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Optimization of Tensile and Impact Behaviours of Randomly Oriented Short Sisal Fiber Reinforced Epoxy Composites Using Response Surface Methodology

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Abstract : The sisal-epoxy composites were fabricated with varying fiber length of 10 mm to 75 mm and fiber loading of 10 % to 50 % by weight as per Response Surface Design. The Response and Contour plots were generated and studied with reference to the ANOVA and Sequential Sum of Squares fit using Response Surface Analysis. The better value of tensile and impact behaviours were determined in nonwoven randomly oriented sisal fiber reinforced epoxy composites using Response Surface Optimization. The multi objective optimization of tensile and impact behaviours were found using Design Expert software package by giving equal weightage to the individual responses.
Keywords: Tensile, Impact Behaviour, Sisal Fiber Reinforced Epoxy Composites, Response Surface Methodology.

Introduction

Fiber reinforced polymer composite play an important role in the applications of engineering materials. The natural fiber reinforced polymers are used in automobiles, constructions, and other Industries because of its availability, low cost, low weight and ease of degradable. The natural fiber composites may spread the application of FRP composites in engineering and structural applications. Satyanarayana et al (1982) extracted fibers from different parts of the coconut palm tree and studied the properties such as size, density, electrical resistivity, ultimate tensile strength, initial modulus and percentage elongation[1]. The effect of fiber length on tensile properties was analyzed by Kalaprasad et al (1997)[2] and the systematic research for the development of sisal – polymer composites was suggested by Kuruvilla Joseph et al (1999)[3]. Mishra et al (2003) studied the effect of glass fibers addition on tensile, flexural and izod impact strength of pine apple leaf fibers and sisal fibers reinforced polyester composites[4]. Harish et al (2009) investigated mechanical behaviours of coir-epoxy composites and compared with glass-epoxy composites[5]. Jayabal et al (2011) investigated the mechanical behaviours of randomly oriented coir fiber reinforced polyester composites with different proportion of fiber length and fiber content[6]. Mishra et al (2002) studied the influence of chemical surface modification on the performance of sisal polyester biocomposites[7]. The introduction of organic particles in addition with natural fiber for the improvement of mechanical behaviours of polymer composites was evolved in recent years[8,9].The research studies on husk fibers (Bhanu Rekha et al (2015))[10] and coconut shell (Udhayasankar et al (2015))[11] introduced new variety of composites in material science and engineering. In this continuation, the role of bio composites were also reviewed by Balaji et al (2015)[12]. The use of Response Surface optimization methods in composites were suggested by Adalarasan et al (2015)[13]. The water absorption studies in composites[14,15], role of bio materials[16-18] and conductivity studies[19] carried out by various researches contributed the development of natural fiber/particle composites in Engineering applications.

Even though most of the research has been carried out on sisal-polymer composites, there is a possibility to find the optimum value of mechanical properties using optimization methods in order to suggest suitable applications and corresponding values of fabrication parameters while manufacturing the products using sisal-epoxy composites. Keeping in this mind, the present investigation is focussed for determining better value of tensile and impact behaviours in nonwoven randomly oriented sisal fiber reinforced epoxy composites using Response Surface Optimization.

Materials and Methods

Materials and Manufacturing

The short sisal fiber was selected as reinforcement material in this study. The maximum length of the short sisal fiber was taken as 70 mm. The five different fiber lengths (10, 20, 30, 40, 50, 60 & 70 mm) were obtained by cutting fiber bundles using sawing machine. The epoxy resin was selected as matrix material for this study because of its availability and strength as compared to other synthetic resins. Liquid epoxy resin and hardener (HY951) in 10:1 ratio was taken in a plastic container and mixed thoroughly for 20 min. The sisal fiber was added and it was mixed thoroughly and poured into a plastic mould. A stainless steel mould having size of 300 × 300 × 3 mm was used for composite plate fabrication using compression molding process. The composite plates were kept under the load of 2.6 MPa for 30 minutes to get uniform curing at room temperature.

Tensile and Flexural Testing

The samples were cut from the composite plate according to ASTM D 638-10. The tensile behaviour of sisal-epoxy composites was measured using the Dual Column Table Top Universal Testing Machine (Tinius Olsen H10K).

Figure 1.Photographic images of fractured tensile and impact specimens

The length, width, and thickness of each sample in tensile testing were 165, 25, and 3 mm, respectively. The izod impact test was carried out using Tinius Olsen (Model: 104) Impact Tester as per ASTM D 256-10 standard and the sample size of 62.5 × 12.5 × 3 mm was used. The photographic image of fractured specimens is shown in Figure 1.

Response Surface Methodology

The user-defined designs were used to ensure the possible factor combinations from the candidate points in the design. Once the model was selected, Analysis Of Variance (ANOVA) is used to test the model as whole and individual terms in the model. After each response is analyzed, multiple response optimizations are carried out with the help of optimization tools. The optimization module searches for a combination of factor levels that simultaneously satisfy the criteria placed on each of the responses and factors.

Results and Discussion

Effect of fiber length and fiber loading on Tensile and Impact behaviours

The observed values of tensile and impact behaviours of sisal-epoxy composites are shown in Figures 2 and 3 respectively. The mechanical behaviours are increased for the increased values of fabrication parameters, after getting maximum value of mechanical behaviours, the decreased trend was observed that shows the presence of feasible points in that region.

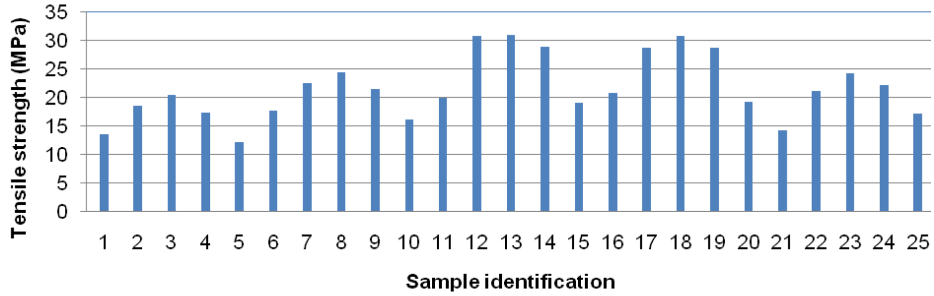


Figure 2. Tensile strength of sisal-epoxy composites

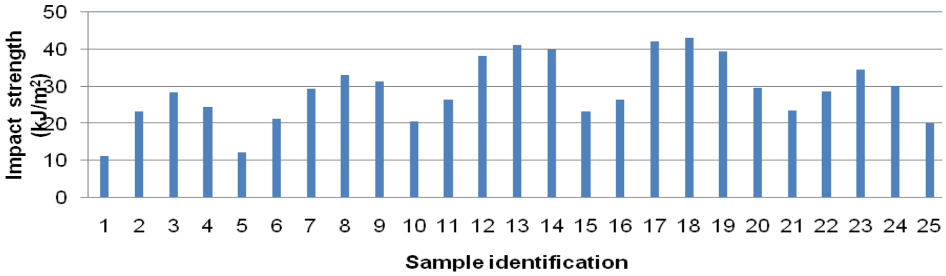


Figure 3. Impact strength of sisal-epoxy composites

Response surface Design of Tensile and Impact behaviours

Response Surface Methodology includes design, analysis, optimization and post optimization. As it is a statistical based optimization method, it absorbs the statistical terms initially as indicated in Table 1.

Table. 1. Statistical inferences of tensile and impact behaviours

Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio
Tensile strength	MPa	25	Polynomial	12.2	31	21.64	5.582413	2.540984
Impact strength	kJ/m^2	25	Polynomial	11.23	43.08	28.9064	8.72667	3.836153

The cubic models were selected for tensile and impact behaviours of sisal-epoxy composites based on the sequential sum of squares fit and better values of coefficient of correlation (R^2). The R^2 values of 0.96 and 0.97 were obtained for tensile and impact behaviours respectively.

Response Surface Analysis of Tensile and Impact behaviours

The response surface and contour plots for tensile and impact behaviours of sisal-epoxy composites are shown in Figures 4 and 5 respectively. The curvatures were obtained in all the interactions, and the maximum value of the mechanical strength for various combinations of fiber parameters was studied using the 3D surface plots. The contour lines in the graph indicate the mechanical strength values for the interaction of the fabrication parameters, and the maximum value of the mechanical strength for various combinations of the fabrication parameters. The points within the contour lines were also identified and the better value of mechanical behaviours was obtained.The nonlinear regression models for the tensile and impact behaviours were developed and listed in Equation 1 and 2. The cubic models were generated using Design Expert 10.0

software package. In the equations, t and i represent the tensile strength and impact strength respectively whereas f_l and f_c represents fiber length and fiber loading respectively.

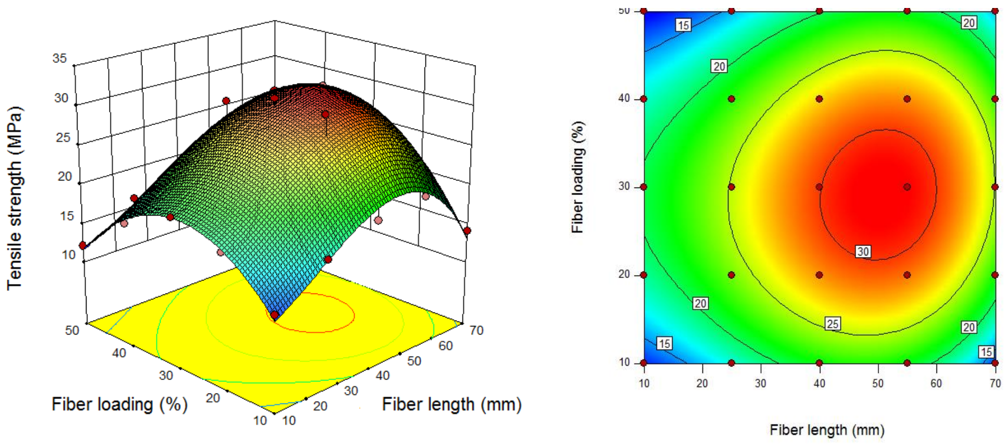


Figure 4. Response and contour plot for tensile behaviours

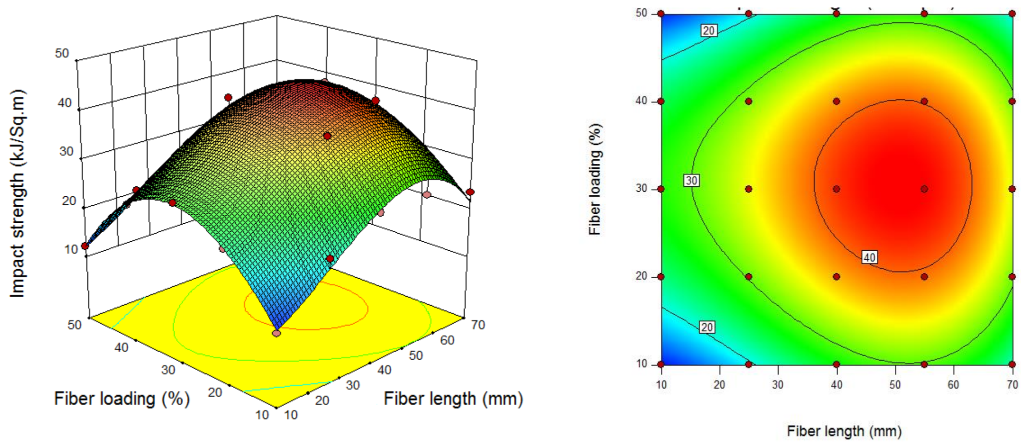
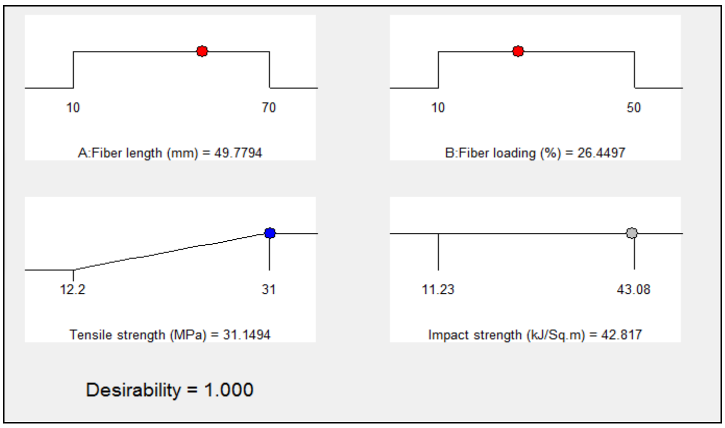


Figure 5. Response and contour plot for impact behaviours

$$t=0.72431+0.057033f_l+1.27757f_c+0.00252413f_lf_c+0.01111f_l^2-0.024250f_c^2-0.000065\, f_l^2f_c-0.0001043\, f_lf_c^2-0.0017679\, f_l^3+0.000058333\, f_c^3 \quad (1)$$

$$i=-8.40058+0.13154f_l+2.02275f_c-0.007197f_lf_c+0.019755f_l^2-0.022972f_c^2+0.0000029206f_l^2f_c+0.000099524f_lf_c^2-0.000261037\, f_l^3-0.000199667f_c^3 \quad (2)$$

Response surface Optimization of Tensile and Impact behaviours



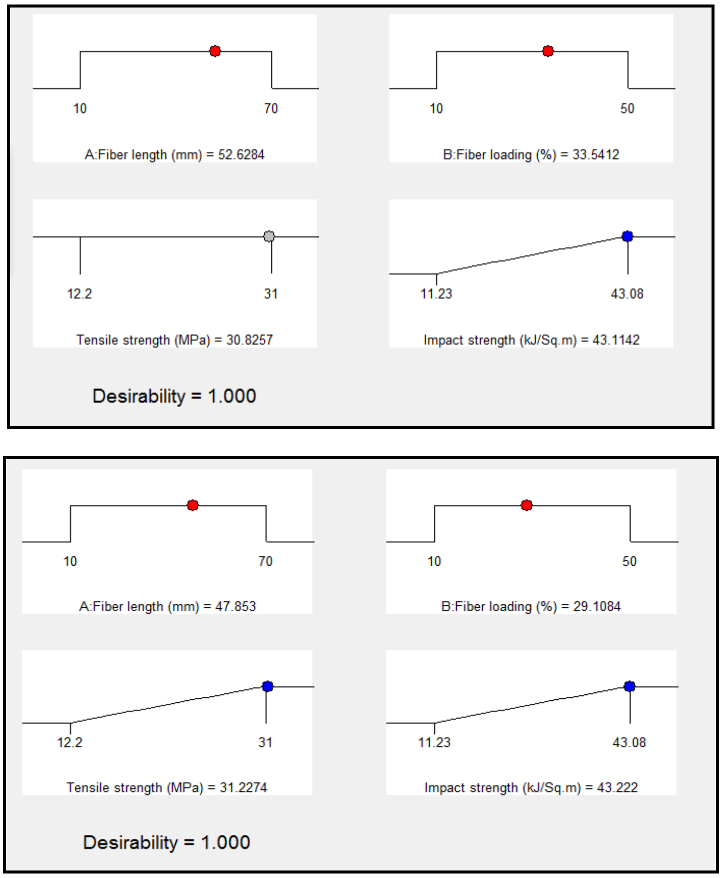


Figure 6 Response Surface Optimization of Tensile and Impact behaviours

The Response Surface Optimization plots of tensile and impact behaviours are shown in Figure 6.The desirability of 1.000 was achieved in all the three cases. The case 1 represents maximization of tensile behaviour, case 2 represents maximization of impact behaviour and case 3 represents maximization of all the mechanical behaviours (Multiobjective optimization).

The better value of tensile strength of 31.1494 MPa was obtained for the fiber length of 49.78 mm and fiber loading of 26.45 % whereas the better value of impact strength of 43.1142 kJ/m^2 was obtained for the fiber length of 52.63 mm and fiber loading of 33.54 %. The better experimental values of tensile and flexural strength are 31 MPa and 43.08 kJ/m^2 respectively.

The optimum value of mechanical behaviours obtained by RSM is also closer to the experimental values which show the effective modelling and optimization of RSM procedure.

Conclusion

The Response surface Methodology was used to determine single and multiobjective optimization of tensile and impact behaviours of sisal-epoxy composites in the present investigation. The systematic way of determining better value of mechanical behaviours using Response surface Design, Analysis and Optimization were suggested in the present investigation. The better value of tensile strength of 31.23 MPa, impact strength of 43.22 kJ/m^2 were obtained for the fiber length of 47.9 mm and fiber loading of 29.1 % by weight. The results revealed that there is possibility to further improve the mechanical behaviours of sisal – epoxy composites by developing good adhesion between sisal fiber and epoxy resin. It may be done with the aid of treatment of fibers or fiber coating or particle inclusion.

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