MECHANICAL BEHAVIOUR OF ISTLE FIBRE COMPOSITE REINFORCED WITH EPOXY AND E-GLASS AT DIFFERENT FIBRE ORIENTATIONS

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ABSTRACT

This paper was aimed to study the mechanical properties of Istle fibre composites. The process of fabrication was done by hand layup technique at three different fibre orientations i.e., unidirectional, bidirectional and 45 degrees inclined, and also its effect on tensile and flexural property that was studied in the Instron Testing Machine. The fibre volume ratio was kept uniform for the entire specimen as 50:50. The treatment of istle fibre was done with sodium hydroxide to increase the fibre matrix bonding. The effect of E-glass reinforcement has also been studied in both bending tests and flexural tests. The maximum tensile and bending modulus recorded were from unidirectional fibre specimen.

Keywords: natural fibre composite, tensile test, flexural test, istle fibre composite, istle fibre composite.

INTRODUCTION

There is a demand for class of eco-friendly materials like synthetic fibre composite that possess features like sustainability and biodegradability. Besides this, lignocellulosic fibres (LCF's) are cheap, light in weight, nonabrasive and flexible in nature. Moreover, natural fibres have additional advantage of being renewable, recyclable and also emits less CO_2 than synthetic fibre which in turn contributes to revert global warming [1, 2]. Istle or Tampico fibres are extracted from the agave plant's leaves and is mainly a hard plant fibre usually grown in hot semiarid climate. These types of fibres are rich in lignin and cellulose and are called lignocellulosic fibres (LCF's) [3]. The LCFs have the ability to check close value to the tensile strength levels of glass fibre. The experts have suggested that there is an inverse correlation between the fibre diameter and strength of the composite [4]. The natural fibres with small cross-sectional area have a smaller number of defects. The smaller fibres are circular in shape, less porous and thicker fibres which have more rupture per micro fibril [5]. The istle fibre's diameter is only about 20 μm. Cross section of this fibre is in oval shape. Natural Fibre Reinforced Composites (NFRC's) were at the top with comparable tensile strength as stronger as metallic alloys. The authors have estimated that NFRC made by thinner fibres tend to show an improved mechanical property [6]. Since the istle fibre offered good results, it can be used in engineering applications. The NFRC have been used earlier in many engineering applications such as automobile sectors, machineries, electronics and packaging industries [7]. Also, German automotive companies like Mercedes, BMW, Audi and Volkswagen have used 65 % blend of hemp, flax and sisal for making interiors like door panel of car [8].

Authors have discussed the fabrication of the composites is important to know about the fibre interaction of istle fibre with the moisture and matrix phase. In general, the LFCs have high moisture absorbing tendency and are hydrophilic in nature which can deteriorate its bonding ability. Fibre pre-treatment can increase the adhesion between fibre and matrix phase because hydroxyl is present in both lignin and cellulose that can be involved in hydrogen bonding in fibre structure. Treatment with certain chemicals can activate these groups and increase the bonding strength between fibre and matrix. The pre-treatment, cleans the fibre, stops the moisture retention ability and increases the surface roughness of the fibre [9, 10].

The polypropylene composite reveals that anisotropic behaviour of the composite is not favourable and with a slight change in fibre orientation changes in mechanical properties were found [11 - 13]. Authors have observed that the change in young's modulus (E) was seen till 45° fibre orientation, after that 'E' was almost constant [14 - 16]. In general, the tensile specimen which is aligned unidirectional should follow isostrain behaviour and specimen which has bidirectional alignment should follow both isostrain and isostress behaviour [17]. The unidirectional E-glass fibre shows better mechanical properties than the bidirectional E-glass fibre [18].

From the literature reviewed on the natural fibres' composites, it is evident that there is a lack of research on istle fibres reinforced with E-glass fibres with different orientations such as uniaxial, biaxial and criss-cross. Istle fibres are known to have high strength to weight ratio, good tensile strength and insulating properties, when compared to synthetic fibres. Improving this natural fibre composite with E-glass fibres, which has more tensile strength than steel, can lead to better mechanical properties. This, in turn can offer a wide spectrum of application in aerospace, automobile and many more industries.

The main objective of this paper is to determine and comprehensively analyse the tensile and flexural strengths of the multiple variants of istle fibre composites. Three different orientations, namely uniaxial, biaxial and criss-cross specimens are prepared and tested to obtain different results. This is done to provide insight and conclusive evidence as to which orientation provides the best output result. The specimens were prepared along with the layers of E-glass fibres and tested to observe the change in the strengths of the composites.

EXPERIMENTAL

The Istle fibre is a hard plant fibre used for various applications in textiles, furniture, ropes and brush industry. It is cultivated in Mexico.

Fig. 1. Istle fibre.

Istle fibre was supplied by a firm near Vijayawada in Andhra Pradesh where optimum atmospheric conditions are present for the cultivation of this fibre.

After steaming the leaves for 2 - 4 h, the fibres length is extracted and this ranges from 30 - 102 cm. Fig. 1. shows the chemically treated Istle fibre.

The cross section of istle fibre depicts the oval shape with small polygonal geometrical voids, and the diameter ranges from 9.6 μm to 20 μm with density of 1.26 - 1.50 g cm^{-3}. The elongation of the fibre is 4.8 % and moisture content lies in between 5 and 10 [11].

In this study, the matrix phase consists of Epoxy LY556 and Hardener HY951. The epoxy LY556 is a pale-yellow liquid and HY951 is used as a catalyst for bonding purpose [12].

The tensile test moulds were made according to ASTM D3039 [13] and flexural test moulds were made according to ASTM D7264 [14]. The moulds were designed in SolidWorks and then moulds were prepared using CNC machine. The length of the tensile mould is 165 mm, the depth and width of the specimen are 6mm and 19 mm respectively. The length of the bending mould is 127 mm, the depth and width of the specimen are 3.2 mm and 12.7 mm respectively. The entire mould depth of tensile mould and bending mould are 10 mm and 5 mm as shown below.

The istle fibres were first cleaned manually and then treated with 0.5 % NaOH. After the treatment, fibres were kept for natural drying. Then fibres were cut into

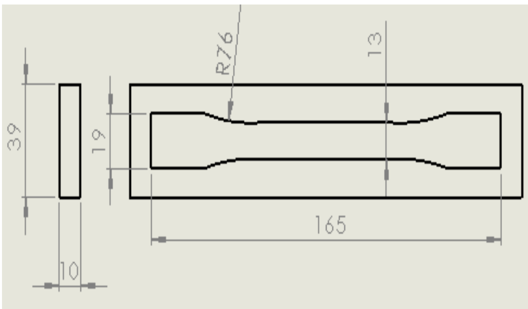


Fig. 2. Tensile mould.

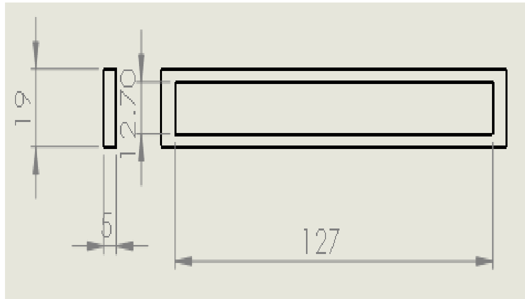


Fig. 3. Bending mould.

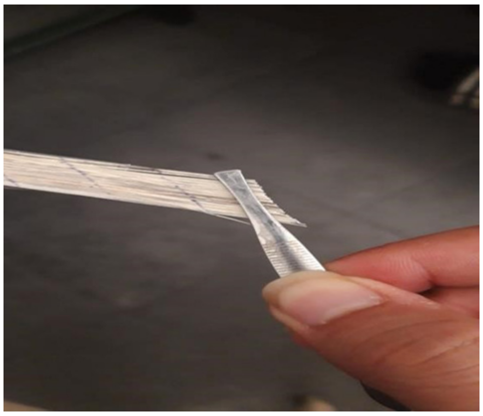


Fig. 4. Inclined layer of natural fibre.

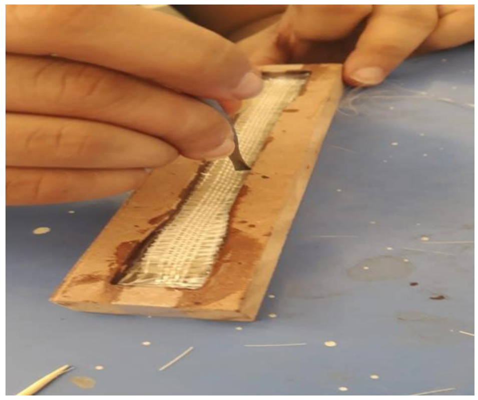


Fig. 5. Tensile Bidirectional fibreglass specimen.

finite length and several layers were made. The length of the fibre was marked according to the requirement of the mould and then the fibre was kept under the load to straighten its layers.

The composites were made by Hand layup technique, where the istle fibre was the reinforcing phase and epoxy was the matrix phase. The fibre epoxy volume ratio was kept as 50:50 for the entire specimen, which is obtained carefully by measuring the mould's volume. The first half of the volume is measured for matrix and the other half is for the fibre. The matrix phase was made by mixing the hardener and epoxy in the ratio of 1:10. Fig. 4. shows the inclined layer of natural fibre.

After every layer of natural fibre, epoxy solution was applied to maintain the 50:50 volume ratio as shown in Fig. 5. Usually for tensile specimen 7 - 8 layers of natural fibre and 10 mL of epoxy was used. For the flexural specimen 4 - 5 layers of natural fibre and 5 mL of epoxy was used. The three orientations such as unidirectional, bidirectional and inclined at 45^o were used. There a definite pattern is followed for every orientation.

Fig. 6. and Fig. 7. show the bidirectional layer sequence of the fibre in the order of 1 - 5. The first layer is of unidirectional natural fibre which is arranged in a longitudinal direction and then the second layer is arranged at 90^o in a transverse direction. This process is repeated till the mould was completed. Fig. 7. shows a bidirectional fibre glass sheet at which the glass fibre is introduced in between the natural fibres.

Fig. 8. shows the inclined sequence of arrangement

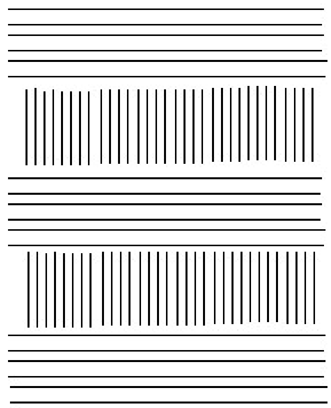


Fig. 6. Bidirectional layer sequence.

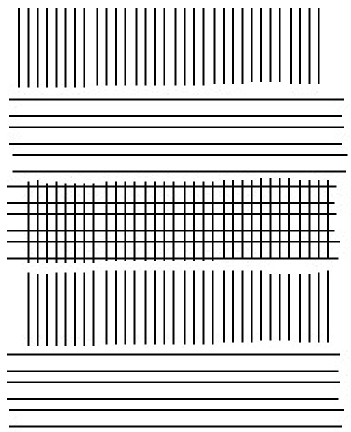


Fig. 7. Bidirectional E-glass sequence.

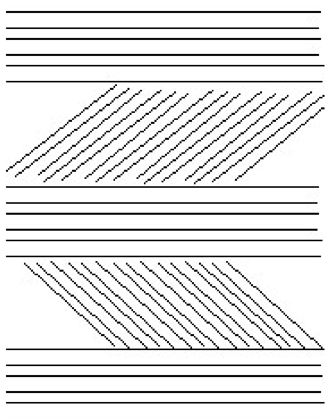


Fig. 8. Inclined layer sequence.

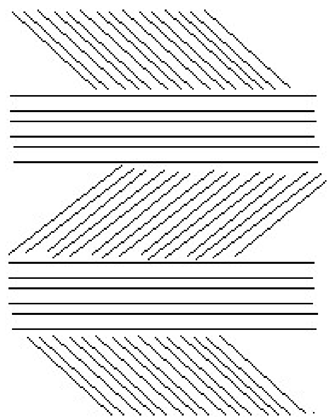


Fig. 9. Inclined E-glass sequence.

of fibre in the order of 1 to 5. Fig. 9 shows sequence arrangement of natural fibre plus E-glass fibre. A single layer of natural fibre and a single layer of E-glass fibre are alternatively placed in the mould. The first layer was of unidirectional natural fibre arranged in a longitudinal direction and then the second layer is arranged in a 45^{o} inclined direction. This process is repeated till the mould preparation is completed.

Instron 8801 UTM was used for both tensile and bending tests. The maximum axial force capacity of this machine is 100 kN. The load cell used is patented dynacell load cell. The controller has 8800MT digital controller, with Bluehill Universal as interface software.

The specimens are tested in Instron 8801 universal testing machine and the results are generated through the software. The strain rate was set as 1mm/min, humidity and temperature were recorded as 60 % and 25°C respectively. The specimens were placed longitudinally in the fixture which is shown in Fig. 10.

The bending tests were carried out in Instron 8801 UTM where the Instron software generates the results in the form of tables and graphs. The strain rate was set as 2mm/min, humidity and temperature recorded as 60 % and 26°C. Fig.11. shows that the three point bending test fixture and the flexural test were conducted according to the ASTM test standards. As per the standards, the distance between the two supporting roller is kept as 16 times the depth of the specimen.

Fig. 10. Tensile fixture.

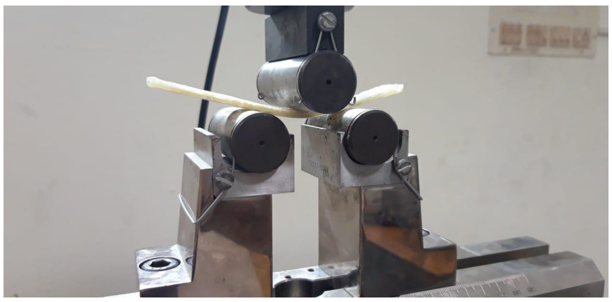


Fig. 11. Three point bending test.

RESULTS AND DISCUSSION

Tensile test results

The results from Table 1 shows that without glass fibre specimen, the maximum Young's modulus was observed for unidirectional specimen is 3748.58 MPa which bears the maximum load of 2882.65 N. This shows about the isostrain nature where strain has dominated and it was observed at 5.85 % of tensile strain. Similar trend was observed for fibre glass specimen and it was observed that the unidirectional fibreglass specimen strain has dominated.

The load versus extension graph is drawn for non-fibre glass specimens which is shown in Fig. 12a, b and c. It shows that the young's modulus is almost similar, but maximum load capacity is different. Maximum load capacity was observed for unidirectional followed by inclined and then bidirectional arrangement of fibre. This is because the fibres were aligned in the direction of load which is not in the case of bidirectional and inclined specimen. Since, the fibre orientation and strength are related by cosine of angle of orientation, the bidirectional specimen bears least maximum load and least tensile strain.

In the Fig. 13d, and f, the load versus extension graph is drawn for fibre glass specimen whose Young's modulus of unidirectional fibre glass specimen is very

Table 1. Tensile test results.

S.No.	Comment	Tensile strain at maximum load, %	Load at break, (standard), kN	Tensile stress at break (standard), MPa	Maximum load, N	UTS, GPa	Modulus (automatic young's), MPa	Tensile strain at break (standard), %
1	ISTLE FIBRE UNI	1.42724	0.15	1.95	2882.65944	0.037	3748.587	5.859
2	ISTLE BI	0.68747	0.73	9.40	1514.42289	0.019	3722.344	1.192
3	ISTLE CRC	1.04328	0.62	8.00	2071.45214	0.027	3649.758	1.357
4	ISTLE EGLASS UNI	1.86482	3.01	38.64	8196.54465	0.105	7405.103	1.965
5	ISTLE EGLASS BI	1.02913	2.14	27.50	2439.86845	0.031	4029.758	1.259
6	ISTLE EGLASS CC	1.47948	0.60	7.64	3047.54972	0.039	3952.411	1.636
Max		1.86482	3.01	38.64	8196.54465	0.105	7405.103	8.460
Mean		1.25403	1.26	15.52	3106.14279	0.040	4198.699	3.104
Min		0.68747	0.15	1.95	1514.42289	0.019	3649.758	1.192

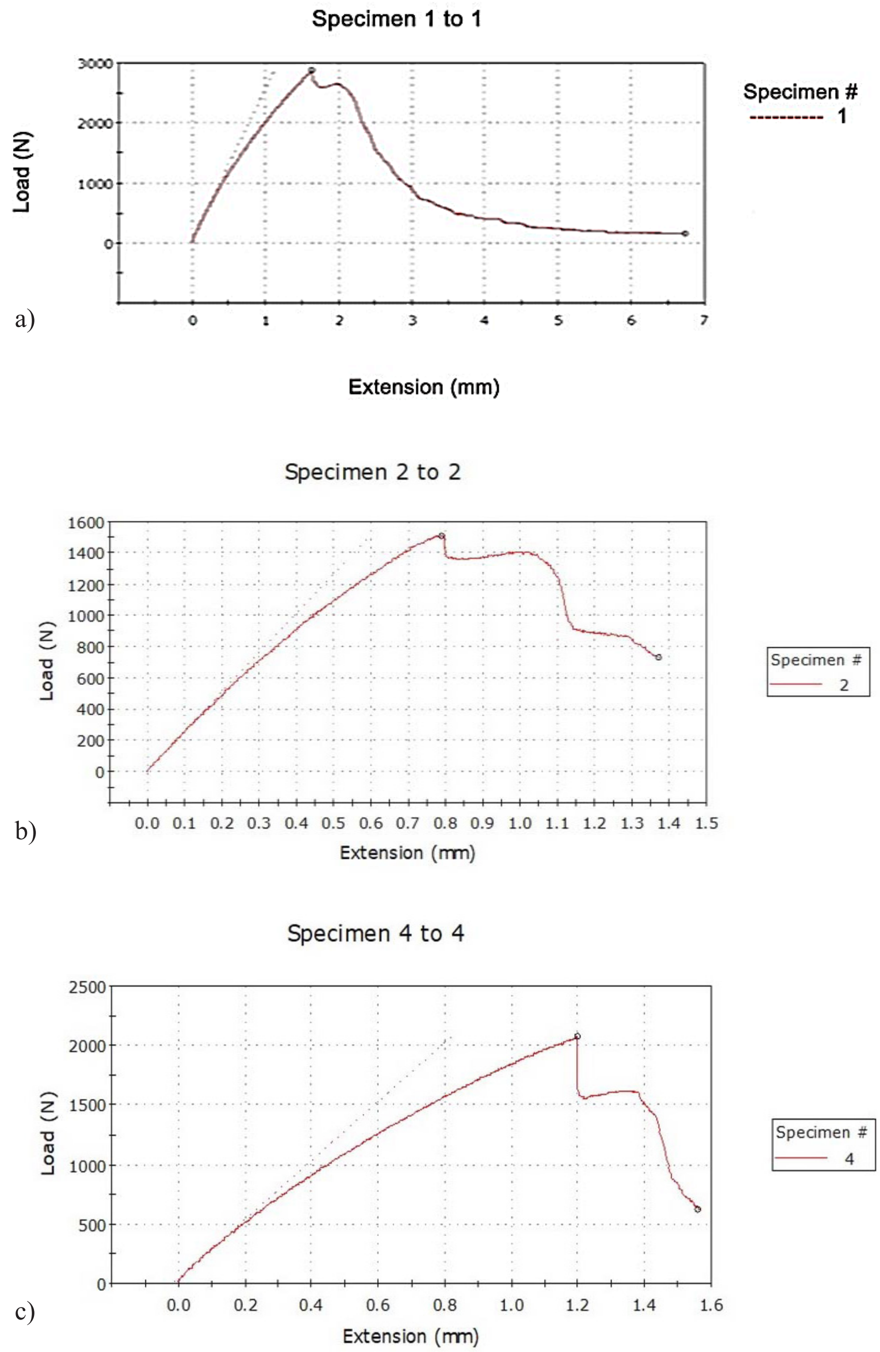


Fig. 12. Tensile test load vs extension curve.

high and proves that unidirectional orientation plus fibre glass is the best combination. The same behaviour is observed for the other two orientations as seen in without E-glass specimen.

For other two orientations, i.e., without glass fibre composites, it is observed that the bidirectional specimen has Young's modulus of 3722.34 MPa and the inclined orientation has Young's modulus of 3649.75 MPa. But, the UTS of inclined specimen was greater than bidirectional specimen and unidirectional specimen with the maximum UTS. The 1.192 % strain rate was recorded which depicts the isostress behaviour in bidirectional specimen. The bidirectional specimen beared only 1514.4 N because the fibre orientation was

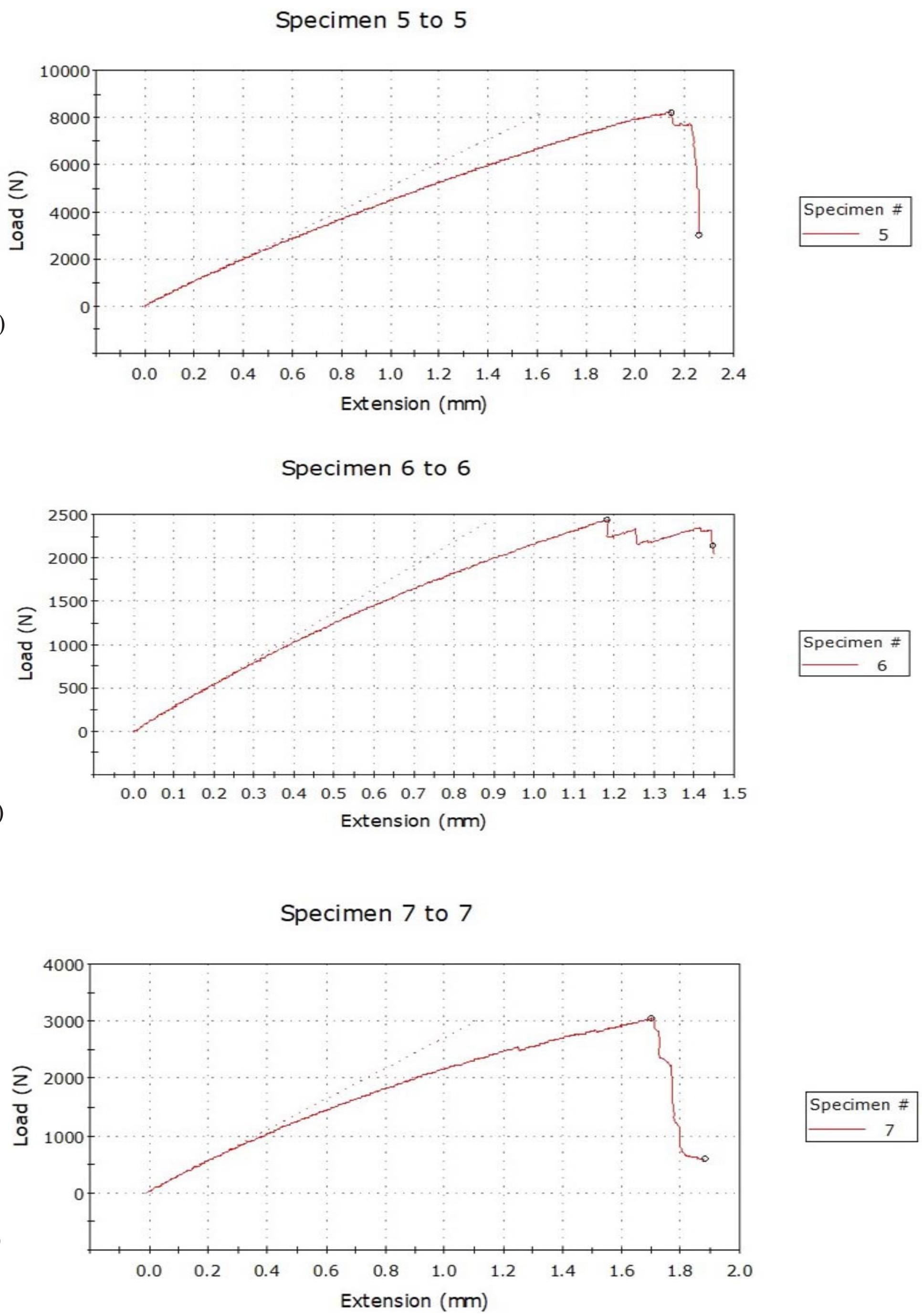


Fig. 13. Tensile test load vs extension curve.

perpendicular to the fibre loading and also the number of voids in bidirectional specimen were more.

For E-glass specimen, the maximum Young's modulus was observed for unidirectional glass fibre specimen is 7405.103 MPa which bears the maximum load 8196.54 N at which strain break was observed as 1.96 %.

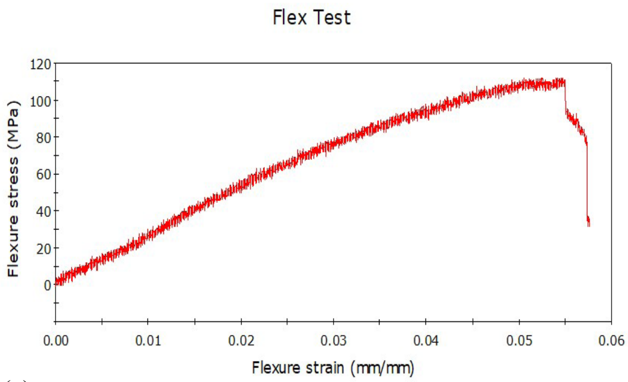
For other two orientations with glass fibre composites, the bidirectional specimen has Young's modulus of 4029.75 MPa and 45^{o} inclined specimen has Young's modulus of 3952.41 MPa.

Bending test results

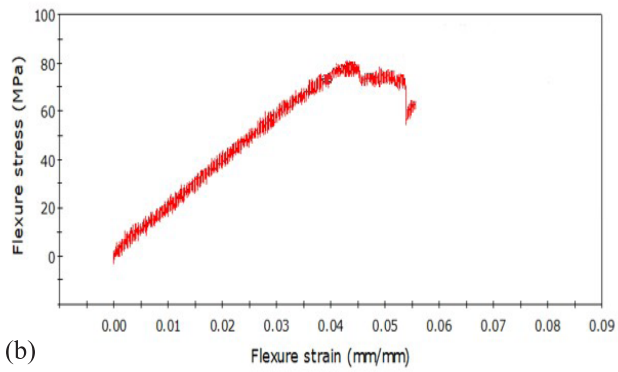
From the Table 2, without glass fibre specimens, the maximum Young's modulus observed for unidirectional

Table 2. Flexural test results.

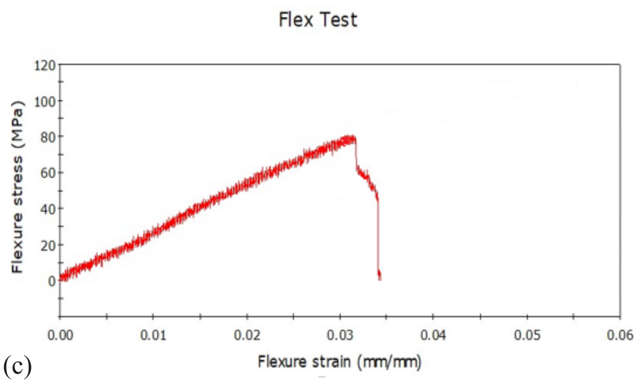
S.No.	Specimen type	Maximum flexure extension, mm	Flexure stress at yield (Zero slope), MPa	Maximum flexure stress, MPa	Maximum load, N	Flexural modulus, MPa	Flexure strain at maximum flexure stress, mm mm^{-1}
1	ISTLE FIBRE UNI	5.961	106.49088	106.49088	177.55	3357.86130	0.04232
2	ISTLE BI	7.529	103.33456	102.49764	170.89	2611.27594	0.05346
3	ISTLE CRC	7.239	45.14100	45.14100	75.26	1112.38987	0.05140
4	ISTLE EGLASS UNI	5.028	200.97704	200.97704	335.09	6214.87521	0.03570
5	ISTLE EGLASS BI	7.635	112.41815	112.41815	187.43	2829.31673	0.05421
6	ISTLE EGLASS CC	9.417	96.11991	96.11991	160.26	1933.48197	0.06687
Max		9.417	200.97704	200.97704	335.09	6214.87521	0.06687
Mean		7.135	112.2294	110.6074	184.41	3009.8668	0.05066
Min		5.028	45.14100	45.14100	75.26	1112.38987	0.03570



(a)



(b)



(c)

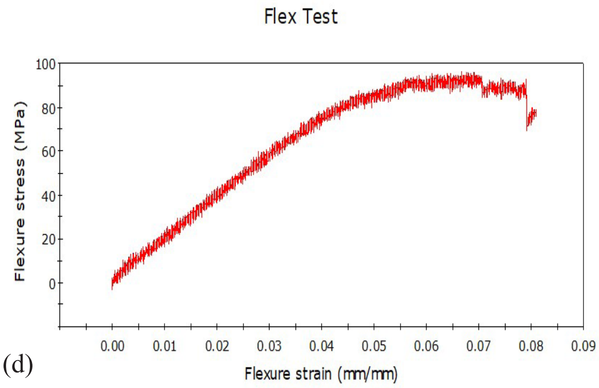
Fig. 14. Flexural load versus flexural strain.

specimen is 3357.86 MPa which bears the maximum load of 177.55 N and maximum flexural strain at maximum flexural stress was 5.3 % for bidirectional specimen.

From the E glass specimen results, the maximum Young's modulus observed for unidirectional E-glass specimen was 6214.87 MPa which bears the maximum load of 335.09 N. The maximum flexural strain at maximum flexural stress was 6.6 % for the inclined specimen.

The bidirectional specimen shows that the best maximum flexural extension without fibre glass reinforced composite was 7.529 mm. Also, the similar trend was observed in fibre glass reinforced composites. The flexural stress versus flexural strain graph is drawn for non-fibre glass specimen which is shown in the Fig. 14a - c flexural load versus flexural strain.

The strain rate was set at 2 mm min^{-1} and the load



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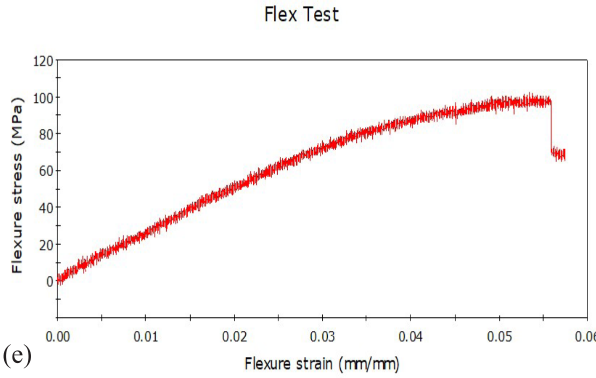

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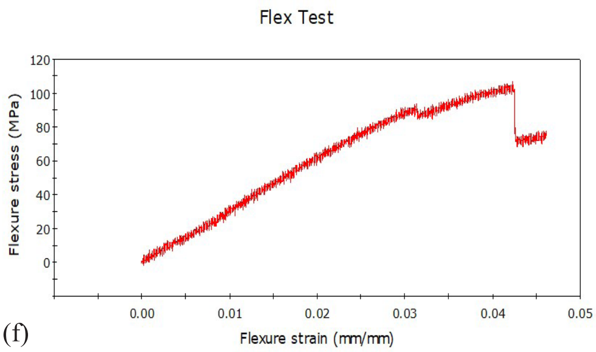

(f)

Fig. 15. Flexural load versus flexural strain.

was applied perpendicularly. The bending properties of the specimen were obtained in the order of Unidirectional > Bidirectional > 45^o inclined. The possible reason for obtaining the above-mentioned conditions is because the shear strength of the fibre is low. The 45^o inclined fibre's structure pattern showed less load carrying capacity than the bidirectional and unidirectional specimens.

These graphs show the results of adding glass fibre to these specimens in the order Unidirectional > Bidirectional > 45^o inclined. After addition of E-glass fibre, the most significant effects were observed in unidirectional and 45degree inclined specimens as the yield strength of these orientations got increased by one fold.

CONCLUSIONS

From the results, it is concluded that the unidirectional fibre orientation is the best both tensile and bending properties. The tensile test result sequence was mostly unaffected by the fibre orientation except in the case of unidirectional fibre glass tensile specimen which gave exceptionally superior values. Significant changes in the values of flexural modulus were observed in flexural test specimen with different fibre orientation, the maximum flexural modulus was recorded for unidirectional specimen followed by bidirectional specimen and 45^o inclined specimen. A drop of 22.2 % was observed in flexural modulus in bidirectional specimen and 67 % reduction was observed in inclined specimen when compared to unidirectional specimen. By incorporating the fibre glass, the unidirectional fibre glass bending specimen gave exceptionally superior values (85 % increment) when compared to conventional unidirectional specimen. The unidirectional tensile specimen performed well because it followed the isostrain model with superior properties along the fibre direction. Bidirectional and 45^o inclined orientation resembles the isostress model which was matrix dominated when the load was applied. Thus, after evaluating all the composites, it is concluded that the unidirectional istle fibre composite is the most suitable one for engineering applications.

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