MECHANICAL BEHAVIOUR OF PINEAPPLE LEAF FIBRE REINFORCED EPOXY COMPOSITES AT DIFFERENT ORIENTATIONS

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ABSTRACT

This paper aims to fabricate pineapple leaf fibre epoxy reinforced with three different orientations which are unidirectional, bidirectional and inclined 45°. E-glass fibre is also introduced in every orientation to observe the change in strength. Fabrication of all these epoxies reinforced pine apple fibre is being done by Hand Layup technique. Two tests are done on these composites that are Tensile Test and Flexural Test. The tensile strength of unidirectional oriented fibre is increased when the E-glass is introduced with composites. The tensile property of unidirectional fibre is reinforced when the E-glass is brought together with composites. The maximum tensile strength was observed in the E-glass unidirectional pineapple fibre composite. Optimum Flexural strength is observed for inclined 45° specimen without E-glass reinforcement, whereas with the introduction of E-glass unidirectional composite maximum flexural strength is yielded. From the results, it can be proposed that Pineapple Leaf Fibre (PALF) reinforced with epoxy and E-glass showed best characteristics for unidirectional orientation of fibre for tensile and in flexural loading. Based on the results obtained, this pineapple composite material is recommended to use for lightweight packaging applications like food industries.

Keywords: pineapple leaf fibre (PALF), tensile strength, flexural strength, epoxy.

INTRODUCTION

Composites comprise of two segments namely matrix and reinforcement. The chemical composition of reinforced phase can be varied to obtain the composites which leads to improve the mechanical properties [1]. Recently, the natural fibre is widely used in industry due to high tensile strength of the materials. Natural fibre composites are extensively used by replacing traditional materials in excessive strength and lightweight applications. Such composites show high strength to weight ratio, as well as bending strength, and density. Natural fibres reinforcing with bio plastics are examples of bio-degradable composites, which can be easily decayed by enzyme [2].

In the tropical region, pineapple has always a greater demand for plantation. From the pineapple leaves the fibres are extracted to provide optimal strength for fabricating composite materials [3]. The pineapple fibre is smooth, glossy in nature and it has great mechanical strength and sturdiness [4 - 6]. A single pineapple leaf yields two to three percentages of fibres which can be extracted by retting and mechanical methods [7]. The pineapple fibre consists of various chemical components such as lignin and pectin substance. Due to the presence of high cellulose and pectin content, the pineapple fibres are joined together [8].

The recent studies have shown that there is a 4%

increase of annual growth in the composite market, hence the natural fibre composites have high demand in the market [9]. The fibres are treated with sodium hydroxide solution to remove the moisture content and this tends to improve the atmospheric resistance of the materials. Besides this, the alkali treatment of the fibres enhances the mechanical strength of the materials [10].

The fibres are mixed with epoxy ratio of 50:1. High lignin and cellulose present in the fibres enables high mechanical strength and this makes them suitable for acting as reinforcement in composites. Further, these composites have the tendency to carry high loads [11 - 12]. Orientation of reinforcement in the matrix affects the flexural strength. Among the various orientations of the fibres, the arrangement of fibre at a 45^o provides better results than the unidirectional and bidirectional fibre arrangements [13].

Arib et al. discussed the mechanical properties and uses of pineapple reinforced polymer composites [16]. Experts have discussed the development of pineapple reinforced polymer composites, its uses and mechanical properties [16]. Authors have concluded that the future researchers can carry out research on creep, fatigue, physical and electrical properties of pineapple reinforced polymer composites. Moreover, incorporation of pineapple fibre with fillers will further improve the properties of the composites.

George et al. have examined the impact of the tiny pineapple fibre and LDPE composites. Authors have suggested that the composite specimens can be developed by two techniques, namely solution mixing and melt mixing. In addition, the experts have assessed the effects of fibre length, fibre loading and fibre orientation. Finally, by using scanning electron microscope, fibre breakage and damage of the specimen were analysed [17].

The mechanical properties of pineapple fibre reinforced with polyester composites were studied by Uma Devi et al. Authors have discussed the influence of fibre loading, length, and surface modifications [18]. With the inclusion of fibre content, tensile strength, impact strength and the Young's modulus of composites were found to be increased. A successful attempt has been made to improve the mechanical behaviour of pineapple reinforced composites. One of the significant improvements was found in the research of silane A-172 treated fibre composites. Further, the experts concluded that the pineapple reinforced polyester composites show better mechanical properties when compared to other natural fibre polyester composites.

EXPERIMENTAL

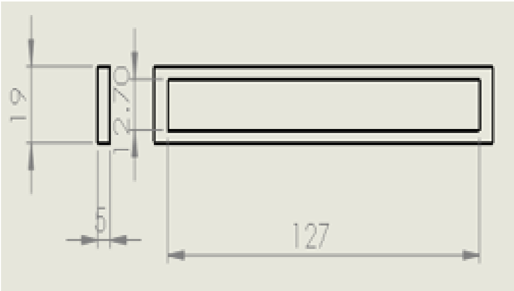
For fabrication of composite wooden moulds of ASTM (American Society for Testing and Material) standard of ASTM D3039 and ASTM 7264 manufactured by CNC machine are used. PALF fibre is used as reinforced phase and mixture of epoxy LY 556 and hardener HY 951 is used as matrix phase. PALF fibres were supplied by Go Green Products based in Chennai.

The PALF fibre used in the composite making process is shown in Fig. 1. The pineapple is perennial herbaceous plant with 1 - 2 m height and width belonging to the botanical family *Bromeliaceae*. The pineapple is of 1 - 2 m height and width. It belongs to botanical family *Bromeliaceae.* It is a perennial herbaceous plant. These pineapple fibres are cultivated in coastline and tropical regions, primarily for its fruits. In India, pineapple fibre is cultivated in surplus amount and is constantly expanding its production. The PALF fibre has high definite strength and stiffness and it is hydrophilic in nature because of the high cellulose content.

At the present time PALF is an attractive material for fibre reinforced polymer as reinforcing fibre. The mechanical properties of PALF fibre are given in Table 1. Araldite LY556 is a pale-yellow liquid and Araldite HY 951 is a bonding agent used as catalyst.

Fig. 2(a) shows Bending Mould model. The CAD model shown is used in facilitating the mould making process. The fibres are very thin and soft. Initially the fibres are converted into long threads, such that they can be handled easily during the preparation process. Then, in the ratio of 10:1, the epoxy-hardener solution is made. Finally, by a hand lay-up technique, the fabrication of

Fig. 1. PALF fibre.



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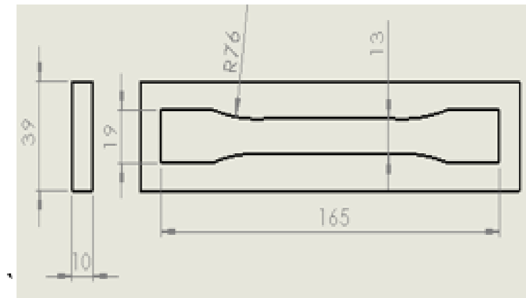


(b)

Fig. 2. (a) Bending mould model, (b) Tensile mould model.

Table 1. Mechanical properties of pine apple fibre [14].

Properties of the pine apple fibre	Value
Density of the Material, g cm^{-3}	1.526
Softening Point of the material, °C	104
Tensile strength of the material, MPa	170
Young's modulus of the material, MPa	6260
Specific modulus of the material, MPa	4070
Elongation at break, %	3
Moisture regain, %	12

the composite specimens is done, followed by a soft compression moulding technique. Fig. 2(b) shows the tensile mould model. To prepare the tensile test specimen, the fibres are cleaned and are arranged in a randomly distributed manner. In order to minimize the fibre pull-out, Epoxy-Hardener mixture in the ratio of 10:1 is added to the fibre composite, which also increases the interfacial adhesion strength of the fibre. In these composites, the epoxy layers and the natural fibre are placed in an alternate manner, beginning with the epoxy layer followed by natural fibre.

Methods

Alkali Treatment

PALF is cleaned by untangling and hand picking the contaminants. Then, it is cut into equal lengths and washed well with water for removing the dirt. After water washing, fibre is treated with 0.5 % concentration of NaOH, which cleans the fibre and also increases the bonding between matrix phase and reinforced phase. Then it is left for curing in room temperature for 2 - 3 days.

Epoxy-Fibre Volume Ratio

The moulds that were used to make these specimens were measured for their capacity by adding some millilitres of liquid, then half of that quantity (measured) of epoxy hardener mixture was put to mould and the rest was filled with fibres.

Fabrication

Fabrication of composites with fibre orientation of unidirectional, bidirectional and inclined 45° with and without E-glass fibre is done by layer-by-layer technique followed by hand layup technique. Tensile and bending specimens of unidirectional, bidirectional and inclined 45° orientation with and without E-glass are shown in Fig. 3. From the six specimens, first specimen shows unidirectional, second specimen shows bidirectional and the third shows inclined at 45°.

Layer by layer technique should be used for maintaining the 50:50 fibre and epoxy volume ratio, i.e. epoxy and hardener mixture is applied after every layer. For bidirectional and inclined arrangement of fibres the layers of natural fibre have to be marked properly and measured with proper angle as shown in Fig. 4. Normally, for unidirectional composites the layers can be directly applied to the mould before cutting it to appropriate length but for bidirectional and inclined orientation, it has to be cut into proper width and required angle before applying into the mould with the help of clamper.

Mechanical Testing

Instron 8801 testing system was used for tensile and bending test. The specification of the machine is given in Table 2. Fig. 5. shows the flexural fixture.

(a) (b)

Fig. 3. (a) Tensile specimens and (b) bending specimens labelled for testing.

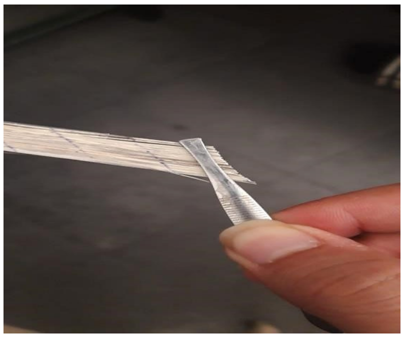


Fig. 4. PALF inclined 45° layer preparation.

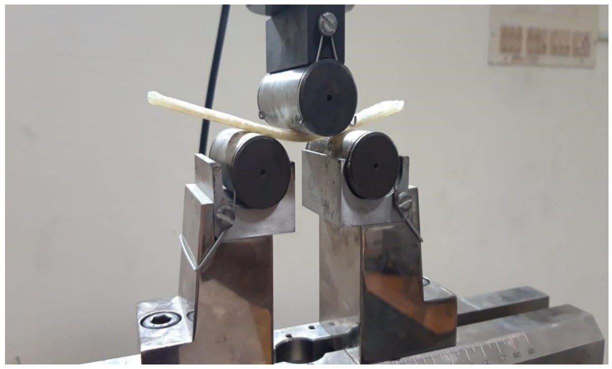


Fig. 5. Flexural fixture.

Table 2. Instron 8801 testing system specification.

Specification	Description
Company/ Supplier	Instron
Model	8801
Maximum axial force capacity	± 100 kN (22.500 lbf)
Load cell	Patented Dynacell load cell contains compensation for inertial loads caused by heavy grips and fixtures.
Controller	8800 MT Digital Controller
Software	Bluehill Universal

RESULTS AND DISCUSSION

Tensile test

The specimens are placed longitudinally between the heavy metal fixtures as shown in Fig. 5. The force was applied longitudinally at 1mm/min strain rate. The temperature at which the test was carried out was 25°C and humidity was 60 %.

The tensile test is carried out on Instron tensile testing machine, as shown in Fig. 5, for the specimens prepared as per the ASTM D638 standard. The specimens were strongly clamped by the top and bottom grips attached to the tensile testing machine. Next, the tension test grips are moved apart at constant rate of 10 mm min^{-1} to stretch the specimen. The gage length of the ASTM D638 standard specimen was kept as 50 mm for 165 mm long specimen. During the testing, the force on the specimen and its displacement is continuously monitored and graph is plotted until the specimen fails. The specimen was cut in two pieces, after critical load applied on the specimen.

From the result, it is observed that for specimen without E-glass the maximum Young's modulus was observed for unidirectional specimen (1408.092 MPa), which bears the maximum load 2606.52 N in which strain at break was observed at 5.78 %. For E-glass specimen the maximum Young's modulus was observed for unidirectional E-glass specimen (2883.32 MPa) bears the maximum load 6278.61 N in which strain at break was observed at 11.5 %.

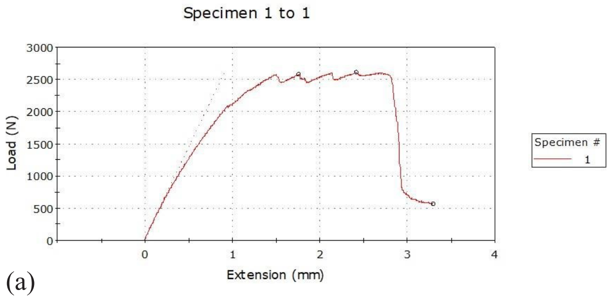
The graphs obtained after the tensile test for 6 specimens are illustrated in Fig. 6.

The tensile test of PALF specimens without E-glass (Fig. 6) shows the extension of PALF composite when particular quantity of load is applied. It is perceptible that in the beginning stage the curves attained in all graphs are linear ensuing Hooke's Law. When it deflects from linear curve yield point is obtained and the load at that point is known as yield strength of the specimen. Moreover, when the load is increased, extension exceeds the yield strength. This conveys that increment in the extension is very rapid when there is a small change in the load. Also, during more extension the ultimate tensile strength is attained which is noticeable in almost all the graphs.

Unidirectional E-glass gives the best result, i.e., 0.023 GPa. Additional load is produced beyond this point that causes fracture in the specimen. The unidirectional showed the maximum tensile strength because the load was applied in the same direction of the fibre orientation. But in the case of bidirectional orientation composite the force applied was perpendicular and for the inclined specimen it is at a certain angle, hence less strain and Young's modulus is observed for the bidirectional and inclined specimen.

The tensile test of E-glass PALF specimens (Fig. 7) shows the extension of PALF composite when some amount of load is applied. Unidirectional gives the best result, i.e., 0.055 GPa. Additional load is produced beyond this point that causes fracture in the Specimen. Similar pattern can be seen in E-glass specimen, i.e., Uni > Bi > Inc. E-glass doubled the strength of the specimen in unidirectional fibre specimen.

In tensile test without E-glass ultimate tensile strength, Young's modulus, tensile strain at break, and maximum load are observed. The tensile test values of PALF shows that the Young's modulus of unidirectional specimen is the highest (1408 MPa) followed by inclined specimen (1331 MPa) and then bidirectional specimen (1315 MPa). But the maximum load supplied to bidirectional (1944.5 N) was greater than the inclined 45 specimen (1587.34 N). The tensile strain of unidirectional composite is 5.7 % whereas of bidirectional composite and inclined 45° is 4.3 % and 3.6 %, respectively. In the case of E glass reinforced composite the Young's modulus of unidirectional composite is the highest (2483.32 MPa) followed by



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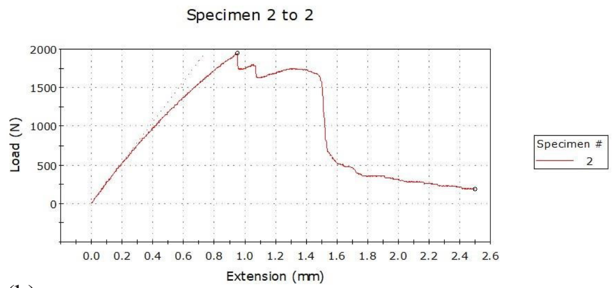

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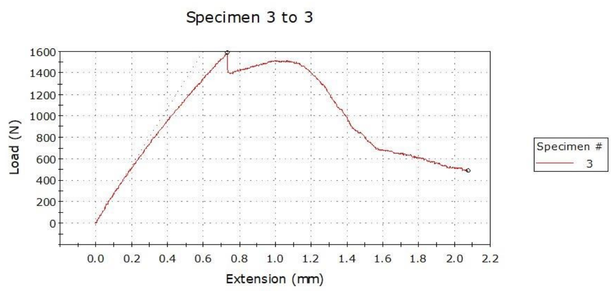


(c)

Fig. 6. Load vs Extension curve of PALF for (a) Specimen 1 is Unidirectional, (b) Specimen 2 is Bidirectional, (c) Specimen 3 is Inclined 45°.

bidirectional (1464.5 MPa) and inclined 45° (1369.3 MPa). But the maximum load supplied to bidirectional (1924.6 N) was greater than the inclined 45° specimen (1534.92 N). The maximum load of unidirectional E-glass specimen is exceptionally high 6278.6 N. The tensile strain of unidirectional E-glass specimen is 11.5 % whereas of bidirectional E-glass specimen and inclined 45° is 3 % and 5 %, respectively.

The combination of E-glass with unidirectional orientation of fibre gave the best results because it had the perfect adhesion between the matrix phase and reinforcing fibres. This can be explained by adverse anisotropic behaviour of fibre reinforcement. The effect of reinforcement decreases when the fibre orientation is greater than 45°, and when the fibre orientation is 90°, the delamination effect between the fibre and composite

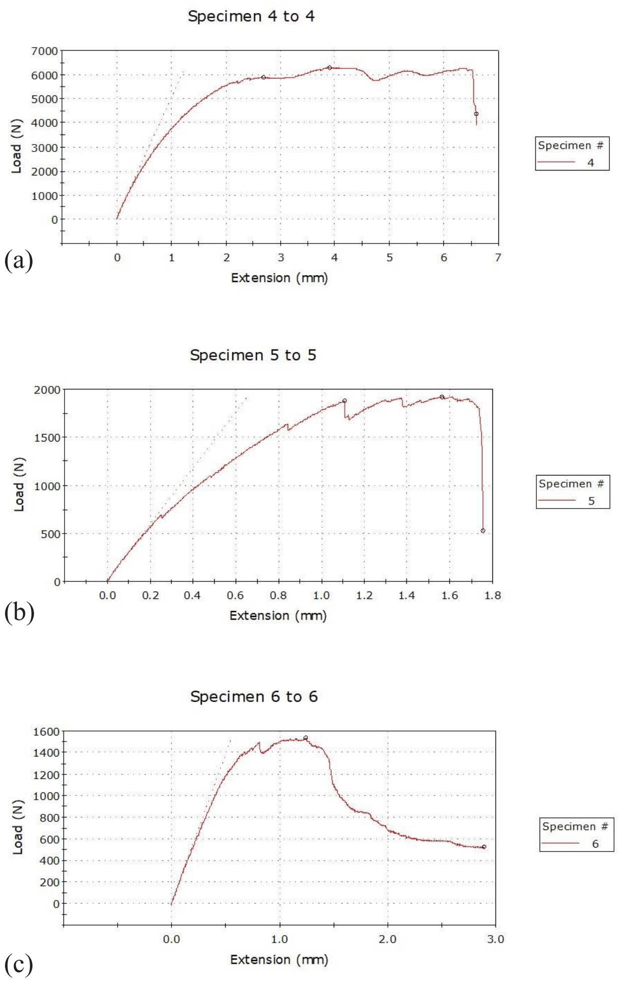


Fig. 7. Load vs extension curve of E glass PALF for (a) Specimen 4 is Unidirectional; (b) Specimen 5 is Bidirectional; (c) Specimen 6 is Inclined 45°.

leads to low UTS and E-modulus.

The better adhesion in the matrix leads to more reinforcement effect. The adhesion effect is better if the epoxy amount is more. This leads to desirable distribution of the fibres in the matrix and the gaps between the fibres are also joined successfully. Stress distribution is constructive because of the presence of glass fibre which results in better strength.

Flexural Test

According to the ASTM test standards the flexural test was conducted. Three points flexural test is done as shown in Fig. 5. According to the standards, the distance between the two supporting roller is kept as 16 times the depth of the specimen. The force was applied longitudinally at a strain rate of 1 mm min^{-1}. The test was carried out at 26°C temperature and 60 % humidity.

From the results, it is concluded that for without E-glass specimen the maximum Young's modulus was observed for inclined 45° specimen (4199.57) which bears the maximum load 231.11 N and maximum flexural strain at maximum flexural stress (4.3 %) was of unidirectional PALF. For E-glass specimen we infer that maximum Young's modulus was observed for unidirectional E glass specimen (4582.93 MPa) which bears the maximum load 243.65 N and maximum flexural strain at maximum flexural stress (4.6 %) was of inclined PALF.

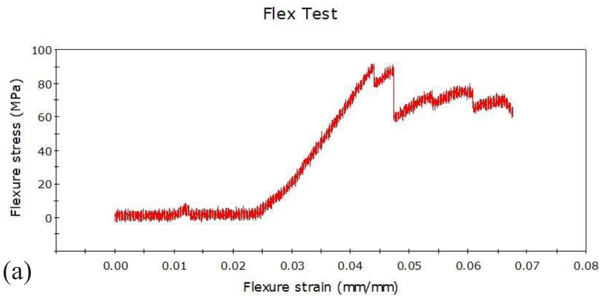
The graphs obtained after the flexural test for 6 specimens are shown in Figs. 8 and 9.

Fig. 8 shows the flexural test of without E glass PALF specimens. In the initial stage the curves obtained in all graphs are linear. Hence, they are following Hooke's Law. When it deflects from linear curve that Point is known as yield point and the stress at that point is known as yield strength of the specimen. The region after yield point is known as elasto-plastic region. When the strain exceeds elasto-plastic region strain hardening of the specimens starts. After that up to until fracture point the region is called necking which can be seen in the graphs shown. Further, the maximum flexural stress is achieved. Inclined 45° gave the best result, i.e., 136.479 MPa. Additional stress produced beyond this point causes fracture in the specimen.

From Fig. 9 is obvious that the flexural test of with E glass PALF specimens, the strain of PALF composite when some amount of stress is applied. Unidirectional gives the best result, i.e. 143.885 MPa. Additional stress produced beyond this point causes fracture in the specimen.

In flexural test of without E glass PALF maximum load, maximum flexural stress, Young's modulus, and maximum flexural extension are observed. The maximum flexural stress is of inclined 45° specimen (136 MPa) and then of unidirectional (91.6 MPa) and bidirectional specimen (49 MPa). The same pattern is followed by the maximum flexural stress, i.e. Inclined 45° (231.11 N) > Unidirectional (155.23 N) > Bidirectional (83.09 N). But the Young's modulus shows some different results, i.e. inclined 45° (4199.57 MPa) > Bidirectional (2954.95 MPa) > Unidirectional (1631.36 MPa).

When reinforced with E glass fibre, the maximum flexural stress is of unidirectional (143 MPa) then



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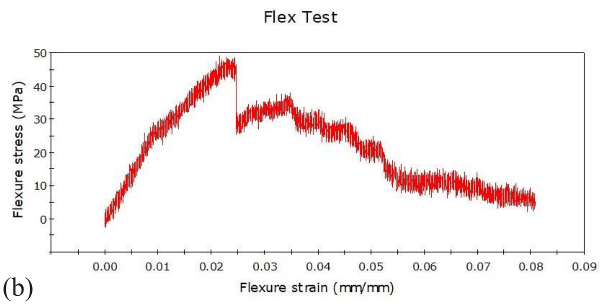

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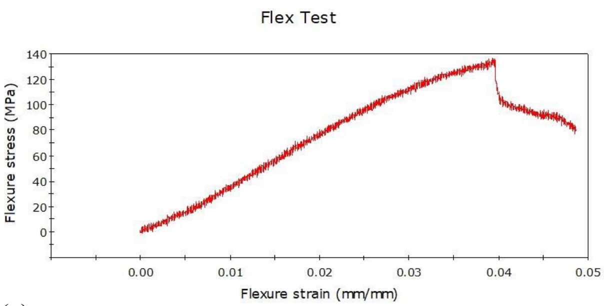

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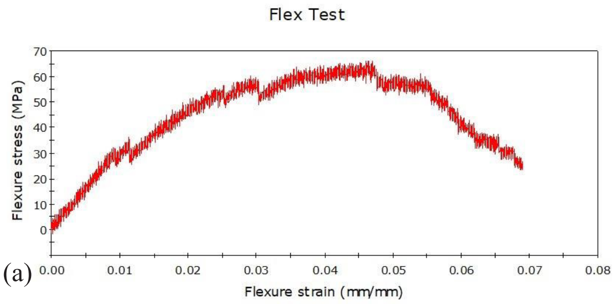
Fig. 8. Stress vs strain curve of PALF for (a) Unidirectional, (b) Bidirectional, (c) Inclined 45°.



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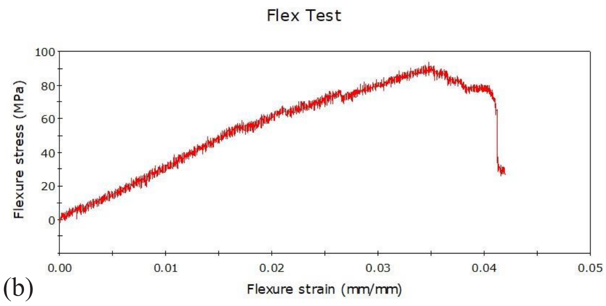

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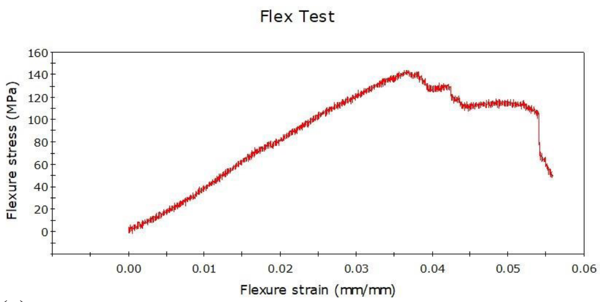

(c)

Fig. 9. Stress vs Strain curve of PALF for (a) unidirectional E glass; (b) bidirectional E glass; (c) inclined 45° E glass.

bidirectional (93 MPa) and at last inclined 45° composites (66 MPa) which is due to the fact that the E glass for bidirectional composite is a premade sheet which can be directly put as a layer but in unidirectional and inclined 45° specimen the E glass has to be cut first and measured for specific angle and then applied. This creates some defects and voids which affects its property. The Young's modulus and load also shows the same pattern of unidirectional (4582.93 MPa, 243.65 N) then bidirectional (3334.37 MPa, 157.93 N) and then inclined 45° (3127.14 MPa, 111.87 N).

CONCLUSIONS

The tensile test and flexural test were conducted for the composites of PALF. Due to the fibre orientation on mechanical properties was studied by reinforcing with and without E Glass fibre the effect has occurred. In the tensile testing of PALF composites, maximum Young's modulus was of unidirectional specimen followed by inclined specimen. Maximum strain and load carrying capacity was of unidirectional, similar trend was observed when reinforced with E-Glass. The E Glass reinforcement with unidirectional orientated fibre composite proved to be the best agglomeration. For the bending properties of the PALF composite specimen, we found that the maximum Young's modulus was of inclined specimen followed by bidirectional and then unidirectional. Inclined 45° > Bidirectional > Unidirectional. Reinforcing with E-Glass fibre in bending specimen of PALF fibre gave different results i.e. Unidirectional > Bidirectional > Inclined 45°. Hence it is clearly visible that orientation of fibre and E-glass reinforcement greatly affects the properties of composite.

Thus pineapple fibres can be used for manufacturing bearing liners, brake pads and cams by improving its mechanical properties.

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