TENSILE ASPECTS OF THE COMBINATIONS OF BANANA FIBRE WITH OTHER NATURAL BIO-FIBRES POLYMER COMPOSITE

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ABSTRACT

Last three decades have seen fibre reinforced composite materials being used predominantly in various industrial applications. This review paper discusses the tensile properties of polymer/polyester composites reinforced with banana fibre combined with few other natural bio-fibres. Banana fibre is reported to be one of the best bio-fibres with relatively good mechanical properties. Tensile strength of reinforced composite materials is an important factor in the manufacturing of wide variety of cross-sectional forms such as stiffeners, truss members, rotor blade, automobile body parts, spares, sports goods, including aircraft structures where are extensively used. Use of composites in manufacturing help reduce viz. flexural, tensile, impact strength and hardness have been reported to be influenced by one or more factors such as variation in fibre volume/weight fraction, variation in stacking sequence of fibre layers or fragments, fibre treatment and environmental conditions. Certain new combinations of naturally occurring fibres like Banana fibre and Entada Rheedii-African dream herb or Sea bean fibre or kakkumkaya climber fibre or parandavalli fibre (in Malayalam)- to form a novel variety of hybrid fibre reinforced epoxy resin composites possess a mix of favorable qualities viz. biodegradability, low density, low cost, low handling charges and improved energy recovery which make them desirable candidates for effective reinforcement of epoxy resin composites. These natural bio fibres reinforced composites are basically epoxy resins containing additives or hardeners, accelerators, catalysts.

Keywords: *Tensile properties, Natural fibres, Banana fibres and Entada Rheedii fibre.*

I. INTRODUCTION

Banana is one of the rhizomatous plants and currently grown in 129 countries around the world. It is the fourth most important global food crop. India is the largest producer of banana in the world with an estimated annual output of 13.5 million tons, of which 80% is generated from six states in India, viz. Tamil Nadu, Maharashtra, Karnataka, Kerala, Andhra Pradesh and Gujarat. Annually about 1.5 million tons of dry banana fibres could be produced from the outer sheath of pseudo-stem. Different parts of banana trees serve different needs, including fruits as food sources, leaves as food wrapping, and stems for fibre and paper pulp. The abundant availability of natural fibre in India, has been investigated for their use in plastics, including banana fibre, sisal, coir, grass reeds, water pennywort, kapok , pineapple leaf fiber, paper-mulberry, raphia, cane (sugar and bamboo), flax, hemp, jute, kenaf, ramie, papyrus, straw, wood fiber, oil palm, empty fruit bunch, rice husks, wheat, barley, oats and those could be alternately used to reduce the weight and cost of the composites.

Now-a-days, a family of newer polymer matrix composites reinforced with fibres such as glass, carbon, aramid, graphite, etc. is getting a steady expansion in uses because of their favorable mechanical properties. However, they are quite expensive materials and also heavier than natural bio-fibres. Natural fibre composites gained prominence due to a host of favorable properties which include low cost, low density, eco-friendliness, high toughness, superior thermal properties, ease of separation, enhanced energy recovery, CO_2 neutrality, biodegradability and recyclable nature. For automotive applications, the need for reduction in energy consumption in production of motor vehicles and improvement in fuel economy has created avenues for accelerated use of natural fibre composites.

Through, synthetic polymer composite materials find wider industrial applications satisfying light-weight and high strength requirements, they also worsen environmental issues such as disposal treatment, waste disposal services etc. Apart from the aforesaid advantages, natural fibres also have a good potential for chemical treatment due to the presence of hydroxyl groups in lignin and cellulose in them.

II. LITERATURE SURVEY

Banana fibre with other natural bio-fibres incorporated as reinforcement into various polymer resin composites have been investigated by different researchers in the recent decades.

S.M. Sapuan et. al (2006) (1). The experimental evaluations of tensile and flexural tests were carried out using natural fibre with composite materials (Musaceae /epoxy). Average results of the tensile strength and Young's modulus stress in x-direction and y-directions were computed in three different points. These results generated much interest about the use of this composite as villages across the globe use woven banana fibre especially in producing household utilities.

D. Chandramohan et. al. (2011) (2) investigated the application of biomaterials progress in the field of orthopedics. An effort to utilize the advantages offered by renewable resources of natural bio-fibres for the development of bio-composite materials based on bio epoxy resin and natural fibres such as Agave sisalana ; Musa sepientum; Hibiscus sabdariffa and their applications in bone grafting substitutes were studied. Composite coated with calcium phosphate and hydroxyapatite have potential future applications for both internal and external fixation on the human body for fractured bone healing.

Ayşe Betül Yıldız et. al. (2012) (3) study extruded polycarbonate polymer fibres mixed with pieces of crushed/recycled PET bottles. Polymer fibres, glass fibres and banana fibre were used to produce polymer composite materials. The results showed that the glass-pet bottle-banana fibre hybrid reinforced polyester composite possessed maximum tensile strength and impact energy of 9 MPa and 4 J, respectively.

Hetal Shah et. al (2012) (4) attempted study on the effect of silane treatment on woven banana fabric based unsaturated polyester resin composites. The fabric was treated with vinyl triethoxysilane. Woven banana fabric (WBF) reinforced unsaturated polyester resin (UPR) composites were fabricated by hand lay-up technique. The fabric content in the composite was kept constant at 35 %. The results obtained in this work show that the silane treated WBF composites have higher strength than that of the untreated WBF composites.

Chandramohan D et. al (2013) (5) fabricated, using molding method, a bio-epoxy resin reinforced with natural fibres such as Sisal (Agave sisalana), Banana (Musa sepientum) and Roselle and sisal (hybrid). The hybrid composites exhibited comparatively better performance. Sisal fiber composites, on tensile loading condition, showed a brittle like failure. Elliptical cracks and their fast propagation could be observed. Maximum tensile strength and Young’s modulus of sisal and banana fibre hybrid reinforced epoxy composite were 7 MPa and 18587 MPa, respectively.

Madhukiran.J et.al (2013)(6) investigate the hybrid composites prepared using banana /pineapple fibres of 0/40, 15/25, 20/20, 25/15, and 40/0 weight fraction ratios, while overall fiber weight fraction was fixed as 0.4Wf. The banana/pineapple hybrid composite with weight fraction of 25/15 showed maximum mechanical properties. The hybridization of these natural fibres provided considerable improvement of mechanical properties when compared to individual reinforcement.

T. Hariprasad et. al (2013) (7) made an attempt to establish the tensile, flexural, and impact properties of banana-coir reinforced composite materials with a thermoset for treated and untreated fibres. Composite plates were prepared with resin 392 g, coir 54 g, and banana 69 g. The tensile strength, Young’s modulus, flexural strength, flexural modulus and impact energy of 20% of alkali treated banana and coir fibres reinforced hybrid epoxy composite were 16 MPa, 1 GPa, 20 MPa, 4 GPa and 0.7 J, respectively. While, the values of these properties for the untreated banana and coir fibres hybrid reinforced epoxy composites were 14 MPa, 0.9 GPa, 36 MPa, 4 GPa and 0.3 J, respectively.

Hybrid composite laminates of banana-glass-banana (BGB) and glass-banana-glass (GBG) were fabricated by R. Sakthivel et. al (2014) (8) using epoxy resin combination. Hand lay-up method and cold press method were employed. The tensile strength and flexural strength increased with increasing fibre volume fraction of hybrid. Tensile strength and Young’s modulus of banana fibre reinforced epoxy composite were 54 MPa and 3 GPa, respectively; and those of S-glass fibre reinforced epoxy composite were 48 MPa and 5 GPa, respectively. The hybridized laminate matrix included 25percentages each of banana fibre and glass fibre which exhibited tensile, flexural and impact strengths of 51 MPa, 116 MPa and 10 J/mm, respectively.

J. Santhosh et. al 2014) (9) carried out an experimental evaluation of tensile and impact strength of treated/untreated banana fibre-coconut shell powder epoxy/vinyl ester resin non-hybrid/hybrid reinforced composite samples fabricated by hand lay-up method. Maximum tensile strength of treated banana fibre-coconut shell powder hybrid of 30 wt. % total fibre loading and 70 wt. % of total resin loading (30:70 wt. %) epoxy resin/vinyl ester resin composite was 19.8 MPa and 19.6 MPa, respectively. Maximum impact strength of untreated and treated banana fibre epoxy resin composite at 30 wt. % of total fibre loading was 4 MPa and 8 MPa, respectively.

Glass (G), banana (B) fiber and silica powder hybrid reinforced composite materials were fabricated for G. Navaneethakrishnan et. al (2015) (10). and investigated. The fibre matrix adhesion, BF and GF ply interface bonding, and modes of failure such as fibre breakage, matrix cracking, fibre pull out and dispersion of silica nano-particles were examined using scanning electron microscope. Increases in tensile strength and tensile modulus are due to effective dispersion of nano-particles into their epoxy matrix (Naureen Shahid et.al 2005, Manjunatha et.al 2010 and Raoi et.al 2011). However the tensile strength and modulus decreased with addition of nano-particles above 3 wt %. This was due to the agglomeration of nano-particles in epoxy matrix.

P Surya Nagendra et. al (2015) (11) conducted in their work that renewable natural fibres such as flax, pineapple, sisal and banana stem etc. can be utilized to obtain new high performance polymer materials. Five different samples were produced by varying the banana nano-fibre weight percentages as 0, 2, 4, 6 and 8%. The percent tensile strength, % elongation, flexural strength and modulus of the composite were analyzed. The composite's mechanical properties were affected with the addition of nano-fibre.

The main objective of an experimental study by Shailesh Kumar singh et. al (2015)(12) was to fabricate the sunnhemp fibres reinforced hybrid composites and evaluate their mechanical properties such as flexural, tensile and impact strengths. Natural fibres like sunnhemp, coir, banana, and sisal which are abundant in nature were used in the study in various patterns and the material characteristics of the resulting composites evaluated.

Banana fibre which is widely used as a raw material in industry for production of papers, tea bags, currency can also be used a reinforcement in polymer composites. Natural fibres are cheaper, low in density and reasonable durability when compare to synthetic fibers. Fibre treatments help improve the mechanical properties of natural fibres. In a work by Ravi Bhatnagar et.al (2015)(13) various applications of applications of banana fibres in composite were compared and it was conducted that the banana fibres provided better chemical composition and hence enhancement in composite properties.

The purpose of a study by Jamiu K. Odusote et al (2016)14 was to investigate the tensile, flexural, and hardness properties of banana pseudo stem reinforced epoxy composite materials. Such a composite is projected to serve as a replacement to the currently used synthetic glass fibre in transtibial prosthetic socket. Composite samples, after treatment of the continuous fibres with 5 % NaOH and 2 % ascetic acid solution, were prepared manually using hand-lay-up method with the fibre ratio of 0, 20, 30, 40 and 50 %. The results of 30 % glass fibre polyester composite (GFPC) studies were compared with those of banana pseudo stem epoxy composite (BPEC) produced in this work. The tensile, impact and hardness tests of BPEC at 40 % fibre content were 64 MPa, 63 MPa, 55 BHR, respectively. These were slightly lower than those of the glass fibre composite, which were respectively 65 MPa, 66 MPa, and 61BHR.

An investigation of impact behaviors natural fibre composite consisting of Jute & Banana fibre as reinforcement in epoxy resin matrix was carried out by P. B. Lokare et.al (2016) (15). The Banana fibres were treated with acetone to improve its surface properties. The conventional hand lay-up technique was used to prepare different composite specimen samples.

A research work by Shashank T.A. et.al (2016) (16) dealt with fabrication and investigation of fracture toughness of banana and glass fibre reinforced hybrid composite. Composites of different combinations with varied fibre fractions were prepared using hand lay-up technique. Banana fibre with 15, 20, 25 and 30% were hybridized with 20, 15, 10 and 5% of glass fibre to form composites and compared with non-hybrid 35% glass and banana fibre composites. The results thus obtained signified that the fracture toughness got improved in banana-glass hybrid composite with increased glass fibre content from 5% -15%. The combination of fibres acted as a positive reinforcement in providing extra strength and smooth surface finish to the composite, simultaneously the banana fibre imparting elasticity to the composite**.**

An experimental work by A. Thirumurugan et.al (2016) (17), the hand-layup process was employed to fabricate two types of composites: a normal GFRP and a GFRP hybrid. The hybrid, named GABGRP (glass – aluminium - banana-glass-reinforced plastic) comprises of layers of both aluminium and banana fibres as reinforcements in a glass fibre-base. The aluminium in this study was employed in two different forms: foil and wire mesh. Also, the GABGRP (with Al wire mesh) hybrid composite has the highest tensile load capacity when compared with the other two composite types. Composites with the higher mechanical properties are suitable chosen and used in automobile sector, industries, aerospace, sports, and also in medical fields for making the components required.

Musa Acuminata, locally called banana is a natural resource found abundantly in many parts of India, whose potential as reinforcement in composite has not been explored much till date. In their work, Anurag Thawait et.al (2016) (18) made an attempt to prepare and study the mechanical and environmental behavior of Musa Acuminata reinforced epoxy. Ligno-cellulose fibres are inherently polar and hydrophilic, meaning they readily absorb moisture. This poor adhesion effectively dilutes the composite matrix and causes the fibres to act as flaws in the composite, greatly reducing the mechanical strength.

S P Jagadish et.al **(**2017)(19)aimed at an experimental investigation to evaluate various physical and mechanical properties of hybrid natural fibre polymer composite (Epoxy with Jute, Banana, Sisal and Hemp fibres) at different weight percentages (16 and 24) with epoxy resin. Tests on the basis of comprehensive study the 24 wt % of hybrid natural fibres was found to be having better mechanical properties compared to other 16 wt % of hybrid natural fibres combinations. Also oxidative biodegradation test was carried out according to ISO standard.

Table 1 shows the tensile strength of hybrid polymer/polyester composite reinforced with banana fibre and other natural bio-fibre combinations. Details of researchers are also presented.

Table 1 -Tensile strengths of various polymer /polyester composites reinforced with combinations of banana fibre and other bio-fibres.

Sl No	Researcher & Year	Fibre combination used	Matrix used	Tensile Strength of composite (MPa)
1	S. M. Sapuan et al (2006)	Banana fibre	Epoxy	26
2	Ayse Betul Yildis et. al (2012)	Glass/pet bottle/Banana fibre	Polyester	9
3	Hetal Shah et. al (2012)	Banana fabric	Polyester	45
4	Narra Ravi kumar et. al (2013)	Polypropylene/ glass/ banana	Poly-propylene	24
5	Ashwani Kumar et. al (2013)	Banana/glass fibre	Epoxy	93
6	T. Hariprasad et. al (2013)	Banana/Coir fibre	Epoxy	14
7	R Sakthivel et. al (2014)	Glass/Banana/Glass	Epoxy	51
8	H. Venkatasubramanian et. al (2014)	Abaca/banana/glass fibre	Epoxy	57
9	Mohammed Khalifa et. al(2014)	Treated banana fibre	Epoxy	29
10	Navaneethakrishnan et. al (2015)	Banana/silica/glass fibre	Epoxy	108
11	Surya Nagendra et.al (2015)	Banana nano fibre	Epoxy	164
12	Lina Herrera Estrada et. al (2015)	Pretreated banana/ epoxy	polyester	40
13	Jamiu K Odusote et. al (2016)	Banana pseudo stem fibre	Epoxy	65
14	A K Chaitanya et. al (2016)	Treated banana	Polyester	88
15	Shashank T A et. al (2016)	Banana-glass fibre	Epoxy	Toughness
16	M Shantharaj et al (2016)	Aloe ferox /banana	Epoxy	95
17	Prejisha. J et al (2016)	Rubber coated banana fibre - soil	Local soil	19
18	T. Balasubramani et al (2016)	Banana/mesquite/glass/sisal	Epoxy	105
19	S P Jagadish et al (2017)	Jute/Glass/Banana/ Hemp	Epoxy	43
20	Dawit Wami Nagera et al (2019)	False banana/sisal fibre	G P resin	69
21	R Varunraj et. al (2019)	Jute/glass/banana	Epoxy	3733
22	A V. Devurkhkar et al (2019)	PAN nano fibre/banana fibre	Epoxy	57
23	Unnikrishnan. C P et. al (2021)	Entada Rheedii/banana fibre	Epoxy	92

III. BANANA FIBRE

Naturally occurring banana fibres are available worldwide and are extracted from their plants or pseudo-stem or agricultural waste from banana cultivation. Banana fibres, seen as helically wound cellulose micro-fibrils in amorphous matrix of lignin, can be extracted manually or mechanically [Fig. 1(a) to (e)] according to the required thickness from the stem of the plants. Banana fibres are eco-friendly in nature having the desirable qualities such as preferred mechanical properties, low density, low cost and bio-degradability. Fig.1 (a-e) shows the banana fibres extracted mechanically and manually for making daily-use articles.

Fig.1,(a) Banana plants, (b) Banana plant stem, (c) Bark of banana plant, (d)Colored Banana fibres extracted by mechanically, (e) Banana fibres extracted by manually and (d)Banana fibre products used in day-to-day life.

IV. NATURAL FIBRES

Natural fibre is a fibre obtained from natural sources, like plants or animals or minerals. Natural fibres can be classified as cellulose/ligno-cellulose or plant and vegetables based, according to their origin. Some predominant natural fibres viz. cotton, banana, coir, jute and sisal (ref. Fig.2). Some of the natural fibres are available in today's world market, produced by various firms, as shown in Fig.3(a).The animal or protein based fibres include wool, silk and mohair, apart from asbestos and inorganic whiskers.

For other natural fibres are animal fibres which can be sourced to animals, viz. Cashmere goat (cashmere wool), Angora rabbit (angora wool), Yak (yak fibre) and Camel (camel fibre). Animal fibres (Fig. 3(b)) are generally made up of different kinds of their proteins.

The most popular animal fibres viz. silk and wool fibres vary from species to species. The textile fibres are made in soft and rough textures derived from animal fibres, which are usually produced from animal skin, animal hair (e.g. Mohair, horse hair), animal fur and some insects secretions viz. silkworm and avian. Animal fibres – fine and soft in texture - of varying properties extracted from different animals have been employed in the production of soft warm coats, jackets, shawls, wraps, ponchos, blazers, whereas the rough ones for covers, carpets and rugs.

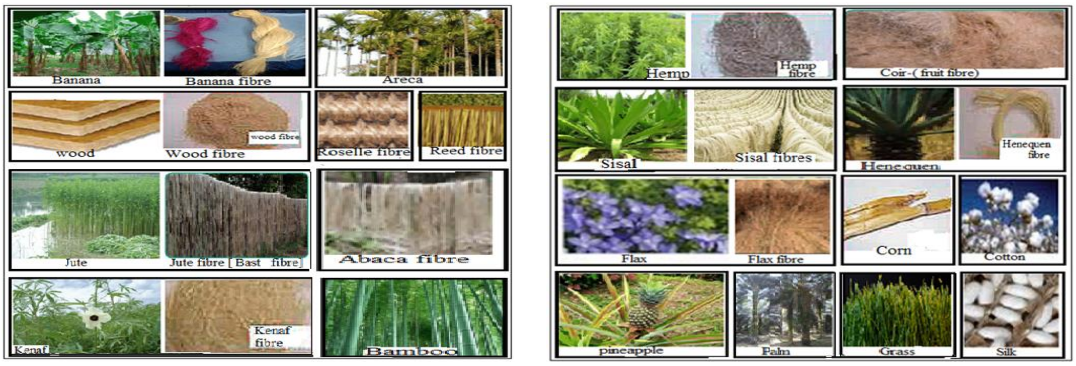

Fig.2. Different types of natural fibres (plant, Cellulose and lingo-cellulose based)

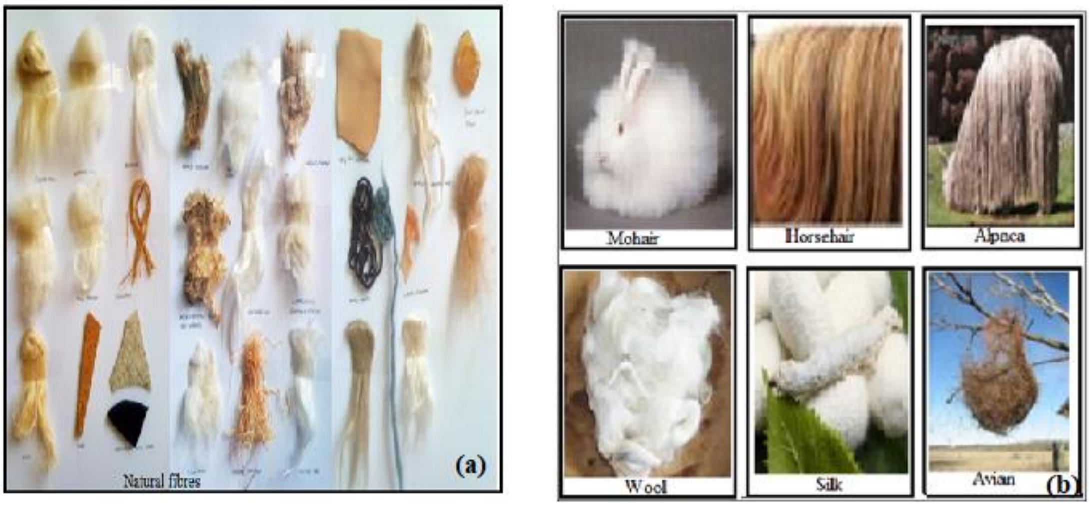

Fig.3 (a) Various natural fibres (Ref. Textilecreativities.blogspot.com) and (b)Different kinds of animal fibres (Ref. researchgate.net)

V. ENTADA RHEEDII FIBRE

The fibres of the plant Entada Rheedii or African dream herb or Parandavalli (P), available in forests in Kerala, South India and elsewhere in the world is extracted from its stem manually or mechanically. The main stem of Entada Rheedii climber that can grow up to 75 m long with girth of about 400 mm; have about 80 % fibre and the rest sap (flesh). The Entada Rheedii herb or climber and their salient features are shown in Fig. 3. The Entada Rheedii fibre layer is shown in Fig.4

Fig.4. Salient features of Entada Rheedii climber

Fig. 5 (a) Entada Rheedii fibre layers extracted from their stem and (b) Single layer of Entada Rheedii fibre after washing with normal water

VI. EXPERIMENTS

The schematic of the fibre layer fabrication set-up with the metallic mould, roller is shown in Fig.6 [(a) - (b)]. Polymer resin matrix, gumas a releasing agent, hardener and accelerator were used in the hand lay-up method of fabrication process. A suitable mixing unit was also employed. The calculated quantities of polymer resin mixed with suitable proportions of hardener, both thoroughly mixed, were added with accelerator and catalyst. After pouring into the mould, fibres were impregnated into the mixture within the mould cavity. The composite mixture was, then, allowed to cure up to about to 24 hours either in the atmospheric condition or hot air oven in auto cut-off mode. After curing, test specimens were cut as per ASTM D 638 standards for tensile test on a computerized universal testing machine.

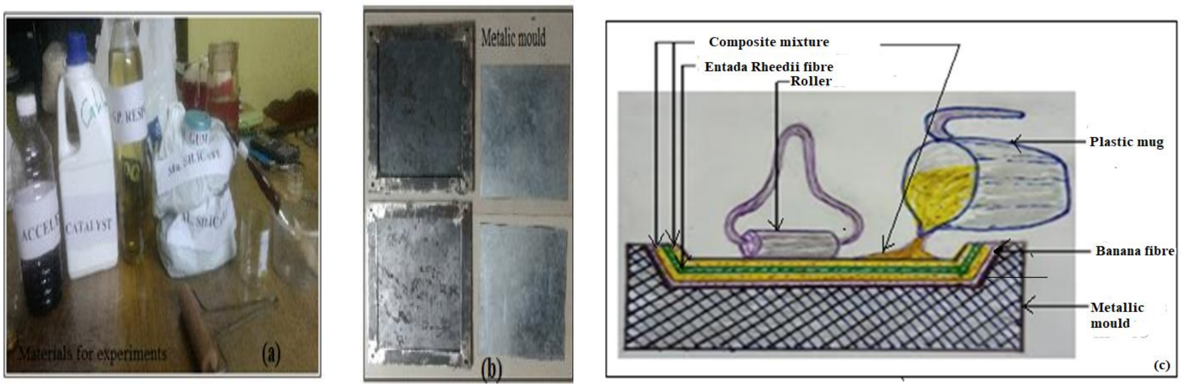

Fig.6 (a) Experimental set-up, (b) Metallic mould and (c) Schematic of fibre layer fabrication set-up (Hand lay-up method)

VII. TENSILE TEST

Tensile test of the samples of reinforced epoxy resin composite impregnated with Entada Rheedii and banana fibres, fabricated by hand lay-up method, was carried out as per ASTM D 638 standard on an Universal Testing Machine [Fig.7(a-b)]. Varying volume fractions of banana fibre [(Fig. 1(d)] and Entada Rheedii fibre [Fig. 5 (b)] were impregnated into the epoxy resin with 24% hardener. The results of tensile test of Entada Rheedii and banana fibre reinforced epoxy resin composite are shown in Table 2. The mechanical properties of banana and Entada Rheedii fibre hybrid reinforced epoxy resin composite improved depending upon percentage volume fraction of bio-fibres. Tensile properties of the composite varied depending on the mono or multi-layer orientation of the reinforcing fibres impregnated into the composite.

The samples [Fig.8 (a)] were marked T13BP, T13BPB, T13PBP, T1 3BPBP. with, 'T' denoting tensile test, second alphabet samples' test number, third digit percentage of additive mixed (3 for 24% of hardener in 20 ml multiples of epoxy resin) to the polymer, 'B' for banana fibre layer and 'P' for Entada Rheedii fibre layer (Parandavalli fibre).

Tensile strength of reinforced epoxy composite specimens was calculated using equation of $\sigma_t = W/A$ in N/mm^2, where, σ_t -Tensile strength in N/mm^2, W - Load applied during test, A - Cross sectional area of the specimen in mm^2, (= b * t; where, 'b' and 't' width and thickness in mm of test sample).

Load vs. Displacement graphs shown in Fig.9 pertain to the tensile tests conducted on the composite specimens with varying combinations of fibre reinforcements or number of reinforcement layers. In Fig.9, with specimen T13BP of the single layer each of Entada Rheedii and banana fibre hybrid reinforced composite. A sandwich type composite (T1 3BPB) with double layers of banana fibre and single layer of Entada Rheedii fibre exhibited greater load bearing capacities as evidenced by Fig.9. With increased volume fraction of reinforcements, double-layers each of Entada Rheedii and banana fibre epoxy resin composite exhibited a higher percentage of elongation due to its superior strength (specimen T1 3PBPB). It can be concluded that the tensile strength of the epoxy composite increases with increasing volume fractions of both reinforcing fibres.

Fig.7 (a) UTM with computer interface (b) Broken specimen after tensile test on computerized UTM

Fig.8 (a) Different specimens of Entada Rheedii-Banana fibre reinforced hybrid epoxy composite and (b) broken specimen after tensile test on UTM

VIII. RESULTS AND DISCUSSION

The results of the tensile test, viz. tensile strength, 200 % modulus and percentage elongation of different combinations of Entada Rheedii-banana fibre layer reinforcements are tabulated.

Table 2 - Tensile properties of the Entada Rheedii and banana fibre hybrid reinforced epoxy composites of varying fibre volume fractions.

Specimen type	Hardener, %	Fibre volume, %	Load (W), N	Tensile Strength (σ_t), N/mm^2	200% Modulus (E_t), kg/cm^2	Elongation %
$T_1$3BP	24	22.52	3254	47	453.3	6.7
$T_1$3BPB		29.64	3586	54	436.4	6.3
$T_1$3PBP		37.92	5235	87	191.4	8.8
$T_1$3PBPB		45.04	5837	91	225.2	9.7

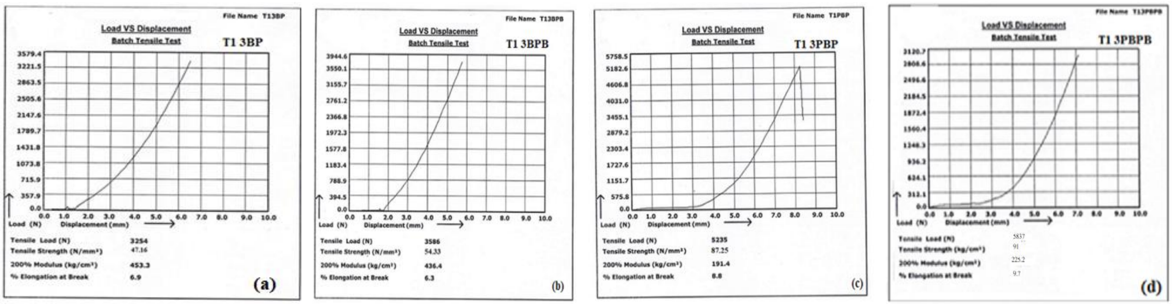

Fig. 9(a) Load vs. Displacement graphs of specimen-T1 3BP, (b) T13BPB,(c) T13PBP and (d) T1 3BPBP

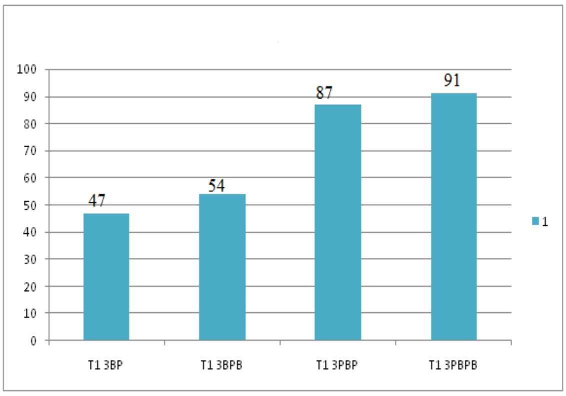

Fig.10 Specimen vs. Tensile strength plots

IX CONCLUSION

From the results it is seen that the maximum tensile strength of double layers sandwich of Entada Rheedii fibre and banana fibre hybrid reinforced epoxy composite was 91 MPa at 24% of hardener mix. Tensile strength of the combinations of Entada Rheedii fibre- banana fibre hybrid reinforced epoxy composite increased with the addition of fibre layers embedded in the matrix. Such an increase can be attributed to the enhanced intra-granular adhession of fibre-rmatrix particles. In the literature survey, I have understood that, the literature study ahead of the present work has strongly indicated that the mechanical, physical and chemical properties of different compositions of banana fibre/banana fibre hybrid composites /natural fibre hybrid polymer matrix composites are suitable for making various products meeting industry requirements.

X. FUTURE SCOPE

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

X1. ACKNOWLEDGEMENT

The authors would like to thank the laboratory staff of Maharaja's Technological Institute, Thrissur, Kerala and Karunya University, Coimbatore, Tamil Nadu, for assisting in the fabrication and testing procedures

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