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Optimization of Mechanical Properties of Green Coconut Fiber / HDPE Composites

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Abstract

Natural fibers have become alternative to researcher as an alternative reinforcement for fiber reinforced polymer (FRP) composites. The main objective of this investigation is to evaluate the optimum combination of process parameters to maximize the mechanical characteristics viz., Tensile strength, Flexural strength and Impact strength respectively using Taguchi method and utility concept. In fact the traditional Taguchi method cannot solve a multi-objective optimization problem; to overcome this limitation utility concept has been coupled with Taguchi method. Test specimens are prepared by injection molding technique as per L_9 orthogonal array in Taguchi's Design of experiments, the process parameters considered are percentage fiber weight fraction (% wt_f) and fiber length (F_l). The individual performance characteristic of the composite material has been transformed to corresponding utility values. Individual utility values have been aggregated to compute the overall utility, which serves as representative objective function for optimization using Taguchi method. Based on the Taghuchi's Signal-to-Noise ratio (S/N), analysis has been made on the overall utility degree and optimal process parameters has been selected finally which corresponding to highest S/N ratio. Optimal results have been verified through confirmatory test.

Keywords: *Green coconut fiber, HDPE resin, Utility concept, multi-response, ANOVA*

1. Introduction

Natural fibers were historically added to plastics as fillers rather than as reinforcing components. The advantage of natural fibers over inorganic materials has traditionally been associated with reduced cost but other attributes include low density, high specific strength to density ratio, biodegradability, low abrasiveness and the fact is that they are produced from renewable resources. Natural fibers can mix with and molded with polymers using high intensity, high volume production machinery such as extrusion and injection molding wit minimum strength degradation [1]. The major problem associated with integrating natural fibers in to thermoplastics is the chemical incompatibility between the hydrophilic fibers and the hydrophobic polymers [2]. Incompatibility leads to poor adhesion and reduction in ability of the matrix to transfer stress to the fibers. The adhesion is often improved in practice through the addition of coupling agent. Many investigations have been made on the potential of the natural fibers as reinforcements for composites and in several cases the result have shown that the natural fiber composites own good stiffness, but the composites do not reach the same level of strength as the glass fiber composite [3]. Coconut fiber has been used as reinforcement in low-density polyethylene. The effect of natural waxy surface layer of the fiber on fiber/matrix

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interfacial bonding and composite properties has been studied by single fiber pullout test and evaluating the tensile properties of oriented discontinuous fiber composites [4]. 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 [5]. Sathiyamurthy *et.al.*, [6] have investigated the mechanical properties of coir fiber reinforced polymer composites, prediction model was developed using artificial neural networks and optimum fiber parameters for maximum and minimum values of mechanical behavior are determined using response surface methodology.

The present investigation, illustrate the application of Taguchi method couple with utility concept was used for multi-objective optimization of mechanical properties of green coconut fiber reinforced HDPE composite. The objective of the investigation is to evaluate the optimum combination of process parameters such as fiber weight fraction (%Wt), and fiber length (F_l) to maximize simultaneously the mechanical properties viz., tensile strength, flexural strength and impact strength of the composite material.

2. Materials and Methods

The fiber material considered in this investigation is green coconut fiber and the matrix material is HDPE (High Density Poly-ethylene).

2.1. Chemical Treatment of Green Coconut Fibers

The green coconut fibers are chemically treated with two different types of chemicals namely H_2O_2 and NaoH at varies concentration levels. The purpose of chemical treatment is to remove the moisture content of green coconut fiber and to increase the tensile strength of green coconut fiber. The green coconut fibers (100g) were pre-treated with 1Litre alkaline solution which is prepared in different concentrations as 2, 3 and 4% of NaoH, for an hour under constant stirring and for 24hrs at room temperature and then dried in open air for 6 to 7 days. Thereafter fibers are tested for its tensile strength. From the experimental results it is found that, green coconut fiber treated with NaoH 2% concentration has attained highest tensile strength of 42.09Mpa.

2.2. Composite Fabrication

The composite material was fabricated using green coconut fiber as a reinforcement and HDPE (High Density Poly-Ethylene) as a matrix material. Exhaustive literature review on mechanical behavior of polymer composites reveals that parameters viz., fiber length and wt % of fiber loading *etc.*, largely influence the mechanical behavior of polymer composites. Composite materials were fabricated according Taguchi's L_9 orthogonal array in the design of experiments (DoE) [7], which needs 9 runs and has 8 degrees of freedom. The process parameters used and their levels chosen are given in Table 1. The treated fibers were chopped of length 3, 6 and 9mm length. The proper proportion of fiber (30%, 40% and 50% by weight for each of 3, 6 and 9mm) and HDPE were then properly blended to have homogeneous mixture. The mixture is then placed in the barrel of a hand injection molding machine. The machine was maintained at the constant temperature of 80°C. At this temperature the resin melts and the pressure is applied to inject the molten material in to the die. Then after pressure is released and the specimen is taken out from the die and dipped in water for curing. The inner cavity of the dimensions of the mould is 163x12.5x6mm.

Table 1. Process Parameters and their Levels

Process parameters	Designation	Level 1	Level 2	Level 3
Percentage Fiber weight fraction ($\%wt_f$)	A	30	40	50
Fiber length in 'mm' (L_f)	B	3	6	9

2.3. Utility Concept

Quality is a key attribute that customers use to evaluate product or services. So the modern quality control and improvement programs have to make their products more acceptable by the customers. On the other hand, customer evaluates a product performance based on a number of diverse qualitative characteristics. To improve the rational decision making, the evaluations of various attributes should be combined to give a composite index. Such a composite index is known as utility of a product. The sum of utilities of each quality attribute represents the overall utility of a product. It is difficult to obtain the best combination of process parameters, when there are multi-responses to be optimized. The adoption of weights in the utility concept helps in this difficult situations by differentiating the relative importance of various responses [8, 9]. In order to determine the utility value for a number of different quality characteristics, a performance scale has to be devised. The minimum acceptable quality value for each quality characteristics is allotted a performance number '0' and the best available quality value for each quality characteristics is assigned a performance number '9'. The performance number (P_i) is given by

$$P_i = A \log_{10}\left(\frac{Y_i}{Y_i'}\right) \quad (1)$$

Where $A = 9 / \text{Log}_{10}(Y_i^*/Y_i')$ (2)

Y_i is the value of quality characteristic 'i'

Y_i' is the minimum value of quality characteristic 'i'

Y_i^* is the optimum value of Y_i

The next step is the calculation of overall utility value (U). For this weighing factors (W_i) is assigned to each quality characteristics such that

$$\sum_{i=1}^{n} W_i = 1 \quad (3)$$

In this investigation, the weights to the quality characteristics viz., Tensile strength, Flexural strength and Impact strength were assigned as given below:

$W_{TS} = 0.4$

$W_{FS} = 0.4$

$W_{IS} = 0.2$

The overall utility value can be computed as:

$$U = \sum_{i=1}^{n} W_i P_i \quad (4)$$

Among various quality characteristics types, viz. Lower-the-Better (LB), Higher-the-Better (HB), and Nominal-the-Best (NB) suggested by Taguchi, the utility function would be Higher-the-Better type. Therefore, if the quality function is maximized, the quality characteristics considered for its evaluation will automatically be optimized (maximized or minimized as the case may be).

In the proposed approach utility values of individual responses are accumulated to calculate overall utility index. Overall utility index servers as the single objective function for optimization.

2.4. Taguchi Method

Taguchi Method was proposed by Genichi Taguchi, a Japanese quality management consultant. The method explores the concept of quadratic quality loss function and uses a statistical measure of performance called signal-to-noise (S/N) ratio ([10]. It is the ratio of the mean (Signal) to the standard deviation (Noise). The ratio depends on the quality characteristics of the product/process to be optimized [11]. The optimal setting is the parameter combination, which has the highest S/N ratio. Based on the signal-to-noise (S/N) analysis, the signal-to-noise (S/N) ratio for each level of process parameters are computed. Larger S/N ratio corresponds to better performance characteristics, regardless of their category of performance. It means that the level of process parameters with the highest S/N ratio corresponds to the optimum level of process parameters. Finally, a confirmatory experiment is conducted to verify the optimal processing parameters obtained from the parameter design.

3. Results and Discussions

In this investigation composite material is fabricated according to L_9 orthogonal array using hand injection molding technique, then the test specimens were cut as per ASTM standards and were tested to evaluate the mechanical properties like Tensile strength, Flexural strength and Impact strength. The experimental results are shown in Table 2.

Table 2. Experimental Results

Exp. No	Wt_f (%)	L_f (mm)	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (J/m)
1	30	3	17.07	14.47	135.9
2	30	6	16.87	13.46	154.7
3	30	9	16.36	13.41	128
4	40	3	17.86	13.59	124.5
5	40	6	17.31	13.31	142.6
6	40	9	17.12	13.09	108.2
7	50	3	17.34	13.29	133.9
8	50	6	16.72	13.26	142.8
9	50	9	16.7	13.52	124

3.1. Data Analysis

Experiments are performed according to L_9 Taguchi's orthogonal array in design of experiments and the experimental responses viz., Tensile strength, flexural strength and Impact strength were determined. The obtained experimental data has been utilized to calculate the utility values of individual response by using equations (1-2). For all the responses higher-the- Better (HB) criterion has been used. The objective of this investigation is to improve the mechanical properties of green coconut fiber reinforced HDPE composite. The individual utility measures of the response have been furnished in Table 3.

The overall utility index has been computed using equation (4) with their corresponding (Signal-to-Noise) S/N ratio is tabulated in Table 3. In this computation it has been assumed that all the quality features are equally important. The common practice in the solution of multi-objective optimization problem, it is necessary to convert initially three multi-objectives into an equivalent single objective function (overall utility degree). While deriving the equivalent objective function, different priority weightage are assigned to different responses, accordance to their relative importance.

Table 3. Utility Values of Individual Responses

Exp. No	Tensile Strength	Flexural Strength	Impact Strength	Overall utility degree	Corresponding S/N ratio
1	1.6688	2.86	1.0566	5.58	14.9411
2	1.2056	0.7952	1.6574	3.66	11.2653
3	0	0.6892	0.779	1.47	3.3357
4	3.446	1.0696	0.6506	5.17	14.2634
5	2.2172	0.4756	1.28	3.97	11.9819
6	1.784	0	0	1.78	5.0279
7	2.2852	0.432	0.988	3.70	11.3762
8	0.8548	0.368	1.262	2.48	7.9058
9	0.808	0.92	0.63	2.36	7.4509

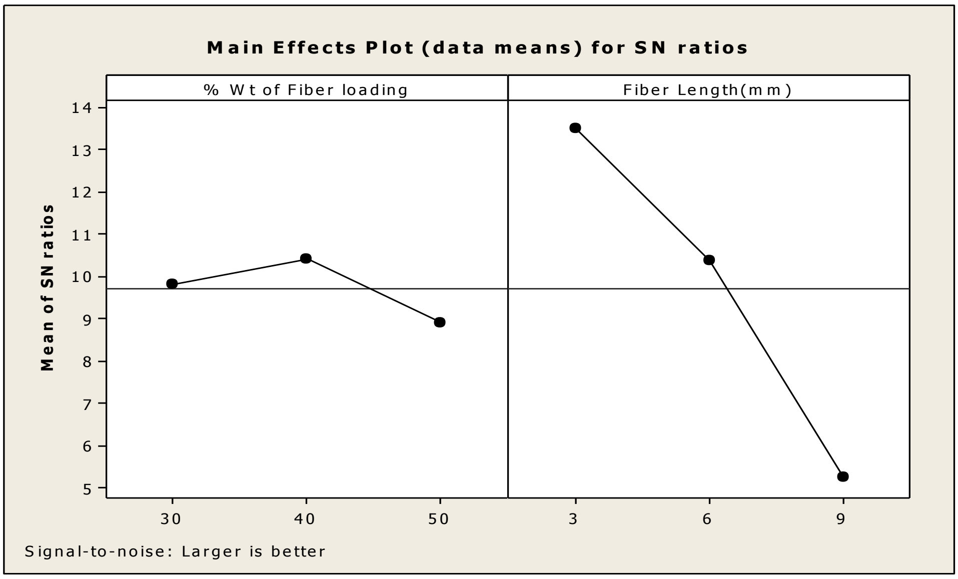

Figure 1. S/N Ratio Plot for Overall Utility Index

Figure 1 shows the S/N plot for overall utility index. The overall utility index is then optimized using Taguchi method. Taguchi's Higher-the Better criterion has been explored to maximize the overall utility index. The optimal combination of process parameters has been evaluated from Figure 1. The optimal combination of process parameters becomes A2, B1.

3.2. Analysis of Multiple Responses

The optimal combination of process parameters for simultaneous optimization of mechanical properties of green coconut fiber reinforced HDPE composite like tensile strength, flexural strength and impact strength are obtained by the mean values of the multi-response S/N ratio of the overall utility value are shown in Table 3. Table 4 shows the analysis of variance (ANOVA) for multiple response characteristics from the table it is inferred that the fiber length (L_f) is the most significant parameter affecting the multiple performance followed by percentage weight fraction of fiber ($\%Wt_f$).

Table 4. ANOVA for Multiple Responses

Source	Dof	SS	MS	F	% Cont
%Wt of fiber loading (%Wt_f)	2	3.50	1.75	0.32	2.70
Fiber length (L_f)	2	104.17	52.08	9.60	80.53
Error	4	21.70	5.42		16.77
Total	8	129.36			100

3.3. Optimality Confirmation

Once the optimal levels have been fixed, the next step is to predict and verify the improvement of the multiple responses. The predicted optimal values ($\eta_{Predicted}$) can be calculated by means of additive law.

$$\eta_{Predicted} = \eta_m + \sum_{j=1}^{k}(\eta_j - \eta_m)$$

where

η_m = Grant mean , η_j= Mean at optimum level, k= No. of main design parameters.

The Summary and comparison of results are shown in Table 5.

Table 5. Summary and Comparison of Results

Method	Responses	Optimal conditions	Optimal values	Actual Confirmation experiments
Single response optimization	Tensile strength	A_2, B_1	17.81MPa	-
	Flexural strength	A_1, B_1	14.08MPa	
	Impact strength	A_1, B_2	153.5J/m	
Multi-response optimization	Tensile strength	A2, B1.	17.81MPa	18.9MPa
	Flexural strength		13.63MPa	15.72MPa
	Impact strength		123.8J/m	137.5J/m

4. Conclusions

The present investigation is concerned with exploring the optimal setting of process parameters for multi-response optimization of mechanical properties of green coconut fiber reinforced HDPE composites. Based on the experimental observations the following conclusions are drawn.

- The Taguchi method and utility concept can be used to determine the optimal setting of the process parameters for multi-response optimization.
- The optimal setting of process parameter for individual response is
  For Tensile strength = A_2, B_1
  For flexural strength = A_1, B_1

For Impact strength = A_1, B_2

- The optimum combination of process parameters for optimization of multi-response optimization are: A_2, B_1
- The results obtained in this investigation have been validated by confirmation experiments.
- From the experimental results, it is found that the Mechanical properties viz., Tensile strength, flexural strength and impact strength have been improved by
- Careful section of weights for different quality characteristics plays a very important role in multi-response optimization.

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