Tensile properties characterization of okra woven fiber reinforced polyester composites

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ABSTRACT

The present research exploits a new natural fiber namely okra for the preparation of okra fiber reinforced polyester composites. Chemically treated (chemical treatment-2) okra woven FRP composites showed the highest tensile strength and modulus of 64.41 MPa and 946.44 MPa respectively than all other composites investigated in the present research. Specific tensile strength and modulus of untreated and treated okra FRP composites is 34.31% and 39.84% higher than pure polyester specimen respectively.

Key words: Okra woven fiber, Density, Tensile strength, Tensile modulus, Specific tensile strength, Specific tensile modulus.

1. INTRODUCTION

Chemically treated and untreated henequen natural fibers were used as reinforcement for the preparation of composites and they were micromechanically characterized using pull out and single fiber fragmentation test [1]. A film stacking method was used for processing sisal, kenaf, hemp, jute and coir by compression molding. Tensile, flexural and impact properties were determined and compared [2]. Natural rubber is reinforced with untreated sisal and oil palm fibers chopped to different fiber lengths. The effects of concentration and modification of fiber surface in sisal/oil palm hybrid fiber reinforced rubber composites have been studied. Increasing the concentration of fibers resulted in reduction of tensile strength and tear strength, but increased modulus of the composites [3]. Composites of cellulose acetate butyrate reinforced with cellulose sheets synthesized by Gluconacetobacter xylinus were produced by solvent evaporation casting. The composites contained 10% and 32% volume cellulose, and showed a Young's modulus of 3.2 and 5.8 GPa, and a strength of 52.6 and 128.9 MPa, respectively, in tensile tests [4]. Coconut fiber has been used as reinforcement in low-density polyethylene. The effect of natural waxy surface layer of the fiber on fiber/matrix interfacial bonding and composite properties has been studied by single fiber pullout test and evaluating the tensile properties of oriented discontinuous fiber composites [5]. Tensile and flexural behaviors of pineapple leaf fiber–polypropylene composites as a function of volume fraction were investigated. The tensile modulus and tensile strength of the composites were found to be increasing with fiber content in accordance with the rule of mixtures [6]. Investigations of the effect of maleic anhydride grafted polypropylene (MAHgPP) coupling agents on the properties of jute fiber/polypropylene (PP) composites have been considered with two kinds of matrices (PP1 and PP2). Both mechanical behavior of random short fiber composites and micro-mechanical properties of single fiber model composites were examined [7]. The composites were formulated with arecanut fiber with a maximum volume fraction of 0.39, resulting in mean tensile strength and modulus of 24 and 40% [8]. The used reinforcement was made of long Alfa fibers, extracted from the stem of the Alfa plant by the soda process. The used matrix is based on unsaturated polyester resin. Experiments show that the specific tensile properties of these fibers are very interesting and are close to those obtained on some man-made fibers. Composite plates were prepared using unidirectional Alfa cloths, from which specimens are cut for mechanical experiments. The influence of fibers orientation and fibers fraction on the mechanical properties of the Alfa/Polyester composites have been evaluated [9]. Hemp, hard wood A. hard wood B, rice hulls, silane treated e-glass fibers were used as reinforcement for the thermoplastic HDPE (Formolene HB5502B) for fabricating composites and the tensile properties were tested [10]. The composites were formulated up to a maximum of 31% volume of fiber resulting in a tensile strength of 80.55 MPa and tensile modulus of 1.52 GPa for elephant grass fibers extracted by retting. The tensile strength and modulus of chemically treated elephant grass fiber composites have increased by approximately 1.45 times to those of elephant grass fiber composite extracted by retting [11]. Rice straw polyester composites having volume fraction of 40% resulted in mean tensile strength 1045 MPa [12]. PLA (polylactic acid) was reinforced with Cordenka rayon fibres and flax fibres, respectively. The mechanical properties of these composites which are examples for completely biodegradable composites were tested and compared. The samples were produced using injection moulding. The highest impact strength (72 kJ/m^2) and tensile strength (58 MPa) were found for Cordenka reinforced PLA at a fibre-mass proportion of 30%. The highest Young's modulus (6.31 GPa) was found for the composite made of PLA and flax. A poor adhesion between the matrix and the fibers was shown for both composites using SEM [13]. All-cellulose composites were successfully prepared by a surface selective dissolution method of aligned ligno-cellulosic fibers using lithium chloride/N, N-dimethylacetamide as a solvent. The effect of the immersion time of the aligned fibers in the solvent during preparation was investigated. The structure and mechanical properties of the composites were characterized by X-ray diffraction, scanning electron microscopy, and tensile testing [14]. The monotonic tensile behavior of a high performance sisal natural fiber was studied. Tensile tests were performed on a microforce testing system using four different gage lengths. The cross-sectional area of the fiber was measured using scanning electron microscope (SEM) micrographs and image analysis. The measured Young's modulus was also corrected for machine compliance. Weibull statistics were used to quantify the degree of variability in fiber strength, at the different gage lengths. The Weibull modulus decreased from 4.6 to 3.0 as the gage length increased from 10 mm to 40 mm, respectively. SEM was used to investigate the failure mode of the fibers [15]. Effect of stacking sequence on tensile, flexural and interlaminar shear properties of untreated woven jute and glass fabric reinforced polyester hybrid composites has been investigated experimentally [16]. A study on the effect of alkaline treatment on tensile properties of sugar palm fiber reinforced epoxy composites was presented in the paper [17]. The unidirectional biodegradable composite materials were made from kenaf fibers and an emulsion-type PLA resin. Thermal analysis of kenaf fibers revealed that tensile strength of kenaf fibers decreased when kept at 180^0 C for 60 min. The unidirectional fiber-reinforced composites showed tensile and flexural strengths of 223 MPa and 254 MPa, respectively. Moreover, tensile and flexural strength and elastic moduli of the kenaf fiber-reinforced composites increased linearly up to a fiber content of 50% [18]. This paper presents extensive experiments and micromechanics-based modeling to evaluate systematically the tensile properties of kenaf bast fibers bundle (KBFB) and kenaf bast fiber-reinforced epoxy strands. Uniaxial tension behaviors of KBFBs and KBFB-reinforced epoxy strands were evaluated statistically using large sample sets. The elastic modulus, tensile strength, as well as failure strains of KBFBs, displayed large scatter statistically ranging from 10% to 30%. The loading rate-dependency was evaluated at three strain rates ranging from approximately 10^{-4} ~ 10^{-2}/s. The tensile strength increases gradually as the loading rate increases, while the tensile modulus almost remains the same as the loading rate increases until the loading rate reaches 10^{-2}/s, at which a much higher modulus was presented [19]. Natural fibers used in this study were both pre-treated and modified residues from sugarcane bagasse. Polymer of high density polyethylene (HDPE) was employed as matrix in to composites, which were produced by mixing high density polyethylene with cellulose (10%) and Cell/ZrO2_nH2O (10%), using an extruder and hydraulic press. Tensile tests showed that the Cell/ZrO2_nH2O (10%)/HDPE composites present better tensile strength than cellulose (10%)/HDPE composites [20].

In the present research hybrid okra (botanically called as “Abelmoschus esculentus”) fiber was taken for the preparation of composites. It is referred by a synonym “Hibiscus esculentus L”. Hybrid okra variety 2405133 seeds were supplied by Syngenta India Linited, Shivaji Nagar, and Pune, India. The characteristics of seed are given in **Table 1**.

Table 1: Seed characteristics

Germination (Min.)	65%
Physical purity (Min.)	99%
Inert matter (Max.)	1%
Moisture (Max.)	8%
Genetic purity (Min.)	95%

The chemical used for seed treatment is THIRAM.

2. MATERIALS

2.1. Hybrid okra variety 2405133 fiber extraction

The removed okra stems were placed in a pit containing stagnant mud water for 6 days (i.e. 30th August, 2008 to 4th September, 2008) at ambient conditions. On 7th day i.e. 5th September, 2008 the stems were washed out with sufficient quantity of water till the complete pulp detached from the fiber. Then the fiber was dried for 7 days at ambient conditions. The fiber obtained is 5 ft. to 7 ft. long. Up to 2 ft. fiber length okra fiber was in woven form. Now onwards this is called as Okra woven (OW) fiber. Extracted okra woven fiber was shown in **Figure 1**.

FIGURE 1: Extracted okra woven fiber

2.2 Matrix

Ecmalon 4413 general purpose unsaturated polyester resin of medium reactivity was used in the present investigation. The properties of the liquid resin were tested in accordance with IS 6746-1994 and the values can vary within tolerances mentioned therein **Table 2**.

Table 2: Matrix characteristics

Appearance	Clear
Viscosity @ 25^0C	500 (Brookfield viscometer)
Specific gravity (25/25^0C)	1.13
Acid value (mgKOH/g)	25
Volatiles @ 150^0C (%)	35
Gel time @ 25^0C (minutes)	20

The resin contains a volatile monomer with a flash point at 32^0C and is of moderate fire hazard.

3. CHEMICAL TREATMENT (CT)

Extracted hybrid okra fiber was treated with different chemicals to investigate the variation in the properties after treatment.

3.1. Chemical treatment-1 (CT-1): Okra woven fiber was treated with 0.125 M NaOH solution for 6 hours. Pre treated okra fiber with sodium hydroxide was treated with 0.03163 M $KMnO_4$ solution in presence of 0.01876 M H_2SO_4 for a period of 14 hours. Now onwards it is okra woven chemical treatment-1 (OW CT-1).

3.2. Chemical treatment-2 (CT-2): Okra woven fiber was treated with 0.125 M NaOH solution for 45 minutes. Pre treated okra fiber with sodium hydroxide was treated with 0.006327 M $KMnO_4$ solution in presence of 0.00375 M H_2SO_4 for a period of 5 minutes. Now onwards it is okra woven chemical treatment-2 (OW CT-2).

4. METHODS

4.1. Fiber volume fraction: The volume fraction of fiber was calculated by a method which enables the rule of mixtures and analysis of measured composite properties. The method involves measuring the density of the composite (ρ_C) of mass M_C at a given mass fraction of the resin M_R. Volume fraction of resin (V_R) was calculated using the formula

$$V_R = \frac{M_R \times \rho_C}{M_C \times \rho_R}$$

Where ρ_R = density of resin in kg/m^3

Then the fiber volume fraction is determined by the relation

$$V_F = 1 - V_R$$

4.2. Moisture removal: The fiber was placed in a NSW-143 Oven Universal (Super deluxe model), supplied by Narang Scientific Works Private Limited, New Delhi, India, at a temperature of 70^0 C for 1 hour. Then fiber was allowed to cool to room temperature. The fiber was then taken out for the preparation of composite specimen.

4.3. Physical dimensions: The prepared specimens were measured according to ASTM D 5947-06. Mitutoyo Micrometer, model 293-230 having L.C. 0.001 mm, range 0-25 mm, supplied by Haresh Machine Tools Company, Mumbai, India was used for the measurement of dimensions.

4.4. Samples weighing: Fiber and prepared composite specimens were weighed using Shimadzu, Electronic Balance, Type BL-220H, Readability 0.001 g, and Supplied by Vinay Scientific Company, Vijayawada, India.
4.5. Tensile properties characterization: The specimens were prepared according to ASTM D 5083-02 using hand-lay up technique and were tested using Electronic Tensometer, supplied by Kudale Instruments Private Limited, Pune, India.

5. RESULTS AND DISCUSSION

Variation of density with increase in percentage volume fraction of untreated and chemically treated okra woven fiber reinforced polyester composites is shown in **Figure 2, 3 and 4**. The density of all the composites decreased with increase in volume fraction of fiber. This is due to the low density of the fiber than that of the matrix and thereby resulting composite density obviously decreased.

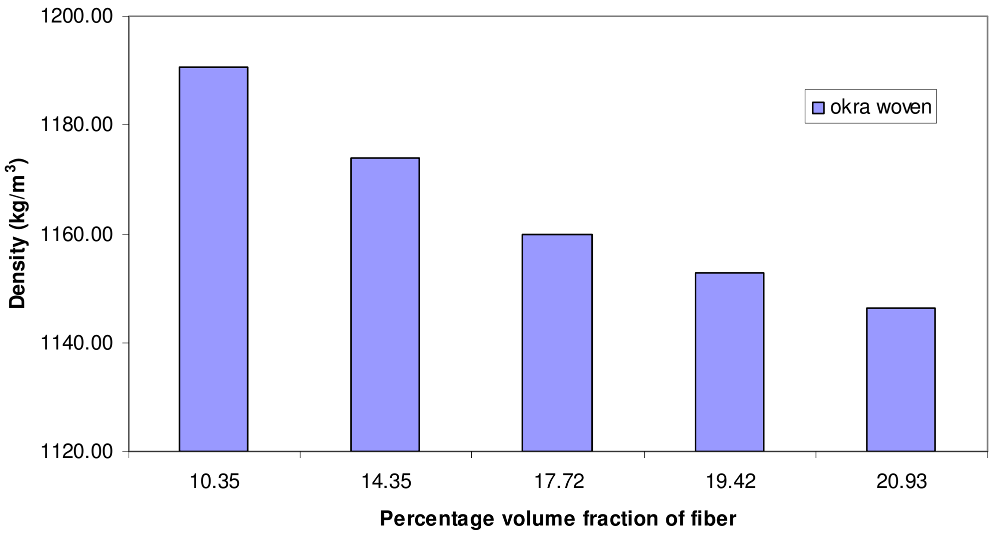

FIGURE 2: Density of okra woven fiber reinforced polyester composites with varying percentage volume fraction of okra fiber

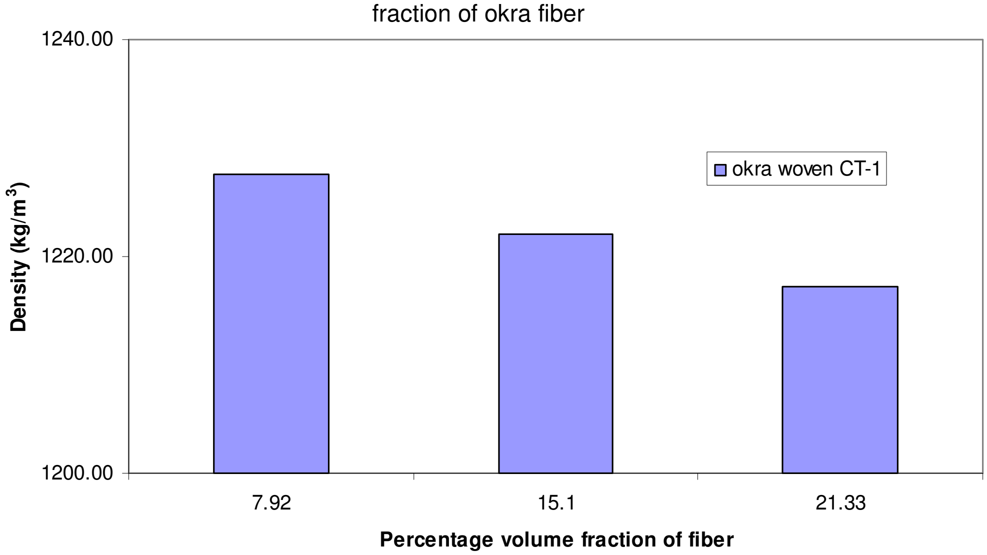

FIGURE 3: Density of okra woven chemical treatment-1 fiber reinforced polyester composites with varying percentage volume fraction of okra fiber

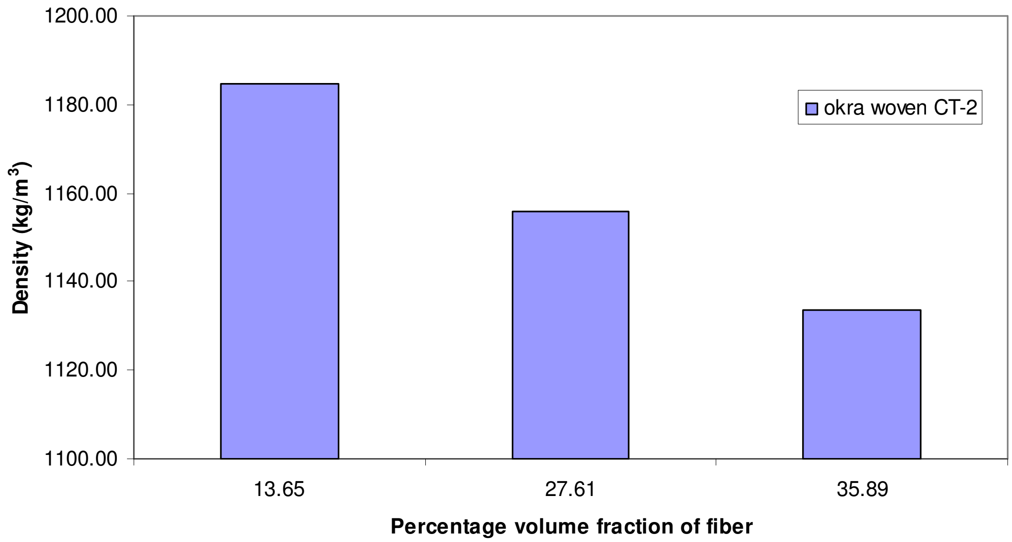

FIGURE 4: Density of okra woven chemical treatment-2 fiber reinforced polyester composites with varying percentage volume fraction of okra fiber

Okra woven fiber chemical treatment-2 reinforced polyester composites showed linear increase in their tensile strength up to the volume fraction of 27.61% **Figure 5**. There is a clear increase in the tensile strength and its value was 76.9%, 79.82%, 134.47% higher than okra woven CT-1, okra woven untreated FRP composites and plain polyester specimens respectively.

Figure 6 shows variation of specific tensile strength with percentage volume fraction of untreated and chemically treated okra woven fiber reinforced polyester composites. From the volume fraction of 14.35% to 19.42% specific tensile strength is almost same for okra woven FRP composites before and after chemical treatment of okra woven fiber. At highest volume fraction, untreated okra woven FRP composites have shown specific tensile strength 4.48% higher than okra woven CT-1 FRP composites. Increase in treatment time under H_2SO_4 caused ingestion of lingo cellulose content in the fiber and also weaken the knot portions in the okra woven fiber.

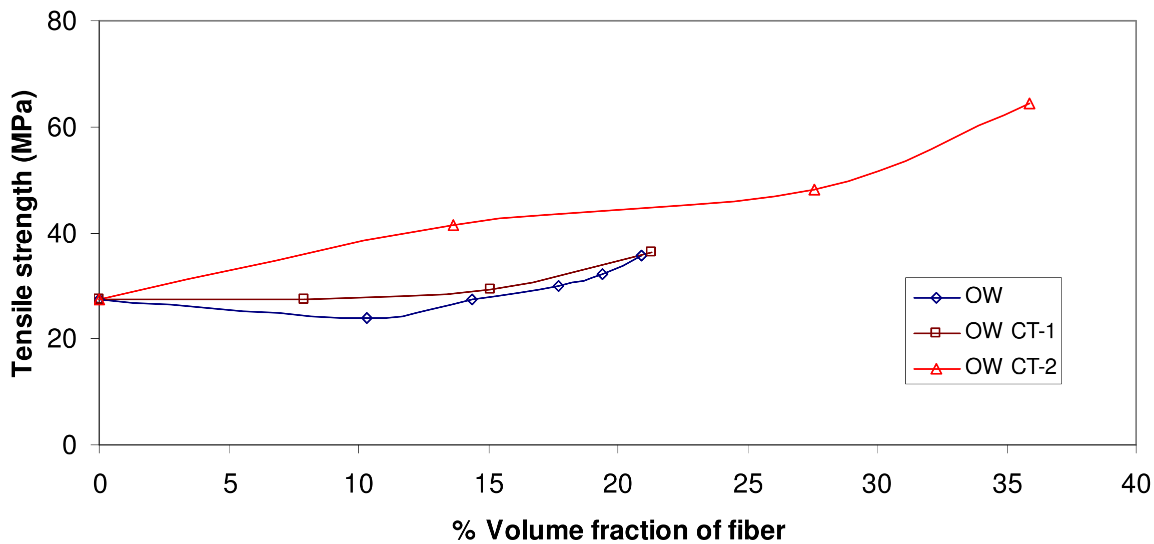

FIGURE 5: Effect of percentage volume fraction of fiber on tensile strength of untreated and treated okra woven fiber reinforced polyester composites

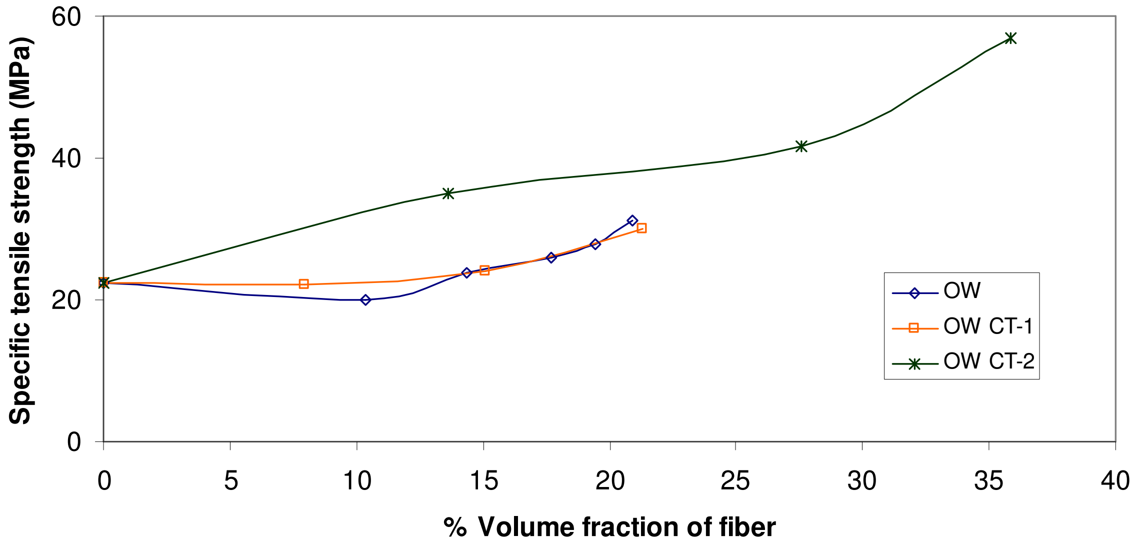

FIGURE 6: Effect of percentage volume fraction of fiber on specific tensile strength of untreated and treated okra woven fiber reinforced polyester composites

Tensile modulus of okra woven chemical treatment-2 fiber reinforced polyester composites shown linear increase in its value with increase in percentage volume fraction of fiber and is higher than all other composites considered in the present research **Figure 7.** Composites fabricated using okra woven CT-2 fiber showed tensile modulus of 30.58%, 18.03% than okra woven CT-1 and untreated okra woven FRP composites respectively.

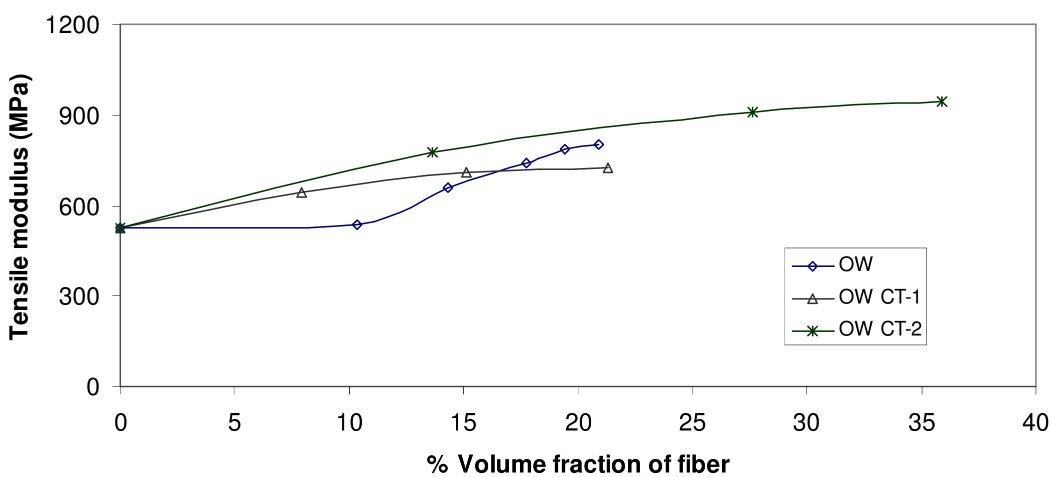

FIGURE 7: Effect of percentage volume fraction of fiber on tensile modulus of untreated and treated okra woven fiber reinforced polyester composites

Figure 8 shows specific tensile strength variation with increase in percentage volume fraction of untreated and chemically treated okra woven fiber reinforced polyester composites. Specific tensile modulus of okra woven FRP composites increased linearly from 14.35% to 20.93% volume fraction and chemical treatment-1 of okra woven fiber caused uniform and linear increase in its value with increase in volume fraction.

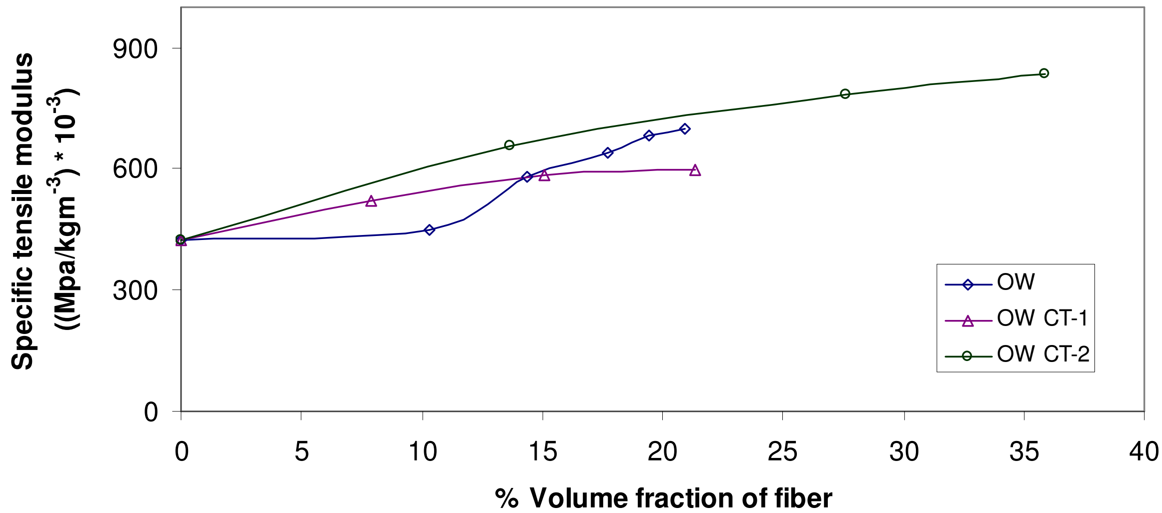

FIGURE 8: Effect of percentage volume fraction of fiber on specific tensile modulus of untreated and treated okra woven fiber reinforced polyester composites

6. CONCLUSIONS AND FUTURE WORK

1. Okra woven natural fiber extracted manually and optimum period of placing stems in mud water is 6 days. Changes in the time period on either side caused the pulp adhere to fiber in the former case and putrid of fiber in the later case.
2. Special care must be taken starting from seed selection, growth of plant till the extraction of fiber. If it is not happened resulted in fiber breakage.
3. Knot portions of the fiber must be properly impregnated with resin.
4. Okra FRP composites is useful for the preparation of doors for house hold purposes with light weight.
5. Practical suitability of okra natural fiber in domestic and industries is to be tested.

7. REFERENCES

1. Valadez-Gonzalez, J.M. Cervantes-Uc, R. Olayo, P.J. Herrera-Franco. *"Effect of fiber surface treatment on the fiber–matrix bond strength of natural fiber reinforced composites".* Composites Part B: engineering, 30 (3): 309-320, 1999

2. Paul Wambua, Jan Ivens, Ignaas Verpoest. "*Natural fibres: can they replace glass in fibre reinforced plastics?"*. Composites Science and Technology, 63(9): 1259-1264, 2003

3. Maya Jacob, Sabu Thomas, K.T. Varughese. *"Mechanical properties of sisal/oil palm hybrid fiber reinforcednatural rubber composites".* Composites Science and Technology, 64(7-8): 955-965, 2004

4. Wolfgang Gindl, Jozef Keckes. *"Tensile properties of cellulose acetate butyrate composites reinforced with bacterial cellulose".* Composites Science and Technology, 64(15): 2407-2413, 2004

5. M. Brahmakumar, C. Pavithran, R.M. Pillai. *"Coconut fibre reinforced polyethylene composites: effect of natural waxy surface layer of the fibre on fibre/matrix interfacial*

bonding and strength of composites". Composites Science and Technology, 65(3-4): 563-569, 2005

6. M.N. Arib, S.M. Sapuan, M.M.H.M. Ahmad, M.T. Paridah, H.M.D. Khairul Zaman. *"Mechanical properties of pineapple leaf fiber reinforced polypropylene composites"*. Materials and Design, 27(5): 391-396, 2006

7. Thi-Thu-Loan Doan, Shang-Lin Gao, Edith Mader. *"Jute/polypropylene composites I. Effect of matrix modification"*. Composites Science and Technology, 66(7): 952-963, 2006

8. A.V. Ratna Prasad, K. Murali Mohan Rao, K. Mohan Rao, A.V.S.S.K.S. Gupta. *"Effect of fiber loading on Mechanical Properties of Arecanut fiber reinforced polyester composites"*. National Journal of Technology, 2(1):56-62, 2006

9. Sami Ben Brahim *, Ridha Ben Cheikh. *"Influence of fiber orientation and volume fraction on the tensile properties of unidirectional Alfa-polyester composite"*. Composites Science and Technology, 67(1): 140-147, 2007

10. Angelo G. Facca, Mark T. Kortschot, Ning Yan. *"Predicting the tensile strength of natural fibre reinforced thermoplastics"*. Composites Science and Technology, 67(11-12): 2454-2466, 2007

11. K. Murali Mohan Rao, A.V. Ratna Prasad, M.N.V.Ranga Babu, K. Mohan Rao, A.V.S.S.K.S. Gupta. *"Tensile properties of elephant grass fiber reinforced polyester composites"*,42 (9): 3266-3272, 2007

12. Ratna Prasad, K. Murali Mohan Rao. *"Tensile and impact behaviour of Rice straw polyester composites"*, 32 (4): 399-403, 2007

13. Benjamin Bax, Jorg Mussig. *"Impact and tensile properties of PLA/Cordenka and PLA/flax composites"*. Composites Science and Technology, 68(7-8): 1601-1607, 2008

14. Nattakan Soykeabkaew, Noriko Arimoto, Takashi Nishino, Ton Peijs. *"All-cellulose composites by surface selective dissolution of aligned ligno-cellulosic fibres"*. Composites Science and Technology, 68(10-11): 2201-2207, 2008

15. Flavio de Andrade Silva, Nikhilesh Chawla, Romildo Dias de Toledo Filho. *"Tensile behavior of high performance natural (sisal) fibers"*. Composites Science and Technology, 68(15-16): 3438-3443, 2008

16. K. Sabeel Ahmed, S. Vijayarangan. *"Tensile, flexural and interlaminar shear properties of woven jute and jute-glass fabric reinforced polyester composites"*. Journal of materials processing technology, 207 (1-3): 330-335, 2008

17. D. Bachtiar, S.M. Sapuan, M.M. Hamdan. *"The effect of alkaline treatment on tensile properties of sugar palm fiber reinforced epoxy composites"*. Materials and Design, 29 (7): 1285-1290, 2008

18. Shinji Ochi. *"Mechanical properties of kenaf fibers and kenaf/PLA composites"*. Mechanics of materials, 40 (4-5): 446-452, 2008

19. Yibin Xue, Yicheng Du, Steve Elder, Kunpeng Wang, Jilei Zhang. *"Temperature and loading rate effects on tensile properties of kenaf bast fiber bundles and composites"*. Composites Part B: engineering, 40 (3): 189-196, 2009

20. Daniella Regina Mulinari, Herman J.C. Voorwald, Maria Odila H. Cioffi, Maria Lúcia C.P. da Silva, Tessie Gouvêa da Cruz, Clodoaldo Saron. *"Sugarcane bagasse cellulose/HDPE composites obtained by extrusion"*. Composites Science and Technology, 69(2): 214–219, 2009