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Evaluation of Mechanical Behavior of Hybrid Natural Fiber Reinforced Nano Sic Particles Composite using Hybrid Taguchi-Cocoso Method

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Abstract*: For this present research investigation, hybrid natural fiber reinforced Nano SiC particles composite was fabricated and their mechanical properties has been studied. Experiments have been planned as per Taguchi's Method. After preparing the composite material by hand layup technique and then the mechanical characterizations are performed. Multi-response optimization has been carried out by employment of a recently developed method for multi-criteria decision making (MCDM), i.e. combined compromise solution (CoCoSo) method. For defining the relative significance of measured norms, pairwise comparison matrix was used. Optimal results have been verified through confirmatory experiments. Based on the experimental observations ultimate tensile strength (UTS), density and flexural strength, ANOVA result indicated that density has highest impact for a better mechanical behaviour. This can be useful in different field of application for fabrication of different structures, parts etc.

Keywords: Palm-Wood-SiC Composite material, Taguchi's method, COCOSO method, Strength analysis.

I. INTRODUCTION

Natural fibers display numerous benefits above conformist fibers which includes less density, cost, worthy thermal properties, shielding assets, renewable, bio-degradable, etc. [1]-[4]. Due to their many advantages they are widely used in different types of manufacturing sectors viz. aerospace industries, commercial mechanical engineering uses like machine components, automobile industries, railway coaches and aircraft structures, sports goods manufacturing units, marine structures, biomedical equipments, military and defence organisations, etc. In recent years, apart from natural fibers or any artificial fiber which were used for fabrication of any composite, nano-particles have been used by the researchers as partial replacement of filler materials for producing composites with higher-performance and enriched properties. SiC, Al_2O_3, ZnO, TiO_2, B_4C, SiO_2 etc. are those type of nano-particle which can essentially increase the mechanical properties and tribological possessions of any type of fiber/polymer composites [4], [5], [11]-[15]. Different researchers have studied the mechanical properties fiber polymer composites and almost all the fiber shows good mechanical properties in polymer composites. In this study, the effects of SiC nano-particles in combination with palm fiber, Sal wood dust on mechanical strength of composites was carried out. Taguchi's method is used for Experimental design, and multi response optimization techniques i.e. combined compromise solution (CoCoSo) method is used to find optimum results.

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II. MATERIAL USED AND EXPERIMENTAL SETUP

For fabrication of composites, matrix material of unsaturated polyester resin Ecmalon 4413, hardener material of methyl ethyl ketone peroxide (MEKP) and accelerator of cobalt octoate are used. Palm fiber along with SiC nano-particles was employed for fabrication of composite. Composites were prepared using mold of dimension 20cm x 10 cm. cellophane sheets are employed both at top and bottom in mold for achieving better exterior texture of the specimen. Silicon spray was spurted on whole mold surface since it has good lubricating, non-reactive and anti-corrosive properties. The low temperature curing polyester resin was equivalently extent using a brush. Layer of fiber material was positioned on Polyester surface after which a wooden roller was rolled putting a slight pressure over fiber material/resin layer for removal of trapped air and excess resin which may be present. This process was repeated for every layer of resin/polymer and fiber material. Different percentage of reinforcement were taken as shown in Table 1 and total 9 experiments were planned to form L_9 orthogonal array. After fabrication, the specimen was kept under pressure for better bonding of fiber/resin and drying. Prepared composites are tested by using a capacity of 600 KN universal testing machine (UTM BSUT 60JD) and with crosshead speed = 15mm/min [5]. Equation (1) was used for calculation of UTS:

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

Where σ_u = ultimate tensile strength (MPa), F = extreme load applied in kN and A = 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 = flexural strength, F = extreme load applied on the specimen, L = distance between supports provided, b and d are breadth and thickness of specimen respectively.

Table- I: Input parameters

Parameters	Symbol	Level 1	Level 2	Level 3
Palm fiber	A	5%	10%	15%
Sal wood dust	B	3%	6%	9%
SiC nano particles	C	1%	1.5%	2%

A. Calculation of Weights Between Conditions by Pair-Wise Comparison

Using geometric mean approach of the AHP method, relation significance of output responses was determined. Saaty's nine-point preference scale for construction of pair-wise comparison matrix as shown in Table II. Output response weights of the experiments were calculated by using following equations -

$$GM_i = \left(\prod_{j=1}^{n} b_{ij}\right)^{1/n} \quad (3)$$

$$w_j = GM_i / \sum_{j=1}^{n} GM_i \quad (4)$$

Table- II: Pair-wise comparison table between criterions

	Density	UTS	Flexural strength
Density	1	3	3
UTS	0.3	1	0.3
Flexural strength	0.3	3	1

Output response weights were obtained as w = [0.60, 0.13, 0.27]. For 3 considered output response criteria, random index of 0.58, consistency index, consistency ratio of 0.037, 0.064 were acquired. Consistency index and consistency ratio values shows that determination of output response criteria weights are equitable since for consistency the value of consistency ratio ≤ 0.10 [6], [7], [8], [9]. The weights obtained for each quality characteristics will be used with COCOSO method for the process parameter optimization.

B. Combined Compromise Solution (COCOSO) Method

The following steps are used to solve COCOSO decision problem [10]:

1) Determination of initial decision-making matrix using equation (5):

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}; \quad (5)$$

2) Using compromise normalisation equation, normalisation of criteria values is done:

$$r_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \text{ ; for benefit criterion;} \quad (6)$$

$$r_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \text{ ; for cost criterion:} \quad (7)$$

3) Determination of total weighted comparability sequence and whole of power of weight of comparability sequences for respective alternate as S_i and P_i, respectively:

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \quad (8)$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \quad (9)$$

4) Three appraisal score are used for generation of comparative weights of other options derived using equation (10), (11), (12):

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \quad (10)$$

$$k_{ib} = \frac{S_i}{\min S_i} + \frac{P_i}{\min P_i} \quad (11)$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{(\lambda \max S_i + (1-\lambda) \max P_i)} \quad (12)$$

5) Ranking of all alternatives is determined from higher to lower based on k_i values:

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + (k_{ia} + k_{ib} + k_{ic}) \quad (13)$$

III. RESULTS AND DISCUSSION

Samples are prepared by using Taguchi's experimental design which is shown in Table III. L_9 orthogonal array was used as design of experiment. The samples are cut into desired size by using electric cutter which is shown in fig 2. The experimental results for the density, UTS and bending stress are listed in Table 2.

Fig. 1. Prepared specimen (Before and After testing)

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Table- III: L_9 orthogonal array design with output results

Run No.	A	B	C	Density (g/cc)	UTS (MPa)	Flexural strength (MPa)
1	5	3	1	1.54	75.88	2115.34
2	5	6	1.5	1.49	101.93	2473.65
3	5	9	2	1.73	96.46	2116.42
4	10	3	1.5	1.25	84.12	2107.25
5	10	6	2	1.40	112.15	2033.66
6	10	9	1	1.45	95.63	2519.49
7	15	3	2	1.35	71.00	1342.35
8	15	6	1	1.30	87.96	2111.84
9	15	9	1.5	1.35	80.51	2186.51

A. Optimization using Combined Compromised Solution

The first step demonstrates forming of the normalised decision-making matrix (using compromise equation (max–min)), which is shown in Table 6. The further step is to generate the comparability sequence matrix. In this process, the weights of decision-making criteria are involved in the algorithm. The Si and Pi vectors must be generated using formulas (8) and (9), respectively. The values of K_a, K_b, and K_c are calculated using equations (10), (11) and (12). Equation (13) used to calculate the ranking score by k shown in Table 6.

Table- IV: Weighted comparability series (S_j), Exponentially weighted comparability sequence (P_i), Final aggregation and COCOSO ranking of the alternatives

Run no.	S_i	P_i	k_{ia}	k_{ib}	k_{ic}	k_i	Rank
1	0.4462	2.3085	0.1117	4.6592	0.7351	2.5613	5
2	0.3442	1.9123	0.0915	3.6772	0.6022	2.0443	8
3	0.1392	1.6309	0.0718	2.0275	0.4724	1.2669	9
4	0.7803	2.7018	0.1412	7.3075	0.9293	3.7787	2
5	0.5253	1.5877	0.0857	4.7739	0.5639	2.4211	6
6	0.4036	1.6136	0.0818	3.9157	0.5383	2.0685	7
7	0.8764	2.8707	0.1519	8.1041	1.0000	4.1572	1
8	0.7046	2.6175	0.1347	6.7107	0.8866	3.5062	3
9	0.6527	2.5482	0.1298	6.2940	0.8542	3.3130	4

From table IV, for a particular values of input parameter in experiment no. 7 has the highest k_i value. Therefore, experiment no. 7 is an optimal parameter combination for fabrication of hybrid Palm-Wood-SiC composite specimen according to COCOSO technique optimization.

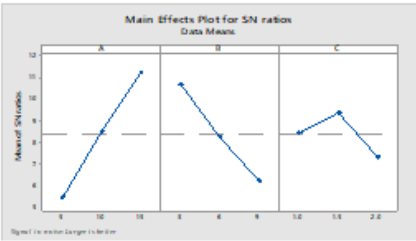

Fig. 2. Main effect plot with factors and their levels for K_iNow the k_i values of alternatives were used to plot mean effect. In Figure 2, A3 B1 C2 shows the largest value combination in main effect plot for the three factors i.e. A, B, C respectively. Hence, A3 B1 C2 i.e. Palm fiber with 15%, Sal wood dust 3% and SiC nano particles with 1.5% is optimum parameter arrangement for fabrication of hybrid Palm-Wood-SiC composite specimen.

B. Most influential factor

Table V gives the results of the ANOVA for the Density, UTS and Flexural strength using the calculated values from the k_i of alternatives of Table IV. According to Table V, factor A, Palm fiber with 57.71%, is the most significant controlled parameters for hybrid Palm-Wood-SiC composite specimen followed by factor B, Sal wood powder with 34.51% of contribution and factor C, SiC nano particles with 7.12% of contribution if the maximization of Density, UTS and Flexural strength are simultaneously considered.
S=0.5311, R-Sq=99.34%, R-Sq(adj)=97.37%

Table- V: ANOVA result for k_i

Source	DOF	Adj SS	Adj MS	F-test	P-test	% Influence
A	2	49.6032	24.8016	87.94	0.011	57.71
B	2	29.6623	14.8311	52.59	0.019	34.51
C	2	6.1163	3.0582	10.84	0.084	7.12
Error	2	0.5640	0.2820			0.66
Total	8	85.9458				

C. Confirmatory experiment

To confirm the enhancement of output quality features after finding the best level of input parameters, a confirmatory experiment is performed. The total relative importance of alternatives estimated using the formulae given in equation (14) [9].

$$\mu_{predicted} = a_{2m} + b_{1m} - 3\mu_{mean} \quad (14)$$

where a_{2m} and b_{1m} are specific mean values of k_i with optimal equal values of constraints and μ_{mean} is the total mean of total k_i of alternatives [9].

Table- VI: Initial and optimal level performance

Optimum input parameter setting	Predicted Optimum value	Experimental Optimum value
A3B1C2	4.62159	4.2752

IV. CONCLUSIONS

This paper presents prediction and optimization of designing parameters leading to a maximization of density, ultimate tensile strength(UTS) and flexural strength during static loading of the fabricated composite. The predictive values determined using recently developed optimization technique i.e. COCOSO method is close to the values determined by Taguchi based COCOSO method approach.

Optimal factor setting for fabrication of hybrid Palm-Wood-SiC composite using two optimization approach are stated in table VII:

Table- VII: Optimal Factor settings

Algorithm	Palm fiber	Sal wood powder	SiC nano particle
COCOSO	15%	3%	2%
Taguchi-COCOSO	15%	3%	1.5%

According to ANOVA, factor A, Palm fiber is most influencing parameter for the composite fabrication than other two factors if the maximization of density, UTS and flexural strength are simultaneously considered. Also, the confirmatory test results are found incredibly good agreement with those predicted. The optimal values will be useful for the industry selection of combination of different fiber for fabrication of desired composite. More reliable prediction of unit process will enable industry to develop more optimized composite which can be used in many areas.

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