INVESTIGATION OF MECHANICAL AND PHYSICAL PROPERTIES OF PANDAN LEAF FIBRE REINFORCED COMPOSITES WITH EPOXY AND POLYESTER RESINS

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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. Pandan leaf fibre can be considered as a new fibre for reinforcing composites. Pandan shrubs are commonly found in Sri Lankan home gardens.

In this study, Pandan leaf fibres (PLF) were used as reinforcing material for the composites. PLF 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%, 6% and 7% 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 PLFs with water retting was used without fiber damage and dried under sunlight. Part of them were alkali treated with a NaOH concentrations for one hour. After that, they were immersed in water and allowed to dry. Alkali-treated PLFs have shown higher single fibre tensile strength, breaking elongation, fibre bundle strength, and moisture absorption than untreated fibers. Further, the effective length of PLFs was measured as being 62.3cm. Based on the findings, It is recommend that 6% NaOH treated Pandan fibres be used for making the fibre reinforced composites,

In PLF reinforced composites, with the 6% alkali treated Pandan fibre reinforced composites, the tensile strength, elongation, flexural strength, hardness, and impact strength were higher at the 40% fiber ratio than with the other ratios. However, the compressive strength exhibited good behavior at 40% fiber ratio. Further, epoxy-based reinforced composites have indicated much better physical and mechanical properties than polyester-based composites. Therefore, 6% alkali-treated Pandan fibre based composites made with epoxy resins with a 40% fiber ratio is recommended for industrial applications.

Keywords: Pandan leaf fibres, fiber reinforced composites, mechanical and physical properties of composites, fiber reinforcement

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1. INTRODUCTION

Composites are heavily used today as an alternative to conventional materials in many industrial applications. In manufacturing the composites, there is a greater interest in using natural fibers with various polymer matrix materials [1, 2]. Because, the natural fibers can give good reinforcement for these commercial thermoplastics and they are eco-friendly, light in weight with higher mechanical properties, bio degradable, abundant, renewable, easy processing and economical [1]. Pandan leaf fibre can be considered as a new filler in fibre reinforced composites. Pandan shrubs are commonly found in Sri Lankan home gardens, and it is a tropical plant in the pandanus genus which is widely used for flavoring the cuisines of South Asia[1, 2]. The scientific name is *"Pandanus amaryllifolius roxb"*. There is no research yet found in Sri Lanka on the application of this Pandan leaf fiber for composites. Further, no research was found about pandan leaf fibre reinforced composites made with Epoxy. These were identified as a research gap. Therefore, this research investigated the physical and mechanical properties of Pandan fiber reinforced composites made with Epoxy and Unsaturated Polyester resins with various fibre weight ratios.

2. METHODOLOGY

2.1 Fiber extraction

To extract the fibres, matured green pandan leaves which were in length around 50-60cm were collected and water retting method was used for two weeks to extract the fibres. During the water process, enzymatic reactions took place in the pandan leaves and loosened the fibres out of the leaf. The fibers were easily separated from the leaves after the fermentation has reached the suitable level. However, the retting process had to be closely monitored at regular intervals to avoid fiber damage. After that, extracted fibres were dried under sunlight for a day.

2.2 Treatment with Mild NaOH

Part of the extracted and dried Pandan fibres were treated in mild alkali solutions of 5%, 6% and 7% NaOH for one hour. This treatment is important to remove lignin, oil and wax in the fibre structure and also to improve fiber density and fiber matrix adhesion while increasing fibre roughness. After that, alkali treated Pandan fibres were immersed in a water bath with a liquor ratio of 1:20 for 2 hours and finally, washed and oven dried at 80° for 1 hour. After that, it was allowed to dry for 2-3 days under sunlight.

2.3 Preparation of Composites

Treated fibers were combed and cut into nearly 10mm length to make composites based on the literature survey [1]. Thereafter, the cut fibers were hand-laid in multi-directions in the prepared stainless steel mold (size of 12cm x 21cm x 0.7cm) as a fiber web. Further, random orientation of the Pandan fibres in composites caused hindrance for crack propagation, which resulted in the improved mechanical properties in composites [2, 3]. In preparation of composites, 20%, 30%, 40%, and 50% fiber weight ratios were considered and Epoxy and Polyester resins were used as matrix materials to develop composites.

2.4 Physical and Mechanical Properties Testing

2.4.1 Physical properties of extracted Pandan fibers

Following are the properties of the extracted Pandan fibers before and after mild NaOH (alkali) treatment.

(a) Staple fiber length
The staple length of fibers was measured using a bundle of long fibers, excluding their tips. Before measuring, the fiber bundle was placed parallel to the hand doubling and drawing method, and placed on a black velvet pad in a straight form using a 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 regain and moisture content
These were determined according to the ASTM D2495-01 standard.

2.4.2 Properties of Pandan fibre reinforced composites

The following physical and mechanical properties of composites prepared with Unsaturated Polyester and Epoxy resins under 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 and done 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. 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 a suitable set-up 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 Regain and Moisture Content.

3. RESULTS AND DISCUSSION

3.1 Physical and mechanical properties of extracted Pandan fibres
Following physical and mechanical properties of alkali treated and untreated fibres were tested and the results are given below.

(a) Effective fibre length

The effective fibre length of the fibre bundle was measured as 62.3cm, which was important to laying the fibres in a web form for the composites and also to obtain the better physical and mechanical properties of reinforced composites. Compared to several other leaf fibres such as Sisal (1-1.5m), Abaca (about 3m) and Pineapple (97cm), the effective length of Pandan is slightly less, but this length is good enough to impart better mechanical properties.

(b) Fibre bundle strength of alkali treated and untreated Pandan fibres
To do this test, the standard Pressly index method was used. According to this method, fibre bundle strength was measured as the tenacity of the fibre bundle in g/tex. For the tested samples, the untreated and Alkali treated Pandan fibers with 5%, 6% and 7% NaOH concentrations have used. Table 1 shows the results.

Table 1: Tenacity of treated and untreated Pandan fibres

Mechanical property	Untreated Pandan fibres	Treated Pandan fibres with different NaOH concentrations		
		5%	6%	7%
Tenacity of (g/tex)	7.525	9.733	12.081	8.897

According to these results, the alkali treated Pandan fibres showed higher fibre bundle tenacities compared to that of untreated fibres. Thus, untreated Pandan fibres depicted a 18.23% lower fibre bundle tenacity than the lowest tenacity shown by 7% alkali treated Pandan fibres. Further, the 6% NaOH Alkali treated fibres have given the highest fibre bundle tenacity. The reasons would be the NaOH treatment removes waxes, oils, hemicellulose, lignin, and other impurities, it leads to more closely packed cellulose polymer chains, and also the release of internal tension to increase the bundle tenacity. Furthermore, the alkali treatment also roughens the surface of the fibre and improved fibre-matrix adhesion [1, 2, 3].

(c) Single fibre strength of alkali treated and untreated fibres
The single fibre strength of alkali-treated and untreated Pandan fibres are given in Table 2.

Table 2: Single fibre strength of treated and untreated Pandan fibres

Mechanical property	Untreated Pandan fibres	Treated Pandan fibres with different NaOH concentrations		
		5%	6%	7%
Single fibre strength (N)	3.551	2.828	3.208	2.016

Single fibre strength was measured using the breaking load of the Pandan fibre. According to these results, the higher breaking load was given with untreated and 6% treated sample. 6% NaOH concentration is recommended to obtain higher breaking strength, because, untreated fibres cannot be used for better bonding in composites, due to lower interface adhesion between fiber and matrix. Further, the concentration of 6% NaOH showed the lowest breaking strength, because, concentrated NaOH may negatively impact on the single fibre strength as a result of an attack on the glucose unit of the cellulose structure of the Pandan fibres. Therefore, the treated single fibres tend to have inter laminar crack and which weakened with alkali treatments. Table 3 shows the extension at break of treated and untreated Pandan fibres.

Table 3: Extension at break of treated and untreated Pandan fibres

Mechanical property	Untreated Pandan fibres	Treated Pandan fibres with different NaOH concentrations		
		5%	6%	7%
Extension (mm)	2.097	2.284	2.526	2.119

According to the results, 6% NaOH concentration showed the highest extension at break and the untreated fibres showed a lower extension than the 6% NaOH concentration treatment . Fibre extension is important for bearing the applied loads without damaging the fibre to a certain extent. In the composites, the Pandan fibres bear the applied tensile loads as a bundle. Therefore, the good extension at break given with 6% NaOH concentration would be very useful in applications.

(d) Moisture absorption of alkali-treated and untreated Pandan fibres
Moisture absorption was determined in the terms of moisture content and moisture regain. Following Table 4 depicts these results for alkali-treated and untreated Pandan fibres.

Table 4. Moisture content and moisture regain of alkali-treated and untreated pandan fibres

Physical property	Untreated Pandan fibres	Treated Pandan fibres with different NaOH concentrations		
		5%	6%	7%
Moisture regain (%)	7.0	14.60	14.50	13.30
Moisture content (%)	7.5	17.10	16.90	13.40

According to the results in Table 3, moisture absorption increased after alkali treatment compared to untreated Pandan fibres and gave comparatively high values As alkali treatment changes the fibre structure during moisture absorption, cellulose polymer chains in pandan fibres may be pushed apart by the absorbed water molecules, allowing for more absorption. Further, the 5% and 6% NaOH concentrations gave higher moisture absorptions than with the 7% concentration of NaOH. However, higher moisture absorption is not a favorable physical property of the reinforcing fibres used for composites, because it may effect the mechanical properties of the fibre reinforced composites. However, these fibres are used with resins, therefore, moisture absorption can be minimized.

Based on the above given physical and mechanical properties of the extracted Pandan fibres, alkali treated fibres can be used to develop composites with good mechanical properties used for industrial uses. As a compromise, it is recommended that 6% NaOH treated Pandan fibres be used for making the fibre reinforced composites, because, they have shown higher fibre bundle strength and higher single fibre strength with higher elongation than other NaOH concentrations, which is very important to bear the stress and strain applied for fibre reinforced composites in various applications.

3.2 Physical and mechanical properties of Pandan fibre reinforced composites

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

(a) Tensile strength of Alkali treated Pandan fibre reinforced composites
Figure 1 shows the tensile strength and breaking load variations of epoxy and polyester based Alkali treated Pandan fibre reinforced composites prepared with different fibre ratios. According to the figure 1, tensile strength and breaking elongation show highest values at 40% fibre weight ratio. The reason would be that, the strong interfacial bonding between two phases of fibres and matrix has taken a place at 40% fibre ratio than at the other fibre ratios. Thus, epoxy based composites show a higher tensile strength and breaking elongation compared to the polyester based composites. The reason would be that the higher tensile strength reported by epoxy resin itself as 73 MPa than the tensile strength of polyester resin itself as 40 MPa. Thus, the tensile strength at 40% fibre ratio (30.69MPa) is good enough to make the epoxy based Pandan fibre reinforced composites for car dash boards and door panels, for which the requirement is in the range of 20-40Mpa.

(b) Compressive strength of Alkali treated Pandan fibre reinforced composites
Composite compression testing methods provide a means of introducing a compressive load into the material while preventing it buckling. Figure 2 shows the obtained results. According to Figure 2, Epoxy based composites have given the highest comprehensive strength at 40%, but, Polyester based composites have given the highest comprehensive strength at 30% fibre ratio

and after that no compressive strength was recorded. This may be due to poor interfacial bonding between fibres and resins. Thus, the comprehensive strength of Polyester based composites with 30% fibre ratio is 53.44% higher than that of Epoxy based composites with 40% fibre ratio. According to Figure 2, 40% epoxy or 30% PES based pandan fibre reinforced composites are suitable for making car dash boards and door panels, because the minimum requirement is 25Mpa.

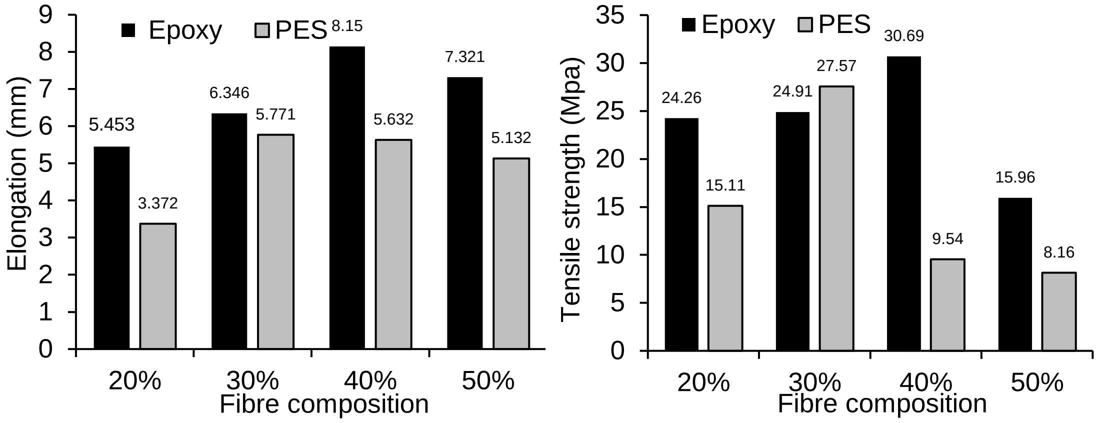

Figure 1. Tensile strength and breaking elongation of composites with fibre ratios

(c) Impact resistance of Alkali treated Pandan fibre reinforced composites

Figure 3 depicts the impact resistance of the prepared composites. Epoxy based Pandan fibre reinforced composites show a much higher impact resistance than the polyester resin based composites, at each fibre ratio selected. At 40% fibre ratio, Epoxy based composites had a higher impact resistance, whereas Polyester based composites had the highest impact resistance at 30% fibre ratio. Further, Considering the maximum impact resistances, Epoxy based composites showed 89% higher values than that of Polyester based composites. One reason would be the higher impact resistance reported with Epoxy than the Polyester resin. According to the Figure 3, 40% epoxy based pandan fibre reinforced composites are suitable for making car dash boards and door panels, because the minimum requirement is 25Mpa.

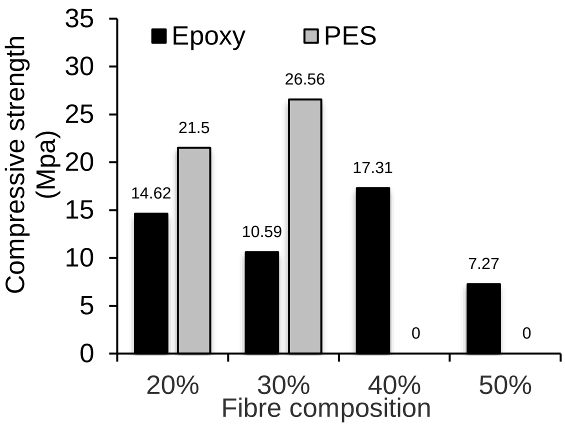

Figure 2. Compressive strength of composites with fibre ratios

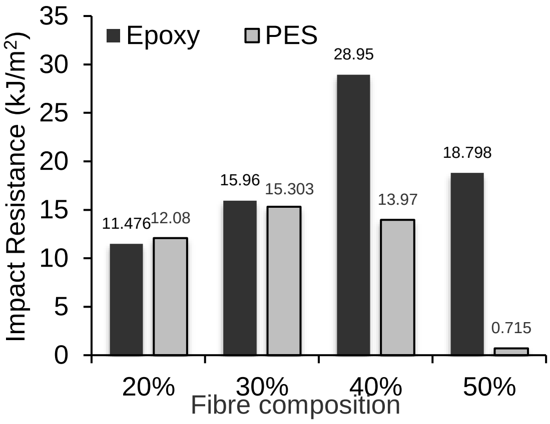

Figure 3. Impact resistance of composites with fibre ratios

(d) Flexural strength of Alkali treated Pandan fibre reinforced composites

Figure 4 shows the flexural strength variations of tested composites. Flexural strength of Epoxy based composites showed a higher value at 40% fibre ratio, whereas Polyester based composites showed a higher value at 30% fibre ratio. Further, consider the higher flexural strengths, 40% fibre ratio with epoxy based composites showed 15.57% higher value than that of Polyester based composites. Thus, Epoxy based composites showed a higher Flexural strengths at all fibre ratios, compared to Polyester based composites. This would be because the higher flexural strength of Epoxy resin than the Polyester resin. According to Figure 4, 40% epoxy based pandan fibre reinforced composites are suitable for making car dash boards and door panels.

(e) Hardness of Alkali treated Pandan fibre reinforced composites

Figure 5 shows the variations of Hardness of tested composites. Hardness of Epoxy based composites showed a higher value at 40% fibre ratio, where as Polyester based composites showed the higher value at 30% fibre ratio. Further, consider the higher Hardness , 40% fibre ratio with epoxy based composites showed 64.32% higher value than that of Polyester based composites. Thus, Epoxy based composites showed higher Hardness at all fibre ratios, compared to Polyester based composites. The reason would be the higher hardness of Epoxy resin than the Polyester resin. According to the Figure 5, 40% epoxy based pandan fibre reinforced composites are suitable for making car dash boards and door panels.

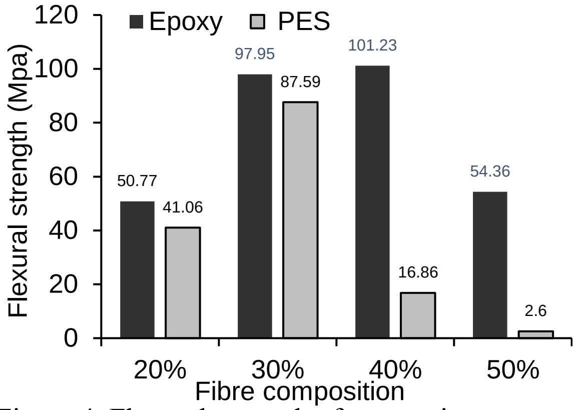

Figure 4. Flexural strength of composites with fibre ratios

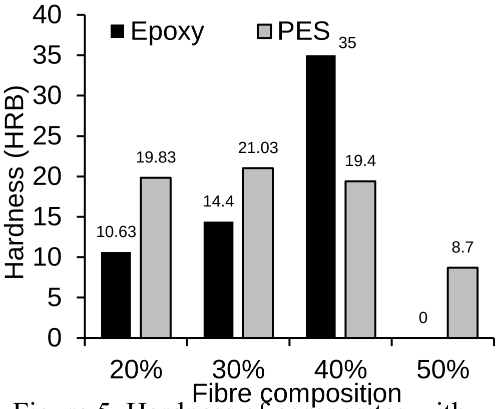

Figure 5. Hardness of composites with fibre ratios

(f) Moisture Absorption of Alkali treated Pandan fibre reinforced composites

Table 5 shows the moisture absorbency variations with the tested composites and it indicates the moisture regain values. Moisture absorbency increased with the amount of Pandan fibres included in the composites. Further, Epoxy resin based composites showed comparatively higher moisture absorbency than polyester based composites. Because, epoxy itself has a moisture regain of 3% and that of polyester is almost 0%. Comparing with Table 4, composites have shown very much lower moisture absorbency than the Pandan fibres,

Table 5: Moisture regain of tested Pandan reinforced composites

Fibre weight ratio	Moisture regain (%)	
	Epoxy based composites	Polyester based composites
20%	0.80	0.73
30%	0.87	0.79
40%	1.20	1.10
50%	1.59	1.56

4. CONCLUSION

In this study, the physical and mechanical properties of Pandan fibre reinforced composites, prepared with epoxy and unsaturated polyester, were investigated. Alkali treated Pandan fibres showed a higher bundle strength and single fiber strength with higher breaking elongation and higher moisture absorbency properties. With the 6% alkali treated Pandan fibre reinforced composites, the tensile strength, elongation, flexural strength, hardness, and impact strength were higher at the 40% fiber ratio than with the other ratios. However, the compressive strength exhibited good behavior at 40% fiber ratio. Further, epoxy-based reinforced composites have indicated much better physical and mechanical properties than polyester-based composites. Therefore, 6% alkali-treated Pandan fibre based composites made with epoxy resins with a 40% fiber ratio is recommended for industrial applications.

5. REFERENCES

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