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RESEARCH ARTICLE

Mechanical properties of natural fibers reinforced polyester hybrid composite

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Abstract

In this investigation, the mechanical properties of natural fibers reinforced polyester hybrid fiber reinforced polyester composite were analysed based on the wt% and length of the fibers. The glass fiber polyester composites were also prepared to compare the properties. The fractured surfaces of the composite specimens were investigated using scanning electron microscopy. The tensile and the flexural strength increases with the fiber length and content. On the other hand, the impact strength decreases with the fiber length and content. The experimental results were compared with predicted results using regression model.

Keywords: Polymer-matrix composite • Natural fibers • Hybrid composite • Mechanical properties • Scanning electron microscopy

Introduction

In recent years, the natural fibers composites have received a full attention in many applications. Natural fibers are satisfying both economic and ecological interests. They are suitable alternatives for glass fibers due to their specific strength and stiffness [1]. The extensive research work has been carried out on the natural fiber reinforced composite materials in the light of the growing environmental awareness. They are naturally available in abundance and can be used to reinforce polymers to obtain light and strong materials [2]. The fibers from natural plants are utilized for commercial applications such as household applications, automotive industries, etc. [3]. The composites made of polymeric

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materials are being used in many applications, such as industrial, construction, marine, electrical, household appliances, automotive, sporting goods, etc. The polymeric composites have high strength, high stiffness, light weight and high corrosion resistance [2]. Many investigations have been reported on several types of natural fibers such as jute, flax, hemp, bamboo, and kenaf to study the effect of these fibers on the mechanical properties of composite materials [4–7].

Besides, a number of investigations have been conducted on natural fiber hybrid composite material to study the effect of hybridization of these fibers on the mechanical properties. The tensile strength of plain weave hybrid ramie–cotton fabrics polyester matrix composites was determined as a function of the volume fraction and orientation of the ramie fibers [8]. The dynamic properties such as the storage modulus, damping behaviour and static mechanical properties such as tensile, flexural and impact of randomly oriented intimately mixed short banana/sisal hybrid fibre reinforced polyester composites as a function of total fiber volume fraction and the relative volume fraction of the two fibers were investigated [9]. The effects of concentration and modification of fiber surface in sisal/oil palm hybrid fiber reinforced rubber composites have been studied [10]. The water absorption behavior, the effect of the temperature of immersion, fiber volume fraction, and predrying of the fabrics before their incorporation onto the composites of sisal/cotton, jute/cotton and ramie/cotton hybrid fabric reinforced composites were evaluated [11]. The static and dynamic mechanical properties of kenaf fibers and wood flour hybrid polypropylene composite were studied [12]. An investigation has been conducted on short randomly oriented banana and sisal hybrid fiber reinforced polyester composites to analyse its mechanical performance [13].

Statistical model

The statistical design of experiments is the process of planning the experiments in order to get the output data uniformly distributed all over the ranges of input parameters. If an experiment is to be performed most efficiently, then a scientific approach to planning it, must be considered. The statistical design of experiments is the process of planning experiments so that appropriate data will be collected, the minimum number of experiments will be performed to acquire the necessary technical information, and suitable statistical methods will be used to analyse the collected data. Thus there are two aspects to any experimental design, the design of experiment and the statistical analysis of the collected data. Generally two approaches were used in studies to predict yarn quality from fiber and yarn characteristics: theoretical approaches and statistical approaches. Statistical or empirical models have relatively higher predictive power than theoretical models. Multiple regression analyses are the most common statistical methods. Several regression equations have been established [14–18].

The roselle fiber, a close relative of jute and hemp, was used as reinforcing filler for isotactic polypropylene for the first time, mainly due to the cost-effectiveness and natural abundance [19]. But it has not been explored as a reinforcing material for a commodity thermosetting so for. Besides, there is no previous report on the mechanical properties of short roselle and sisal fiber filled polyester hybrid composite to the best of our knowledge. Each natural fiber (Bast and leaf) has its own special mechanical properties. According to Mohanty et al [20] the bast fibers exhibit a superior flexural strength and modulus of elasticity, but the leaf fibers show superior impact properties. This investigation was initiated with aim of attaining whole mechanical performance within a natural fiber composite. Based on the commercial applications like house-hold furniture and industrial applications, the investigation like the present contribution is essential one in future. In the present work, roselle and sisal fibers were used as reinforcements to polyester matrix. The effects of fiber content and length on mechanical properties of roselle and sisal fiber reinforced hybrid polyester composite were investigated. Besides, the glass/polyester composites were also prepared to compare the mechanical properties. The experimental results were compared with predicted results using regression model.

Experimental details

Materials

Roselle and sisal fibers are extracted from the bast and leaf of the plant *Hibiscus sabdariffa L.* and *Agave sisalana*. The filament length of these fibers is 1m and 0.4m. The sisal leafs were cut from sisal plant and tied into bundles in bags. Then the bags containing the sisal leafs were retted in water for 3–4 days. The retted leafs were washed in running water and the top portion of the leafs were removed either by manually or by mechanicallly. The separated fiber was cleaned and dried in the sunlight. The mechanical properties of the sisal fiber is given as Table 1. To get the good quality of fibers the roselle crops were harvested at the bud stage. The stalks were tied into bundles and retted in water for 3–4 days. The retted stem of the roselle plant was washed in running water. Then the fibers were removed from stem, cleaned and dried in the sunlight. The mechanical properties of the roselle fiber is given as Table 1. The natural fiber reinforced polymers are used in the automotive and construction industry [21–23] because natural fibers exhibit many advantageous properties such as low weight, low cost, low density, high specific properties and availability from renewable resources. In the present work, roselle and sisal fibers with 10–30wt% and length of 50–150 mm were used as reinforcements to unsaturated polyester–based matrices, Trade name Satyan Polymer supplied by GV Traders. Unsaturated polyester is an economical thermoset resin that is widely used due to its excellent process ability and good cross linking tendency as well as mechanical properties when cured [24, 25]. Methyl ethyl ketone and Cobalt napthenate were used as accelerator and catalyst respectively. Typical properties of unsaturated polyester are given in Table 2.

Table 1. Mechanical properties of roselle and sisal fiber

Fiber	Strength MPa	Strain	% of elongation	Modulus of GPa
Roselle	147–184	0.05–0.08	5–8	2.76
Sisal	80–164	0.11–0.15	11–15	1.46

Table 2. Typical properties of unsaturated polyester resin matrix

Appearance	Yellow viscous liquid
Specific Gravity @ 25°C (SP/QA/LWI/11)	1.1
Viscostity	
(a) FC-4 (Seconds) @ 30°C	110
(b) Brookfield (CPS) @ 25°C RVT model	480
Volatile content (%) @150°C (SP/QA/LWI/08)	42.5
Acid value (Mg.KOH/G) (SP/QA/LWI/06)	6.97

Preparation of composite specimen

The roselle and sisal fiber were evenly arranged in a mould measuring 360 mm × 360 mm × 3 mm. The resin was degassed before pouring and air bubbles were removed carefully with a roller. The closed mould was kept under pressure for 24 h. The samples were cured at 30° for 24 h followed by a post curing in an oven at 50°C. The composites were fabricated in the form of flat sheets of thickness 3 mm. The length, width and the thickness of each sample were approximately 150 mm × 20 mm × 3 mm, respectively. However, the glass/polyester composites were also prepared as mentioned above. Several glass/polyester composites were prepared by varying the wt% of glass fibers. The length of glass fibers was kept constant to 5 cm for all glass/polyester composites. To analyse the effect of fiber content and length and proportion of matrix material on hybridization of natural fiber in composites, this range of fabrication parameters were selected. The balance of the mixture was made up of the polyester resin to give a total weight batch size of 100%. The composite specimen for tensile, flexural, and impact strength determination were prepared into standard ASTM test specimens.

Material characterization

The tensile and flexural tests were performed according to ASTM standard testing methods. The tensile strength of the composites were measured with a computerized FIE universal testing machine in accordance with the ASTM D638 procedure at a cross head speed of 2 mm/min. The flexural tests were performed on the same machine using the 3-point bending method according to ASTM D790 with the cross head speed of 2 mm/min. In impact test, the strength of the samples was measured using an Izod impact test machine. All test samples were notched. The procedure used for impact testing was ISO 180. The test specimen was supported as a vertical cantilever beam and broken by a single swing of a pendulum. The pendulum strikes the face of the notch. For statistical purposes, a total of six samples for each tests were carried out at room temperature. The fractographic studies were carried out in detail on the tensile and flexural and impact fracture surfaces of roselle/sisal/polyester hybrid composites using scanning electron microscope (SEM) (Model Hitachi S-3000N).

Regression model

Several prediction techniques have been proposed to model the mechanical properties of composite material in terms of different parameters. The regression model is found to be useful in determining the mechanical properties of fiber reinforced polymer composites. The positive hybrid effect is achieved in tensile and flexural strength. So we are taking tensile and flexural strength data for statistical prediction using RM.

The data collected from the experiments was used to build a mathematical model using regression analysis. The proposed relationship between the response variables and fabrication parameters can be represented by the following form:

$$Y = f\,(l, c) \tag{1}$$

Where l, c are fiber length and fiber content of the fabrication process. Y is the observed response.

Regression equations were found to get the relation between response variable (tensile and flexural strength) and the input parameters (fiber length and content) using software for Statistical Packages for Social Sciences 11 (SPSS 11). The model will be in the form of:

$$\sigma_t \; or \; \sigma_b = k \; x \; l^x \; x \; c^y \tag{2}$$

where k, x and y are constants. σ_t and σ_b are tensile and flexural strength in MPa, l is the fiber length in mm, c is the fiber content in wt%.

Results and discussion

Effect of fiber length and content on tensile and flexural strength

The importance of mechanical properties analysis as a main tool in the study of the performances of natural fiber polymer composites is of paramount importance. Mechanical properties of fiber reinforced composites depend on the nature of the polymer matrix, distribution and orientation of the reinforcing fibers, the nature of the fiber– matrix interfaces and of the interphase region. Major properties to be analyzed on fiber reinforced composites are tensile, flexural and impact strength properties etc. the most important and widely measured properties of composite materials used in structural applications is tensile and flexural strength. The maximum fiber content and length of the composite is maintained at 30wt% and 150 mm and the roselle and sisal fiber content and length varied from 5 to 15wt% and 50 to 150 mm. The tensile and flexural strength of glass/polyester composite with 10wt% and 50 mm were 125.3MPa and 146.3MPa as shown in Fig. 4. But the tensile and flexural strength

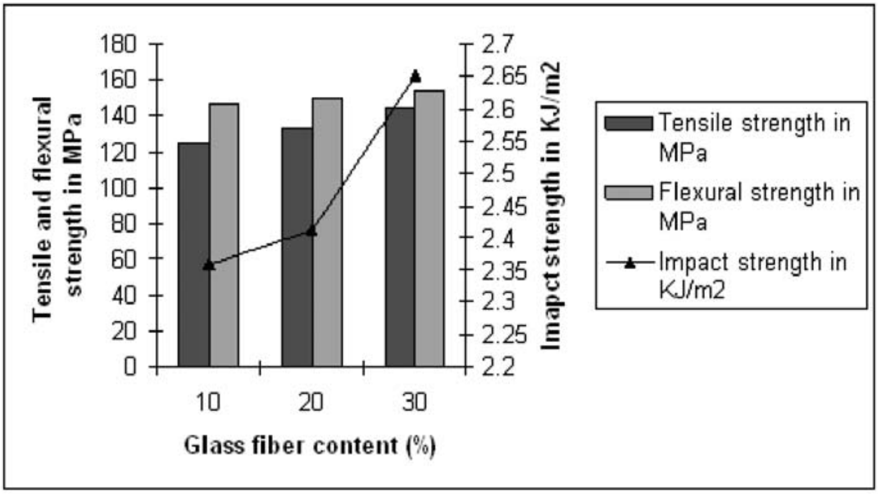

Fig. 4 Tensile, flexural and impact strength of glass/polyester composite

of roselle/sisal fiber hybrid polyester composite with 30 wt% and 150 mm roselle and sisal fibers are 58.7MPa and 76.5MPa as shown in Figs. 1 and 2. It was very low when comparing with glass/polyester composite. But this result may consider as an acceptable one. It was identified that the reason for this low strength is the defects, fiber content and length of roselle and sisal fibers. According to Carlo Santulli [26], the mechanical properties of hybrid composites are decreased as far as a larger volume of plant fibers was introduced. According to McLaughlin EC [28] the plant fibers can work effectively through the limited and controlled occurrence of defects, which are irregularly spaced alone their length. As a result, the tensile strength of the fibers decreases with their length and a pronounced strain rate effect would also be observed. This has also an effect on impact properties of plant fiber composites [26]. Here the roselle fibers take the more responsible than sisal fiber for this tensile and flexural strength. Because the sisal fibers are superior to impact properties [15]. It was proved by

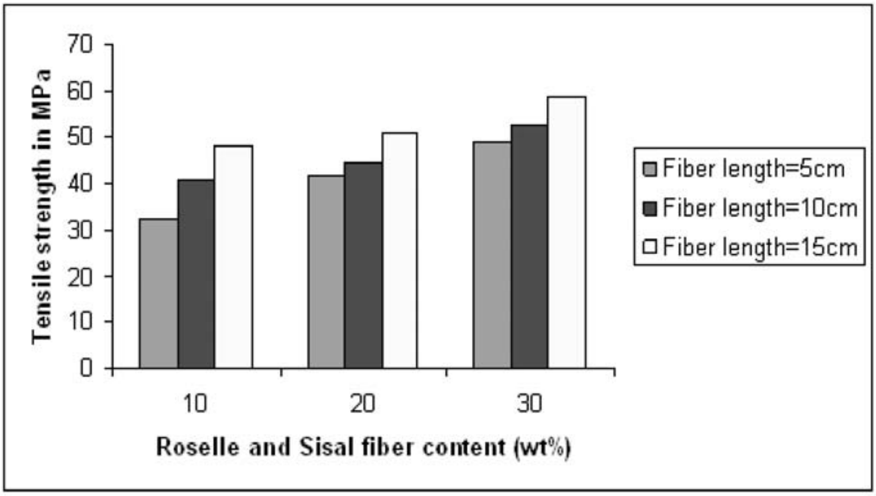

Fig. 1 Effect of fiber content and length on tensile strength

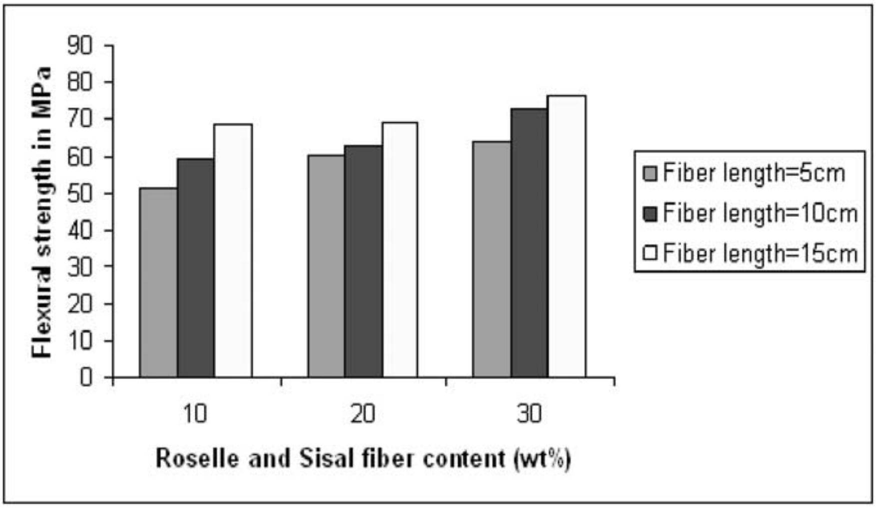

Fig. 2 Effect of fiber content and length on flexural strength

SEM image (Fig. 5 (a) and (b)) of the fractured surface of composites specimen during tensile and flexural tests. Further increasing roselle fiber content and length may increase the tensile strength and flexural strength. Increasing the fiber content from 10 to 30wt % and fiber length from 50 to 150 mm, increased the tensile strength from 32.4 to 58.7MPa, and flexural strength from 51.3 to 76.5 MPa, as shown in Figs. 1 and 2.The hybrid effect of short roselle and sisal

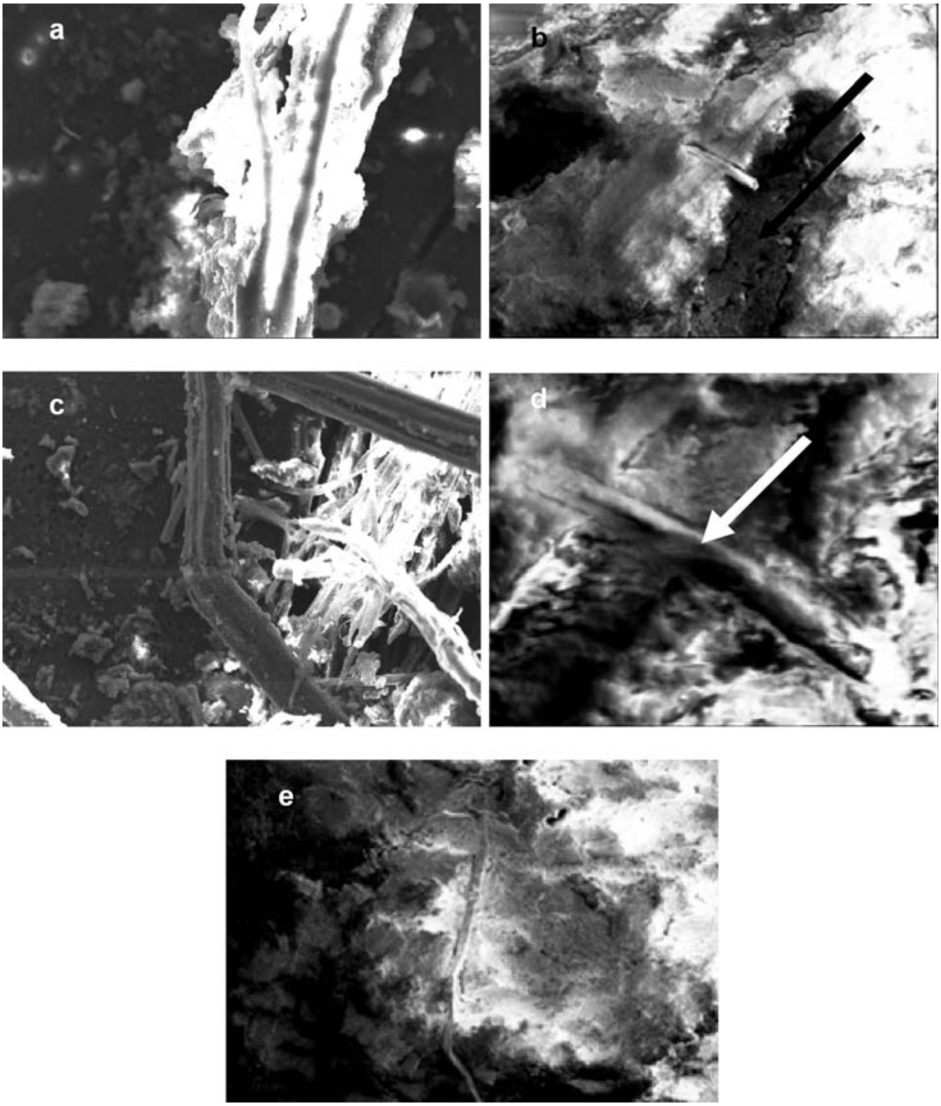

Fig. 5 SEM image of fractured surfaces of composites reinforced with 30 wt% & 150 mm and 10 wt% 100 mm roselle and sisal fibers during: (a) (×500) and (b) (×200) tensile test, (c) (×200) and (d) (×1000) flexural test, and (e) (×200) impact test

fiber on the tensile and flexural strength of roselle and sisal hybrid polyester composite is shown in Figs. 1 and 2. It is also identified that increasing in tensile and flexural strength of the roselle and the sisal fiber hybrid polyester composite with increasing of roselle and sisal fiber content and length was in low level.

Effect of fiber length and content on impact strength

It is identified that the scatter on the measured values of the impact strength of the hybrid composites is quite large and therefore it is difficult to draw conclusions. The impact strength of the glass/polyester composite with 10wt% and 50 mm is 2.36KJ/m^2 as shown in Fig. 4. But the roselle and sisal hybrid composite with 10wt% and 100 mm shows the maximum level of impact strength (1.41 KJ/m2) as given in Table 3. It is comparatively well also very low when comparing with glass/polyester composites. For this impact strength, the sisal fibers take the more responsible than roselle fibers [15]. The low impact strength is observed with maximum level of fiber content and length (30wt% and 150 mm) as shown in Fig. 3. Increasing the fiber content and length of roselle and sisal fibers lowered the impact strength. Here also it is identified that the reason for lowering impact strength is the defects, fiber content and length of roselle and sisal fibers [26, 27]. Carlo Santulli suggested that defects have a more central role in affecting impact properties in plant fiber composites than in glass fiber composites [26]. So if we have increase the sisal fiber content and length than roselle fibers, we can increase the impact strength of the roselle and sisal polyester hybrid composite considerably. Here it is also identified that the pull out of roselle and sisal fibers rather than complete breaking of roselle and sisal fibers were observed (Fig. 5 (c)). The variation in Izod impact strength of short roselle and sisal hybrid polyester composites with short roselle and sisal fibers content is shown in Fig. 3.

Table 3. Experimental values of tensile, flexural and impact strength

SI. No	Fiber length in cm	Fiber content in wt%	Matrix proportion in wt%	Tensile strength in MPa	Flexural strength in MPa	Impact strength in KJ/m2
1	5	10	90	32.4	51.3	1.3
2		20	80	41.7	60.3	1.33
3		30	70	48.8	64.1	1.35
4	10	10	90	40.7	59.1	1.41
5		20	80	44.6	63.2	1.4
6		30	70	52.4	72.9	1.39
7	15	10	90	48.1	68.8	1.28
8		20	80	50.9	69.2	1.25
9		30	70	58.7	76.5	1.32

SEM image of the fractured surface of roselle and sisal fibres hybrid polyester composite with 30wt% & 150 mm in the tensile test is shown in Fig. 5 (a) and (b). The arrows in SEM image indicate the broken sisal fibers during tensile test. SEM image of the fractured surface of the composite specimen with 30wt% and

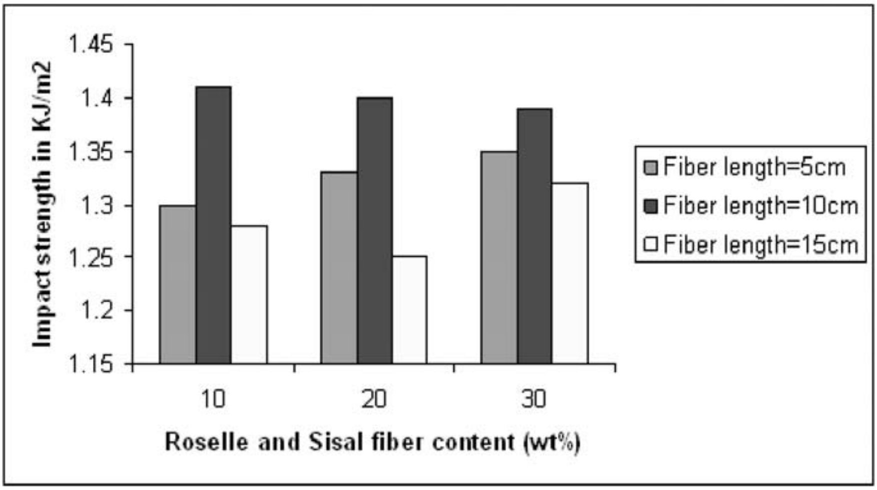

Fig. 3 Effect of fiber content and length on impact strength

150 mm in the flexural test is shown in Fig. 5 (c) and (d). The arrow in SEM image indicates the unbroken roselle fiber during flexural test. The SEM image of the composite specimen with 10 wt% & 100 mm broken under impact is shown in Fig. 5 (e). The fiber pull-out is clearly observed in this figure. It is identified from the fracture surface images of roselle and sisal fiber hybrid polyester composite that there are the composite failures during tensile, flexural and impact tests due to debonding and the fiber pullout. The fiber pull-out combined with matrix failure in roselle and sisal fiber hybrid polyester composites is based on the length of the roselle and sisal fibers.

Development of regression equations

The regression equations for tensile and flexural strength were developed as:

1. Tensile strength (σ_t) = $13.97 \times l^{0.22} \times c^{0.25}$ (3)
2. Flexural strength (σ_b) = $27.98 \times l^{0.18} \times c^{0.15}$ (4)

The squired residual values (R^2) for tensile and flexural strength at dry condition are found to be 0.902 and 0.898 respectively in the regression model. R^2 is a statistic that will give some information about the goodness of fit of a model. In regression, the R^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An R^2 of 1.0 indicates that the regression line perfectly fits the data. The average absolute percentage errors for tensile and flexural strength values are 2.3% and 0.4% respectively. From the values of R^2 and average absolute percentage errors, it is observed that while considering the tensile and flexural strength of the hybrid composites, the regression model (statistical model) is found to be in agreement with experimental results. Figs. 6 and 7 shows the comparison between the experimental and predicted strength values.

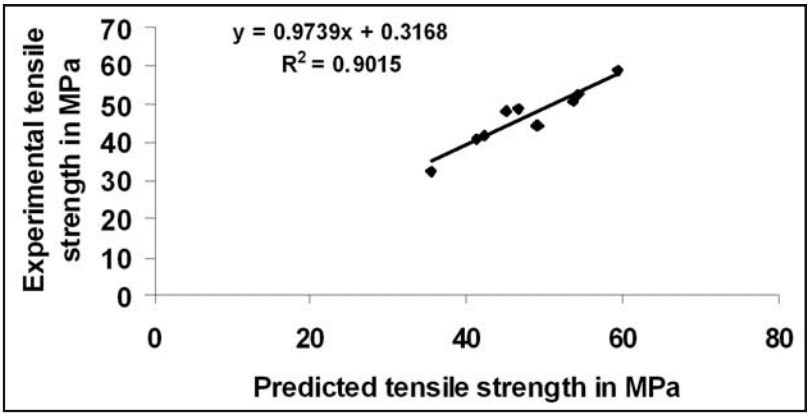

Fig. 6 Comparison of experimental and predicted tensile strength values

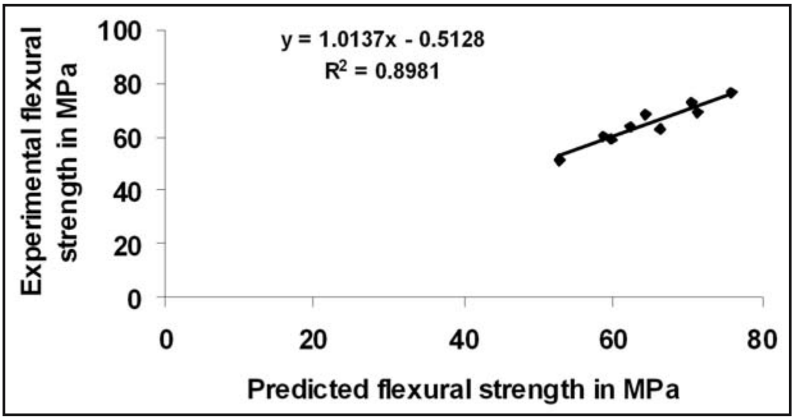

Fig. 7 Comparison of experimental and predicted flexural strength values

Conclusions

This investigation was originally aimed at the replacement of glass fiber reinforced composites. Depending on the exact quality of fiber needed, natural fibers were in most cases cheaper than glass fibers. Natural fibers are also expected to give less health problems for the people producing the composites. They do not cause skin irritations and they are not suspected of causing lung cancer. This investigation reports that increasing the fiber content and length increased the tensile and flexural strength, but lowered the impact strength in the mechanical properties of short roselle and sisal hybrid fiber reinforced polyester composites. The tensile and flexural strengths are mainly depends on the content and length of the roselle fiber while the impact strength is depends on the sisal fibers. It is also observed that the impact strength is decreased with increasing fiber length and content. A relationship between experimental and predicted (Regression model) values was determined to be strong by the high R^2 and low average absolute percentage error values obtained. This means that a good linear relationship was expected. The statistical (Regression) model presented showed a good potential to model the mechanical properties of Roselle and sisal fiber hybrid polyester composites. The comparison between experimental and predicted values showed that they were in good agreement. The results show that the roselle and sisal hybrid fiber polyester composites with the correct or optimum wt% and length of roselle and the sisal fibers can give the expected mechanical performance.

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