A STUDY ON THE PROPERTIES OF SCREW-PINE ROOT FIBER REINFORCED COMPOSITES

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Abstract

Today, many natural fibers are used to develop fiber reinforced composites (FRC). This is due to these FRCs having important properties such as high specific strength and no abrasion during processing; being abundantly available as renewable resources, bio-degradable, low cost; and having minimum health hazards and low density for industrial applications.

In this study, Screw-Pine Root Fibers (SPRFs) were used as reinforcing material for the composites. SPF was used as reinforced fiber with 20%, 30%, 40%, and 50% fiber weight ratios with the composites being made using Epoxy and Unsaturated Polyester matrix polymers. Then the physical and mechanical properties of the 5% alkali-treated and untreated fibers, and composites were investigated. In the fiber state, the fiber bundle strength, single fiber strength, tensile strength, breaking elongation, and moisture absorption and in the composites, the tensile strength, breaking elongation, hardness, flexural strength, impact strength, compressive strength, and moisture absorption properties were tested according to the ASTM standards. The manual extraction of SPRFs with water retting was used without fiber damage and dried under sunlight. Part of them were alkali treated with 5% NaOH for one hour. After that, they were immersed in water and allowed to dry. Alkali-treated SPRFs have shown higher tensile strength, breaking elongation, bundle strength, and moisture absorption than untreated fibers. Further, the effective length of SPRFs was measured as being 16.7cm.

In SPRF reinforced composites, the tensile strength, breaking elongation, hardness, and impact strength were highest at 50% fiber ratio offering a positive correlation to the fiber ratio and a higher correlation with epoxy-based composites. However, the flexural strength of all the tested composites have shown a negative correlation with the fiber ratio and the highest value given with 20%. Thus, the flexural rigidity of the epoxy-based composites were also higher than the polyester-based composites. However, the compressive strength exhibited good behavior in all the tested samples. Thus, moisture absorption was lower with polyester-based composites compared with the epoxy=based composites. Therefore, the use of 5% alkali treated SPRFs with a 35%-40% fiber ratio (middle range) is recommended as is epoxy as a matrix material to make composites. This composite can be used for industrial applications such as cladding boards, automobiles, aircrafts, home appliances, aerospace equipment etc.

Keywords: Screw pine root fibers, fiber reinforced composites, mechanical and physical properties of composites, fiber reinforcement

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1. INTRODUCTION

Today, many natural fibers are used to develop fiber reinforced composites (FRCs). Due to this, these FRCs have important properties such as having a high specific strength and no abrasion during processing; being abundantly available as renewable resources, bio-degradable, and low cost; and having minimum health hazards and low density for industrial applications. Due to these reasons, synthetic fiber usage for composites has been reduced today compared with the natural fibers in the development of FRCs. These reinforced composites are used today in many fields of applications such as in the aerospace, automobile, power industries and the construction sector; and in consumer goods, sports items, , protective equipment, and marine infrastructure (Abral, 2012, Gafar, 2012, Gerald, 2016, Owlabi, 2018). Screw-Pine root fiber (SPRF) is one of the relatively new and potential natural fibers that can be used for reinforcing the composites. There is no research yet found in Sri Lanka on the application of SPRF for reinforced composites (Abral, 2012, Gafar 2012, Gerald, 2016, Owlabi, 2018, Lee, 2020). This study investigated the physical and mechanical properties of SPRF reinforced composites made with different fiber weight ratios, as well as with epoxy and unsaturated polyester resins as matrix materials.

2. METHODOLOGY

2.1 Fiber extraction

The roots of the screw-pine plants were cut to the required length and peeled off the bark. SPRFs were extracted from the peeled barks using the water retting method done for one week. During this period, the non-fibrous cementing elements, primarily pectin and hemicellulose, were consumed by retting microorganisms. The degradation of the less resistant intercellular adhesive molecules gradually softens the peeled barks of the screw-pine roots. The retting process must be closely monitored at regular intervals to avoid fiber damage. The extracted SPRFs were dried under sunlight for two days.

2.2 Treatment with Mild NaOH

At the next phase, a part of the extracted and dried fibers was washed thoroughly to remove any traces of pulp adhering to the fibers. Then, these fibers were treated with mild 5% aqueous NaOH solution at room temperature for two hours to increase the fiber properties, as well as to increase the surface area of the SPRFs, which lead to better bonding of the epoxy and polyester matrix with fibers.

2.3 Preparation of Composites

Treated fibers were combed and cut into nearly 2.5cm length to make composites based on the literature survey (Gafar 2012, Gerald, 2016, Owlabi, 2018). Thereafter, the cut fibers were hand-laid in multi-directions in the prepared stainless steel mold (size: 24cm x 25cm x 0.5cm) as a fiber web. In the preparation of the composites, 20%, 30%, 40%, and 50% fiber ratios (weight % basis) were used and accordingly, first the fiber batt was laid and pressed. After one day, the fiber batt was removed and weighed. Then, the fiber batt was again laid in the mold. The prepared resin (unsaturated polyester with hardener or epoxy with catalyst) was poured carefully on to the fiber batt to fill up to 100% volume. After that, the mold was allowed to cure for 24 hours under moderate pressure.

2.4 Tested Physical and Mechanical Properties

2.4.1 The physical and mechanical properties of the extracted SPRFs

The following are the properties of the extracted SPRFs tested before and after the 5% mild NaOH (alkali) treatment. The results enabled the decision of the suitability of using either treated or untreated fibers for the preparation of fiber reinforced composites.

(a) Effective fiber length
The effective length of the fibers was measured using a bundle of long fibers, excluding their tips. Before measuring, the fiber bundle was made parallel using a comb first, and then using the hand doubling and drawing method. After that, it was placed on a black velvet pad in straight form. The effective length was measured using a meter ruler.

(b) Fiber bundle tenacity
This was measured using a standard Pressley fiber bundle tester according to the ASTM D1445-05 Standard test method.

(c) Single fiber strength
The strength of a single filament was measured using a standard Tensile Strength tester at a dry state according to the ASTM D3822 standard.

(d) Moisture content
These were determined according to the ASTM D2495-01 standard.

2.4.2 The physical and mechanical properties of the SPRF reinforced composites

The following physical and mechanical properties of the composites, prepared with unsaturated polyester and epoxy resins with selected fiber ratios, were measured:

(a) Tensile strength of composites
The tensile strength of composites was measured using the standard Tensile Strength tester suitable for composite testing, according to the ASTM-D3039 standard.

(b) Hardness of composites
This was measured using the standard Rockwell Hardness Tester using the ASTM- D0785-03 standard. The hardness was measured in HRB in the hardness tester with a ball as the indenter.

(c) Compressive strength test
This was measured using the universal material tester with suitable grips according to the ASTM-D5024-01 standards.

(d) Flexural strength test
The three-point bending principle was used to measure the flexural strength of the prepared composite samples using the ASTM-D5023-01 standard. For these experiments, the standard tensile strength tester with suitable accessories were used.

(e) Impact resistant test
To measure the impact resistance of the prepared composites, the standard Pendulum test method was used following the Izod test principle. This was carried out according to the ASTM-D256 – 04 standard.

(f) Moisture absorbency test
The moisture absorbency of the prepared composites was measured according to the ASTM D5229 standard to determine their moisture Content.

3. RESULTS AND DISCUSSION

3.1 The physical and mechanical properties of the extracted SPRF fibers

The following physical and mechanical properties of the alkali treated and untreated fibers were tested and the results are given below:

(a) Effective fiber length
The effective fiber length of the fiber bundle was measured as 16.7cm, which was important to laying the fibers in a web form for the composites, as well as to obtain better physical and mechanical properties of reinforce composites.

(b) Tenacity of alkali treated and untreated SPRFs

The tenacity test results of the alkali treated and intreated fibers, which were obtained using the Pressley bundle tester, are given in Table 1. According to these results, the alkali treated SPRFs depicted a 51.39% higher bundle tenacity than untreated fibers. As the NaOH treatment removes waxes, oils, hemicellulose, lignin, and other impurities, it leads to closer-packed cellulose polymer chains, and also releases the internal tension to increase the bundle tenacity. Furthermore, the alkali treatment also roughens the surface of the fiber and offers improved fiber-matrix adhesion (Gafar 2012, Gerald, 2016, Owlabi, 2018). These changes will provide benefits in composite manufacturing.

Table 1: Tenacity variations of treated and untreated fiber bundles

Fiber treatment	Breaking load (lb)	Bundle weight (g)	Pressley Index (lb/mg)	Tenacity (g/tex)
Untreated	6.96	0.0013	5.353	28.820
Alkali treated	6.99	0.0008	8.737	43.632

(c) Single fiber strength of alkali treated and untreated SZ fibers

The single fiber strength of alkali treated and untreated fibers are given in Table 2.

Table 2: Single fiber strength of treated and untreated SZ fibers

Fiber treatment	Breaking force (N)	Elongation (%)
Untreated	2.698	2.84
Alkali treated	5.565	4.69

According to the results, the increasing of the breaking force by 106.26% and breaking elongation by 65.14% were determined in the alkali treated fibers compared with the untreated fibers. This is because alkali treatment removes hemicellulose and other impurities, makes fibrils, and leads to the closer packing of polymer chains in the fibers, which can improve the strength of single SPRFs.

(d) Moisture absorption of alkali treated and untreated SPRFs

The moisture absorption was determined in terms of the moisture content and moisture regain. The following Table 3 depicts these results for alkali treated and untreated SPRFs.

Table 3: Moisture content and regain of alkali treated and untreated SPRFs

Fiber treatment	Moisture regain (%)	Moisture content (%)
Untreated	9.15	8.388
Alkali treated	12	10.736

According to the results in Table 3, the moisture absorption increased after alkali treatment and gave comparatively high values. As alkali treatment changes the fiber structure during moisture absorption, cellulose polymer chains in SPRFs may be pushed apart by the absorbed water molecules, allowing for more absorption. Based on the physical and mechanical properties of the extracted SPRFs, treated fibers can be used to develop composites with good mechanical properties for industrial uses.

3.2 The physical and mechanical properties of SPRF reinforced composites

Composites were molded with polyester resins and epoxy resins separately with different fiber ratios such as 20%, 30%, 40%, and 50%, and the following properties were tested:

(a) Tensile strength of SZ reinforced composite

Figure 1 shows the tensile strength and breaking load variations of epoxy and polyester-based SPRF composites prepared with different fiber ratios. According to the Figure 1, tensile strength and breaking force show positive correlations to the fiber ratio. Thus, epoxy-based composites show higher tensile strength and breaking force compared to the polyester-based composites. The reason would be the higher tensile strength reported by epoxy resin itself as 73 MPa than the tensile strength of polyester resin itself as 40 MPa Therefore, using epoxy resins based composites with 50% fiber weight ratio is recommended to obtain a higher tensile strength and breaking force in composites.

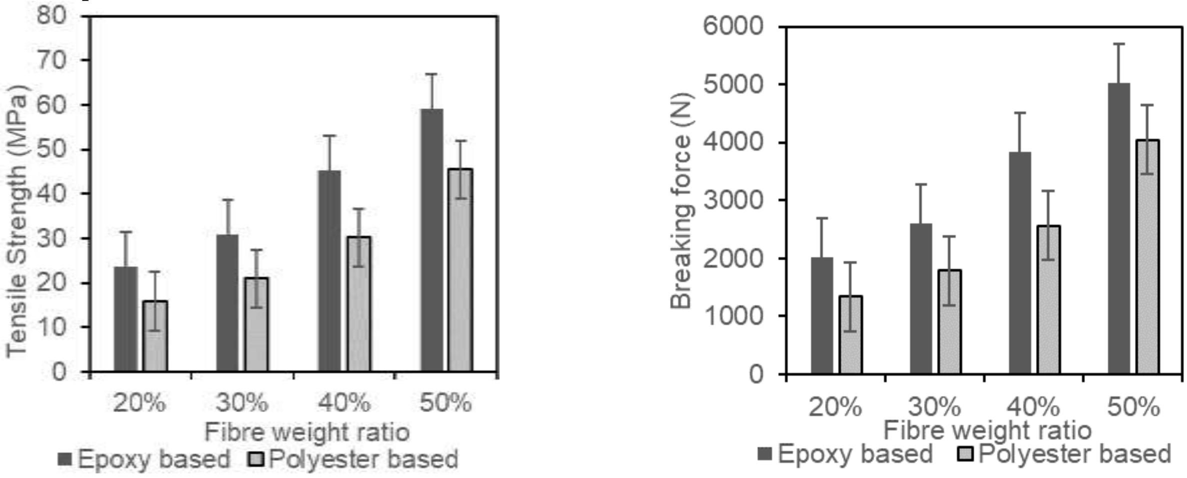
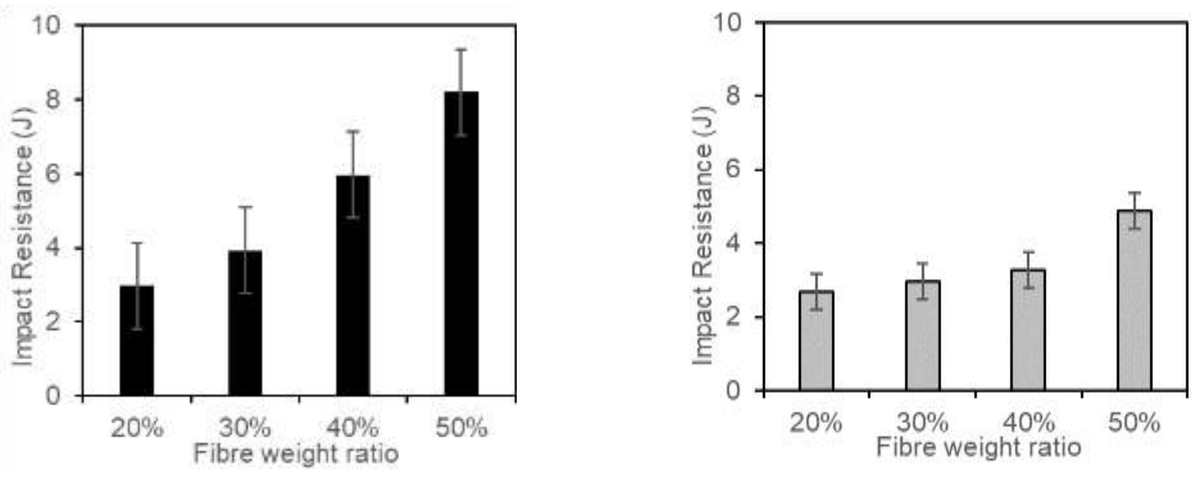


Figure 1: Variations of tensile strength and breaking force of composites with fiber ratios

(b) Impact resistance of SPRF reinforced composites

Figure 2 depicts the impact resistance of the prepared composites. Epoxy-based SPRF composites have given much higher impact resistance to the SPRF composites than the polyester resin-based composites, at each fiber ratio selected.



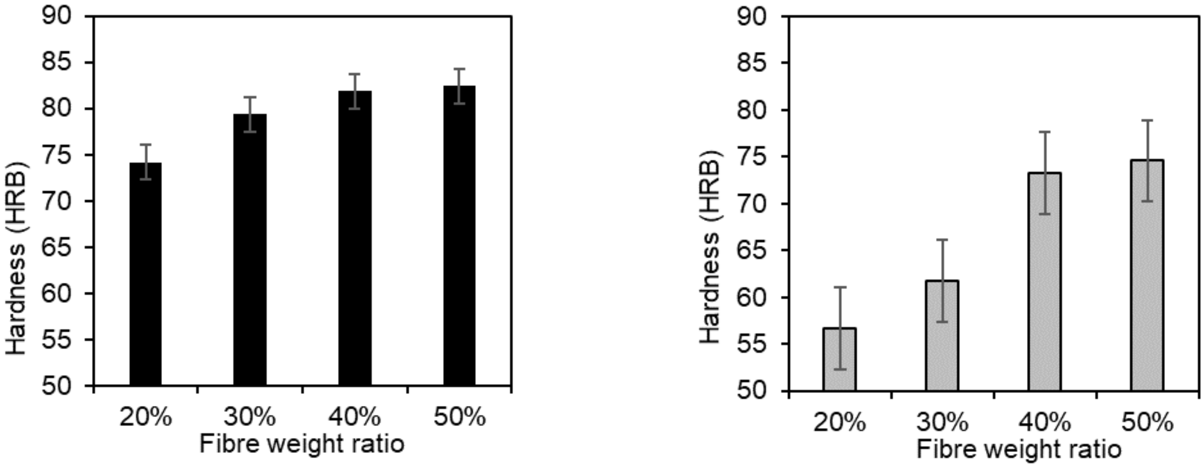
(a) Epoxy based SPRF composites (b) Polyester based SPRF composites

Figure 2: Variations of impact resistance of composites with fiber ratios

Thus, impact resistance shows a positive correlation to the fiber ratio with both epoxy and polyester-based SPRF composites, and then the highest impact resistance was indicated with 50% fiber ratio. In conclusion, it was found that epoxy-based SPRF composites with a 50% fiber weight ratio gave much higher impact resistance than other fiber ratios tested. However, lower fiber ratios like 20%-30% could not offer good impact resistance properties due to the lack of reinforcement provided by the small quantity of fibers. Further, the random orientation of the SPRF fibers in composites causes hindrance for crack propagation, which results in their improved impact strength (Gafar, 2012, Gerald, 2016, Owlabi, 2018).

(c) Hardness of SPRF composites

Figure 3 shows the variations of the hardness of epoxy and polyester-based composites. It shows that epoxy-based SPRF composites gave a comparatively higher hardness than polyester-based composites. This implies that the resin type can influence the hardness of the fiber reinforced composites. In both figures, the maximum hardness was given with the 50% fiber ratio. Higher fiber ratios of more than 50% were not tested because many researchers have reported that lower resin contents (with higher fiber ratios) make poor interface bonding with reinforcing fibers and that it is possible to have micro crack propagation under the various mechanical loads applied.



(a) Epoxy-based SPRF composites (b) Polyester-based SPRF composites

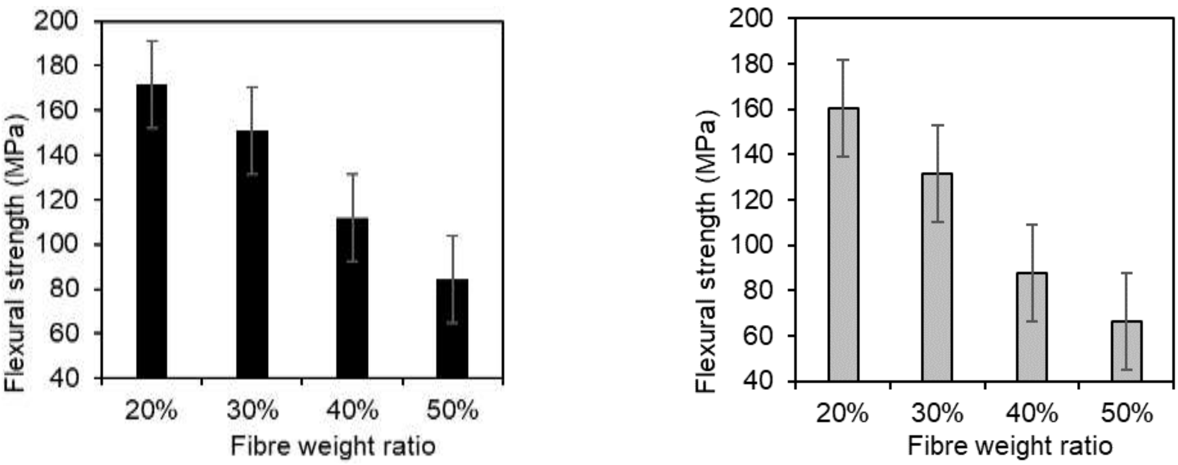
Figure 3: Variations of hardness of composites with fiber ratios

(d) Compressive strength of SPRF composites

Composite compression testing methods provide a means of introducing a compressive load into the material while preventing it from buckling. During the compressive strength testing procedure, both the polyester and epoxy composite samples did not crack even under the maximum force of 10KN applied with 5mm/min to 100mm/min speed. Therefore, it was concluded that SPRF reinforced composites prepared with epoxy and polyester resins and 20% to 50% fiber weight ratios exhibited good compression strength. The high compressive strength is due to the properties of the epoxy and polyester matrix resins and the fibers being laid under random orientation.

(e) Flexural strength of SPRF reinforced composites

Figure 4 depicts the flexural strength of the prepared composites. It clearly shows that epoxy-based SPRF composites have given higher flexural strength compared with polyester-based composites.



(a) Epoxy-based SPRF composites (b) Polyester-based SPRF composites

Figure 4: Variations of the flexural strength of composites with fiber ratios

The reasons behind this could be the better interface bonding between epoxy and SPRF, and the higher flexural strength properties of epoxy resin (60 MPa) compared with polyester resin 45 MPa (Gerald, 2016). Thus, both figures show a negative correlation between flexural strength and the fiber ratio. This may be due to the poor interface bonding between SPRF and the matrix at higher fiber ratios, whereas other tested mechanical properties showed a positive correlation

(f) Moisture content of SPRF reinforced composites

Table 4 shows the moisture regain and moisture content of developed composites.

Table 4: Moisture content of tested SPRF composites

Fiber weight ratio	Moisture content (%)	
	Epoxy-based SPRF composites	Polyester-based SPRF composites
20%	2.11	0.94
30%	2.25	1.20
40%	2.92	1.40
50%	3.46	1.71

According to the table 4, the moisture absorbency increased with the amount of SPRFs included in the composites. Epoxy resin-based SPRF composites showed a comparatively higher moisture absorbency than polyester-based composites because epoxy itself has a moisture regain of 3% and while that of polyester is 0%, based on the literature (Abral, 2012, Gafar 2012, Gerald, 2016).

4. CONCLUSION

In this study, the physical and mechanical properties of SPRF based composites, prepared with epoxy and unsaturated polyester, were investigated. Alkali treated SPRF composites showed a higher bundle strength and single fiber strength, and had lower breaking elongation and higher moisture absorbency properties. With the alkali treated SPRF based composites, the tensile strength, hardness, and impact strength were higher at the 50% fiber ratio than with the other ratios. However, the compressive strength exhibited good behavior in all the tested fiber ratios. Thus, flexural strength showed a negative correlation to the fiber ratio. Further, epoxy-based reinforced composites have indicated much better physical and mechanical properties than polyester-based composites. Therefore, the use of alkali-treated SPRF based composites made with epoxy resins with a 35-40% fiber ratio is recommended for industrial applications.

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