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STUDIES ON PRODUCTION AND PROPERTIES OF BIO-COMPOSITES PRODUCED FROM SISAL AND ARECA FIBRES

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Abstract

Recently there have been enormous and rapid developments in research and innovations in the natural fibre composites (NFCs). Interest in natural fibre composites is due to advantages of these materials over synthetic fibre composites. NFCs are based on low environmental impact, low cost and sustainability. Bio-fibres such as plant fibres are replacing synthetic fibres in composites. In the present work biocomposites are produced using two different plant fibres viz., sisal and areca (beetle nut) with epoxy resin as matrix material at three different volume fraction of fibres (20%, 30% and 40%). Compression moulding technique was used to produce biocomposites. Composites were also produced after treating sisal and areca fibres with sodium hydroxide of 4% concentration. Fibers were characterized for linear density, tensile strength, elongation at break, initial modulus, moisture regain using standard testing methods. Composites were tested for moisture content, tensile strength, tensile modulus, flexural strength and flexural modulus. It was found that sisal fibres were strong and absorb more moisture than areca fibres whereas, areca fibres were more flexible and hydrophobic than sisal fibres. Alkali treatment reduced the moisture regain of both the fibres and improved tenacity, and elongation. Composites produced from sisal fibres were stronger than composites produced from areca fibres with respect to tensile and flexural properties. Composites produced from alkali treated fibres were more hydrophobic and stronger than composites produced from untreated fibres.

1. Introduction:

Over the last few years, there has been an increasing interest in using natural fibres in the production of fibre reinforced composites. Increasing number of research publications during the recent years reflect the growing importance of natural fibres in production of fibre reinforced composites [1-9]. Due to increased awareness, that, the nonrenewable resources are becoming scarce, dependence on renewable resources has become inevitable. A combination of properties like non-toxicity, low cost, high specific properties, recyclability, sustainability, low weight, smooth processing etc., have motivated the manufacturing industries to go for production of composites from natural fibres [10,11]. But, there are number of problems associated with incorporation of hydrophilic natural fibres into matrix materials due to fibre-matrix incompatibility. Compatibility problem may further create

dimensional instability of the resulting composites in many conditions [12]. Thus in order to develop bio-composites with good properties, it is necessary to enhance interfacial bonding between fibre and matrix by suitable modification of fibres. Methods such as etherification, saline treatment, plasma treatment, treatment with alkali, use of compatibilizers etc. [11, 13-16] are being used to improve the natural fibre surface, so as to improve interfacial properties of bio-composites. Objective of the present work was to produce bio-composites from two natural fibres viz. Sisal and Areca using epoxy as matrix material. Composites were produced from both untreated and alkali treated sisal and areca fibres at three different volume fraction of fibres (20%, 30% and 40%). Both untreated and treated fibres were tested for various physical and mechanical properties and the composites produced from these fibres were also treated for physical and mechanical properties.

2. Brief details on sisal and areca fibres:

a. Sisal Fibres:

Sisal or sisal hemp is an agave which has sword shaped leaves. The sisal plant has 7-10 years of life span. Each leaf measures 1-2 m long and 10-15cm wide and 6mm thick and contains an average of 1000 fibres/leaf. The fibres account for only about 4% of the sisal plant by weight and is extracted by decortication process [17]. The sisal leaf fibres are bundles with approximate length of 1-2m. The ultimate of sisal fibres are 1-8mm long and about 20mm wide. Traditionally sisal fibres were used to produce ropes and cordages, baskets etc. Sisal fibres are brittle and sensitive to temperature and their tensile strength, modulus and toughness decreases with temperature. Of late sisal fibres are used for production of bio-Composites, especially in interiors of car, door panel inserts and trunk liners etc. [18].

b. Areca Fibres:

The term areca originated from south world during 16^{th} Century, when Dutch and Portuguese sailors took the nut to Europe. Areca nut plant is a plantation crop grown in clay, loamy and black soil. India is the largest producer and consumer of areca nut. In India, Karnataka is the largest producer (47%) of areca nut.

Areca nut husk is the hard fibrous portion covering the endosperm. It constitutes 40-50% of the total volume of the fruit. The fibres adjoining the inner layer are irregularly lignified group of cells called hard fibres and the portion of the middle layer below the outer most layers is called soft fibres. Areca fibres are predominantly composed of cellulose and varying proportions of hemicelluloses,lignin and pectin. Extraction of Arecafibres depends on the type of plants. Selected areca husk is soaked in water for 4-5days for softening the fibres. Fibres are separated from the loosened husk manually, washed and dried.

3. Experimental

3.1 Materials

a. Sisal fibres: For the present study the sisal fibres were procured from local markets ofChallakere-town-Chitradurga-District-Karnataka-State.

b. Areca fibres: For the present work areca husk was procured from local arecagrowers of Davangere district

c. Epoxy: L-12 and hardener K-6 were used for the production of composites and were procured from YUJE enterprises-Bengaluru-Karnataka.

3.2 Testing of Fibres:

a. Linear density of fibres:Linear density of fibres is usually used to understand whether the fibres are coarser or finer. For measuring linear density of fibre, the following procedure was followed. 100 fibres of 3 cm length was accurately cut and weighed in electronic balance in conditioned laboratory. From the weight in grams and to total length of 50 fibres linear density of the fibre was calculated in Tex units (Tex- weight in grams of 1000m of fibre).

b. Moisture regain*:* Moisture regain (MR) is weight of water present in the fibre expressed as percentage of oven dry weight of fibres. Moisture regain of fibres for the present study was determined using hot air oven and well calibrated electronic balance. Procedure involves continuous drying of fibres at 105°C in a hot air oven until all the moisture is given off and later allowing the fibres to reabsorb the moisture till equilibrium is attained. 5 grams weight of fibre was taken for the measurement. Moisture regain offibres was calculated using following equations:

$$\% \text{ Moisture regain } = \frac{W-D}{D} X\ 100$$

W= Initial wt. of the sample

D= Oven dry wt. of the sample

c. Tensile properties:Universal Tensile Testing Machine (UTM- HOUNSFIELD, UK) was used for determining the tensile properties of the fibres. Tensile test was done at a crosshead speed of 200 mm/min with a test length of 3 cm. Parameters like tensile strength (tenacity) in cN/Tex, elongation at break in percentage and initial modulus (E) in cN/Tex were determined.

3.3 Alkali treatment of fibres: Fibres were soaked in alkali solutionat two different concentrations (4% and 8%) of NaOH. The breakers were kept in water bath maintained at room temperature for 4 hours. The fibres were then removed and washed with distilled water to remove the excess of NaOHand air dried at 80^0C to remove free water and placed in a glass container in laboratory maintained at standard atmospheric conditions. Linear density, weight loss due to chemical treatment and tensile properties of alkali treated fibres were measured.

3.4 Production of composites:

Fibres were opened thoroughly by hand and were cut in to 30mm length. Initially the required amount of fibres and the resin for a particular Vfwere weighed accurately using an electronic balance, then fibres and the resin (hardener + resin) were then poured in to a plastic bucket and were mixed to get uniform mixture of fibres (pre-peg). Care was taken to see that fibres were evenly wetted by the matrix. Then the pre-peg was kept for 10 minutes before putting them in to the mold. The pre-peg formed by the above method was filled in to square shaped mold. Mold was placed on an acrylic sheet and after filling the mold with pre peg, another acrylic sheet was kept on the top. Care was taken to spread the pre-peg evenly in the mold. Acrylic sheets were coated with wax for easy removal of composite after curing.Mold with the pre-peg was converted to composites using compression molding machine and composites were cured in the machine for 12 hrs. Composites were produced at three volume fraction of fibres (20%, 30% and 40% Vf). Fibres which were alkali (4% Conc.) were also converted to composites at 30% Vf.

3.5 Testing of Composites:

a. Moisture Content:The composites were cut in to 75mm wide and 50mm long with full thickness of composite(10mm). Specimens were kept in conditioned atmosphere for 24 hrs. Each specimen was weighed to an accuracy of +/- 0.01gms. The specimens were dried in moisture oven at a temperature of 105+-2^{0}C until constant mass is obtained. Weighing was done after 30 min. and at successive ten minutes till a constant weight was obtained. Moisture content of the composites were calculated using the formula:

$$\text{Moisture Content (\%)} = \frac{Initial\ Weight - Oven\ dry\ Weight}{Initial\ Weight} \times 100$$

Three specimens were tested in each case and average moisture content was determined.

b. Tensile Strength and Modulus:Tensile testing was conducted on Universal Tensile Testing Machine(UTM). Bio-composites were cut into dumbbell shaped specimen. Length and width of the sample was 200 and 20mm respectively. The thickness of the sample was 10mm and gauge length was 100mm and testing width was 10mm. Cross head speed used was 10mm/min. Standard specimen was mounted and load was gradually increased till the specimen fractured. Breaking load was noted and from the width and thickness of the specimen tensile strength was calculated in MPA. Four tests were carried out for each sample and average of three tests was found. Initial modulus was found by taking the slope of initial portion of stress strain curve.

c. Flexural Strength and Modulus: Specified test fixtures on universal testing machine were used to conduct the test. Specimen for bending test was carefully cut from the bio-composites. Specimen was supported on the testing apparatus of UTM. Top pin was made to touch the specimen and load was gradually increased till the specimen failure occurred. Four tests were carried out for each variety of specimens and average was determined. In the three point bending method maximum axial fibre stress is located under the loading point and the deflection is measured using cross head motion. The specimen length was 127mm in the direction corresponding to test direction and 25mm wide and 10mm thick. The span was 76mm. Cross head speed used was 10mm/ min.

The flexural stress (f) was calculated using the formula:

$$f = \frac{3PL}{2bd^2},$$

Where b = breadth of the specimen.
P = maximum load in Newton.
d = thickness of the specimen.

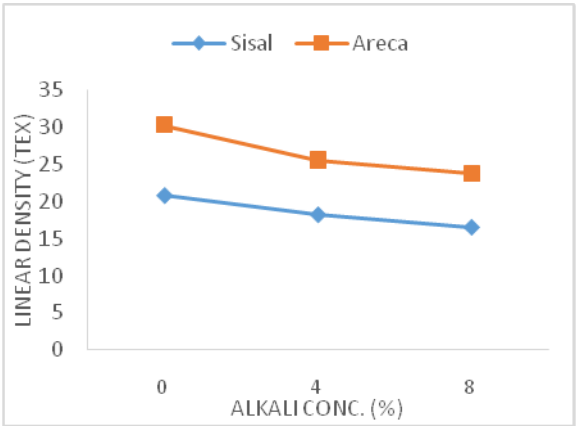
4. Results and Discussion

4.1Physical Properties of fibres:

Linear density and moisture regain values of untreated and treated sisal and areca fibres are presented in **Table 1** and **Fig. 1 to Fig. 3**. It can be observed that both sisal and areca fibres are coarser than conventional textile fibres like cotton, wool and silk fibres. From the moisture regain value of these fibres it can be observed that both the fibres are hydrophilic and sisal absorbs more moisture than areca. Alkali treatment makes the fibres finer and more hydrophobic. Changes in the properties were more at 8% conc. of alkali than at 4% conc.

Table 1 Physical properties of fibres

Fibre type	Linear Density (Tex)	Moisture Regain (%)	Wt. loss due to alkali treatment (%)
Sisal			
Untreated	20.8	13	--
Treated (4% Conc.)	18.2	11.5	15.23
Treated (8% Conc.)	16.5	9.4	20.24
Areca			
Untreated	30.2	8.0	--
Treated (4% Conc.)	25.5	6.0	15.5
Treated (8%Conc.)	23.7	5.5	22.1



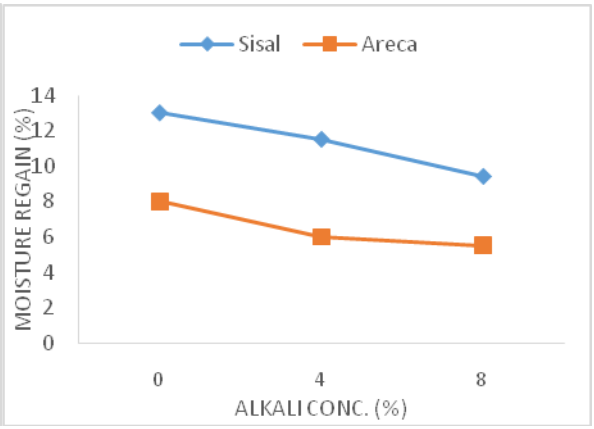


Fig. 1 Effect of Alkali treatment on linear density.

Fig. 2 Effect of Alkali treatment on moisture regain.

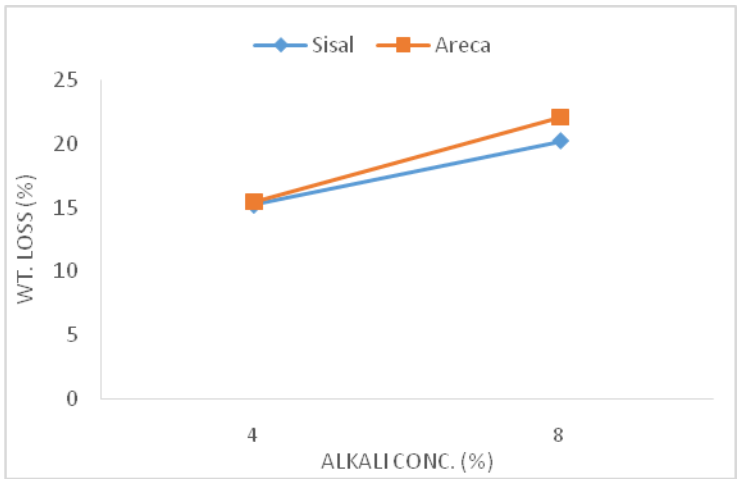


Fig. 3 Effect of Alkali treatment on Wt. loss (%).

From the results of weight loss it can be seen that both the fibres lose weight after alkali treatment.Weight loss and decrease in linear density may be attributed to dissolution of hemicelluloses and other impurities from sisal and areca fibres. As hydrophilic hemicelluloses and other impurities are removed, the fibres become more compact and denser resulting in decrease in moisture regain and increase in density of these fibres.

4.2 Tensile Properties of Fibres:

Tensile properties i.e. tenacity (cN/Tex), initial modules (cN/Tex) and elongation at break (%) of sisal and areca fibres are shown in **Table 2** and **Fig 4 to Fig 6**. From the results it can be seen that sisal fibres are stronger and stiffer than areca fibres and chemical treatment increases tenacity, elongation at break and initial modulus of both the fibres.

Table 2 Tensile properties of fibres

Fibre type	Tenacity (cN/Tex)	Initial modulus (cN/Tex)	Elongation at break (%)
Sisal			
Untreated	35	1024	4.5
Treated (4% Conc.)	41	1030	5.2
Treated (8% Conc.)	46	1019	5.8
Areca			
Untreated	24.5	560	8.5
Treated (4% Conc.)	29.0	550	10.8
Treated (8%Conc.)	32.5	568	11.4

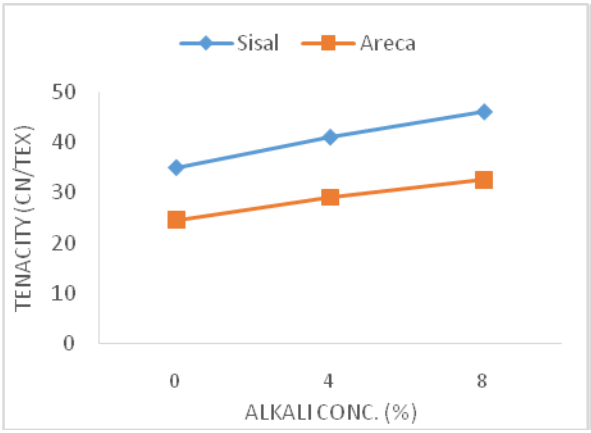


Fig. 4 Effect of Alkali treatment on tenacity.

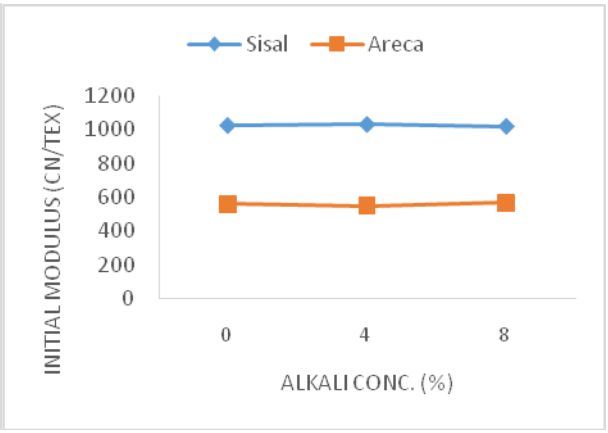


Fig. 5 Effect of Alkali treatment on initial modulus.

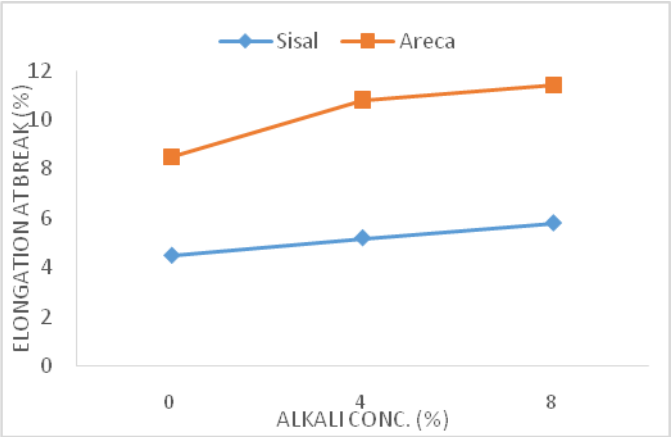


Fig. 6 Effect of Alkali treatment on elongation at break (%).

Increase in tenacity may be attributed to the improvement in the uniformity of fibre structure, removal of hemicelluloses and other impurities. Lower elongation at break of untreated fibres may be due to 3-dimensional network of cellulose and lignin. Alkali treatment may break this network structure,

thereby reducing the resistances of microfiber to stretching. Increase in the initial modulus of fibres due to alkali treatment was not appreciable which may be due to increase in tenacity as well as elongation at break (initial modulus is the ratio of stress and strain within the elastic limit).

4.3 Moisture Content of Composites: Results of moisture content of various composites is presented in **Table 3 and Fig. 7** and **Fig. 8.** It can be observed that moisture content of all the composites is less than that of respective fibres. This may be attributed to the presence of hydrophobic epoxy resin in the composites. As the fibre volume fraction is increased the moisture content of composites increases, which may be due to increase in hydrophilic fibre content in the composites. From the results it can be observed that moisture content of composite get decreased after treating the fibres with alkali. This shows that alkali treatment improves hydrophobicity of composites. As sisal fibres are more hydrophilic than areca fibres moisture content of composites produced from sisal fibres show more moisture content than composites produced from areca fibres

Table 3 Moisture content of composites produced from sisal and areca fibres

Composite	Moisture content (%)
Sisal	
20%	2.94
30%	3.85
40%	5.24
Alkali Treated (30 Vf %)	2.23
Areca	
20%	1.89
30%	2.48
40%	3.36
Alkali Treated (30% Vf)	1.54

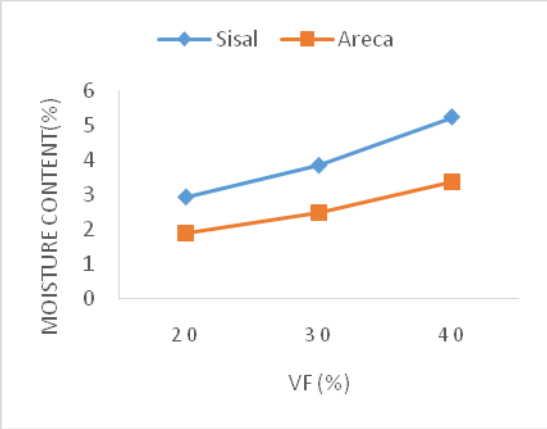


Fig. 7 Effect of Vf on moisture content.

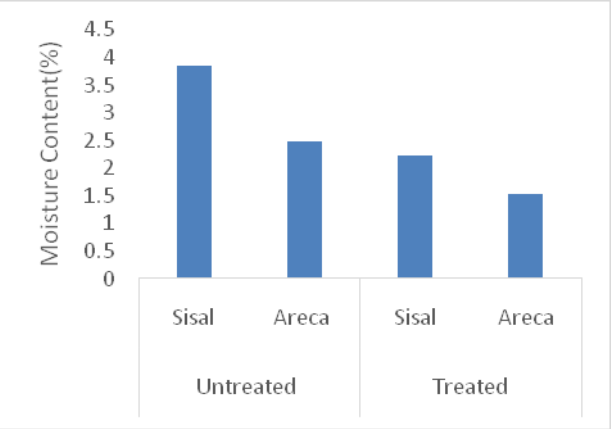


Fig. 8 Effect of alkali treatment on moisture content.

4.4 Mechanical Properties of composites:

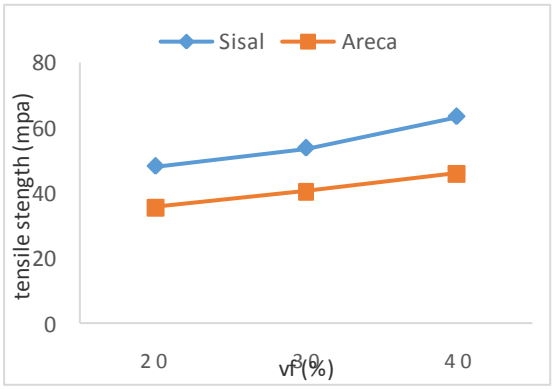
Tensile strength, tensile modulus, flexural strength and flexural modulus of composites are presented in **Table 4 and Table 5** and **Fig. 9 to Fig. 13.**

Table 4 Tensile properties of composites produced from sisal and areca fibres

Composites	Tensile Strength (MPA)	Tensile modulus (GPA)
Sisal		
20%	48.2	2.54
30%	53.8	3.12
40%	63.5	3.46
Alkali Treated (30 Vf %)	72.2	4.04
Areca		
20%	35.5	1.82
30%	40.3	1.96
40%	46.1	2.44
Alkali Treated (30% Vf)	49.3	2.69

Table 5 Flexural properties of Sisal and areca fibre composites

Composites	Flexural Strength (MPA)	Flexural modulus (GPA)
Sisal		
20%	52.2	3.64
30%	60.4	4.2
40%	69.9	4.85
Alkali Treated (30% Vf)		5.46
Areca		
20%	40.1	3.11
30%	48.4	3.49
40%	54.4	3.85
Alkali Treated (30 Vf %)	61.3	4.38



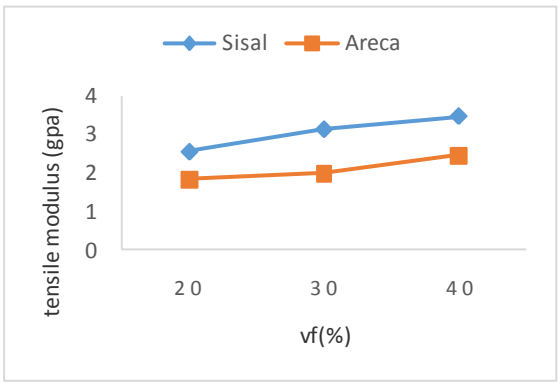
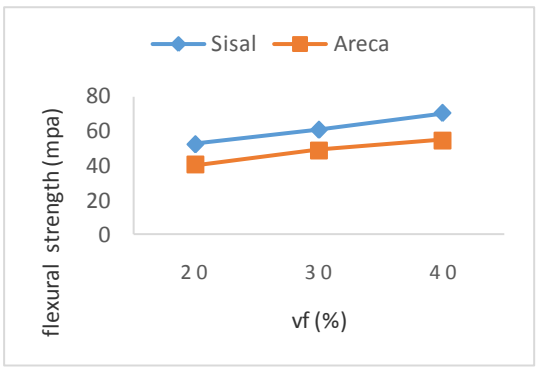


Fig. 9 Effect of Vf on tensile strength of composites. **Fig. 10** Effect of Vf on tensile modulus of composites



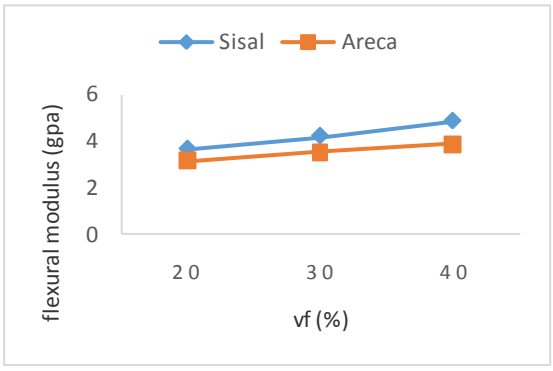
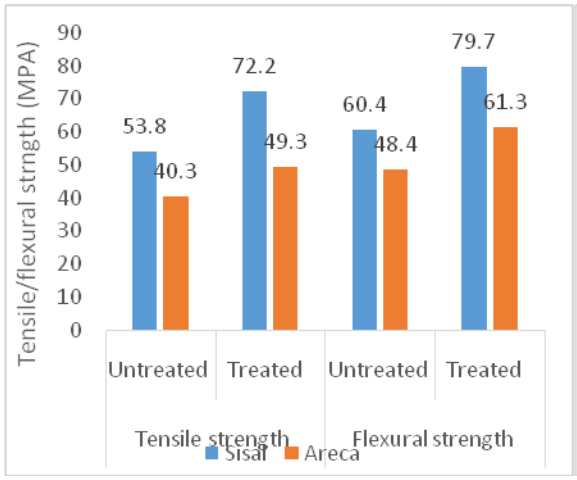
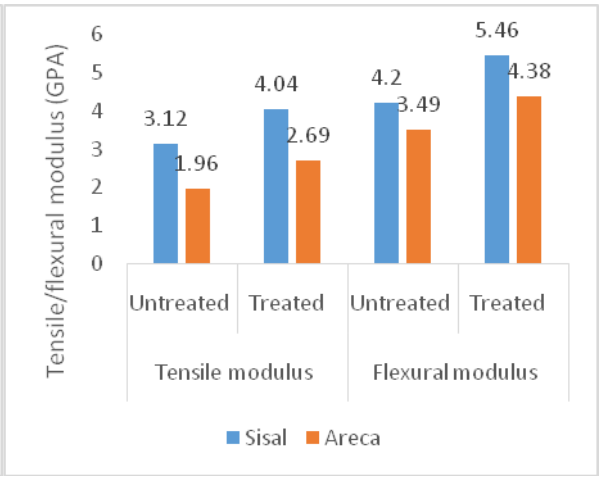


Fig. 11 Effect of Vf on flexural strength of composites **Fig. 12** Effect of Vf on flexural modulus of composites





a. b.

Fig. 13 Effect of alkali treatment on tensile/flexural strength (a) and modulus (b) of composites.

From the results, following observation can be made. As fibre volume fraction increases tensile and flexural properties get improved. Composites produced from alkali treated fibres exhibit better mechanical properties than composites produced from untreated fibres. Composites produced from

sisal fibre exhibit better mechanical properties than composites produced from areca fibres. As the fibre content increases reinforcement effect of fibre increases and ability of composites to withstand tensile and flexural load increases. At low volume fraction of fibres, interfacial bonding will be weak and failure of composites will be dominated by matrix material. Alkali treatment of fibre improves tensile and flexural properties of composites. During alkali treatment, fibrillation takes place which increases effective surface area available for matrix contact. Alkali treatment improves uniformity of fibre structure, reduces spiral angle, removes impurities from the fibre and makes the fibre more hydrophobic. All these results in better wetting of fibres by matrix [19] and results in improvement in tensile and flexural properties of composites.

Conclusions

Sisal and areca fibres can be effectively used to produce biocomposites using epoxy resin and these fibres can be effectively modified by alkali treatment. Alkali treatment makes fibre finer and improves hydrophobicity, tenacity and elongation at break of fibres. Sisal fibres are stronger and more hydrophilic than areca fibres. Tensile and flexural properties of composites depend on volume fraction of fibres. Composites produced from sisal fibres exhibit better tensile and flexural properties than composites produced from areca fibres. Alkali treatment of fibres prior to composite production enhances interfacial interaction and improves tensile and flexural properties of composites.

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