THE EFFECTS OF REGRESSORS ON TENSILE STRENGTH RESPONSES OF RHUS FIBER REINFORCED THERMOSET COMPOSITES

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Abstract.

Due to environmental concern on synthetic fibers (such as glass, carbon, ceramic fibers, etc.) natural fibers such as rhus, hemp, jute, kenaf, etc. are widely used. In this research work, rhus fiber reinforced polyester matrix composites have been developed by hot compression moulding technique with varying process parameters, such as fiber condition (untreated and alkali treated), fiber sizes (1, 2 and 4 mm) and percentages (5%, 10% and 15% by weight). The developed rhus fiber reinforced composites were then characterized by tensile test, and the effects of regressors on tensile strength responses analyzed. The results show that tensile strength increases with increase in the fiber size and fiber percentage; however, after a certain size and percentage, the tensile strength decreases again. Compared to untreated fiber, no significant change in tensile strength has been observed for treated rhus fiber reinforcement.

Keywords: *Regressor analysis, Rhus fiber, Thermoset, Composites, Tensile strength responses.*

1. Introduction.

Now-a-days, newer polymer matrix composites reinforced with fibers such as glass, carbon, aramid, etc., is getting a steady expansion in uses because of their favourable mechanical properties. However, they are quite expensive materials. For this, natural fibers such as jute, flux, hemp, etc. can be alternately used to reduce the cost of the composites (Mohanty et al., 2002). Moreover, production of environmentally friendly materials is another important issue. Natural fiber composites focus well into this ecological image. The use of natural fibers, derived from annually renewable resources, as reinforcing fibers in both thermoplastic and thermoset matrix composites provide positive environmental benefits with respect to ultimate disposability and raw material utilization.

The prominent advantages of natural fibers include acceptable specific strength properties, low cost, low density, high toughness, good thermal properties, and so on. Low specific weight, which results in a higher specific strength and stiffness than glass is a benefit especially in parts designed for bending stiffness. In the fields of automotive industries, reduction of energy consumption in production of motor vehicles and improvement of their day to day fuel economy are growing upwards due to accelerating use of natural fiber composites.

In the case of thermoplastic composites, adhesion between the hydrophilic fiber (such as jute fiber) and hydrophobic matrix (such as polypropylene) is poor (Karmaker and Young Quist, 1996). Therefore, the bond between them needs to be improved. This may be improved by alkali treatment. It is believed that the alkali treatments results in an improvement in the interlocking, hence promoting more matrix/fiber interpenetration at the interface (Gassan and Bledzki, 2000).

In this project, rhus fiber reinforced polyester composites were prepared under various processing parameters using hot compression molding technique. The goal of this work is to analysis the changes of tensile strength under various process parameters.

2. Materials and Methods

2.1. Materials.

The composites were produced using treated (rhus fibers were treated with 20% sodium hydroxide) and untreated rhus fiber and polyester. The treated and untreated rhus fibers were chopped into various lengths of 1, 2 and 4 mm. For all lengths of fibers, composites were developed with 5, 10 and 15% (by weight) of rhus.

2.2. Methods.

Composite Fabrication: The chopped fibers were sieved with 1, 2 and 4 mm sieves for obtaining the desired variation in rhus fiber length. The fibers were conditioned at 110°C for 24 hours to remove moisture and polyester was also conditioned at the same temperature. Proper proportion of fibers (5, 10 and 15% by weight for each of 1, 2 and 4 mm length) and polyester were then properly blended in the blender to get a homogeneous mixture for each length type. The mixture was placed in a mould and composites were made with 50 kN load at180°C.

Tensile Test: Tensile testing of the samples was performed according to ASTM D 638-98 on a universal test machine operated at a crosshead speed 3 mm/min. Three test samples from every composition (combination of predefined fiber length and wt percentage with polypropylene) were tested at the same time and the averages of results were used.

3. Results and Discussion.

In this research work, selected tensile samples were prepared according to ASTM specification and were tested. Analyses were ran also and observed with their results presented in tabular forms as well as in Figures (Alam et al., 2004).

3.1. Tensile strength.

The typical load-stroke curve obtained from the tensile test is shown in Figure 1. From this curve, it can be observed that the failure behaviour of the rhus fiber reinforced thermoset composite is brittle type.

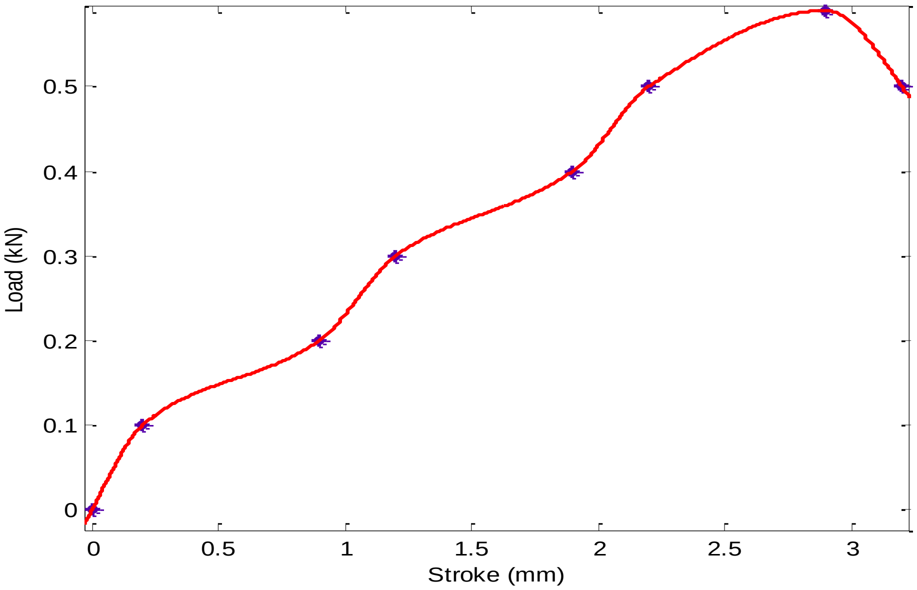

Fig. 1. An observed load-stroke curve obtained from tensile test

Table 1. Analysis table for the observed load-stroke curve obtained from tensile test

X_i	$df(X_i)/dX$	$d^2f(X_i)/dX^2$	$integral\ f(X_i)$
0	0.579365	0.935634	0
0.32	0.16763	-0.540011	0.0246785
0.64	0.103449	0.138884	0.0711156
0.96	0.328451	1.46479	0.130053
1.28	0.169719	-0.452347	0.217222
1.6	0.110746	0.0837679	0.325027
1.92	0.258524	2.1907	0.445639
2.24	0.195639	-0.0543028	0.592856
2.56	0.140697	-0.289086	0.764771
2.88	0.0106241	-0.523869	0.950453
3.2	-0.428571	0.285714	1.12897

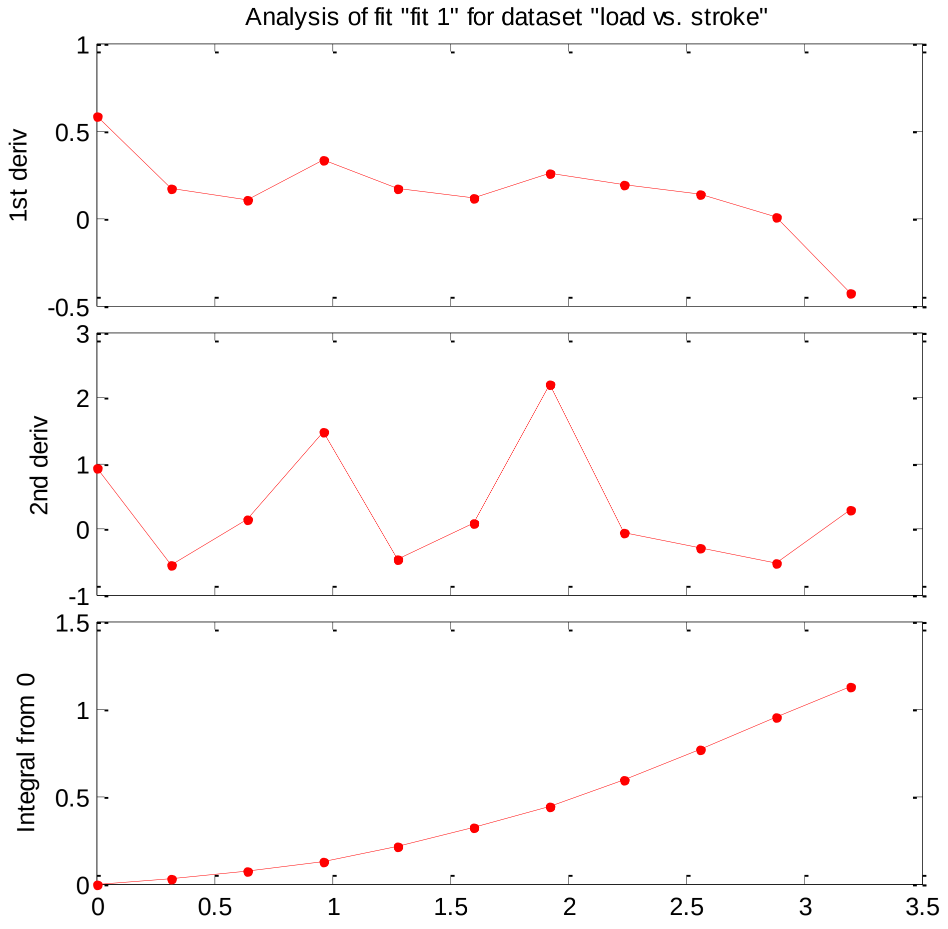

Fig. 2. Analysis Figure for the observed load-stroke curve obtained from tensile test

The tensile test results have been plotted in Figures 3 and 5 as a function of fiber length. From these Figures, it is clear that as the fiber length increases, the value of tensile strength increases and then decreases. This observation is true for almost all cases (with exception in the case of 5% treated specimens). Figures 7 and 9 represent the relationship between fiber percentage (wt %) and tensile strength value. As per these fits, in general, as the fiber percentage increases, the tensile strength also increases and then decreases.

As observed from the curves, tensile strength was increased to a maximum at 2 mm fiber length and then dropped. Also, tensile strength was found to increase to a maximum at 10% fiber (by weight) and then decreased. 2 mm and 10% treated fiber composites gave better results than untreated fiber composites but not so distinguishable.

Fiber length has profound impact on the properties of composites. Besides holding the fibers together, the matrix has the important function of transferring applied load to the fibers. The efficiency of a fiber reinforced composite depends on the fiber-matrix interface and the ability to transfer stress from the matrix to the fiber (Karnani et al., 1997). In small fiber size (here, 1 mm), tensile strength is low due to the fact that length may be not sufficient enough for proper distribution of load. As proper length is not available for stress distribution, failure occurs easily.

On the other hand, for the composites of longer fiber size (here, 4 mm), tensile strengths were decreased compared to 2 mm fiber reinforced composites. The probable reason is that a long fiber may not become compatible with the matrix properly. Thus improper bonding occurs between the fibers and the matrix. Moreover, fibers may be folded and there is no bonding between the folded and unfolded portion of fiber which resulted in a lower strength. Fiber entanglement may also contribute to reduce the strength (Joseph et al., 2002). For 5% treated fiber composites, the exceptional behaviour is probably that 4 mm size of fiber is still not enough to create fiber entanglement or folding inside the matrix.

In phenol formaldehyde/banana fiber composites, with the increase of fiber length tensile strength was found to be increased (Joseph et al., 2002). The trend of increase followed by decrease of tensile strength observed in current project was found in sisal/polypropylene composites (Jayaraman, 2003).

According to Figures 7 and 9, after 10 wt. percent fiber as reinforcement in the composites, tensile strength was decreased with higher percentages of fiber. The incorporation of fibers into thermoset leads to poor dispersion of fibers due to strong inter fiber hydrogen bonding which holds the fibers together. Improper adhesion hinders the considerable increment of tensile strength (Beckermann et al., 2004). Thus, as fiber percentage increases, gathering of fibers takes place instead of dispersion and melted polyester cannot wet them properly due to non entrance of melt through the adjacent two fibers. Since no adhesion is present between the fibers and fibers are also not bonded with matrix, failure occurs before attaining the theoretical strength of composite. Thus high fiber content was limited by the incompatibility issue unless coupling agent is used (Wollerdorfer and Bader, 1998).

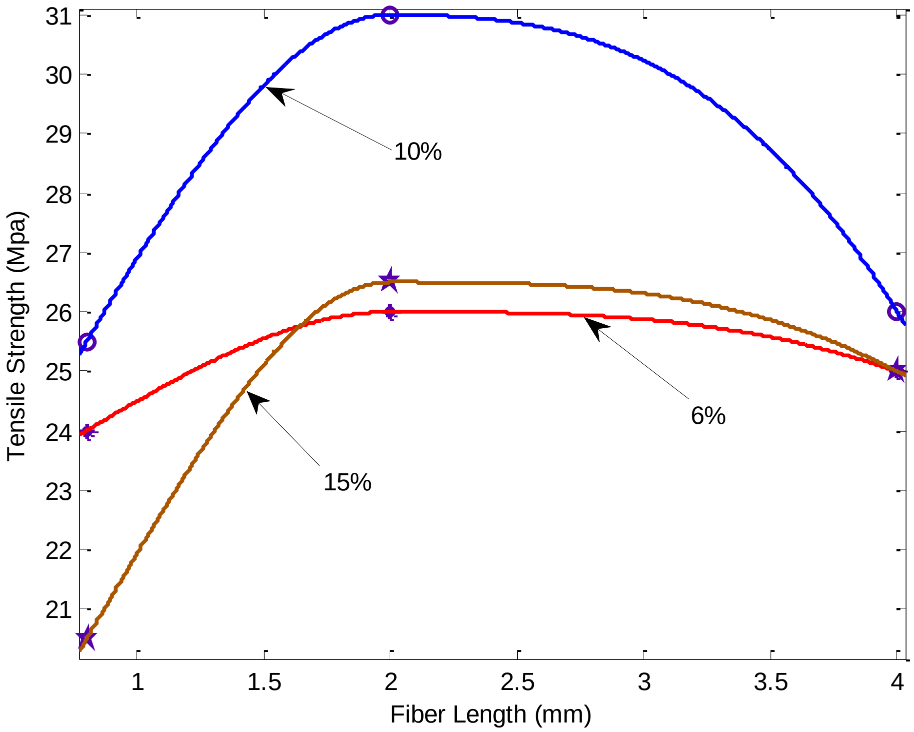

Fig. 3. Tensile Strength of Untreated Rhus Fiber Composites at Different Lengths

Table 2. Analysis table for the Tensile Strength of Untreated Rhus Fiber Composites at Different Lengths

X_i	$df(X_i)/dX$	$d^2f(X_i)/dX^2$	$integral\ f(X_i)$
0.8	2.47917	0.0694444	0
1.12	2.31917	-1.06944	7.80576
1.44	1.79472	-2.20833	15.8459
1.76	0.905833	-3.34722	24.0667
2.08	-0.0024	-0.06	32.3775
2.4	-0.06	-0.3	40.6967
2.72	-0.1944	-0.54	49.0091
3.04	-0.4056	-0.78	57.3009
3.36	-0.6936	-1.02	65.5506
3.68	-1.0584	-1.26	73.7286
4	-1.5	-1.5	81.7975

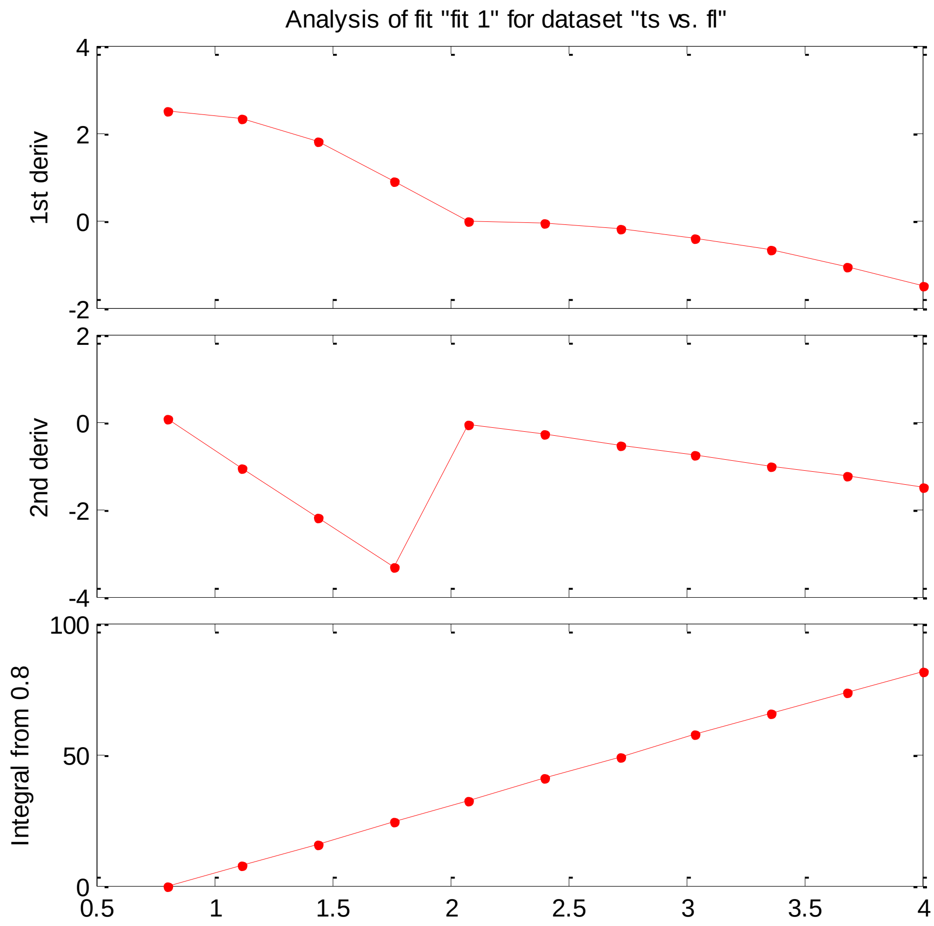

Fig. 4. Analysis Figure for the Tensile Strength of Untreated Rhus Fiber Composites at Different Lengths

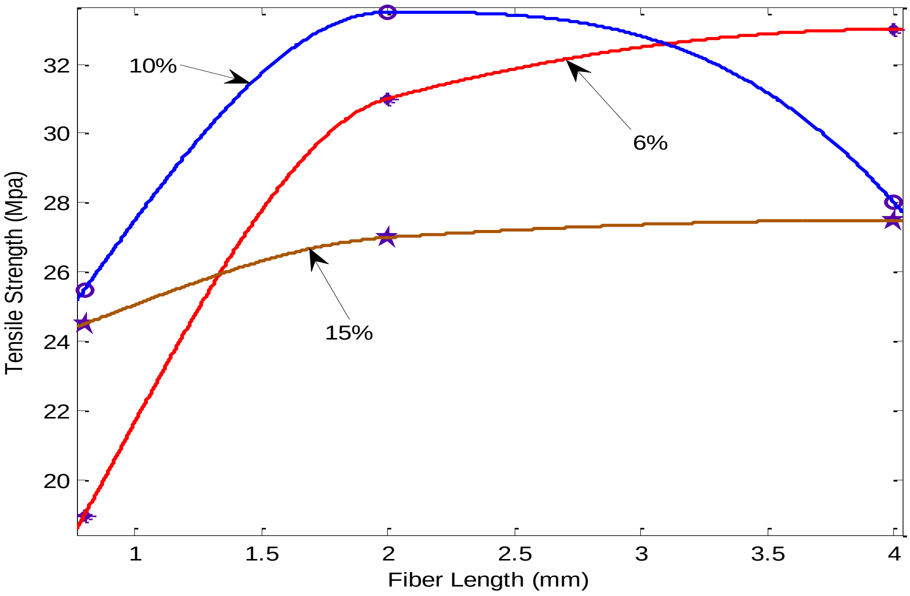

Fig. 5. Tensile Strength of Treated Rhus Fiber Composites at Different Lengths

Table 3. Analysis table for the Tensile Strength of Treated Rhus Fiber Composites at Different Lengths

X_i	$df(X_i)/dX$	$d^2f(X_i)/dX^2$	$integral\ f(X_i)$
0.8	13.375	2.16463	0
1.12	13.0706	-4.06707	6.76811
1.44	10.7721	-10.2988	14.8576
1.76	6.47939	-16.5305	24.0332
2.08	1.87879	-0.908293	33.857
2.4	1.58439	-0.931707	43.9172
2.72	1.2825	-0.955122	54.1397
3.04	0.973112	-0.978537	64.4933
3.36	0.656234	-1.00195	74.9466
3.68	0.331863	-1.02537	85.467
4	0	-1.04878	96.0213

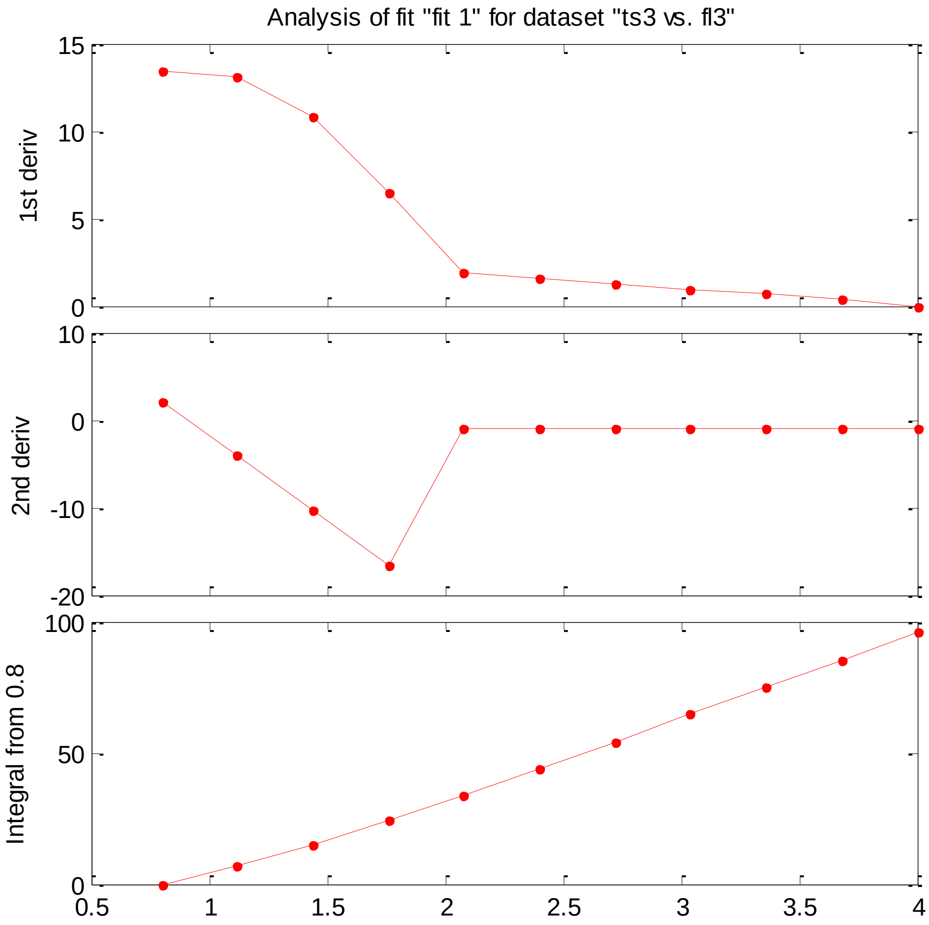

Fig. 6. Analysis Figure for the Tensile Strength of Treated Rhus Fiber Composites at Different Lengths

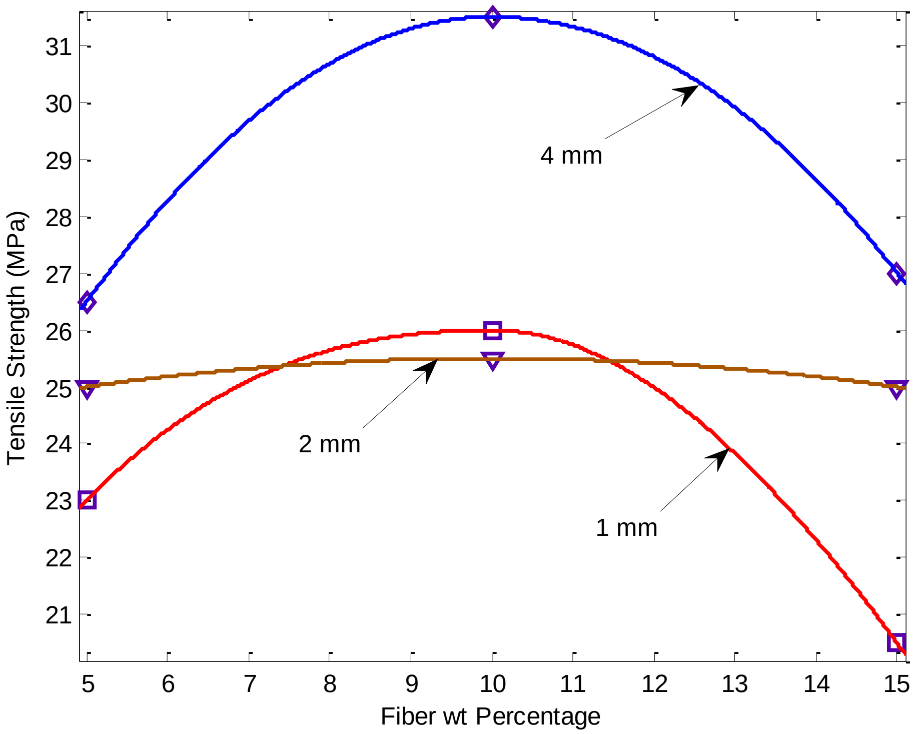

Fig.7. Tensile Strength of Untreated Rhus Composites at Different Fiber wt. Percentages

Table 4. Analysis table for the Tensile Strength of Untreated Rhus Composites at Different Fiber wt. %

X_i	$df(X_i)/dX$	$d^2f(X_i)/dX^2$	$integral\ f(X_i)$
5	1.45	-0.44	0
6	1.04	-0.38	23.6542
7	0.69	-0.32	48.3533
8	0.4	-0.26	73.7475
9	0.17	-0.2	99.5467
10	0	-0.54	125.521
11	-0.51	-0.48	151.433
12	-0.96	-0.42	176.841
13	-1.35	-0.36	201.293
14	-1.68	-0.3	224.401
15	-1.95	-0.24	245.833

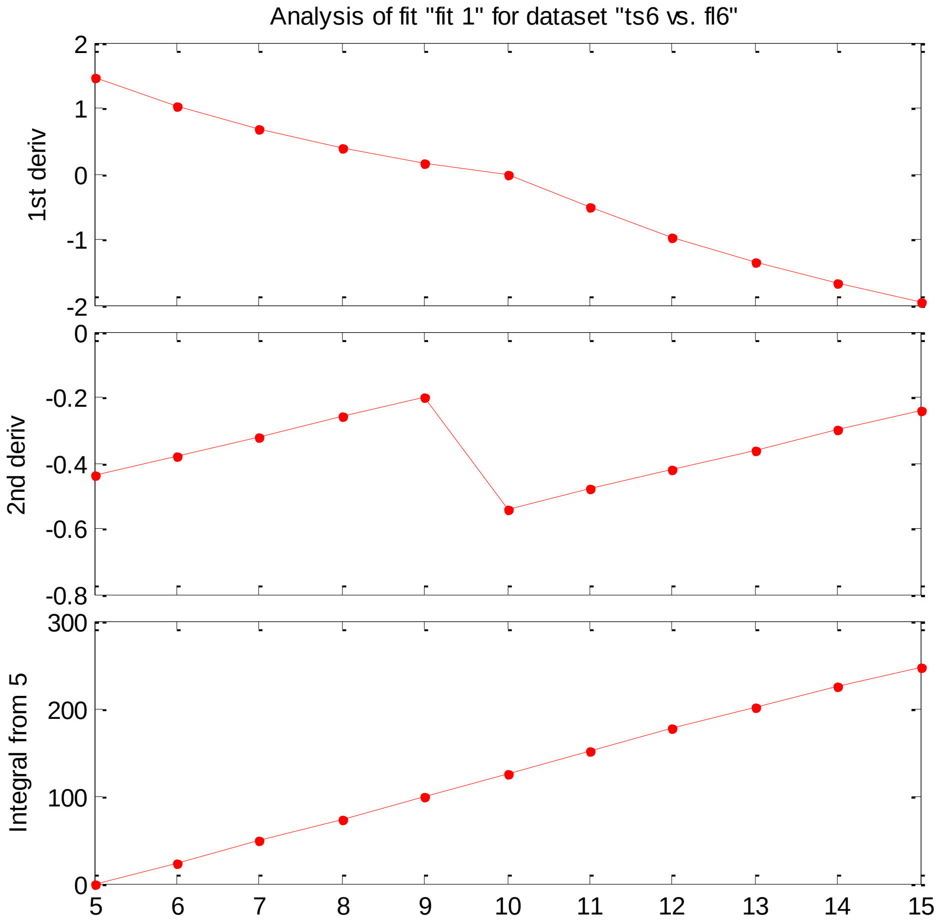

Fig. 8. Analysis Figure for the Tensile Strength of Untreated Rhus Composites at Different Fiber wt. %

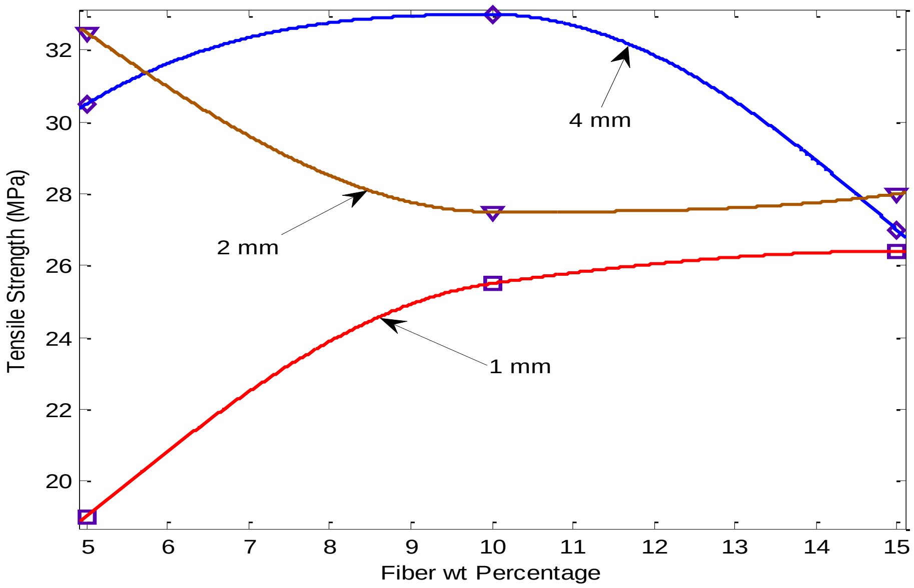

Figure 9. Tensile Strength of Treated Rhus Fiber Composites at Different Fiber wt. Percentages

Table 5. Analysis table for the Tensile Strength of Treated Rhus Fiber Composites at Different Fiber wt. Percentages

X_i	$df(X_i)/dX$	$d^2f(X_i)/dX^2$	$integral\ f(X_i)$
5	1.86	-0.0544865	0
6	1.75466	-0.156195	19.9167
7	1.54761	-0.257903	41.5795
8	1.23885	-0.359611	64.7815
9	0.828389	-0.461319	89.2139
10	0.316216	-0.036973	114.466
11	0.273989	-0.0474811	140.118
12	0.221254	-0.0579892	166.042
13	0.158011	-0.0684973	192.187
14	0.0842595	-0.0790054	218.489
15	0	-0.0895135	244.875

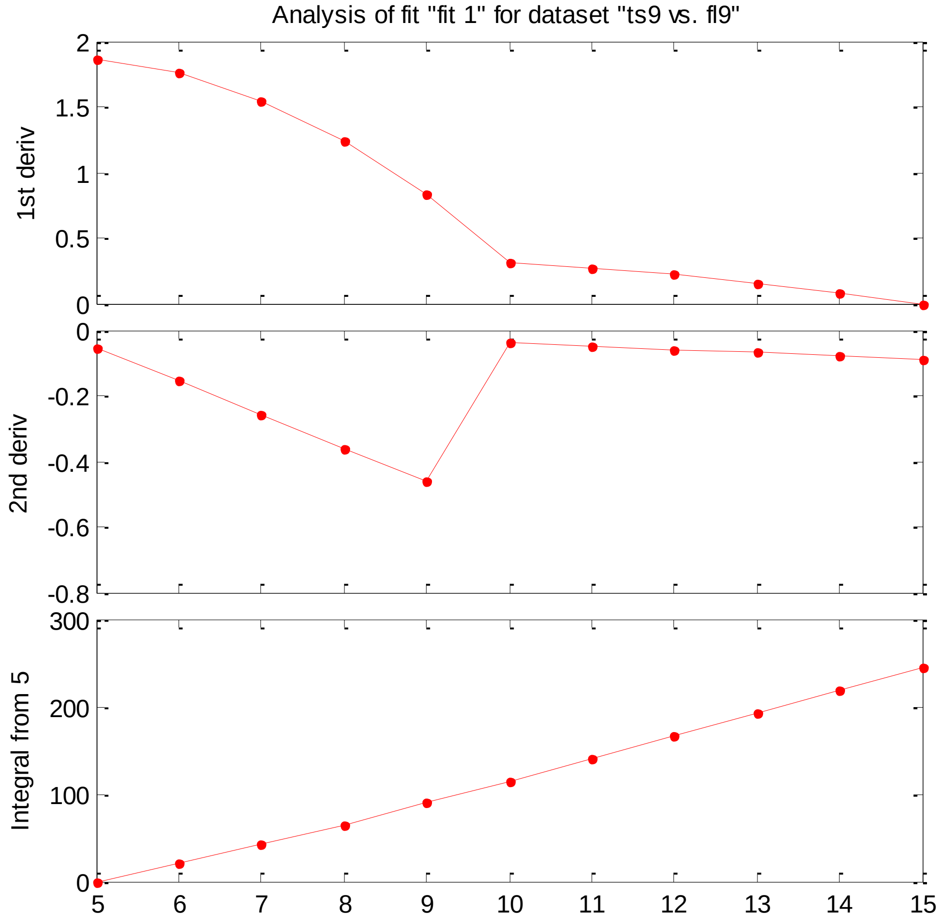

Fig. 10. Analysis Figure for the Tensile Strength of Treated Rhus Fiber Composites at Different Fiber wt. %

It has been reported that initially strength may decrease after a slight increase in strength and then at very high fiber content it may again increase (Wambua et al., 2003, Jayaraman, 2003). In polypropylene/wood composites, tensile strength was found to decrease after a certain percentage of fiber (Beg and Pickering, 2004).

The tensile strengths of the uncoupled composites have values in close range for all fiber percentage levels (Karmaker and Schneider, 1996, Rowell and Stout, 1998). Without coupling agent, fiber content and fiber length do not have significant effects on composite tensile properties (Sameni et al., 2003). There exist incompatibilities between the different surface properties of the polar fibers and non-polar polyester. Due to presence of hydroxyl and other polar groups in various constituents of natural fiber, the moisture uptake is high for dry fibers. All these lead to poor wettability with matrix and weak interfacial bonding between the fiber and relatively more hydrophobic matrices. To improve affinity and adhesion between fiber and matrix, chemical coupling agents can be used so that tensile strength increases (Khan et al., 2001, Saheb and Jog, 1999).

As a coupling agent, MAPP may be used to enhance interfacial adhesion that may react or interact favourably with the hydroxyl group on the fiber surface (Mohanty et al., 2004). Use of coupling agent reduces the number of fiber pull-out (Gassan and Bledzki, 1997).

As evident from Figures 3 - 9, tensile strength was not significantly improved by alkali treatment. But, alkali treatment generally increases the strength of natural fiber composites (Dieu et al., 2004, Gañán and Mondragon, 2004, Razera and Frollini, 2004). A strong sodium hydroxide treatment may remove lignin, hemicellulose and other alkali soluble compounds from the surface of the fibers to increase the numbers of reactive hydroxyl groups on the fiber surface available for chemical bonding. So, strength should be higher than untreated fiber composites. The probable cause of this unlike phenomenon may be, alkali react on the cementing materials of the fiber specially hemicellulose which leads to the splitting of the fibers into finer filaments. As a result, wetting of fiber as well as bonding of fiber with matrix may improve which consequently make the fiber more brittle. Under stress, these fibers break easily. Therefore, they cannot take part in stress transfer mechanism (Ray et al., 2001). So, high concentration of sodium hydroxide may increase the rate of hemicellulose dissolution which will finally lead to strength deterioration. Moreover, unnecessary extra time in treatment may also cause increment of hemicellulose dissolution.

4. Conclusions.

a. In the case of fiber length, 2 mm rhus fiber composites give better tensile strength over 1 and 4 mm rhus fiber composites.

b. In the case of fiber amount, 10 percent fiber (by weight) composites has better tensile strength compared to 5 and 15 wt. percent fiber composites.

c. It can be observed that the failure behavior of the rhus fiber reinforced thermoset composite is brittle type.

d. In the case of composites of longer fiber size, tensile strengths were decreased. The probable reason is that a long fiber may not become compatible with the matrix properly. Thus improper bonding occurs between the fibers and the matrix. Moreover, fiber entanglement may also contribute to reduce the strength

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