentage of hardener added (3 for 24%, 5 for 40% and 8 for 64%; multiples of 20 ml measurement), 'P' for Entada Rheedii fibre layer (Paranda valli, local name of the fibre), 'B' banana fibre layer. The percentage compositions of banana and Entada Rheedii fibre in the specimen reinforced epoxy resin composites are shown in Table 3.

Flexural strength of the polymer composite samples was calculated by the equation

$\sigma_b = 3PL/2bt^2$ in N/mm^2

where σ_b is bending (flexural) strength in N/mm^2,
P is load applied at the centre point in N,
L is span of the lower supports (points) in mm,
b is the width of the test piece in mm,
t is the thickness of the specimen in mm.

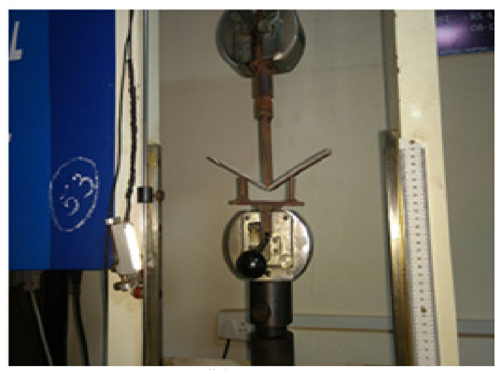
The ratio between the stress and corresponding strain within the elastic limit viz. The flexural modulus was computed as below:

Flexural Modulus $E_b = L^3M/4bt^3$ in kg/cm^2

Where L = distance between lower points (span) in mm,
M = slope of the tangent on outer layer of the specimen during bending,
b = width of the specimen in mm,
t = thickness of the specimen in mm.

The universal Testing Machine used for carrying out the experiments is shown in Fig. 6 (a, b)

(a)



(b)

Fig. 6. Universal Testing Machines.

V. RESULTS

A. Tables

The flexural strengths, determined through experiments, of unreinforced epoxy composite specimens are given in Table 1.

The experiments conducted for varying compositions of bio fibre specimens along with results are given in Table 2.

Table 1: Flexural strength of specimens without fibre addition.

Specimen*	Thickness (t), mm	Width (b), mm	Length (l), mm	Load (P), N	Flexural Strength (σ b), N/mm^2	200% modulus kg/cm^2	Percentage of elongation- (% e)
3F1	4.8	25.5	70	229	41	18	46
3F2	4.7	25.5	70	231	43	13	59
3F3	4.9	25.5	70	279	48	21	54
Average	4.8	25.5	70	246	44	17	53
5F1	6.4	25.7	70	458	50	106	71
5F2	6.1	25.7	70	591	66	112	72
5F3	6.2	25.7	70	499	53	216	71
Average	6.23	25.7	70	516	56	145	71
8F1	4.5	25.2	70	284	58	26	29
8F2	4.9	25.2	70	273	47	23	24
8F3	4.2	25.2	70	276	65	25	28
Average	4.53	25.2	70	277	57	25	27

* For specifications see paragraph above

Table 2: Flexural strengths of reinforced epoxy specimens.

Specimen type	Thickness t in mm	width b in mm	Length l in mm	Load (p) p in N	Flexural strength N/mm^2	200% Modulus Kg/cm^2	% elongation
F1 3B	5.5	25.5	70	276	38	24.5	28
F1 5B	5.5	25.5	70	530	72	37.6	20
F1 8B	5.5	25.5	70	632	86	29.4	22
F1 3P	6	24.5	70	639	76	51.2	263
F1 5P	6	24.5	70	568	68	39.7	22
F1 8P	6	24.5	70	677	81	44.2	22
F1 3BP	5.5	24.5	70	358	51	34.9	25
F1 5BP	5.5	24.5	70	830	118	51.8	24
F1 8BP	5.5	24.5	70	531	75	38.3	23
F1 3BPB	5	25	70	578	97	36.4	24
F1 5BPB	5	25	70	745	125	45.9	25
F1 8BPB	5	25	70	997	167	51.9	22
F1 3PBP	5	24.5	70	1084	186	64.0	27
F1 5PBP	5	24.5	70	928	159	52.2	25
F1 8PBP	5	24.5	70	1004	172	55.4	24
F1 3PBPB	5	24	70	1993	349	80.9	26
F1 5PBPB	5	24	70	1716	300	52.0	25
F1 8PBPB	5	24	70	1379	241	91.8	22

Table 3: Percentage compositions in the specimen of banana and Entada Rheedii fibre reinforced epoxy resin composites.

Specimen type	Percentage composition			Additives (Hardener) (%)	Flexural strength (N/mm^2)
	Banana fibre (%)	Entada Rheedii Fibre (%)	Epoxy resin (%)		
F1 3B	7.13	—	92.87	24	38
F1 5B	7.13	—	92.87	40	72
F1 8B	7.13	—	92.87	64	86
F1 3P	—	15.36	84.64	24	76
F1 5P	—	15.36	84.64	40	68
F1 8P	—	15.36	84.64	64	81
F1 3BP	7.13	15.36	77.51	24	51
F1 5BP	7.13	15.36	77.51	40	118
F1 8BP	7.13	15.36	77.51	64	75
F1 3BPB	14.26	15.36	70.38	24	97
F1 5BPB	14.26	15.36	70.38	40	125
F1 8BPB	14.26	15.36	70.38	64	167
F1 3PBP	7.13	30.72	62.15	24	186
F1 5PBP	7.13	30.72	62.15	40	159
F1 8PBP	7.13	30.72	62.15	64	172
F1 3PBPB	14.26	30.72	55.02	24	349
F1 5PBPB	14.26	30.72	55.02	40	300
F1 8PBPB	14.26	30.72	55.02	64	241

A comparison of tensile and flexural strengths of various composites is presented in Table 4. It is seen that Entada Rheedii fibre and banana fibre reinforced polymer composite has a superior flexural strength.
The experiments conducted for varying compositions of bio fibre layers along with the flexural strengths are shown in The flexural strength of unreinforced epoxy composite was noted to be 52 MPa.

With single layer banana fibre the composite exhibited a flexural strength of 65 MPa, whereas, the single layer Entada Rheedii fibre reinforcement resulted in a flexural strength of 75 MPa. Similarly, Table 5 lists the flexural strengths [17] of various combinations of fibre layer reinforcement. As could be seen, the epoxy composite with double layer reinforcement of both the fibres exhibited the maximum flexural strength due to increased amount of fibre content.

Table 4: The comparison of tensile and flexural strengths of different composites.

Polymers / polyesters	Flexural Strength MPa	Tensile Strength MPa	Reference No.
Entada Rheedii fibre and banana fibre reinforced polymer composite (Present research)	**118**	Not reported so far	—
Polyacrylanitrile nano fibre (PAN) and banana fibre reinforced epoxy nano composite	95	57	[1]
Banana pseudo-stem with epoxy reinforced composite	72	65	[6]
Jute and glass fibre reinforced polyester composite	113	84	[11]
Alkali treated banana fibre epoxy composite	51	22	[12]
Silane treated and woven banana fabric reinforced polyester resin composite	70	45	[16]
Titanium oxide and Tungsten carbide fibre reinforced with polymer composite matrix	64	67	[19]
Tungsten sulphide and Boron carbide fibre with epoxy metal composite	59	33	[20]

Table 5.

Reinforcement		Flexural strength, MPa
Banana fibre layer	**Entada Rheedii fibre layer**	
without fibre reinforcement		52
single layer	—	65
—	single layer	75
single layer	single layer	96
double layer	single layer	130
single layer	double layer	172
double layer	double layer	297

B. Graphs

Load Vs Displacement graphs

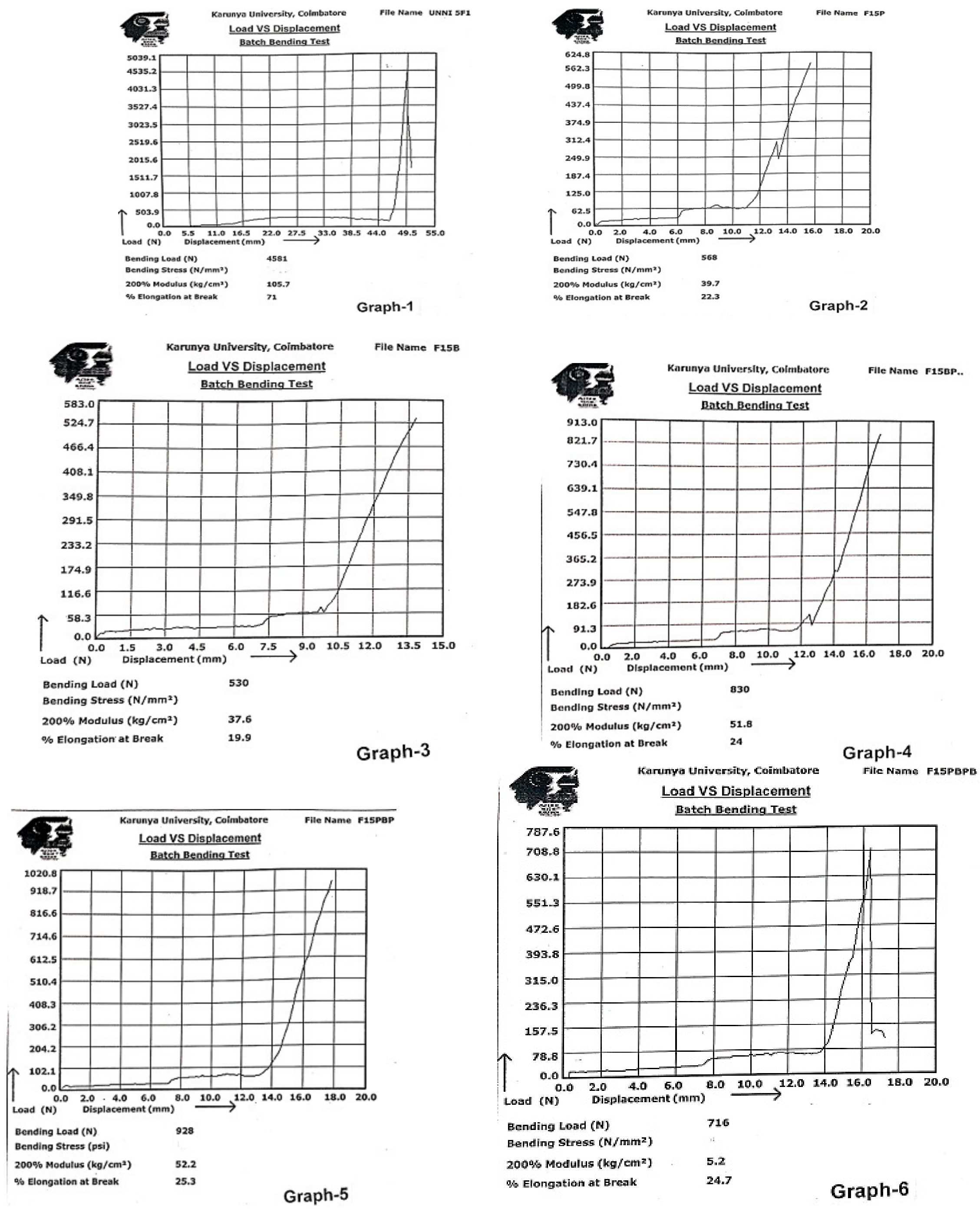


Fig. 7. (Graph 1 to 6).

VI. SCIENTIFIC REASON

Comparisons of the load Vs displacement graphs (Fig. 7) shows that, in a plotted graph (1) of specimen 5F1 indicates the load were suddenly increased steeply at the maximum load points due to unreinforced [18] composite or without fibre content in the composite of act as a brittle materials. In graph (2) of specimen F15P of the composite shows that the load changes due to the Entada Rheedii fibre (P) layer alone. In graph (3), F15B gives the load variations shows due to volume fraction of banana fibre (B) layer alone in the sample. In graph (4) of F15BP gives the load variations due to the fibre interaction, voids and combined fibre fractions of banana and Entada Rheedii fibre in the specimen. In graph (5), F15PBP included the double layer of Entada Rheedii fibre and single layer of banana fibre of sandwich results of flexural strength high due to load changes while bending test. But, in graph (6), F15 PBPB indicates the load gradually goes down after the maximum load due to the fibre interaction and increased flexural strength. In these graphs gives flexural strength enhanced due to the both volume fibre fraction of Entada Rheedii and banana fibre increased with reinforced epoxy composites.

VII. CONCLUSION

– Reinforced epoxy composites were successfully fabricated by simple hand lay-up method.
– The bending strength was experimentally evaluated using the three - point bending test conducted on a computerised universal testing machine.
– Hardener of 24%, 40% and 64% was added resulting in the improvement of flexural strength of the epoxy composites.
– The maximum flexural strength of single layer banana fibre reinforced epoxy composite with 64% hardener was 86 MPa.
–The maximum flexural strength of single layer Entada Rheedii fibre reinforced epoxy composite with 64% hardener was 81 MPa.
– The maximum flexural strength of double layer banana fibre and double layer Entada Rheedii fibre reinforced epoxy composite with 24% hardener was 349 MPa.

VIII. FUTURE SCOPE

Further experiments are suggested by the authors for investigation of the mechanical properties viz. tensile and impact strengths of Entada Rheedii and banana fibre reinforced hybrid composites.

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