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Mechanical Characterization of Hybrid Polymer SiC Nano Composite Using Hybrid RSM-MOORA-Whale Optimization Algorithm

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Abstract. Colossal materials do not provide a wide range of applications due to their mechanical property limitations. Fiber reinforced polymer composites are now considered as an important class of engineering materials. The processing and mechanical characterization of a new class of multi-phase composites consisting of polyester resin reinforced with jute-glass-silk fiber. This research investigation deals with mechanical properties of hybrid polymer composite. Woven palm fiber, teak wood dust and SiC Nano particles have been used for fabrication of the composites. Experiments have been planned as per Response Surface Method. After preparing the composite material by hand layup technique and then the mechanical characterizations are performed. Multi-response optimization has been carried out using Multi objective optimization on the basis of the ratio analysis method (MOORA) and Whale Optimization Algorithm. Optimal results have been verified through confirmatory experiments. Based on the experimental observations density, flexural and Ultimate Tensile Strength, it is concluded that teak wood powder influences the mechanical properties more than that of other two reinforcements but Nano particle filled composites shows better properties.

1. Introduction

In material science, there are numerous sorts of composite material planned so as to improve and amplify the likely quality of the last items. Most basic kind of fiber fortified composite utilized in weighty industry are glass and carbon filaments strengthened thermoset composites because of their boss properties. Consequently, there is a need to supplant engineered filaments with regular strands that are natural benevolent without yielding the quality and solidness offered by these composites. The utilization of characteristic plant filaments as support in fiber-strengthened plastics is accepting more consideration as of late, in view of their points of interest, for example, inexhaustibility, low thickness, and high explicit quality. Characteristic fiber fortified composite can be generally solid, and Light weight, liberated from wellbeing perils and biodegradable. It can possibly be utilized as building materials. Because of their numerous preferences they are generally utilized in the aeronautic trade, in countless business mechanical designing applications, for example, machine parts; inner ignition motors; vehicles; warm control and electronic bundling; railroad mentors and airplane structures; mechanical segments, for example, drive shafts, tanks, brakes, pressure vessels and flywheels; measure enterprises gear expecting protection from high-temperature erosion, oxidation, and wear; dimensionally stable segments; sports and relaxation hardware, marine structures, and biomedical gadgets [1-5].

As of late, miniature, sub-miniature and Nano-scale particles have been considered as filler materials for epoxy to create elite composites with upgraded properties. Numerous analysts have discovered that an extraordinary assortment of Nano-and miniature inorganic fillers, for example, Nano- Si_3N_4, ZnO, SiC, Al_2O_3, SiO_2, TiO_2 and MnO_2 can largely improve the mechanical and tribological properties of the polymer composites.

In this study, Response surface method is used for Experimental design, and multi objective optimization procedures has been employed i.e. Multi objective optimization on the basis of the ratio analysis method (MOORA) and Whale Optimization Algorithm are used to find optimum results. The present work is expected to analyze the effect of Nano particle with natural fiber reinforcement.

2. Experimental Procedure

Unsaturated polyester resin Ecmalon 4413 matrix material, methyl ethyl ketone peroxide (MEKP) as hardener material and cobalt octoate as accelerator are used for composite specimen fabrication. Different types of fiber materials have also been employed for fabrication of composite like woven palm fiber matt along with SiC Nano particle and teak wood dust. Composites were fabricated using mold of dimension 20 cm x 10 cm [3-5]. Different % of reinforcement were used as shown in Table 1.

Table 1. Factors and Their Levels

Factor	Symbol	Level 1	Level 2	Level 3
Palm	A	5%	10%	15%
Wood	B	2%	4%	6%
Nano	C	0.5%	1%	1.5%

The composite was kept for curing for around 24 hours. fifteen samples were prepared according to Response Surface Methodology [6-9]. The specimens were cut into the required size by using electric cutter which has been shown in Figure 1.

Prepared composites are tested by using a capacity of 600 KN universal testing machine (UTM BSUT 60JD) and with a cross head speed of 10mm/min. Ultimate tensile strength (MPa) was found out using the expression:

$$\sigma_u = F/A \quad (1)$$

Where σ_u the ultimate tensile strength (MPa), F is the maximum load (kN) applied and A is the cross-sectional area (m^2) of the composite. The flexural stress in a three-point bending test is found out by using formula

$$\sigma_f = 3FL/2bd^2 \quad (2)$$

Where σ_f is the flexural strength, F is the maximum load applied, L is the distance between the supports, and b and d are breadth and thickness of the specimen respectively.

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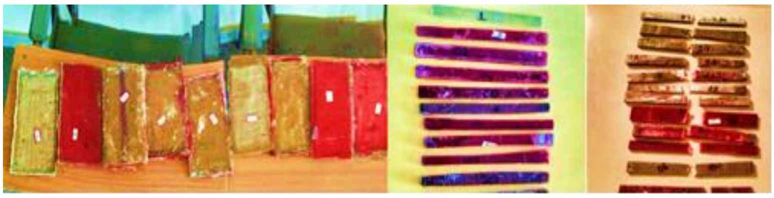

Figure 1. Prepared material, before and after testing of composite sample

3. Multi objective optimization on the basis of the ratio analysis method (MOORA)

The MOORA method (Multi objective optimization on the basis of the ratio analysis) has been used to disregard unsuitable substitutions by selecting the most appropriates an also by collation the selection parameter. The steps are [10-14].

- Decision matrix formation

$$X = \begin{bmatrix} x_{11} & x_{12} & .. & .. & x_{1n} \\ x_{21} & x_{22} & .. & .. & x_{2n} \\ :: & :: & :: & :: & :: \\ x_{m1} & x_{m1} & .. & .. & x_{mn} \end{bmatrix} \qquad (3)$$

- Ratio system formation by decision matrix normalization using the equation (4).

$$x_{ij}^{*} = x_{ij} / \left[\sum_{i=1}^{m} x_{ij}^{2}\right]^{\frac{1}{2}} \qquad (j = 1, 2, \ldots\ldots n) \qquad (4)$$

- Calculation of overall assessment value and ranking of y_i is done from highest to lowest value to know the best alternate among the entire attributes:

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^{*} - \sum_{j=g+1}^{g} w_j x_{ij}^{*} \qquad (5)$$

4. Whale Optimization (WO)

It is a nature galvanized metaheuristic optimization process and which is derived from hunting behaviour humpback whales. They search and hunt for food by the extraordinary method entitled bubble-net feeding method where they create bubbles via enclosing or over a ‘9’- formed route. This performance of probing is exhibited arithmetically as dual levels [15].

4.1. Probing and enclosing target

Probing for the target can be demonstrated using Eqs. (6) and (7):

$$D = |C.X_{rand} - X| \qquad (6)$$

$$X(t+1) = X_{rand} - A.D \qquad (7)$$

Here, coefficient vectors A and C are

$$A = 2.a.r - a \qquad (8)$$

$$C = 2.r \qquad (9)$$

Here, ‘a’ = linearly subsiding commencing 2 to 0 & ‘r’ = arbitrary number amongst 0 and 1.

$$D = |C.X^{*}(t) - X(t)| \qquad (10)$$

$$X(t+1) = X^{*}(t) - A.D \qquad (11)$$

4.2. Spirally apprising locus

Point apprising is signified by Eq. (12):

$$X(t+1) = \begin{cases} X^{*}(t) - A.D, & if\ p < 0.5 \\ D.e^{bl}.\cos(2\pi l) + X^{*}(t), & if\ \ p \geq 0.5 \end{cases} \qquad (12)$$

where ‘l’ = amongst -1 and 1; ‘p’ = arbitrary numeral amongst 0 and 1; ‘b’ = continual for recounting the coiled form.

5. Results and Discussion

Table 2 shows the RSM experimental design using which samples were prepared. The experimental results were optimized and analyzed by MINITAB 18 software.

Table 2. Experimental Results

Sl. No.	Palm	Wood	SiC	Density (g/cc)	UTS (MPa)	Flexural Strength (MPa)
1	5	2	1.0	1.54	84.69	1773.76
2	15	2	1.0	1.38	65.33	1674.05
3	5	6	1.0	1.68	104.44	2577.58
4	15	6	1.0	1.52	85.08	2477.87
5	5	4	0.5	1.48	114.90	2157.24
6	15	4	0.5	1.32	95.54	2057.53
7	5	4	1.5	1.45	109.09	2460.10
8	15	4	1.5	1.29	89.72	2360.39
9	10	2	0.5	1.29	77.66	1533.15
10	10	6	0.5	1.43	97.41	2336.97
11	10	2	1.5	1.26	71.84	1836.01
12	10	6	1.5	1.40	91.59	2639.83
13	10	4	1.0	1.20	111.01	2487.44
14	10	4	1.0	1.35	111.18	2485.11
15	10	4	1.0	1.30	110.13	2466.36

MOORA optimization method was applied to find out the optimal parameters for fabrication of composite. The MOORA overall assessment value is designed using equation (5) and ranked according to the highest value of the overall assessment value shown in Table 3.

Table 3. Computational values using MOORA

Sl. No.	Density	UTS	Flexural strength	Y_i	Rank
1	0.094	0.075	0.067	-0.048	3
2	0.084	0.058	0.063	-0.037	1
3	0.103	0.093	0.098	-0.088	7
4	0.092	0.076	0.094	-0.077	5
5	0.090	0.102	0.082	-0.093	10
6	0.080	0.085	0.078	-0.082	6
7	0.089	0.097	0.093	-0.102	12
8	0.078	0.080	0.089	-0.091	9
9	0.079	0.069	0.058	-0.048	3
10	0.087	0.087	0.089	-0.088	8
11	0.077	0.064	0.070	-0.057	4
12	0.085	0.081	0.100	-0.096	11
13	0.073	0.099	0.094	-0.120	15
14	0.082	0.099	0.094	-0.111	13
15	0.079	0.098	0.093	-0.112	14

In the above table, the overall assessment value is highest in experiment no. 2. Hence, experiment number 2 which is having the factor setting A3 B1 C2 is the optimal parameter combination for fabrication of composite. From Figure 2, A3 B1 C1 (larger the better in this case) is the optimal parameter combination for fabrication of composite

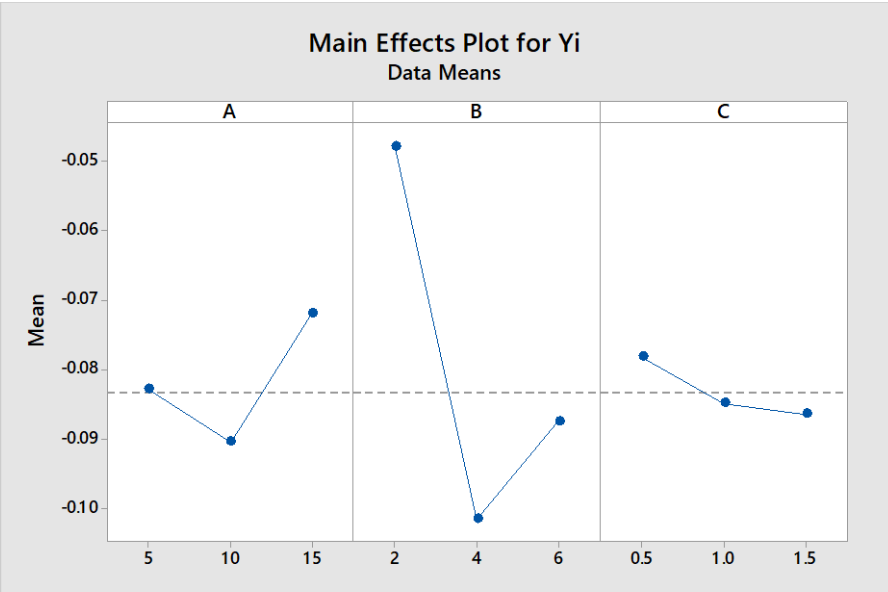

Figure 2. Main-effect plot for Yi

After performing MOORA method optimization, a regression equation was generated which will serve as a fitness function in Whale Optimization Algorithm techniques which will be used in the later stage. Employing the MOORA method the regression equation is developed as:

$$Yi = 0.1538 - 0.01166a - 0.08112b - 0.0581c + 0.000637a^2 + 0.008901b^2 + 0.02489c^2 - 0.000000ab + 0.000000ac + 0.00000bc \quad (13)$$

According to previous investigations by respective researchers, it has been reported that meta-heuristic optimization techniques results are more precise then statistical one, hence in this study also metaheuristic optimization techniques is used for finding a more precise composite fabrication constraint. The algorithm was coded in MATLAB R2018a software and ran on SONY VAIO VPCEH3AEN Notebook Computer with the configuration of the Intel Core i5 2nd Gen processor with a speed of 3.1 GHz, 4GB of RAM and Microsoft Windows 7 Ultimate OS.

For achieving a compound score of the responses, Whale Optimization was formulated to achieve the best fitness. In the Whale Optimization technique, the pod of the whale was set to 100 with iteration perimeter to 50. Figure 3 shows the convergence curve plotted by Whale Optimization. Figure 4 shows the best fitness value spawned -0.1182 along with parameter configuration with 10% Palm fiber, 6% teak wood powder and 1.5% SiC Nano-particle which can be reported as optimum configuration.

The analysis of variance (ANOVA) was done by using the values of overall assessment value calculated using the MOORA method for finding the most influential fabrication parameter and goodness of the relationship between them. From Table 4, teak wood powder with 86.63 % is the most influential parameter among the 3 parameters.

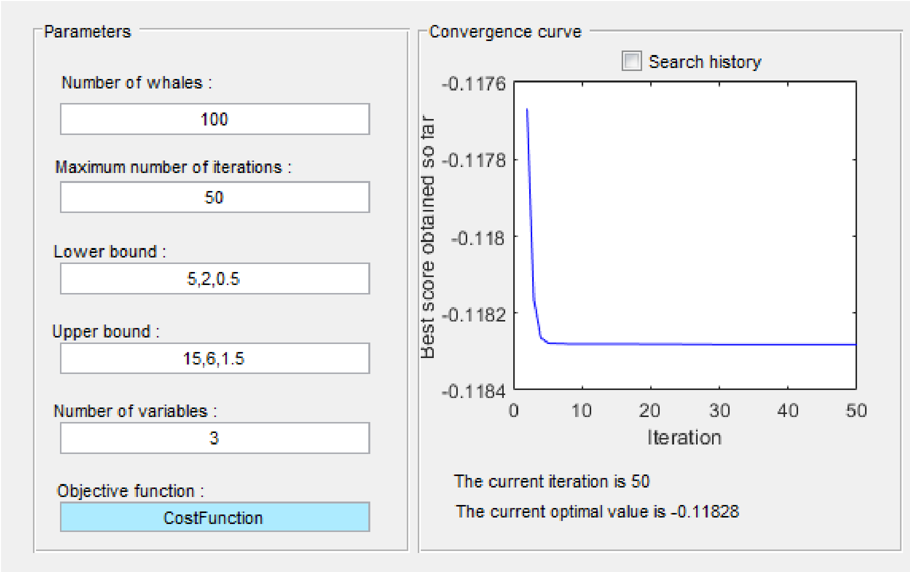

Figure 3. Convergence Curvature of WO

Table 4. ANOVA of Y_i

Source	DF	Contribution	Adj SS	Adj MS	F-Value	P-Value
A	2	9.70%	0.001177	0.000588	101.42	0.000
B	2	86.63%	0.007822	0.003911	674.16	0.000
C	2	3.14%	0.000280	0.000140	24.16	0.000
Error	8	0.52%	0.000046	0.000006		
Lack-of-Fit	6	0.00%	0.000000	0.000000	0.00	1.000
Pure Error	2	0.52%	0.000046	0.000023		
Total	14	100.00%				

To check the enrichment of output quality features after outcome of best factor setting, a confirmatory experiment is done.

Table 5. Initial and optimal level performance

Algorithm	Optimum setting	Predicted value	Expt. value
RSM-MOORA	A3 B1 C1	-0.0374	-0.0371
MOORA-WO	A2 B3 C3	-0.1182	-0.1101

6. Conclusions

This research presents forecast and optimization of parameters prominent to maximization of density, flexural strength and ultimate tensile strength thru static loading of fabricated composite. The analytical values determined using hybrid MOORA method coupled with Whale optimization is more precise as compared to value determined by RSM based MOORA method approach.

According to ANOVA, teak wood powder is most influencing parameter for the composite fabrication than other two factors if the maximization of density, flexural strength and ultimate tensile strength are concurrently considered. Also, the confirmatory test results are found exceedingly good contract with those forecasted which can be beneficial for fabrication of desired composite.

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