Chapter 20
Effect of Chemical Treatment on the Mechanical Properties of Okra-Fiber-Reinforced Epoxy Composites

T. N. V. Ashok Kumar, J. Madhu Kiran, S. Madhusudan and J. Subash Kumar

Abstract The aim of this paper is to investigate chemical modification and mechanical characterization of okra fiber reinforced with epoxy LY556 as matrix material using hand layup technique. Composites are fabricated with different wt% of fibers as reinforcement and pre-calculated weight of the resin. Tensile flexural and impact test specimen are prepared according to ASTM standards. Tensile testing has been carried out on 5-ton universal testing machine. Three-point bend test has been adopted for flexural strength estimation. Impact strength has been estimated through Izod test setup. The results are compared with treated and untreated fiber-reinforced composites, and treated fiber composite exhibits good mechanical properties.

Keywords Mechanical properties · Okra fiber · Hand layup technique · Epoxy

20.1 Introduction

The composite materials consist of two or more distinct material combined together to get superior properties which cannot be obtained by any one individual material. Out of various types of composite materials, polymer matrix composite (PMC) finds potential applications like roofing structures, car interiors, aerospace, automobiles, and defense. Low cost, low density, less abrasiveness, and user friendly are some of the merits of PMC [1–5]. Natural fibers are extracted from

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various plants. These fibers are seed based, leaf based, stem based, and bast. Natural fiber polymer matrix composites are eco-friendly nature, fully biodegradable, tougher, renewable, and economical. High moisture absorption and low thermal stability are the major disadvantages of NFPC [6–12]. Natural-fiber-reinforced polymers can exhibit very different mechanical performances and environmental aging resistances depending on their interphase properties. The principal function of the interphase is to facilitate transfer of stress from fiber to fiber, across the matrix [13]. Kabir et al. [14] revealed the importance of chemical treatment for processing natural fibers. They observed that fibers lose hydroxyl groups due to different chemical treatments, thereby reducing the hydrophilic behavior of the fibers and causing enhancement in mechanical strength as well as dimensional stability of natural-fiber-reinforced polymer composites. Girisha et al. [15] studied the alkali treatment of natural fibers to improve fiber/matrix interface quality which resulted in enhancement of mechanical properties. Mishra et al. [16] observed weaker fibers through excess delignification of the fiber at 10% NaOH concentration. Jayabal et al. [17] reported NaOH treatment concentration and soaking time were also to greatly affect the properties of coir–polyester composite. Hashim et al. [18] reported that increased concentration sodium hydroxide results decreased diameter of the fiber, and mercerization was found to change fiber surface topography. Li et al. [19] suggested the use of potassium permanganate for chemical treatment of natural fibers and proved successful for high thermal stability, increase in stiffness changes in macromolecular and crystallographic structure, and increase in tensile strength. Lix further added that cellulosic fibril and extraction of lignin hemicellulosic compounds degree of polymerization can be achieved through alkaline processing. [20–26]. Geroje et al. concluded that decrease in moisture absorption resulting improved mechanical properties can be achieved through chemical modification which improves hydrophobic nature of the natural fiber and also interfacial bonding between matrix and fiber [27]. With this background, the present paper aims at analyzing the mechanical behavior of alkali treated and untreated okra-fiber-reinforced epoxy composites.

20.2 Materials and Methods

20.2.1 Materials

Okra fiber: Okra plant is originally from Egypt and belongs to Malvaceae family (*Abelmoschusesculentus*), and the fibers are extracted from the stem of plant [28]. The color of okra fiber is quite variable from whitish to yellowish depending on the action of UV radiation [28].

Resins: Epoxy LY556 (diglycidyl ether of biphenyl-A) and HY951 (triethylenetetramine) hardener were purchased from Shakti glass fibers and traders, Chennai.

Chemical treatment: Solution preparation 10% w/v sodium hydroxide solution was prepared in 500-ml beaker by diluting 40 g, pellets of sodium hydroxide in 400 ml of distilled water. 10% v/v acetic acid solution was prepared in a 500-ml beaker by mixing 20 ml of acetic acid in 380 ml of water.

20.2.2 Fiber Preparation

The long continuous okra fiber is used for fabrication of the composite. In order to remove the lignin and other material like wax and pectin, a measured quantity of the okra fibers were soaked in the prepared 10% w/v sodium hydroxide (NaOH) solution. The soaked fibers were subjected to stirring for 20 min and were kept in freezer (about 5 °C). With an intention to neutralize, the excess sodium hydroxide left on the fibers. The fibers were then soaked in the prepared 10% v/v acetic acid solution for 5 min. The fibers finally washed thoroughly with distilled water. The cleaned fibers are dried in the sunlight. Fibers are combed several times to separate the fibers into individual strands. Then, fibers are cut in the length of 220 mm. Later, the fibers are weighted accurately.

20.2.3 Mold Preparation

A mold with dimensions of 210 × 210 × 3 mm is used for the fabrication of composite. A clean smooth surfaced wooden board is taken for preparation of the specimens. Edges of the wooden mould applying releasing agent (wax) for easy removal of the composite.

20.2.4 Fabrication of Composite

Treated and untreated okra fibers were prepared according to mold dimensions of 210 × 210 × 3 mm. Epoxy resin LY556 and hardener HY951 with ratio (10:1) mixed thoroughly. The prepared mold is evenly filled with measured quantity of okra fibers. The samples were made with varying weight fractions of fiber at 0.5, 1.0, 1.5, and 2.0% weight/weight. The wetted okra fiber was placed in an aligned longitudinally in the die, and remaining depth was filled up with prepared resin. To avoid air bubbles and complete wetting and to ensure completing, roller force was applied uniformly throughout the die. With an intension to drain out excess resin and also to ensure a smooth surface, the upper portion of the die is covered with a layer of polythene sheet, and load is applied uniformly. The preparations of composite were left to cure completely and then were removed from the dies. For each weight fraction, the three samples were made.

20.3 Testing of Composites

20.3.1 Tensile Test

The tensile test specimens are prepared according to the ASTM D638 standard [29]. The dimensions of the specimens were 160 mm (length), 12.5 mm (width), and 3 mm (thickness).

20.3.2 Flexural Test

The flexural test specimens are prepared as per the ASTM D790 standard [30]. The dimensions of the specimens were 100 mm (length), 10 mm (width), and 3 mm (thickness).

20.3.3 Impact Test

Impact test specimens are prepared according to the ASTM D256-88 to measure impact strength [31]. The specimen dimensions are 63.5 (length) * 12.7 mm (deep) * 10 mm (wide).

20.4 Results and Discussions

20.4.1 Tensile Strength

The effect of okra fiber content on the tensile strength of the composite is shown in Fig. 20.1. It can be observed that the tensile strength varies from 39.53 to 125.82 MPa for untreated okra fiber composite. It is self-explanatory that an increase in fiber content increases the tensile strength up on loading. It can also be observed that alkaline-treated fiber tensile strength varies from 52.31 to 145.49 MPa. It is true that as the weight fraction of the fiber increases, the tensile strength increases correspondingly. It is also evident from the figure that chemical treatment has improved the tensile strength to a larger extent. This improvement is nominal at lower weight fraction of the composite, and it is reasonable at higher weight fraction of the composite. This is due to the strong fiber matrix interphase (Tables 20.1 and 20.2).

Figure 20.2 shows plot between mean tensile modulus and percentage weight fraction of fiber untreated and chemically treated okra-fiber-reinforced epoxy composites. Tensile modulus values are in close agreement between before and

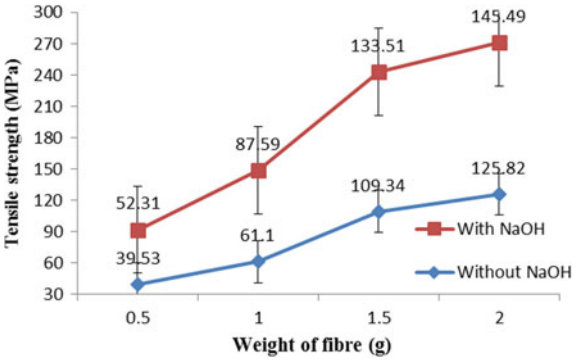

Fig. 20.1 Variation of mean impact strength on with and without NaOH treatment of okra fiber

Table 20.1 Summary results of tensile strength with and without NaOH for different composites

S. No	Weight of fiber (g)	Tensile strength without NaOH (MPa)	Tensile strength with NaOH (MPa)
1	0.5	39.53	52.31
2	1.0	61.10	87.59
3	1.5	109.34	133.51
4	2.0	125.82	145.49

Table 20.2 Summary results of tensile modulus with and without NaOH for different composites

S. No.	Weight of fiber (g)	Mean tensile modulus without NaOH (GPa)	Mean tensile modulus with NaOH (GPa)
1	0.5	3.839	4.576
2	1.0	5.334	5.596
3	1.5	5.503	5.062
4	2.0	6.703	7.011

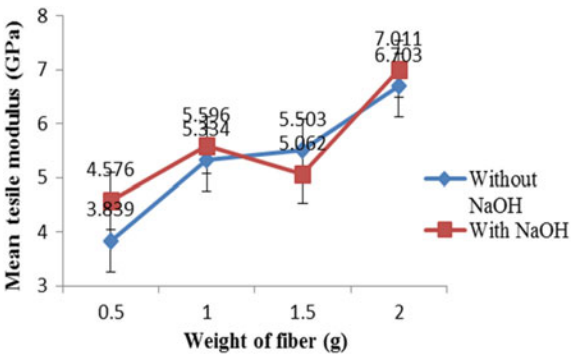

Fig. 20.2 Variation of tensile modulus on with and without NaOH treatment of okra fiber

after chemical treatment of okra fiber. At 2% weight of fiber treated and untreated okra-fiber-reinforced composite values are 7.011 and 6.703 GPa, respectively. A typical trend has been observed that 1.5% fiber weight with NaOH treatment value is low compared to without NaOH. The probable cause of this unlike phenomenon may be due to alkali reaction on the cementing materials of the fiber specially hemicellulose which leads to the splitting of the fiber into finer filament. As a result, wetting of fibers as well as bonding of fibers with matrix may improve which consequently make the fiber more brittle (Table 20.3).

The effect of surface treatment on the flexural strength of composites is shown in Fig. 20.3. It can be observed that alkali-treated okra composites show improvement as compared to untreated composites. A strong sodium hydroxide treatment removes lignin, hemicellulose and other alkali soluble components from the surface of the fiber to increase the number of reactive hydroxyl groups on the fiber surface available for chemical bonding. Hence, chemical treatment has got significant effect on treated fiber composites (Table 20.4).

Figure 20.4 shows that flexural modulus values are low for alkali-treated fibers as compared to without alkali treatment of fibers. The effect of alkali treatment is less significant up to 1.5% fiber content. At 2% fiber weight loading, the alkali treatment played vital for improving the flexural modulus. The drastic improvement in flexural modules for treated composite may be due to combined effect of increased fiber content and chemical treatment effect (Table 20.5).

The impact properties of a composite material are directly related to its overall toughness. Composite fracture toughness is affected by interlaminar and interfacial

Table 20.3 Summary results of flexural strength with and without NaOH for different composites

S. No.	Weight of fiber (g)	Flexural strength without NaOH (MPa)	Flexural strength with NaOH (MPa)
1	0.5	97.22	129.62
2	1.0	152.77	171.29
3	1.5	178.23	208.33
4	2.0	252.31	300.92

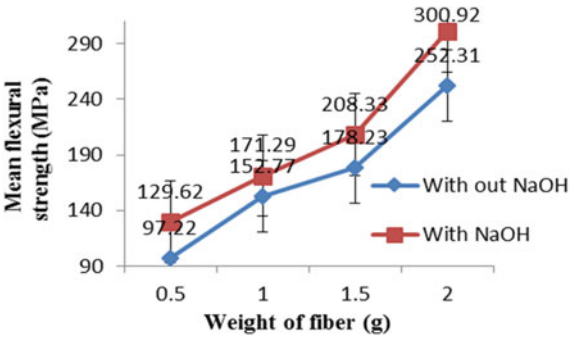

Fig. 20.3 Variation of flexural strength on with and without NaOH treatment of okra fiber

Table 20.4 Summary results of mean flexural modulus with and without NaOH for different composites

S. No.	Weight of fiber (g)	Mean flexural modulus without NaOH (GPa)	Mean flexural modulus with NaOH (GPa)
1	0.5	14.81	11.9
2	1.0	21.44	17.4
3	1.5	23.53	21.39
4	2.0	27.04	34.31

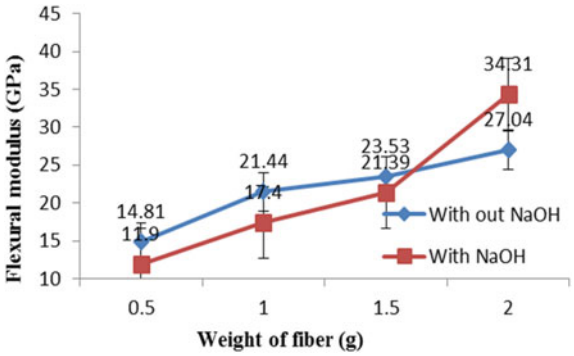

Fig. 20.4 Variation of flexural modulus on with and without NaOH treatment of okra fiber

Table 20.5 Summary results of impact strength with and without NaOH for different composites

S. No.	Weight of fiber (g)	Impact strength without NaOH (J/mm)	Impact strength with NaOH (J/mm)
1	0.5	0.06	0.076
2	1.0	0.08	0.106
3	1.5	0.11	0.133
4	2.0	0.17	0.193

strength parameter [16]. Figure 20.5 shows the effect of untreated and treated okra/epoxy composite on impact strength with variation in fiber weight fractions. From the figure, it is clear that the impact strength increased steadily with increase in filler concentration for both treated and untreated composites showing 0.19 and 0.17 kJ/m^2 with 2 wt% fiber content, respectively. As explained an earlier paragraphs, the chemical treatment as shown enhanced properties as compared to untreated composites.

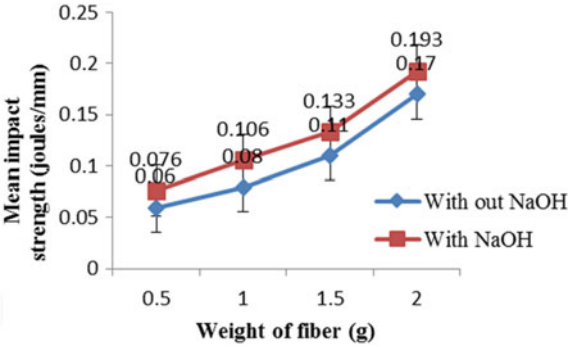

Fig. 20.5 Variation of mean impact strength tngth on with and without NaOH treatment of okra fiber

20.5 Conclusions

- The successful fabrication of the composite by using hand layup technique.
- Composites from treated okra fibers had higher values of mechanical properties than those made from the untreated fibers.
- In the present work significant improvement in tensile, flexural, and impact properties for all weight fractions and it is highest for 2 wt% filler composites.
- Okra FRP composites is useful for the preparation of lightweight automobile components and household purposes.

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