INVESTIGATION OF MECHANICAL PROPERTIES OF A NOVEL LOTUS FIBRE REINFORCED EPOXY COMPOSITES

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ABSTRACT

The focus of this study is to evaluate and compare the mechanical properties, namely tensile and bending strength of natural fibre composites. The natural fibre chosen for the current investigation was lotus fibre. Different fibre orientations like uniaxial, biaxial and crisscross orientations were employed and the results were compared. The introduction of carbon fibre as an intermediate layer and its influence on the mechanical properties was also evaluated. Fibres are alkaline treated in NaOH solution to get better fibre-matrix adhesion. The moulds for tensile and flexural testing were prepared according to the ASTM standards and the traditional hand lay-up method was used for the fabrication of composites. The results showed that of all the fibre orientations, the uniaxial orientation has given better flexural and tensile strengths. Also, the incorporation of carbon fibre was observed to greatly improve the strength of the composites.

Keywords: *lotus fibre, carbon fibre, epoxy, tensile strength, flexural strength.*

INTRODUCTION

Increase in environmental consciousness, new environmental regulations as well as heavy petroleum consumption have enforced people to think about using eco-friendly goods. Natural fibres have better characteristics than synthetic fibres, making them one of the most environmentally friendly materials available [1]. These fibres are divided into three categories: vegetable fibres, animal fibres, and mineral fibres. Cellulose, lignin, and hemicellulose are the components of vegetable fibres. Fibre quality is determined by elements such as fibre form, micro-fibrillar angle, cell size, and flaws [2]. Natural fibres are obtained from plants. Because of many essential inherent features such as low weight, cheap cost, and high specific strength natural fibres are suitable for variety of applications which include packaging, construction materials and vehicle interiors. In addition, when compared to man-made fibres such as glass fibre and carbon fibre, these fibres offer adequate mechanical qualities, making them a centre point of research in composites.

Lotus (*Nelumbo nucifera*) is a subtropical and temperate zone aquatic perennial. It is desired and planted due to its practical, aesthetic and religious features. In addition to lotus roots, Lotus petioles include thin fibres that appear as fine silky threads when the petiole is cut into pieces. Currently, a large number of lotus petioles grown after the flower season or the harvest of lotus root are left in the pond to degrade before being discarded. These leftovers can create cellulosic fibres which can be utilized in textiles. The usage of lotus fibres in textiles can be seen in Buddhist robes created in Myanmar. According to a study, the lightweight lotus-fibre fabric gives cooling effect in hot weather and heating effect in winter conditions. It also has a pleasant lotus aroma that lingers quite some time. However, there are only a few studies on the utilization of lotus fibre at this moment. Presently, hand extraction is the predominant method used for obtaining Lotus fibres.

Lotus fibre closely resemble to cotton fibres in terms of its cellulose content and water absorption capacity thus making them a potential alternative in textile industries. Lotus fibres are ideal for the textile industry since they have a lower density than cotton and a higher moisture absorption rate [3]. In order to have a better understanding on the characteristics of fibres, the features of lotus fibres were compared to cotton and viscose fibre. The fibre strength of lotus was highest in both the dry and normal states. However, cotton had the highest strength in wet conditions. On the other hand, the fibres' creep strength was best when it's wet and worst when it was dry [4].

Chemical treatment of raw fibres is recommended to achieve the best outcomes. This gets rid of the extra cellulose, lignin, wax, and oils present on the surface of the fibre. Sodium hydroxide is one of the most utilized alkalis since it leaves no pectin remnant in the fibre after treatment. The impurities removal rate is observed to increase with the increase in NaOH concentration and treatment temperature [5]. Because of their increased adhesion, the gelatine/hot water treated fibres had higher mechanical characteristics. Treatment increased the tensile strength at the fracture by 41 % [6, 7].

The flexural strength of the lotus fibre composites can be improved by using a fraction of synthetic fibres [8]. An increase of 11 % flexural strength was observed when fiberglass was used along with lotus fibres. The use of lotus fibres increased the strength of the PLA composites from 14.06 MPa to 56.58 MPa [9]. The weight percentage of fibre content used directly impacted the strength of the composite [10]. With an increase in the fibre percentage, the strength of the PLA composites was also noted to increase. Similar results were obtained for wear strength [11 - 15].

Moreover, lotus fibres exhibit good characteristics like moisture absorption, stiffness, quick-drying, etc. and propose immense benefits in sectors like agriculture and textile industry with good economic value. Hence, the lotus fibre has a higher amount of reinforcing elements providing a cumulative crack resistance and are replaced to be used in the cement industry.

EXPERIMENTAL

Materials

In this study the lotus fibre was used to prepare the composites. The fibres were treated with an alkali solution prepared by dissolving NaOH granules in water and then drying them. Carbon fibre was employed as reinforcement for a few samples in this study. Apart from these fibres and reinforcing elements, epoxy, hardener, distilled water, and wax (for coating the mould) were used in this study. The carbon fibre utilized was a plain weave carbon fibre that was tightly woven to keep it safe from falling apart. The thickness of the sheet was 0.3 mm and the weight per square meter was 200 g mm^{-2}.

Methods

Preparation of moulds

The moulds were prepared according to ASTM standards. With the help of a CNC machine, a mould was cut from high-density wood. ASTM D638 Type 1 was used for tensile testing and ASTM D790 was used for flexural testing, Fig. 1.

Chemical treatment of fibres

The fibre surface mostly comprises of indefinite polymers such as pectin, lignin, hemicelluloses and certain waxes. Subsequently, the area of this layer was mostly exposed to the environment and it will be likely

Fig. 1. Moulds for tensile and Flexural testing.

to undergo water absorption. The surface energy and interfacial shear strength persisted steady at various humidity levels.

The mechanical properties of the composite fibres were enhanced when treated with alkali. The reaction with NaOH broke down the surplus amount of cellulose and amorphous materials such as hemicellulose, lignin, pectin and amorphous cellulose.

Also, the alkali treatment reduces lignin, hemicellulose, wax and moisture substituents of fibres because of the increased separation of each fibre from the pile upon the removal of lignin. This tends to decrease in moisture enhances the reluctance to deliquescent behaviour. Therefore, the decrease in the content of wax enhances the mechanical bonding with the matrix.

The hand extracted raw lotus fibres were extracted by phenethyl/alcohol in the ratio of 2:1, v/v for 6 hours to remove waxy and fatty substances. Then, the delignification of lotus fibre was performed by chlorite-acetic acid method, tends to resulting the fibre with a residue lignin content of less than four percentage and it was called holocellulose. The holocellulose was further refluxed in an aqueous solution of 17.5 % NaOH at 20°C for 2 h to remove the hemicellulose fraction generating a solid residue basically composed of cellulose. Before the preparation of specimens, all the samples were swelled in 18 percentage of sodium hydroxide at room temperature for 3 h, Fig.2.

Preparation of Composites

The preparation of composites started with mould preparation. For the tensile and Flexural testing, three different fibre orientations like uniaxial, biaxial and crisscross were adapted. The pre-treated fibres were cut according to the dimensions of the mould and a mixture of epoxy and hardener in 10:1 ratio was used as binding material. Three samples were prepared for each orientation namely uniaxial, biaxial and criss-cross. A total of 36 specimens were thus prepared and tested with and without the carbon fibre. The Table 1 depicts the nomenclature for each type of specimen.

Fig. 2. Chemical treatment of lotus fibres.

Table 1. Nomenclature of different orientations of lotus fiber**.**

S.no	Specimen	Composition	Orientation
1	A (Tensile)	Lotus + Epoxy + Hardener	Uniaxial
2	B (Tensile)	Lotus + Epoxy + Hardener	Biaxial
3	C (Tensile)	Lotus + Epoxy + Hardener	Crisscross
4	D (Tensile)	Lotus + Epoxy + Hardener + Carbon Fiber	Uniaxial
5	E (Tensile)	Lotus + Epoxy + Hardener + Carbon Fiber	Biaxial
6	F (Tensile)	Lotus + Epoxy + Hardener + Carbon Fiber	Crisscross
7	G (Flexural)	Lotus + Epoxy + Hardener	Uniaxial
8	H (Flexural)	Lotus + Epoxy + Hardener	Biaxial
9	I (Flexural)	Lotus + Epoxy + Hardener	Crisscross
10	J (Flexural)	Lotus + Epoxy + Hardener + Carbon Fiber	Uniaxial
11	K (Flexural)	Lotus + Epoxy + Hardener + Carbon Fiber	Biaxial
12	L (Flexural)	Lotus + Epoxy + Hardener + Carbon Fiber	Crisscross

Fig. 3. Lotus fibre specimens for tensile testing.

Fig. 4. Lotus fibre flexural test Specimens.

Tensile testing procedure

The tensile test was performed using the TUE-C-200 Computerized Universal Testing Machine. The specimens were made following the ASTM D638 Type 1 standard. The full length, parallel section width and thickness of the samples were 165 mm, 13 mm and 6 mm, respectively, and the test results were produced accordingly, Fig. 3.

With a strain rate or loading rate of 1 mm min^{-1}, the load was progressively applied by the machine in the centre of the span length.

Flexural testing procedure

The flexural test was performed using the TUE-C-200 Computerized Universal Testing Machine. The specimens were prepared according to ASTM D790 standard. Full length, parallel section width, the thickness of the sample was 127 mm, 12.7 mm and 3.2 mm, respectively, Fig. 4.

With a strain rate or loading rate of 1 mm min^{-1}, the load was progressively applied by the machine in the centre of the span length.

RESULTS AND DISCUSSION

Results of Tensile testing

Comparison based on the orientation of the fibre

The tensile strength was observed to reach a maximum of 14.677 MPa for uniaxial arrangement. Biaxial fibre arrangement has shown the least strength with a value of 7.844 MPa. While comparing the Biaxial and criss-cross arrangement, the biaxial was slightly greater than the criss-cross. The tensile properties of the lotus fibre samples were tested and the results are shown in Table 2.

Carbon fibre was incorporated with the lotus fibre to observe the change in tensile strength properties. The tensile strength was observed to reach a maximum of 30.658 MPa for uniaxial arrangement. Biaxial fibre arrangement has shown the least strength with a value of 25.957 MPa. While comparing the Biaxial and Criss-cross arrangement, it was observed that the crisscross was slightly greater than the biaxial arrangement. The tensile properties of the lotus fibre samples with the incorporation of carbon fibre were tested and the results are shown in Table 3.

The stress-strain plots (Fig. 5) show that the value of stress keeps on increasing with strain till the point of fracture. Also, we can observe a linear stress-strain variation in specimens B and C at the beginning of loading.

Comparison based on the incorporation of Carbon fibre

With the incorporation of carbon fibre, it is observed that the tensile strength of the composite has increased. From Tables 2 and 3 it can be observed that the load at peak value for specimen D was more compared to specimen A. A similar trend in results was observed for other orientations as well. Clearly, the incorporation of carbon fibre has increased the tensile strength of lotus fibre composites. This is because of

Table 2. Results from tensile testing for lotus fibres without carbon fibre.

s. no	Specimen	Load at peak (KN)	Avg (KN)	Tensile Stress (N mm^{-2})	Avg (N mm^{-2})	Elongation at break (mm)	Avg (mm)	Strain	Avg	Young's Modulus (MPa)
1	A	1.098		11.103		8.76		0.053		
		1.413	1.353	15.092	14.677	2.09	5.046	0.013	0.031	479.862
		1.548		17.837		4.29		0.026		
2	B	0.969		9.44		3.03		0.018		
		2.184	1.555	7.547	7.844	6.52	5.253	0.040	0.032	246.369
		1.514		6.547		6.21		0.038		
3	C	0.87		8.691		2.1		0.013		
		0.703	0.831	6.917	7.531	3.63	3.726	0.022	0.023	333.439
		0.921		6.987		5.45		0.033		

Table 3. Results from tensile testing for lotus fibres with carbon fibre.

S. no	Specimen	Load at peak (KN)	Avg (KN)	Tensile Stress (N mm^{-2})	Avg (N mm^{-2})	Elongation at break (mm)	Avg (mm)	Strain	Avg	Young's Modulus (MPa)
1	D	3.077		27.737		5.19		0.031		
		4.703	3.706	38.747	30.658	7.87	7.613	0.048	0.046	664.436
		3.339		25.855		9.78		0.059		
2	E	3.443		24.023		7.65		0.046		
		4.886	4.371	33.592	25.957	7.79	7.963	0.047	0.048	537.828
		4.784		20.258		8.45		0.051		
3	F	4.684		32.596		7.78		0.047		
		2.293	3.321	21.269	26.447	6.18	7.036	0.037	0.043	620.145
		2.987		25.478		7.15		0.043		

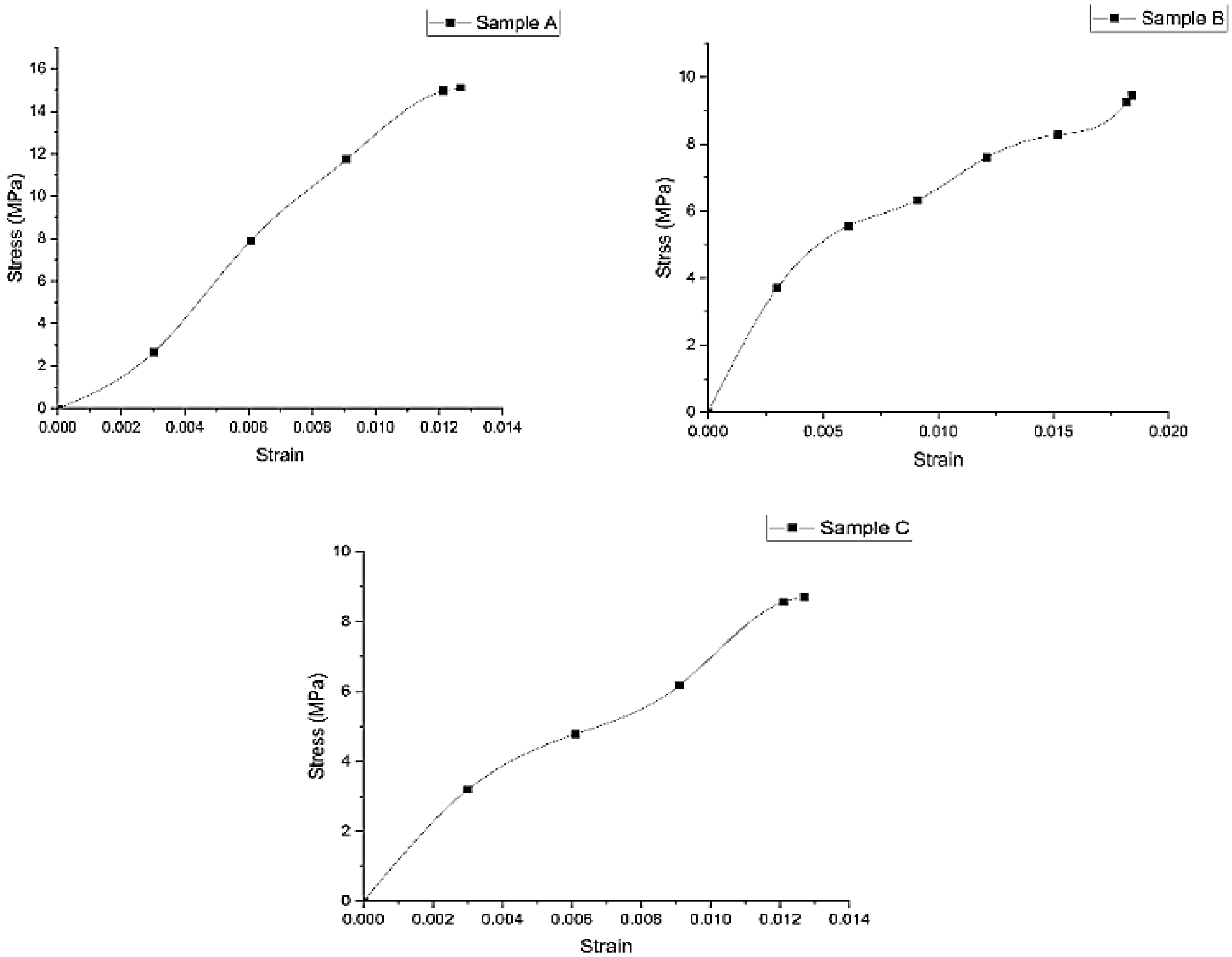

Fig. 5. Stress - Strain plot for samples A, B, C, respectively.

the even stress distribution in the presence of carbon fibre which has ultimately increased the tensile strength of the composite. From the stress-strain plots (Fig. 6) it can be observed that load withstanding capability of specimens has increased with the incorporation of carbon fibre.

Also, the smooth plot of the specimen D and E shows that the load was uniformly distributed in the presence of carbon fibre.

Carbon fiber has high potential which is used for the reinforcement of natural-fiber composites. From this study, it is evident that when carbon fiber is reinforced in the plain composites, there is an enhancement of strength. Due to low stiffness of glass fibers when compared with carbon fiber, the former is often replaced by the latter during the requirement of better mechanical property, light weight and density. The application of carbon fibers is not only limited to defense and aerospace industry but also in fuel cells, sports and leisure and bridge construction, Fig. 7.

Results of Flexural testing

Comparison based on the orientation of fibre

The flexural strength reached a maximum of 34.423 MPa for uniaxial arrangement. Biaxial fibre arrangement showed the least strength with a value of 15.286 MPa. While comparing biaxial and criss-cross arrangement, criss-cross showed greater strength with a value of 18.488 MPa.

Comparison based on the incorporation of carbon fibre

It is observed that with the incorporation of carbon fibre, the flexural strength of the composite has increased. From Tables 4 and 5 and Fig. 8, it can be observed that the load at peak value for specimen J was more

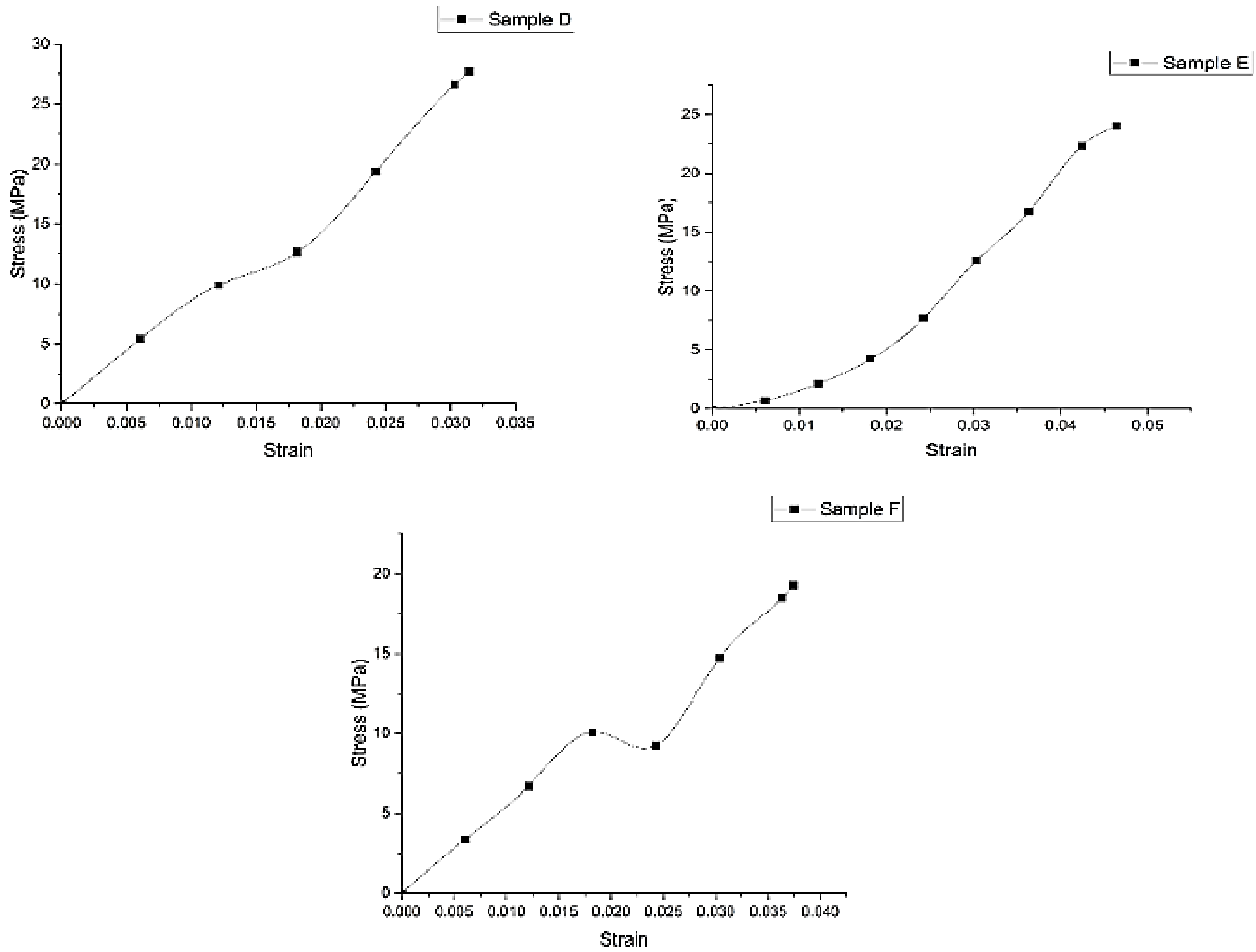

Fig. 6. Stress-Strain plots for specimens D, E and F, respectively.

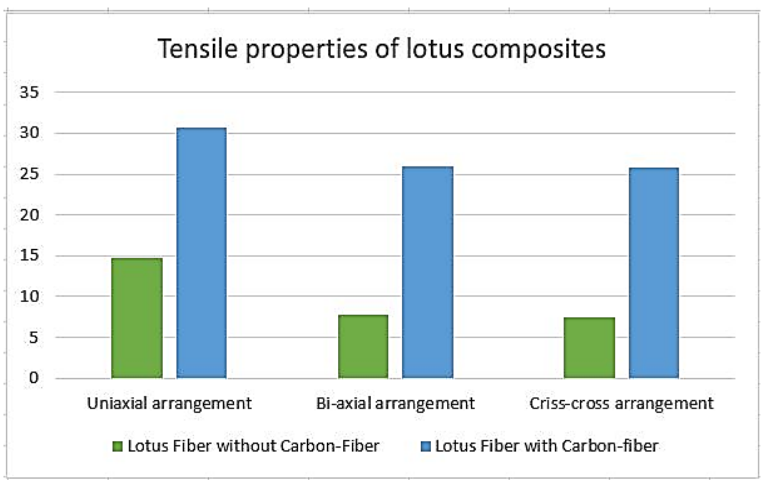

Fig. 7. Comparison of tensile properties of composites with and without carbon fibre.

Table 4. Results show the flexural testing of lotus fibres without the carbon fibre.

S.no	Specimen	Flexural Stress (N mm^{-2})	Avg (N mm^{-2})	Peak Load (N)	Max Deflection (mm)	Flexural Strain	Flexural Modulus (MPa)
1	G	39.6	34.423	59.69	3	0.023	1494.05
		18.39					
		45.28					
2	H	20.26	15.286	26.51	2.1	0.016	947.79
		12.23					
		13.369					
3	I	17.13	18.488	32.06	2.5	0.019	962.92
		20.05					
		18.285					

Table 5. Results show the flexural testing of lotus fibres with the carbon fibre.

S.no	Specimen	Flexural Stress (N mm^{-2})	Avg (N mm^{-2})	Peak Load (N)	Max Deflection (mm)	Flexural Strain	Flexural Modulus (MPa)
1	J	64.90	67.493	117.03	4.8	0.037	1830.86
		66.75					
		70.83					
2	K	50.56	43.638	75.67	3.9	0.030	1456.93
		39.33					
		41.03					
3	L	61.47	60.911	105.62	4.65	0.036	1705.62
		60.69					
		60.57					

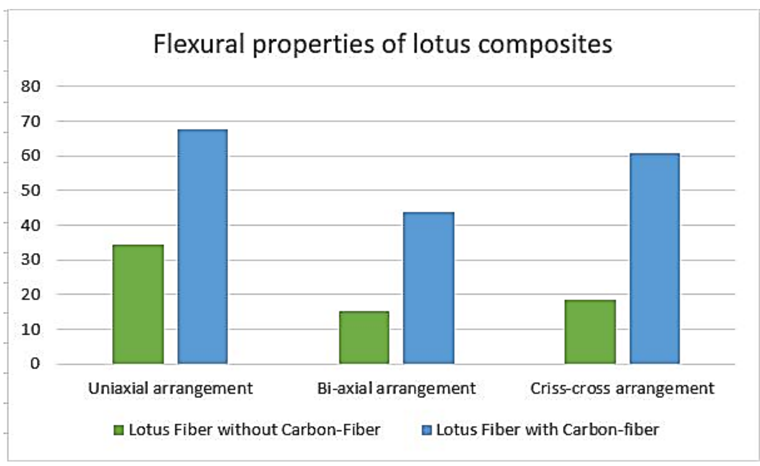

Fig. 8. Comparison of flexural properties of composites with and without carbon fibre.

compared to specimen G. Similar trend was observed for all other orientations as well. The maximum load at the peak drastically increased with the incorporation of carbon fibre. This is because of the higher load-carrying capacity of the carbon fibre.

CONCLUSIONS

In this research, lotus fibre reinforced composites were prepared using hand layup method. The mechanical properties of the composites like tensile and flexural strength were evaluated using Computerised Universal Testing Machine TEU-C-200. Test results showed that the properties of the composites were greatly dependent on the orientation of the fibre. The uniaxial arrangement showed the highest tensile strength followed by biaxial and criss-cross. A similar trend was observed for the flexural strength as well, wherein the uniaxial arrangement showed the highest strength followed by biaxial and criss-cross. The incorporation of carbon fibre showed a clear impact on both the tensile and flexural strength of the composites.

This study will open up a slew of new options for future research. The composites employed in this study can be employed in defence, cars, packaging, and other applications. These composites generally will attract attention if there is a desire for producing lightweight and high-strength material. The study does, however, offer some room for additional investigation by the researchers in the area of thermal analysis for finding the degradation temperature and other thermal properties of the lotus fibre composites. Also, future researchers can focus on wear and impact tests to better understand the various applications of these lotus fibre composites. The major advantage of the lotus fiber has a higher amount of reinforcing elements providing a cumulative crack resistance and are replaced to be used in the cement industry and bridge construction.

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