Journal of Engineering and Applied Sciences 8 (5): 156-161, 2013
ISSN: 1816-949X

The Effect of Sodium Hydroxide Treatment and Fiber Length on the Tensile Property of Coir Fiber Reinforced Epoxy Composites

[1]A. Karthikeyan and [2]K. Balamurugan
[1]Department of Mechanical Engineering, K.S.R. College of Engineering, 637215 Tiruchengode, India
[2]Department of Mechanical Engineering, Institute of Road and Transport Technology, 638316 Erode, India

Abstract: This study is aimed at to investigate the effect of surface modification through NaOH (Sodium hydroxide) treatment and fiber length on the tensile strength of coir fiber of reinforced epoxy composites. The coir fibers was treated with 2, 4, 6, 8 and 10% concentration of NaOH separately for 10 days.The tensile strength of untreated and alkali treated fiber was measured. For each group of the coir fiber experiments were conducted on different fiber lengths, namely; 10, 20 and 30 mm. The experimental results showed that increasing NaOH concentration leads to a decrease in fiber diameter in a linear fashion. This reduction in diameter naturally ends up with reduced tensile strengths. The treated coir fiber was used as a reinforcement and epoxy as a matrix to fabricate the composites. The tensile strength of different samples of composites was measured. Increased NaOH concentration in fibers treatment was found to increase the tensile strength up to 4% and further increase in NaOH concentration reduces the tensile strength and also increased fiber length was found to increase in tensile strength. Maximum tensile strength of the composite was found to be uniformly accruing for 4% NaOH treated samples. Based on the nonlinear regression analysis the tensile strength equation was proposed for coir fiber reinforced epoxy composites.

Key words: Coir fiber, sodium hydroxide treatment, fiber length, tensile strength, composite

INTRODUCTION

Modern engineering field makes use of innumerable engineering materials for different applications. Some of these materials like plastics are widely used as they have attractive mechanical properties. On the other hand, these materials have objectionable properties, such as non degradability, leading to serious environmental problems. Intense research is going on throughout the world to replace the above materials with biodegradable substitute materials having comparable or better mechanical properties. Composites using these biodegradable materials are being tried widely for their various advantages. Some of the advantages of using biodegradable materials on composites is their availability worldwide, strength to weight ratio, high fatigue life, etc. (Rowel *et al*., 2000). Natural fibers from cultivated plants, such as coconut fiber, flax, sisal and cotton have been used in a large variety of products from cloths to house roofing. To day these fibers are appraised as environmentally correct materials owing to their biodegradability and renewable characteristics (Bledzki). Among the numerous natural fibers, coir fiber has shown a great potential in the composite field. Coir fibers are found between the husk and the outer shell of the coconut. The individual fiber cells are narrow and hollow with thick walls composed by cellulose. They are pale when immature. But, later became hardened and yellowed as a layer of lignin is deposited on their walls. There are two varieties of coir. Brown coir is harvested from fully ripened coconut. It is thick, strong and highly resistive to abrasion. It is typically used in mats, brushes and sacking. Mature brown fibers contain more lignin and less cellulose than fibers, such as flax and cotton and so are stronger but less flexible. White coir fibers are harvested from the coconuts before they are ripe. It is CO_2 neutral material. These fibers are abundant, non-toxic in nature, biodegradable, less dense and very cheap. This coir fiber can retaining water to a high degree and also is rich in micronutrients (Sudhakaran, 2007; Fernandez, 2003). Coir fibers decompose in 20-30 years in nature; it can be regarded as an environmentally friendly material. Coir fiber may be used as a reinforcement material in the composite productions (Sapuan *et al*., 2001; Lai *et al*., 2005; Sindhu *et al*., 2007; Li *et al*., 2007; Sharma *et al*., 2006). Monteiro *et al*. (2009) have proved that lignin,

Corresponding Author: A. Karthikeyan, Department of Mechanical Engineering, K.S.R. College of Engineering, 637215 Tiruchengode, India

pectin and other impurities within the coir fiber are considered harmful for its adhesion with the matrix during the composite fabrication. Therefore, alkali treatment of coir fiber improves the adhesion to the polyester matrix and thus increases the composite strength by approximately 50% of the results for a volume fabrication of 30% of treated coir fiber. Many researchers have carried out their studies in different natural fibers (Beaucage *et al*., 1999; Li *et al*., 2008; Qian *et al*., 2000; Joshi *et al*., 2004). Khedari *et al*. (2001) have indicated that the incorporation of natural fibers into polymers could improve the mechanical properties. Coconut coir is the most interesting product as it has low thermal conductivity compared to other natural fibers. Rout *et al*. (2003) have conducted the experiments and proved that the coir fiber loading from 9-15 wt.% have a flexural strength of about 38 MPa. Coir polyester composites with untreated and treated fibers with fiber loading of 17 wt.% were tested. Those results revealed that the treated fiber reinforced composites gave better tensile, flexural and impact strength. Gu (2009) have proves that alkali treatment on the coir fiber removed the impurities like pectin, fats and lignin as a result of rough fiber surface in the fiber. These improve the adhesive ability of the coir fiber with the matrix in the fabricated composites, resulting in a greater tensile strength of the material. Doan *et al*. (2006) stated that fiber length plays an important role in the mechanical performance of fiber reinforced composites. Among the methods to improve the adhesive characters of the coir fiber, alkaline treatment may be consider to be the most economical techniques. Although, a great deal of work has been done on coir fiber reinforced polymer composites very limited research has been done on the effect of fiber length with surface treatment through NaOH on tensile behavior of coir fiber reinforced composites. Against this background, the present research has been undertaken with an object to explore the potential use of coir fiber as a reinforcing material in polymer composites and to investigate its effect on the tensile strength of the resulting composites. In this investigation, coir fibers were treated by NaOH (sodium hydroxide) with various concentrations. The coir fiber was used as a reinforcement and epoxy as the matrix to fabricate the composite by hand lay-up technique. The tensile strength of the produced specimens was measured and SEM analysis was made.

MATERIALS AND METHODS

The coconut husks were soaked in the tap water container for 5 months. This process is called retting which can partially decompose the pulp on the shell allowing the fiber to be removed from the husk easily. After retting, the husks were beaten with a hammer. The coir fibers were removed from the shell and separated with a comb. After drying in the room temperature, the coir fibers were combed in a carding frame to further separate the fibers into an individual state. The epoxy LY556 was used as a matrix with HY951.

Coir fiber treatment: The coir fibers were treated in the NaOH solution at room temperature (27-29°C) with various densities of 2, 4, 6, 8 and 10%. Each group of the coir fiber was treated for 10 days. The treated fiber was washed with water to remove the excess of NaOH sticking to the fibers. Final washing was carried out with distilled water and the fibers were dried in hot air. Finally, the fibers were cut into 10, 20 and 30 mm length for molding the composites.

Preparation of coir fiber reinforced epoxy composite: The coir fiber reinforced epoxy composites were manufactured through a mould box of size 300×300×300 mm. The fabrication of the composite material was carried out through the hand lay-up technique. The top and bottom surface of the mould and the walls were coated with remover and allowed to dry. The chopped fibers with epoxy resin were mixed manually. Epoxy resin properly mixed with coir fiber was transfer to the mold and the mold close then it is pressed in the compression testing machine and left for 24 h for curing. The setup is illustrated in Fig. 1. After the curing process, the samples were cut into the required size prescribed in the ASTM standards.

Tensile test: The fiber strength of the coir fiber was carried out by using the model INSTRON 5500R, single fiber tensile strength tester (SITRA, Coimbatore, Tamil Nadu, India). About 30 samples were tested and the average value is reported. The distance between the two clamps before the test was measured as 60 mm and displacement rate was set as 10 mm min^{-1} as most of the researchers have used this strain rate. It was selected in order to compare the results with that available in the literature. Images of the coir fiber before and after the alkali treatment were taken by using the scanning electron microscope (Model KYKY 2800, Amirtha University, Coimbatore, Tamil Nadu, India). The diameter of the coir fiber before and after the alkali treatment was measured using image analyzer, taken from SITRA Coimbatore, Tamil Nadu, India. From the fabricated coir fiber reinforced epoxy composite, tests specimens were cut as per ASTM D3039 and tested for its tensile strength using computerized universal testing machine (INSTRON model 3369). The setup is illustrated in Fig. 2. The distance between the two clamps before the test was maintained at

Fig. 1: Mould preparation set up

Fig. 2: Universal Tensile Tester Model-Instron 3369

150 mm, the testing speed was 2 mm min^{-1}, the normally used value. About 5 samples were tested and the average value is reported.

RESULTS AND DISCUSSION

Image of the coir fiber: Figure 3-5 represents the surface appearance of the coir fiber before and after the alkali treatment, respectively. From Fig. 3, it was noticed that the surface of the coir fiber is covered with a layer of substance which may include pectin, lignin and other impurities. The surface is not smooth, spread with nodes and irregular strips. Figure 4 represents the surface of the coir fiber after NaOH treatment. It showed that most of the lignin, pectin are removed resulting in a rougher surface. It may notice that there are rows of pits on the surface. These would increase the mechanical bonding between the coir fiber and matrix in the composite fabrication.

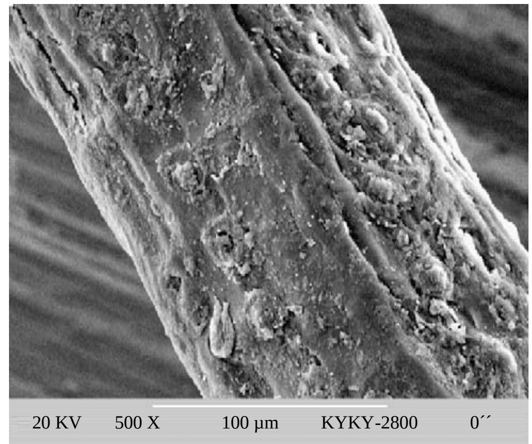

Fig. 3: Surface appearance of the coir fiber before alkali treatment

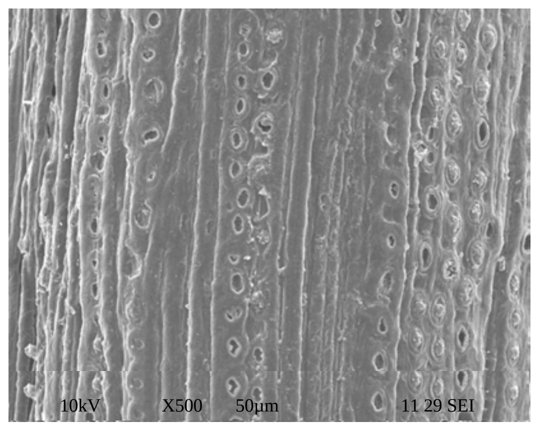

Fig. 4: Surface appearance of the coir fiber after 2% of NaOH treatment

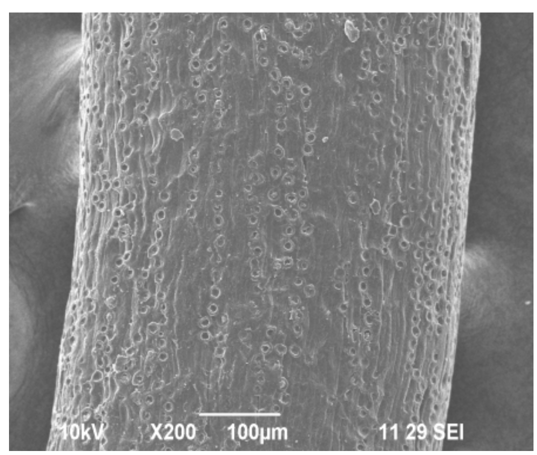

Fig. 5: Surface appearance of the coir fiber after 4% of NaOH treatment

Fiber tensile strength: Tensile strength of NaOH treated fibers is listed in Table 1 for the comparison. The tensile strength of the untreated fiber is also included in Table 1 because of incredible variation of the fiber fitness, tensile strength of the fiber various greatly. To observe the influence of the coir fiber variation, 30 samples were adopted for each group.

Table 1 represents the tensile strength of the coir fiber before and after the alkali treatment. The results revealed that a decreased trend is seen in the fiber tensile strength with increased in alkali density. The different of the tensile strength among each group was proved to be significant. A increased in alkali densities causing greater amount of lignin, pectin to leach out this would be detrimental of fiber strength.

Figure 6 represents the comparison of the coir fiber diameter before and after the alkali treatment. One may noticed that a decreased trend is seen in the fiber diameter with increased in alkali density. This (Fig. 6) was proved that the NaOH treatment reduce the fiber strength drastically because the pH value of NaOH is 14. After the alkali treatment, a rough fiber surface was resulted this might improve the bonding ability of the fiber with matrix.

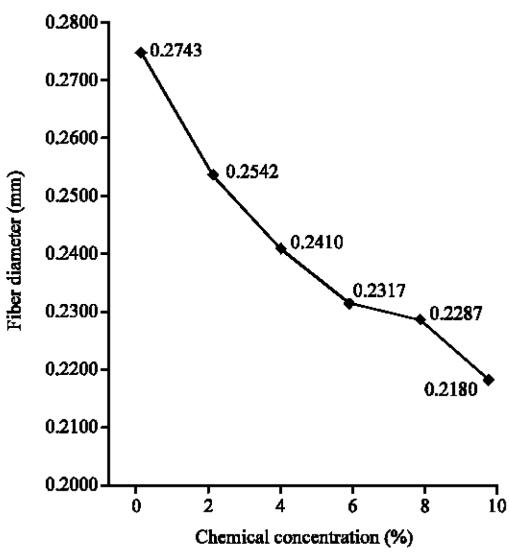

Fig. 6: Diameter of the coir fiber before and after the alkali (NaOH) treatment

Table 1: Coir fiber tensile strength with NaOH treatment

Fibers	Tensile strength (MPa)	Elongation (%)
Original fiber	617.6	18.8
NaOH 2%	582.6	28.0
NaOH 4%	568.7	27.1
NaOH 6%	553.3	23.1
NaOH 8%	544.0	23.9
NaOH 10%	527.7	22.9

Tensile strength of the coir fiber reinforced epoxy composite: Figure 7 showed the appearance of the specimen of the coir fiber reinforced epoxy composites. The weight fraction of the coir fiber in the composite was 30%. Each piece of the fabricated board was cut into set of specimens. The tensile strength of coir fiber reinforced epoxy composites with and without alkali treatment testing results were summarized in Table 2 and 3.

Effect of fiber length on tensile property of coir fiber reinforced epoxy composites: Joseph *et al*. (1999) studied the tensile properties of short sisal fiber/polyethylene composites in relation to processing methods and the effects of fiber content, length and orientation. For this experiment, it is shown (Fig. 8) that the chopped fibers distribution in epoxy is random so the fiber could not hold the load when matrix was transferred. Arib *et al*. (2006) compared the experimental and theoretical tensile strength for pineapple leaf fiber reinforced polypropylene composites and found that the equation for rule of mixture fails to provide a good fit and the discrepancy increases with the increase in fiber volume fraction. The fiber is not

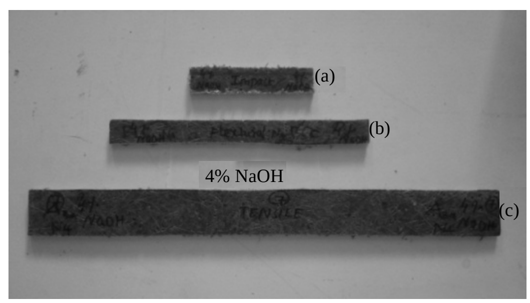

Fig. 7: a) Specimen for impact test (4% NaOH and 20 mm length); b) Specimen for flexural test (4% NaOH and 10 mm length); c) Specimen for tensile test (4% NaOH and 30 mm length)

Table 2: Effect of fiber length on tensile property of untreated coir fiber reinforced epoxy composite

Fiber length (mm)	Tensile strength (MPa)
10	6.208
20	9.155
30	13.050

Table 3: Effect of fiber length on tensile strength of NaOH treated coir fiber reinforced epoxy composites

	NaOH concentration (%)					
Parameters	2	4	6	8	10	Fiber length (mm)
Tensile strength (MPa)						
	8.567	12.845	12.807	9.908	8.455	10
	9.242	13.380	13.327	10.098	8.659	20
	13.171	13.782	13.702	10.498	8.941	30
Elongation (%)						
	0.882	0.300	1.010	0.743	0.720	10
	0.900	0.500	1.067	0.766	0.733	20
	0.920	0.525	1.000	0.797	0.755	30

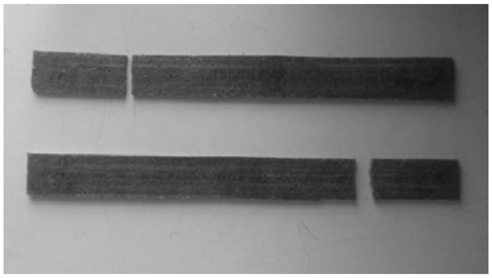

Fig. 8: Specimen for after tensile test (2% NaOH and 25 mm length)

perfectly aligned and the presence of voids in the composites may also be the factor contributing to the lower experimental values. According to Baiardo *et al.* (2004), the mechanical properties of short fiber reinforced composites are expected to depend on the intrinsic properties of matrix and fibers, aspect ratio, content length distribution and orientation of the fibers in the composites and fiber-matrix adhesion that is responsible for the efficiency of load transfer in the composites. Table 3 and 4 as expected, the tensile strength was gradual increases with increase in fiber length reaching a maximum at about 30 mm (13.782 MPa). There can be a reason for this increase in the tensile properties of these composites is that the chemical bonding between the fiber and matrix may be too strong to transfer the tensile.

Effect of alkali treatment on tensile property of coir fiber reinforced epoxy composites: Researchers may notify that the significant difference in the tensile strength between the alkali treated coir fiber reinforced epoxy composites and untreated coir fiber reinforced epoxy composites. The tensile strength of the composites when using the alkali treated coir fibers is usually greater. Because after alkali treatment, most of the impurities like lignin, pectin covered the fiber surface were removed which improved the fiber adhesive character in the combination with the matrix. Especially in Table 3, clearly showed that the important difference in the tensile strength of NaOH treated coir fiber reinforced epoxy composites with varying fiber length and chemical concentration. There is no significant different in the tensile strength in the case of 4 and 6%. To achieve a composite with better strength, NaOH concentration with 4% may be recommended for economical consideration. Significant different is noticed for the elongation at break values between the composites made by using the alkali treated and untreated coir fiber. The higher elongation at break for the alkali treated coir fiber composites indicates that the removal of the lignin and pectin improved the elasticity of the coir fiber.

Table 4: Validation of design equation

Fiber length (mm)	NaOH contraction (%)	Experimental T_S (MPa)	Predicted T_S (MPa)
25	2	11.07	11.71

Regression analysis: It was observed that relationship between fiber lengths (L), chemical concentrations (C) on the tensile strength (T_S) of coir fiber reinforced epoxy composite varies non-linearly. From the parametric study, it is ascertained that interaction between parameters like coir fiber lengths (L), sodium hydroxide concentration (C), influence the Tensile strength (T_S) of the coir fiber reinforced epoxy composite. The non-linear regression analysis is carried out using statistical analysis software SPSS to estimate the arbitrary relationship between the dependent variable (T_s) and a set of independent variables (L and C). The following design equation was developed using non-linear regression analysis:

$$T_s = \left(-1.531\times10^{12}\right) + \left\{\left(2.808\times10^{11}\right)\times L\right\} \quad (1)$$

It is found that for the above mentioned proposed design (Eq. 1) R^2 value (1 - (Residuals sum of squares/Corrected sum of squares)) is found to be 0.962 which is >0.95. Hence, best fits the data obtained using nonlinear analysis.

The experimental investigation has been extended for 15 mm fiber length with 4% of sodium hydroxide concentration. The proposed equation was validated with the help of the extended experimental study. The validation is shown in Table 4.

CONCLUSION

In this investigation, the effect of fiber length and NaOH treatment of coir fiber on the tensile strength was studied. Conclusions from this study are as follows:

- The NaOH treatment on the coir fiber would remove the impurities like pectin, lignin in the fiber. On the other hand, a rougher fiber surface may result after the treatment. These would increase the adhesive ability of the coir fiber with the matrix in the fabricated composites resulting in a greater tensile strength of the material
- This study has confirmed that the length of the fiber increases with increase in tensile strength
- The investigation showed that the higher concentration would deteriorate the fiber strength, the higher the concentration, the greater damage to the fiber
- When the alkali concentration was 10% the decrease of the fiber strength may play a major role as far as the composite tensile strength was concerned

- The results revealed that the NaOH treatment reduce the fiber strength drastically when the concentration was increased
- The design equation for tensile strength was proposed based on non-linear regression analysis. From this investigation, it is concluded that increase in coir fiber length up to 30 mm increases the tensile strength of the composite
- Increased NaOH concentration in fibers treatment was found to increase the composite elongation up to 6% and further increase in NaOH concentration, reduces the composite elongation. This result revealed that the ductility of the surface modified coir fiber had been improved

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