Optimization in Flexural and Physical Behavior of Agricultural Waste Reinforced Epoxy Based Polymer Matrix Composite by Taguchi Technique

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Optimization in Flexural and Physical Behavior of Agricultural Waste Reinforced Epoxy Based Polymer Matrix Composite by Taguchi Technique

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Abstract Researchers and experts in this study strongly emphasize the use of various agricultural and industrial waste materials such as coconut shells, walnut shells, almond shells, crushed nutshells, and fly ash, among others. These discarded materials are used to create new composites, which are essential to long-term sustainability. Epoxy resin was used as the polymer matrix composite material in the development of a new set of polymer composites, which are described in this paper. These polymer composites consist of different weight percentages (2.5, 5.0, 7.5, 10.0, 12.5, and 15.0) wt. percent of coconut shell particulate and walnut shell particulate in equal ratio. At room temperature, epoxy resin and epoxy hardener were mixed in a ratio of 10:1. There are fabricated six specimens of composites by hand lay-up technique. The newly developed composites are characterized by the physical and mechanical behavior of a new class of Agricultural Waste Reinforced Epoxy-Based Composite. Mechanical properties are investigated using L_{18} (6^1 3^1) orthogonal design with MINITAB-19 statistical software. According to the Taguchi technique and analysis of variance outcome, it was found experimentally that the sequence of parameters affects the flexural property in ascending order as filler load and speed. The results concluded that developed composites could be used as eco-friendly and cost-effective materials in lightweight applications.

Keywords: Walnut shell; Coconut shell; Physical properties; Mechanical properties; Taguchi

1. Introduction

Researchers worldwide are working to motivate, investigate, and develop a new type of agricultural waste-reinforced epoxy-based polymer matrix composite[1)]. Polymer materials may be employed in generators, actuators, sensors, and biomedicine due to their diversity, simplicity of production, high strength, strong biocompatibility, temperature stability, adhesive capacity, and lightweight[2)]. Researchers are concentrating their efforts on environmental awareness and the economic worth of various polymer composites[3)]. Recently, experts have been concentrating on how rising crude oil costs are causing greater global waste problems and raising the expenses of operations and procedures. As a result, researchers are focusing on the principles of sustainability and a re-evaluation of renewable resources[4)].

Agricultural waste such as coconut shells and walnut shells are waste products that are treated as contaminant products for soil[5)]. Agricultural waste-reinforced epoxy-based polymer matrix composites were chosen as a research topic because they have several advantages over synthetic fiber-reinforced composites, including a low cost, low density, local availability, good mechanical properties, good insulation properties, better renewable, less soil pollution, complete or partially recyclable, and eco-friendly properties[6, 7)].

Agricultural waste-reinforced epoxy-based polymer matrix composites have some drawbacks, including dimensional stability sensitivity, which reduces their effectiveness with hydrophobic polymers, shape, and size composites that are non-uniform due to filler, passivity to natural environment attacks, biological decay, and inability to withstand higher temperatures. A composite material is made up of two or more materials that combine the qualities of various materials. Researchers discovered that reinforcement-based composites are not only harder but also stronger than matrix-based composites after experimenting. It is possible to insert reinforcement particles at the micro or nano-scale level into it[8)]. The predominant functions of the matrix are not only to transfer stresses between the reinforcing fibers and particulates but also to protect them from environmental and mechanical damage[9,10)].The main functions of particulates introduced into a matrix material include

improving stiffness, performance at high temperatures, resistance to wear and abrasion, reforming electrical and thermal conductivities, improving machinability, improving surface hardness, lowering friction, and minimizing shrinkage[11].

2. Experimental Details

2.1 Materials

The hybrid polymer composite is prepared from Epoxy resin (LY 556), hardener (HY 951), and heavy-duty silicone spray purchased from Savita Scientific and Plastic

Fig. 1: Coconut and walnut shell particles (Mesh 210).

Products, Indira bazaar Jaipur-30200. Coconut shell powder (CSP) and walnut shell powder (WSP) were chosen as reinforced particles to fabricate all the test samples.

2.2 Preparation of Composite

Composites were developed by hand layup methods[12,13,14]. For two weeks, coconut and walnut shells were exposed to the sun's rays and then cleaned with pressured water. After the samples are dried and crushed into micron-sized particles, this process eliminates tiny particles, residues, and organic components. Epoxy resin and hardener (HY951) in the ratio of 10:1 were added to the mixture, followed by CSP/WSP and epoxy resin in six different compositions (95, 90, 80, 75, and 70 wt. percent epoxy and CSP/WSP (1:1), (2.5, 5, 7.5, 10, 12.5, and 15 wt.%). The dough is kneaded mechanically before being vacuum-chambered for 10 minutes to eliminate air pockets. To remove the composite sheets quickly and easily, the epoxy (which has been filled with CSP/WSP (1:1) is slowly poured into the vacuum glass chamber coated with glass paper and a mold release spray is applied to the inside surface. The composite part is removed from the mold after curing for 24 hours at room temperature.

2.3 Design of Experiment

In this research, the Taguchi approach was employed to generate performance characteristics[15]. The L_{18} orthogonal array was chosen because it can control variable interactions. For flexural behavior, Table 1 shows the levels of each parameter.

Table 1: Levels of each parameter used for flexural behavior.

Levels						
Control Parameters	1	2	3	4	5	6
Filler (wt.%)	2.5	5	7.5	10	12.5	15
Speed (mm/min)	1	1	1	1	1	1
	2	2	2	2	2	2
	3	3	3	3	3	3

3. Results and Discussion

3.1 Physical Characterization

Composites have a significant physical property: density. Composites with a low density are preferred because they require fewer production coatings. Material properties, such as the ratio of epoxy resin to fiber filler, play a role in composite density. To conduct the density test, 40 mm long and 20 mm wide samples were cut from the composite product[16]. This formula can calculate density:

Density = $W_1 \times \sigma_w / (W_1 - W_2)$

Where W_2 = weight of the specimen in distilled water.

W_1 = weight of the specimen in air.

σ_w = density of distilled water at NTP.

The density versus wt.% of CSP/WSP (1:1) particle-reinforced epoxy composites is shown in figure 2. Because of superior epoxy resin bonding and maximal void formation, the minimum density (5.975 g/cm^3) was observed for 2.5 wt. percent CSP/WSP (1:1) particle-reinforced epoxy-based composite[17]. Air bubbles trapped inside the PMC, vapor produced during the curing of the epoxy and hardener, and residual solvents have all been implicated in creating voids in composites. Voids are also accused due to the resin being difficult to wet completely after mixing CSP/WSP (1:1) particles[18].

The value of density of CSP/WSP particulates reinforced epoxy-based composite with five weight percent suddenly rose due to an increase in the density of CSP/WSP particulates in composites occurred. It can be seen that the value of the density (15.308 g/cm^3 to 7.167 g/cm^3) of CSP/WSP (1:1) particulates reinforced epoxy-based composites drops even more from 5 to 15 weight percent as a result of the rise in the density of CSP/WSP (1:1) particulates in composites[19]. Since the particles of coconut shell and walnut shell are relatively light yet

occupy a sizable volume of the container, the density of the mixture has decreased[20].

Table 2: Comparison of density for developed composites.

Designation of Specimens	Run	W1 (gm)	W_2 (gm)	σ_w (gm/cm^3)	Average density (gm/cm^3)
A	A-1	3.310	2.700	5.415	5.975
	A-2	3.470	2.940	6.534	
B	B-1	7.100	6.690	17.282	15.308
	B-2	4.810	4.450	13.334	
C	C-1	5.290	4.900	13.537	10.636
	C-2	4.030	3.510	7.734	
D	D-1	4.940	4.280	7.470	7.306
	D-2	5.010	4.310	7.143	
E	E-1	5.370	4.580	6.784	7.277
	E-2	5.450	4.750	7.770	
F	F-1	5.180	4.480	7.385	7.167
	F-2	3.830	3.280	6.950	

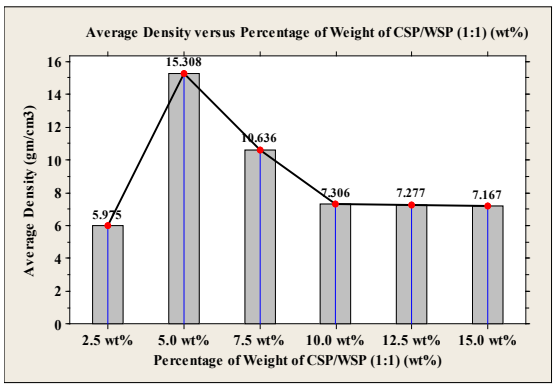

Fig. 2: Comparison of density for developed composites.

3.2 Flexural Test

The flexural test, commonly known as the 3-point bend test, is used to measure the elasticity of materials. The ASTM standard (D2344-84) specifies the size and shape of specimens used in flexural tests[21, 22]. As defined by ASTM D2344-84, Flexural test specimens were 100 mm × 20 mm in dimension, with an average thickness of 41 mm. The flexural test required a gauge length of 60 mm. A total of six specimens of varied CSP/WSP (1: 1) weight percentages (2.5, 5.0, 7.5, and 10) were evaluated at three different speeds: one at 1 mm/min; two at 2 mm/min; and three at 3mm/min.

3.3 Taguchi Analysis of Flexural Property.

The Taguchi method was carried out with MINITAB 19 statistical software[23]. An investigation into flexural behavior was carried out with two control factors, one of them is filler loading with parameters such as 2.5, 5.0, 7.5, 10, 12.5, and 15 wt.% of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) and another one speed with a parameter such as 1, 2, and 3 mm/min in association with L_{18} orthogonal array. It provides excellent accuracy as well as less time in experimental work. The mechanical flexural parameters of various composites are shown in table 3 for all 18 test runs, along with their associated S/N ratios.

On the mechanical flexural properties, the S/N graph represents optimal experimental conditions for filler loading with parameters such as 2.5, 5.0, 7.5, 10, 12.5, and 15 wt.% of coconut shell particle (CSP) and walnut shell particle (WSP) (1:1) and speed with parameters such as 1,2, and 3 mm/min.

After interpreting the flexural test results, it is concluded that the filler loading and speed change parameter combination gives the best mechanical flexural qualities. Figure 3 (a) also shows how the highest mechanical flexural strength is achieved when filler loading (15 wt%) and speed (2 mm/min) are combined. The interaction plot of filler loading and speed for the S/N ratio on the different percentages of the weight of CSP/WSP epoxy-based composites in flexural strength is also shown in figure 3 (b). It was observed that speed was significant after filler loading.

Table 3: Experimental design using L18 orthogonal array for developed composites.

Filler Content (wt.%)	Speed (mm/min)	Flexural Strength (MPa)	SN Ratio	Maximum Flexural Load (kN)	SN Ratio
2.5	1	36.400	31.222	0.207	-13.681
2.5	2	35.980	31.121	0.206	-13.723
2.5	3	32.360	30.200	0.141	-17.016
5	1	30.710	29.746	9.020	19.104
5	2	36.740	31.303	8.120	18.191
5	3	31.630	30.002	8.250	18.329
7.5	1	31.650	30.008	7.500	17.501
7.5	2	31.560	29.983	7.560	17.570
7.5	3	28.500	29.097	7.580	17.593
10	1	30.140	29.583	7.020	16.927
10	2	32.960	30.360	6.950	16.840
10	3	36.840	31.326	6.790	16.637
12.5	1	28.140	28.987	6.490	16.245
12.5	2	32.090	30.127	7.240	17.195
12.5	3	25.350	28.080	6.70	16.522
15	1	39.130	31.850	8.130	18.202
15	2	36.720	31.298	7.950	18.007
15	3	42.500	32.568	8.060	18.127

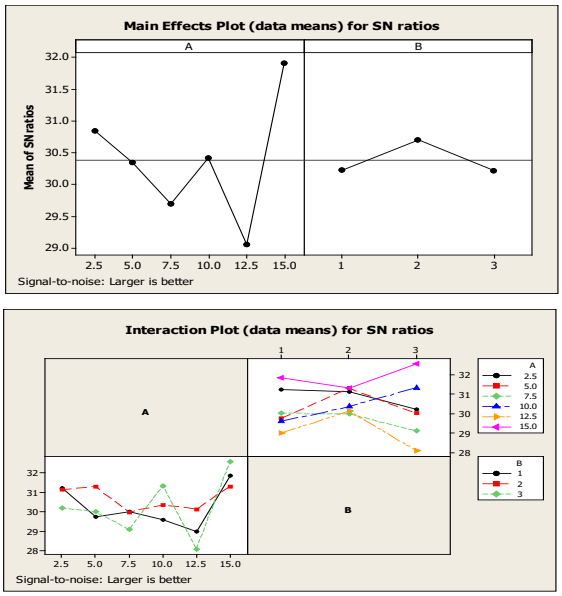

Fig. 3: Main effect and interaction plots for S/N ratio of developed composite for flexural load.

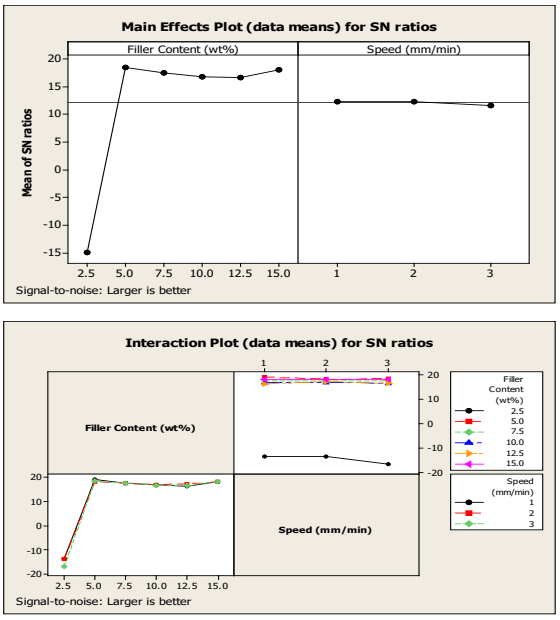

Fig. 4: Main effect and interaction plots for S/N ratio of developed composite for the flexural load

Table 4: Response table of S/N ratio for flexural strength.

Level	Filler Content (wt.%)	Speed (mm/min)
1	30.85	30.23
2	30.35	30.70
3	29.70	30.21
4	30.42	-
5	29.06	-
6	31.91	-
Delta	2.84	0.49
Rank	1	2

Figure 4 (a) represents how filler loading (5 wt%) and speed (1 mm/min) gives maximum mechanical flexural load. Figure 4 (b) also clearly describes the interaction plot of filler loading and speed for the S/N ratio on the different percentages of the weight of CSP/WSP epoxy-based composites in flexural strength. It was also observed that from table 5, speed was significant after filler loading

3.4 Analysis of Variance of Flexural Property

ANOVA is a statistical technique for identifying the influences of various design elements on a target quality attribute[24]. Tables 6 and 7 display the results of an ANOVA on the flexural load and flexural strength variables, respectively. An analysis of variance is performed with a 95 percent confidence level of significance. The value of F was calculated for each design parameter. If the factor's F value is observed greater than four (F>4), that means it is more significant[25]. That factor has an impact on the best attribute. The factor is more significant if its P-value (P 0.05) is observed as less than 0.05.

Table 5: Response table of S/N ratio for the flexural load.

Level	Filler Content (wt.%)	Speed (mm/min)
1	-14.81	12.38
2	18.54	12.35
3	17.56	11.70
4	16.80	-
5	16.65	-
6	18.11	-
Delta	33.35	0.68
Rank	1	2

Table 6: ANOVA analysis table for flexural strength.

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution (%)
Filler Content (wt.%)	5	212.214	212.214	42.443	4.720	0.018	68.007
Speed (mm/min)	2	9.851	9.851	4.925	0.550	0.595	3.157
Error	10	89.983	89.983	8.998			28.836
Total	17	312.047					

The percentage of each parameter's contribution to the overall variance is shown in the last column of tables 6 and 7, indicating the parameter's level of influence on the result. It might be noticed that filler loading (68.007%) had a more significant effect on the maximum flexural strength of epoxy-based composites, while speed (3.157%) had a less substantial impact on it.

It is observed that filler loading (99.424%) had a more significant effect on the maximum flexural strength of epoxy-based composites, while speed (0.042%) had a less substantial impact on it. Filler loading was the most important factor in flexural strength and flexural load, followed by speed.

Table 7: ANOVA analysis table for the flexural load.

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	Contribution (%)
Filler Content (wt%)	5	141.966	141.966	28.393	372.190	0.000	99.424
Speed (mm/min)	2	0.060	0.060	0.030	0.400	0.683	0.042
Error	10	0.763	0.763	0.076			0.534
Total	17	142.789					

3.5 Regression Analysis of Flexural Property

A regression approach is a statistical tool that can be used to approximate the relationships between variables. It provides an equation for calculating how the dependent parameter changes when any of the independent parameters are altered [17].

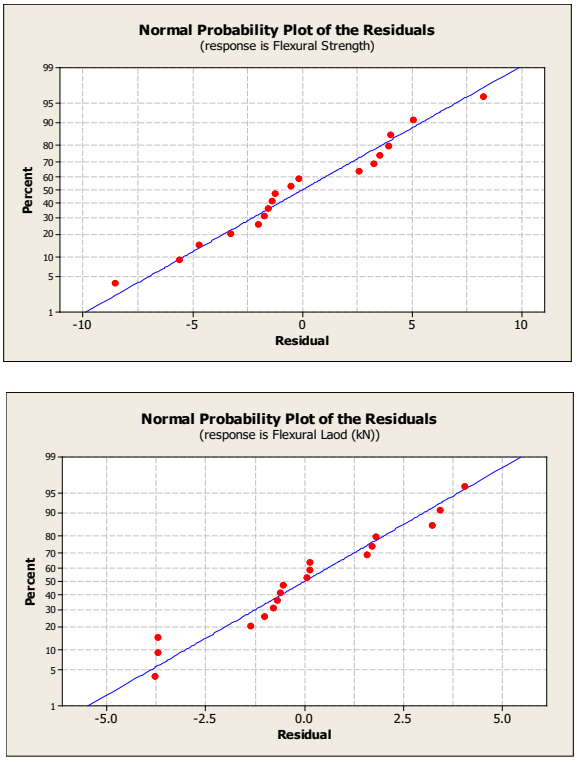

Fig. 5: Normal probability plot for flexural behavior.

A regression analysis was performed for flexural behavior with speed and filler content as independent factors. The normal probability plot for flexural behavior (see Figure 5) illustrates the impact of input parameters. The regression equation for maximum flexural strength

Flexural Strength (N/mm2) = 31.9 + 0.136 Filler Content (wt.%) + 0.08 Speed (mm/min)

The regression equation for maximum flexural load

Flexural Load (kN) = 3.10 + 0.385 Filler Content (wt.%) - 0.071 Speed (mm/min).

4. Conclusion

The flexural behavior of agriculture waste (coconut shell and walnut shell) reinforced epoxy composites was investigated under different filler loadings and testing speeds. The experimental findings verify the effective production of coconut shell and wall nutshell powder composites, which possess good filler characteristics and improve the epoxy-based composite's flexural characteristics. It was discovered that the highest mechanical flexural strength was achieved when filler loading (15 wt.%) and testing speed (2 mm/min) was used. The flexural strength of the composite increases up to 15 wt.% filler and resting speed (2 mm/min); after that, it decreases. The maximal stress rises with increasing testing speed, although at lower filler wt.%, this occurred because the filler has less time to orient itself. Flexural strength may be optimized using Taguchi analysis, and the response table demonstrates a direct correlation between filler quantity and strength. At a 95 percent confidence level, ANOVA results show that filler content and testing speed substantially impact the strength of composites.

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