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Study of Mechanical Behavior of Hybrid Polymer Nano Composite Using Taguchi Experimental Design

Madhusmita Pathal[1] and Kiran Kumar Ekka[2]

Department of Mechanical Engineering,
[1]CAPGS, Biju Patnaik University of Technology, Rourkela, Odisha, 769015, India.
[2]Veer Surendra Sai University of Technology, Burla, Odisha, 768018, India
[1]madhusmita.lipa@gmail.com, [2]kiran2803@gmail.com

Abstract

In this paper mechanical properties of hybrid polymer composite have been explored. Woven palm fiber, teak wood dust and SiC nano particles have been used as reinforcement for the composites. Four different levels of palm (0 to 15%), wood dust (0 to 6%) and SiC nano (0% to 1.5%) were considered for the study. Orthogonal array was chosen according to Taguchi design of experimental technique. Sixteen samples of different composition was prepared by using hand lay-up technique. Mechanical properties were evaluated and the results were analyzed using MINITAB 17 software. From the analysis it was concluded that palm influences the mechanical properties more than that of other two reinforcements but nano particle filled composites shows better properties. Regression and artificial neural network were used to develop models to predict the tensile and flexural strength. It was also observed that artificial neural network was more efficient in predicting the flexural strength than regression.

Keywords- hybrid polymer nano composite, tensile test, flexural test, taguchi method, neural network.

1. Introduction

In material science, there are many types of composite material designed in order to improve and maximize the potential strength of the final products. Most common type of fiber reinforced composite used in heavy industry are glass and carbon fibers reinforced thermoset composites due to their superior properties. Hence, there is a need to replace synthetic fibers with natural fibers that are environmental friendly without sacrificing the strength and stiffness offered by these composites. The use of natural plant fibers as reinforcement in fiber-reinforced plastics is receiving more attention recently, because of their advantages such as renewability, low density, and high specific strength. Natural fiber reinforced composite can be relatively strong, and Light weight, free from health hazards and biodegradable. It has high potential to be used as building materials.[1]

In recent years, micro, sub-micro and nano-scale particles have been considered as filler materials for epoxy to produce high-performance composites with enhanced properties. Many researchers have found that a great variety of nano- and micro-inorganic fillers such as nano- Si_3N_4, SiC, ZnO, Al_2O_3, TiO_2, SiO_2, and MnO_2 can largely improve the mechanical and tribological properties of the polymer composites.[2-8]

Munakaampe, et al.[9] have studied the response of sisal natural fiber composite to flexural three point and four point test. Strength increases with the increase in volume fraction. Kumar et al.[10] in their study of mechanical properties of wood dust reinforced epoxy composite using Taguchi method found out that there was an improvement in the mechanical behavior due to the addition of sundi wood dust. They found out that the mechanical property increases up to certain filler percentage and then properties gradually decreases. Dass, et al.[11] have studied the effects of micro size SiC, Al_2O_3 and ZnO particulates on mechanical and tribological properties of synthesized ortho- and meta-cresol novolac epoxy composites. According to the study the orthocresol novolac epoxy composites filled with SiC filler particulate exhibit the high tensile strength and flexural strength, whereas the ortho-cresol novolac epoxy composites filled with ZnO particulates exhibit the high compression strength.

From the reported survey, very little has been reported on the effects of SiC nano particle with natural fiber reinforcement. In this present investigation, the effects of nano SiC particles in combination with palm fiber and teak wood dust on mechanical properties of composites were carried out. The present work is expected to analyze the effect of nano particle with natural fiber reinforcement.

2. Experimental Procedure

2.1 Material Used and Experimental Setup

Unsaturated polyester resin Ecmalon 4413, methyl ethyl ketone peroxide (MEKP), cobalt octoate was purchased from Ecmas Resins (P) Ltd., SiC nano particle was purchased from Alfa Aesar(Chennai, India) and woven palm fiber matt and teak wood dust was purchased from local store. Composites were fabricated using mold of dimension 18cm x 14 cm. The whole surface of the mold was covered with heat resistant aluminum foil. Different percentage of reinforcement were taken as shown in table 1.

Table: 1 Factors and Their Levels

Factor	Symbol	Level 1	Level 2	Level 3	Level 4
Palm	P	0%	5%	10%	15%
Wood	W	0%	2%	4%	6%
Nano	N	0%	0.5%	1%	1.5%

Before preparing the sample a coat of silicon spray was sprayed over the mold coated with aluminum foil. The composite was prepared by using hand lay-up technique. The composite was kept for curing for around 24 hours. Sixteen samples were prepared according to Taguchi table L_{16} array. The prepared samples were then marked according to the standard size i.e. 16cm x 2 cm. then the specimen were cut into the required size by using electric cutter which has been shown in fig. 1.

Tests of the polyester resin composites filled with palm fiber, teak wood dust and SiC fillers specimens were determined by a capacity of 600 KN universal testing machine (UTM BSUT 60JD). The experimental results of tensile and flexural strength are shown in Table 2. For tensile test the specimen was held stationary in between the two jaws of UTM and force was applied at one end. Ultimate tensile strength (MPa) was found out using the expression: $\sigma_u = F/A$ …..(1)

Where σu the ultimate tensile strength (MPa), F is the maximum load (KN) applied and A is the cross-sectional area (meter^2) of the composite. For flexural test the specimen was kept horizontally over the two supports and force was applied on the middle of the specimen. Flexural strength was found out using the expression:

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

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.

3. Results and Discussion

The variations in tensile and flexural strength of polyester resin composites specimen filled with woven palm fiber mat and teak wood dust and SiC nano particle calculated experimentally is shown in Fig. 13. From this it can be concluded that without wood and palm reinforcement, composite shows the higher value. Nano SiC filled composites show higher value because of the high hardness and high strength of the SiC filler. They have the good interfacial adhesion between the filler and matrix due to the mechanical interlocking with the matrix. This permits the stress distribution which allows the transfer of effective load from matrix to the filler particulates, causing the increase in strength. [11] Tensile and flexural strength values are also analyzed using MINITAB 17 software.

3.1 Tensile Test

Table 3 shows the response value of S/N ratio for tensile strength. It was observed that factor palm (P) has the most influence on tensile strength followed by wood (W) and nano SiC (N). Fig. 2 shows the specimen after test. Fig. 3 shows the main effect plot for S/N ratio of three control parameters on tensile strength. It can be concluded that a factor combination of $P_1W_3N_2$ gives maximum tensile strength. This implies the selection of 0% palm, 4% of wood 0.5% of nano SiC reinforcement for maximum tensile strength. Table 4 shows the analysis of variance table of S/N ratio for tensile strength. Observing the last column it is concluded that the factor palm (P) ,wood (W) nano SiC (N) have the highest contribution with 60.80%, 17.52%, 5.08% respectively.

3.2 Flexural Strength

Table 5 shows the response table of S/N ratio for flexural strength of polymer composite. It is observed that factor palm (P) has the most influence on flexural strength followed by wood (W) and nano SiC (N).Fig. 4 shows the main effect plot for S/N ratio of three control parameters on flexural strength. It can be concluded that a factor combination of $P_1W_1N_2$ gives maximum flexural strength. This implies the selection of 0% palm, 0% of wood 0.5% of nano SiC reinforcement for maximum flexural strength. Table 6 shows the analysis of variance table of S/N ratio for flexural strength. Observing the last column it is concluded that the factor palm (P) wood (W) nano SiC (N) have the highest contribution with 33.84%, 25.74%, 7.17% respectively.

Table 2. Experimental Results

Sl. No.	Palm	Wood	Nano (SiC)	UTS (MPa)	Flexural strength (MPa)	Tensile Strength		Flexural Strength	
						% error Regres sion	% error ANN	% error Regress ion	% error ANN
1	0	0	0	117.60	3095.40	-1.08	-8.93	-10.46	-0.06
2	0	2	0.5	128.80	3108.60	3.05	0.01	-2.21	-14.28
3	0	4	1	129.77	3805.19	-3.03	0.05	1.80	0.80
4	0	6	1.5	149.44	5362.50	2.73	16.03	4.95	0.01
5	5	0	0.5	138.85	6263.27	6.95	8.65	19.93	6.74
6	5	2	0	81.33	2177.08	-12.02	-0.10	-9.57	-3.80
7	5	4	1.5	99.44	2383.33	-1.48	-7.35	-17.20	-0.13
8	5	6	1	93.50	2145.00	-7.31	-7.77	-21.18	-15.67
9	10	0	1	107.15	3258.32	-9.01	-0.01	-38.31	0.05
10	10	2	1.5	81.16	2135.83	1.81	-0.09	19.20	0.50
11	10	4	0	95.68	2528.92	10.22	0.01	8.24	1.94
12	10	6	0.5	93.14	2429.17	7.34	0.01	18.70	-2.05
13	15	0	1.5	85.96	2248.25	4.97	15.18	15.73	-12.38
14	15	2	1	68.51	1252.03	-6.78	0.16	-17.78	7.60
15	15	4	0.5	85.00	2140.42	5.47	-0.04	10.40	-15.81
16	15	6	0	96.19	2929.14	-7.37	-0.01	-10.07	15.37

4. Regression Analysis

Equations (3) and (4) show the regression equation for tensile strength and flexural strength respectively. Where K_t represents tensile strength and K_f represents the flexural strength. In the equations below, the interaction term is also considered along with the squared terms of A, B and C. where A, B and C represents the different percentage level of palm, wood and nano SiC respectively. The regression equation developed with their respective R-value is shown below.

$$K_t = 118.87 - 2.19448\,A - 14.0384\,B + 65.3236\,C + 0.17755\,A^2 - 0.0163864AB - 5.37209\,AC + 1.75219\,B^2 - 3.22364BC - 9.48\,C^2 \qquad R = 0.96 \qquad \ldots (3)$$

$$K_f = 3419.18 + 177.225\,A - 1202.08\,B + 3523.04\,C + 1.5515\,A^2 - 6.69123\,AB - 397.757\,AC + 128.119\,B^2 - 15.4639\,BC - 385.375\,C^2 \qquad R = 0.90 \qquad \ldots (4)$$

Table 3 Response Table for S/N Ratio of Tensile Strength

Level	Palm	Wood	Nano
1	42.34	40.89	39.72
2	40.11	38.83	40.76
3	39.45	40.11	39.75
4	38.41	40.49	40.08
Delta	3.93	2.06	1.03
Rank	1	2	3

Table 4 Analysis of Variance for S/N Ratios for Tensile Strength

Source	DF	P
Palm	3	60.80
Wood	3	17.52
Nano SiC	3	5.08
Residual error	6	-
Total	15	-

Table 5 Response Table for S/N Ratios of Flexural Strength

Level	Palm	Wood	Nano
1	71.47	70.76	68.49
2	69.22	66.29	70.03
3	68.15	68.45	67.61
4	66.23	69.56	68.94
Delta	5.23	4.47	2.41
Rank	1	2	3

Table 6 Analysis of Variance for S/N Ratios of Flexural Strength

Source	DF	P
Palm	3	33.84
Wood	3	25.74
Nano SiC	3	7.17
Residual error	6	-
Total	15	-

5. Modelling of Back Propagation Neural Network

In this paper, multilayer feed forward network with back propagation learning algorithm is used. The input layer consists of three neural cells, corresponding to palm, wood and nano SiC percentage. The output layer consisted of one neural cell corresponding to tensile strength or flexural strength. The program code was generated using MATLAB 17 software. The number of neurons in the hidden layer was chosen to be seven for tensile strength and four for flexural strength. The number of samples used for training, validation and testing were taken to be 62%, 19% and

19%, respectively. Fig.5 shows the mean squared error of training, test and validation samples for tensile strength. Fig.6 shows overall regression plot for training, validation and test samples. The R-value is always desired to be closer to 1. The overall R-value for all samples was 0.94. This shows a good correlation between the experimental value and network response. Hence this trained network was used to predict the tensile strength of the entire network. Fig.7 shows the regression plot for the same. It was seen that the R-value is equal to 0.94 which is acceptable. It was suggested that the trained network could be used for the prediction of tensile strength. Fig.8 shows the mean squared error of training, test and validation samples for flexural strength. Fig.9 shows overall regression plot for training, validation and test samples. The overall R-value for all samples was 0.98. This shows a good correlation between the experimental value and network response. Hence this trained network was used to predict the flexural strength of the entire network. Fig. 10 shows the regression plot for the same. It is seen that the R-value is equal to 0.98 which is acceptable. It is suggested that the trained network could be used for the prediction of flexural strength. Table 2 shows the comparison of error between the predicted and experimental values. Fig. 11 and 12 shows the Comparison of Experimental and Predicted Results for tensile and Flexural Strength respectively. It was observed that ANN and regression are equally efficient in predicting the experimental value for tensile strength. While for flexural strength ANN is more efficient.

6. Conclusion

The experimental investigation on hybrid polymer composites of woven palm fiber, teak wood dust and nano SiC reinforced, polyester matrix composites has lead to the following conclusions

- The response table of tensile and flexural strength shows that factor palm (P) has the most influence on tensile strength followed by wood (W) and nano SiC (N).
- The main effect plot of tensile strength shows that the selection of 0% palm, 4% of wood 0.5% of nano SiC and 0% palm, 0% of wood 0.5% of nano SiC reinforcement is for maximum tensile strength and flexural strength respectively.
- The ANOVA table shows that the factor palm (P) ,wood (W) nano SiC (N) have the highest contribution with 60.80%, 17.52%, 5.08% respectively and flexural strength have the highest contribution with 33.84%, 25.74%, 7.17% respectively for S/N ratio.
- It was observed that ANN and regression are equally efficient in predicting the experimental value for tensile strength. While for flexural strength ANN is more efficient.

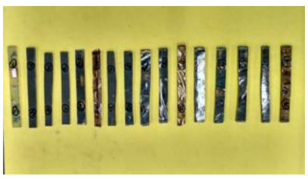
Fig. 1 Prepared Sample


Fig 2 Specimen after Test

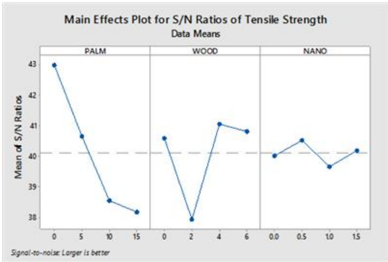

Fig 3 Main Effect Plot for S/N Ratio of Tensile Strength

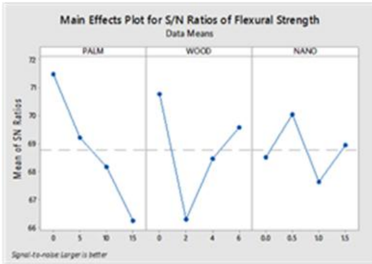

Fig 4 Main Effect Plot for S/N Ratio of Flexural Strength

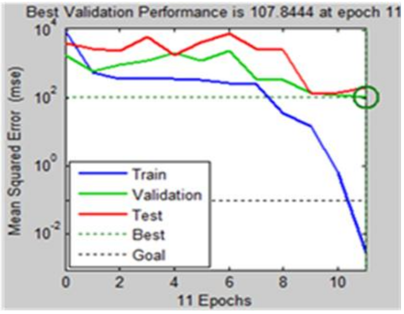

Fig 5 Variation of Mean Squared Error (MSE) With Number of Epochs for Tensile Strength

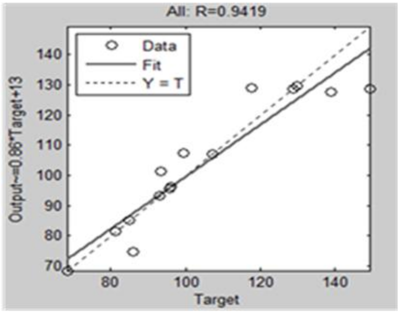

Fig 6 Overall Regression Plot for Trained Network for Tensile Strength

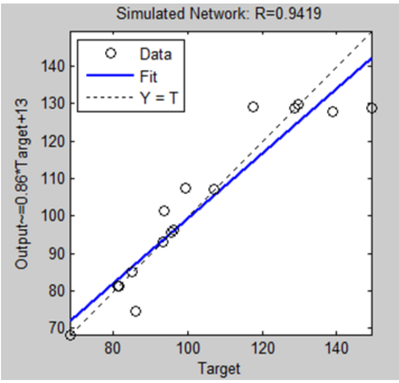

Fig 7 Overall Regression Plot for Simulated Network for Tensile

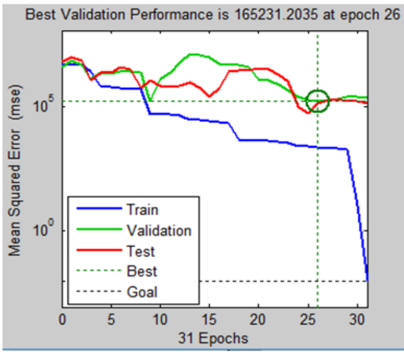

Fig 8 Variation of Mean Squared Error (MSE) With Number of Epochs for Flexural Strength

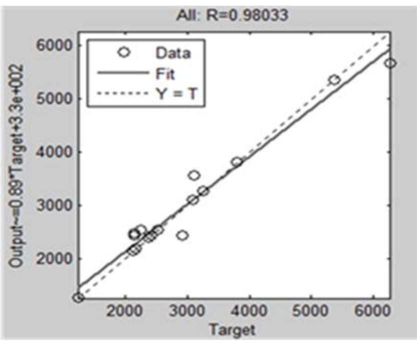

Fig. 9 Overall Regression Plot for Trained Network for Flexural Strength

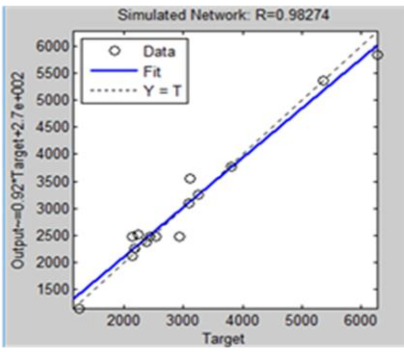

Fig 10 Overall Regression Plot for Simulated Network for Flexural Strength

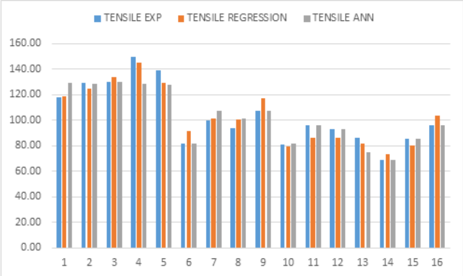

Fig 11 Comparison of Experimental and Predicted Results Tensile Strength

Fig. 12 Comparison of Experimental and Predicted Results for Flexural Strength

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