Manufacturing and Evaluation of jute fiber with gypsum and walnut shell powder Composite with Epoxy Resin

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Abstract. The purpose of this study is to examine the mechanical and physical characteristics of jute fibre composites reinforced with different sizes of gypsum and walnut shell powder in an epoxy resin matrix using hand layup technique. Using a 3x3 orthogonal array that encompasses three parameters at three levels each, composites were created based on a Taguchi design technique. Tensile, flexural, and impact strength tests were performed on the composites, along with thickness swelling and water absorption testing and ANOVA analysis was performed for each test using Minitab. The results show that temperature, size, and composition of the walnut shell powder all improved flexural strength, but composition, size of the walnut shell powder declines the tensile strength upon increasing them, and higher temperatures of jute fiber increased tensile strength. The impact strength was constant in all combinations. Higher temperature produced composites showed better rates of water absorption, especially those with more powdered walnut shell. Notably, the composite with 0% walnut shell powder (size <1mm) produced at ambient temperature showed the maximum tensile strength, whereas the composite heated to 80°C with 5% walnut shell powder (size <4mm) showed the highest flexural strength. The mechanical characteristics and water absorption behaviour of jute fiber-walnut shell powder composites can be optimised for a variety of applications with the help of these results.

1 Introduction

Most of the research on engineered materials, which supports a wide range of applications from daily products, is focused on composite materials [1]. Because even a tiny quantity of composite structure can greatly enhance attributes like mechanical and thermal performance, bio composite materials are very appealing [6]. Composite materials usually form a polymeric matrix and reinforcement, consisting of two or more chemically different elements. In general, the reinforcement makes the composite stiffer and stronger than the matrix, and the matrix holds the reinforcement in place [7]. Owing to their advantageous mechanical characteristics and lightweight design, composites are helping to create ever-

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more efficient and cost-effective products [8]. They are widely used in many different industries, including as sporting goods, automotive, aerospace, and marine [9,13]. Jute fibres are more likely to absorb moisture from the surroundings because of their OH groups. Their compatibility and interaction with hydrophobic polymer matrices are lessened by this hydrophilic characteristic [10].

Partially biodegradable materials are used to create green composites, which are made to support the characteristics of their constituents. Globally, there has been a noticeable shift in the utilisation of natural fibres in the creation of green composites [2]. The majority of research has concentrated on using other materials to the polymer matrix to reinforce single artificial or natural fibres, such as sisal, kenaf, jute, hemp, abaca, and carbon fibre.

Natural fibers have a bunch of advantages over synthetic fibers. They're cheaper, heavier, and denser. And out of all the natural fibers out there, jute is the most practical one. It's affordable and you can easily find it in stores [4]. The literature tells us that jute fibers are great for reinforcing different materials like unsaturated polyester, epoxy resin, polyvinyl chloride, polypropylene, and polyethylene [5]. This study showed that making epoxy resin composites with coconut and jute fiber reinforcements using the hand layup method significantly improved the mechanical properties of the materials. So, here's the deal: Tensile strength, impact strength, and flexural strength all got a nice boost. Turns out, jute fiber really rocked it in these areas [11,12]. But that's not all! Jute fiber has some cool features. It's biodegradable, adaptable, nonabrasive, and renewable [3]. Now, when it comes to how well a composite performs, two things matter a lot: the mechanical characteristics and the ratio of reinforcement to matrix materials. They play a big role in determining the result. There are a bunch of factors that come into play, like fiber orientation, surface features, quantity, and the mechanical and physical attributes of the fibers and the composite structure [14,15].

In our study, we made composites using epoxy resin and different ratios of jute fiber, gypsum, and walnut shell powder. We sifted the walnut shell powder through sieves of varying sizes to get different particle sizes. We focused on three factors in this investigation: the temperature of the jute fiber, the composition of the walnut shell powder compared to the gypsum powder, and the size of the walnut shell powder. We tested the prepared composites for water absorption, thickness swelling, tensile strength, impact strength, and flexural strength.

2 Experimental

2.1 Materials and methods

The resin used was epoxy (Araldite LY 556), which has a good resistance to solvents and high temperatures, and an outstanding mechanical adhesion. The hardener used was Aradur HY 951. For almost half an hour, the mixture was vigorously agitated with a resin-to-hardener ratio of 10:1. Jute fibre was heated in a furnace at three different temperatures (30°C, 80°C, and 95°C) after being purchased from a nearby store. Following the consumption of the edible portions, walnut shells were gathered, crushed, and ground into particles smaller than 1mm, 2mm, and 4mm. Particles of ground and partially ground walnut shell were sieved to produce these sizes. In order to make gypsum powder, calcium sulphate hemihydrate was mixed with water in the appropriate proportion, allowed to solidify into a smooth structure, and then ground into a fine powder. The process parameters and their levels are shown in the below table 1

Table 1. Specifications for process parameters and their levels

Parameters	Levels		
Temperature (^{0}C)	30^{0}C	80^{0}C	95^{0}C
Walnut shell powder (wt%)	0%	5%	7.5
Walnut shell powder size (mm)	<1	<2	<4

The different combinations of composites were designed using Taguchi technique of 3x3 orthogonal array as shown in the below table 2

Table 2. Taguchi design table of 3x3 orthogonal array

Experiment no.	Temperature (^{0}C)	Walnut shell powder (%)	Walnut shell powder size (mm)
1	30	0	<1
2	30	5	<2
3	30	7.5	<4
4	80	0	<2
5	80	5	<4
6	80	7.5	<1
7	95	0	<4
8	95	5	<1
9	95	7.5	<2

2.2 Fabrication of composites

The hand layup technique was used in these composites manufacturing process, using different amounts of gypsum powder, walnut shell powder, and jute fabric. Jute fibre was heated to the appropriate temperature and each composite was made in accordance with the prescribed compositions. Grease was applied to the wooden planks, and then the heated jute fibre was distributed across the greased area. A brush was used to apply and uniformly disperse a resin mixture. Next, the jute fibre was sprinkled with gypsum powder and powdered walnut shell. To keep the resin mixture from solidifying, it was constantly agitated. After that, another layer of heated jute fibre was applied, and so on, until the required thickness was reached. Every single one of the nine composite types underwent this process. After being loaded up to 100 kg, the formed layers were allowed to solidify for 24 hours at room temperature. Following this time, the cured composite plates were gently removed, with the grease helping to prevent deformation or cracks. This process made sure that the composite plates were produced effectively and efficiently.

2.3 Tensile Strength

In in accordance with ASTM D638 requirements, the tensile strength of the composite specimens was assessed using a universal testing machine type MCS/UTE-1T with a 1-ton capacity. The specimens had dimensions of 165 mm for length, 19 mm for width, and 3 mm for thickness, along with a 50 mm gauge length. The grip lengths were adjusted to 50 mm on either side. The tests were carried out at room temperature and with a strain rate of 1 mm/min.

2.4 Impact Strength

Using a FIE machine, the Charpy impact test was performed in accordance with ASTM D256 guidelines. The specimen had the following measurements: it was 55 mm long, 10 mm wide, and up to 5 mm thick. A 45-degree V-notch that was 2 mm deep was employed as shown in the table 3. A Charpy testing apparatus was used for the testing, which was done at room temperature.

2.5 Flexural Strength

In accordance with ASTM D790 guidelines, the flexural strength was assessed using the 3-point bend method on a model MCS/UTE-1T universal testing machine. The equipment can hold one tonne of weight. The specimens were 16 mm wide, 3 mm thick, and had a total length of 100 mm as shown in the table 3, including an 80 mm span length. During the test, a strain rate of 1 mm/min was used.

The dimensional specifications of the testing standards are shown in the below table 3

Table 3. Specimen dimensions for testing of tensile, flexural and impact strength

ASTM specifications for tensile, flexural and impact strength		
Tensile strength	D638	165x19x3mm
Flexural strength	D790	100x16x3mm
Impact strength	D256	55x10x5mm

2.6 Water absorption test

The ASTM D570 guidelines were followed for conducting the water absorption test. For five days, specimens measuring 75 mm in length, 50 mm in width, and up to 10 mm in thickness as shown in the table 4 were submerged in room temperature distilled water. The specimens' initial and final weights were noted in grammes. Five days were spent testing the specimens. After five days, the water absorption test specimens were removed from the experiment, and their weights were noted.
Using the following below formula, the percentage of water absorption rate (%WAR) was determined:
$\%WAR=(W2-W1)/W2 \times 100$
Where W2 represents the weight of the specimen after 5 days of immersion and W1 represents the weight of the specimen before testing.

2.7 Thickness swelling test

The ASTM D570 guidelines were followed for conducting the thickness swelling test as shown in the table 4. For five days, specimens with dimensions of 75 mm in length, 50 mm in width, and up to 10 mm in thickness were submerged in distilled water at room temperature. The specimen's starting and final thicknesses were expressed in millimetres. The following formula was used to get the percentage of thickness swelling (%TS):
$\%TS=(T2-T1)/T2 \times 100$

where T2 represents the thickness of the specimen after 5 days and T1 represents the initial thickness before testing.
The dimensional specifications of the testing standards for water absorption ability and thickness swelling are shown in the below table

Table 4. Specimen dimensions for water absorption and thickness swelling ability

ASTM specifications for Water absorption and Thickness swelling test		
Water absorption	D570	75x50x10mm
Thickness swelling	D570	75x50x10mm

3 Results and discussion

3.1 Experimental results

3.1.1 Tensile strength

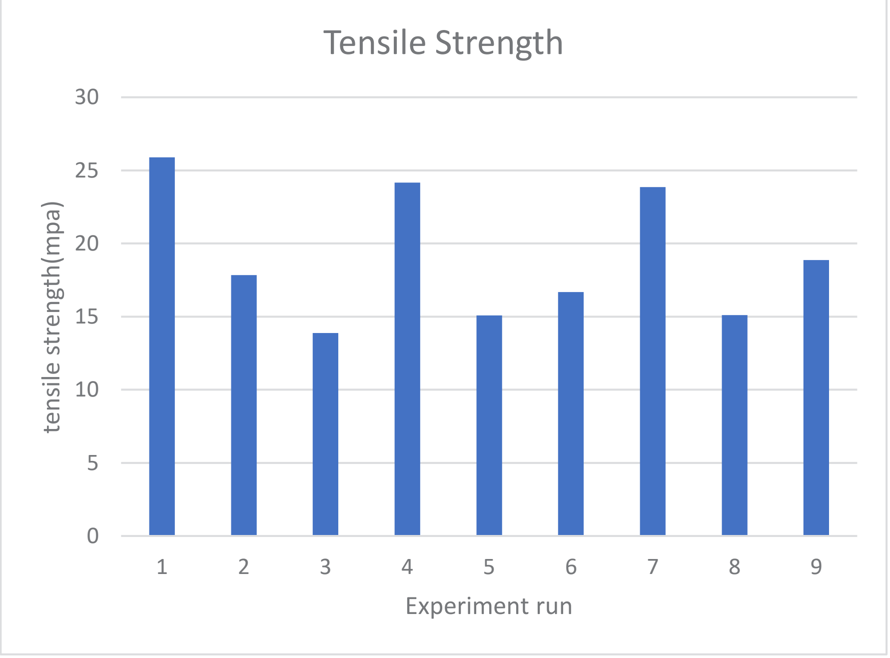

Fig. 1. Tensile strength of composites

The universal testing equipment records the tensile strength of each of the nine distinct composites, and it is evident that the tensile strength falls with an increase in the percentage of walnut shell powder (WSP) as depicted in the fig 1. At all temperatures, the maximum tensile strength is found at 0% WSP (with 10% gypsum powder). Although the addition of WSP still causes a decrease, higher temperatures (80°C and 95°C) aid in maintaining tensile strength more than lower temperatures (30°C). In general, temperature contributes to the preservation of tensile strength to a certain degree, but the addition of powdered walnut shell constantly reduces it.

3.2 Flexural strength

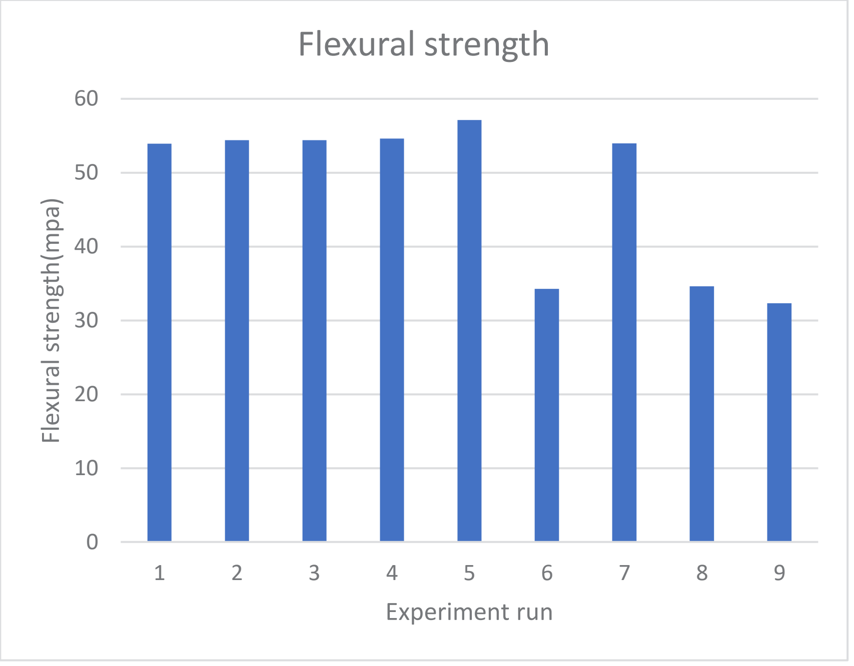

Fig. 2. Flexural strength of composites

The results show that, at 30°C, flexural strength remains constant throughout WSP % for the nine distinct composites whose flexural strengths were measured using a flexural testing machine. A 5% WSP additive raises flexural strength at higher temperatures (80°C and 95°C), but a further increase to 7.5% WSP causes a notable drop as shown in the fig 2. Flexural strength exhibits a consistent drop relationship with the size of the powdered walnut shell at 4mm. Flexural strength is influenced by the combination of temperature and WSP %, with more WSP percentage and higher temperatures resulting in noticeable declines.

3.3 Impact strength

Each of the nine distinct combinations had an impact strength of two joules, which remained constant as shown in the table 5. This homogeneity implies that the impact strength of the composites was not considerably impacted by changes in size, temperature, or the proportion of walnut shell powder. All combinations had the same impact strength, but the tensile and flexural strengths displayed trends that were influenced by these parameters. This may suggest that the variables influencing impact strength are not as susceptible to differences in composite composition as those affecting tensile and flexural strengths, or that the impact testing circumstances were less sensitive to these variations. To have a more comprehensive understanding of the relationship between the composite composition and its impact resistance, additional investigation and testing could be required.

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3.4 Water absorption ability

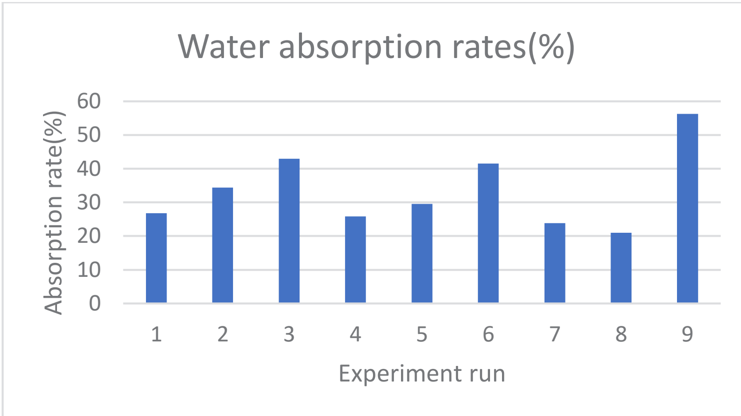

Fig. 3. Water absorption rates of composites

After the samples are taken out of distilled water after five days, the water absorption capacities of the nine distinct composites are measured as shown in the table 5, and it is shown in the figure 3 that water absorption rises with increasing percentages of walnut shell powder (WSP). For composites with 0% and 5% WSP, higher temperatures typically result in less water absorption; however, at 95°C, water absorption is noticeably higher for composites with 7.5% WSP. Water absorption rises as WSP % rises at 30°C. While the trend is similar but less steep at 80°C, at 95°C, water absorption is much higher for 7.5% WSP and lowest for 5% WSP when compared to other combinations. The analysis of walnut shell powder sizes reveals that the 1 mm size exhibits the lowest mean water absorption rate. Temperature and the proportion of walnut shell powder have a major impact on the composites' ability to absorb water.

3.5 Thickness swelling ability

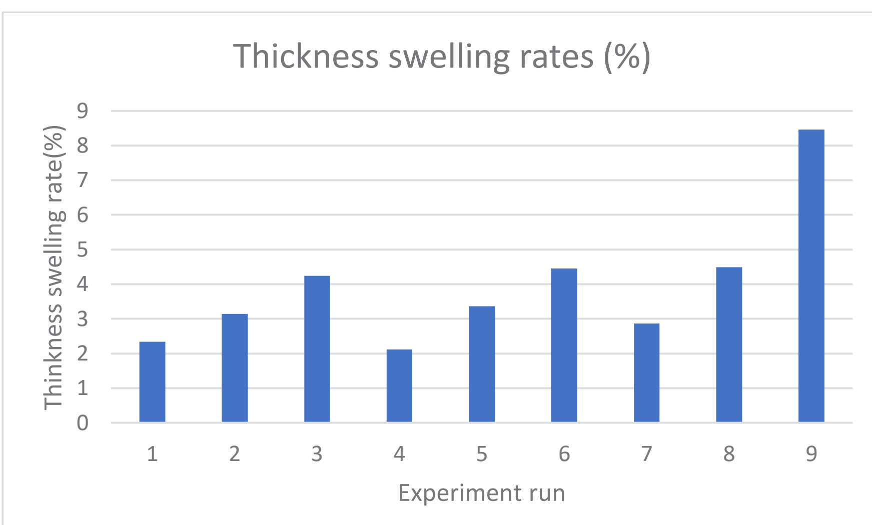

Fig. 4. Thickness swelling rates of composites

The ability of the nine distinct composites to swell in thickness is measured after five days of removing the samples from distilled water. The results shown in the table 5 and fig 4 depict that increasing percentages of walnut shell powder (WSP) lead to more robust thickness swelling. Thickness swelling increases with temperature, especially at 7.5% WSP, where the swelling increases dramatically at 95°C. Thickening trends upward with a greater WSP percentage between 30°C and 80°C. When comparing 7.5% WSP to 0% and 5% WSP at 95°C, thickness swelling is noticeably greater. The thickness swelling rates are influenced by the size of the powdered walnut shell. The 1 mm size has a moderate consistency and the lowest mean swelling rate.

Table 5. Mechanical and physical testing results

Experiment no	Tensile strength in mpa	Flexural strength in mpa	Impact strength in joules	Water absorption %	Thickness swelling %
1	25.89	53.92	2	26.78	2.34
2	17.84	54.42	2	34.38	3.14
3	13.89	54.42	2	42.96	4.24
4	24.16	54.62	2	25.88	2.12
5	15.08	57.12	2	29.56	3.36
6	16.67	34.27	2	41.52	4.45
7	24.89	53.96	2	23.84	2.86
8	15.1	34.62	2	20.98	4.49
9	18.86	32.33	2	56.31	8.46

4 Analysis

Using Minitab software, the tensile, flexural, and impact strength values of the nine composite combinations were examined in order to create a response table and identify the parameter that has the most influence on the final strength. Graphs of the signal-to-noise ratio were produced in order to determine the best combination of parameter settings for increased strength. Regression equations and ANOVA tables were obtained, this investigation helped determine the best composite formulation for improved performance by demonstrating the substantial effects of temperature and the proportion of walnut shell powder on the mechanical properties of the composite.

4.1 Regression Equation for Tensile strength

Tensile strength =25.38 + 0.0018 temp - 1.229 wsp % - 0.529 wsp size

Table 6. ANOVA table for tensile strength

Source	DF	Adj SS	Adj MS	F-value	P-Value	Percentage
temp	2	1.453	0.7267	0.16	0.865	0.844
wsp %	2	153.102	76.5509	16.43	0.057	88.98
wsp size	2	8.187	4.0933	0.88	0.532	4.75
Residual Error	2	9.319	4.6594	0.16	0.865	5.41
Total	8	172.061	0.7267	16.43	0.057	

From the above table 6 it can be said that the tensile strength of the composites is mostly determined by the amount of walnut shell powder present; jute fibre temperature and walnut shell powder size have significantly less of an impact.

4.1.1 Response table for tensile strength

Table 7. Response table for signal-to-noise ratio tensile strength (larger is better)

Level	Temperature	WSP %	WSP size
1	25.38	27.95	25.43
2	25.22	24.06	26.07
3	25.67	24.27	24.78
Delta	0.45	3.89	1.29
Rank	3	1	2

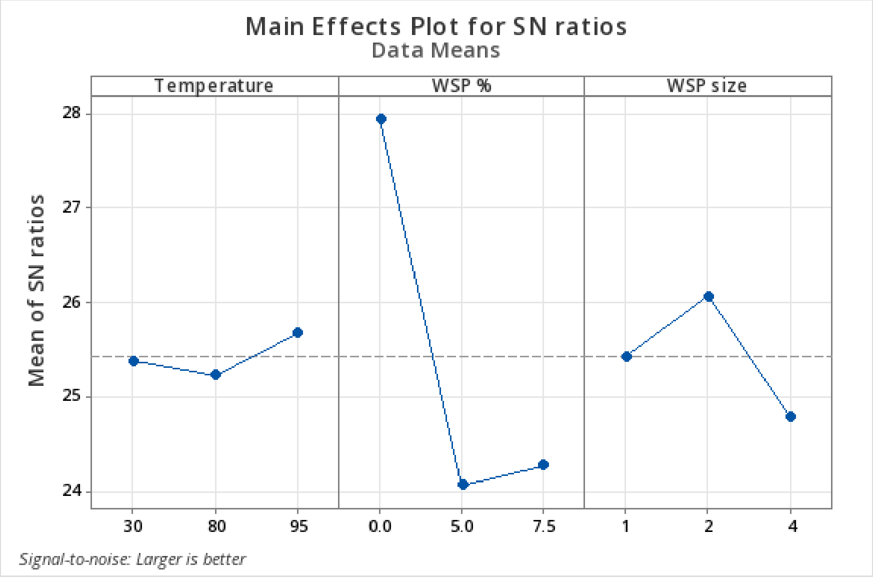

Fig. 5. Signal-to-noise ratio graph for tensile strength

The walnut shell powder percentage (WSP%), which has the highest rank as shown in the table 7 and the most impact on tensile strength, is the most important parameter, according to the response table analysis for tensile strength. The powdered walnut shell comes in second place in terms of size, suggesting a minor effect on tensile strength. It has been determined from the signal-to-noise ratio graphs that 95°C, 0% WSP means 10% of gypsum are the ideal parameters for increased tensile strength. This ranking emphasises how crucial it is to concentrate on temperature and gypsum % in order to maximise the composite's tensile strength.

4.2 Regression Equation for Flexural strength

Flexural strength =57.04 - 0.1887 temp - 1.736 wsp % + 4.64 wsp size

Table 8. ANOVA table for flexural strength

Source	DF	Adj SS	Adj MS	F	P	Percentage
temp	2	295.777	147.889	1640.57	0.001	33.13
wsp %	2	291.067	145.534	1614.45	0.001	32.612
wsp size	2	305.463	152.731	1694.30	0.001	34.22
Residual Error	2	0.180	0.090			0.020
Total	8	892.488				

The flexural strength of the composites is largely influenced by three parameters as shown in the above table 8, the temperature of the jute fibre, the amount of walnut shell powder, and the size of the powder, with the size of the powder having a somewhat bigger impact. All three factors are important and almost equal. There is very little residual error, which suggests that the model fits well.

4.2.1 Response table for flexural strength

According to the flexural strength response table analysis shown in the below table 9, temperature is the most important factor, closely followed by the amount of walnut shell powder (WSP). The flexural strength is least affected by the size of the powdered walnut shell. More specifically, temperature is the most influential component since it causes the biggest variances in flexural strength values. Not as much as temperature, but still a considerable influence on flexural strength is the WSP %.

Table 9. Response table for signal to noise ratio of flexural strength (larger is better)

Level	Temperature	WSP %	WSP size
1	34.69	34.67	32.04
2	33.53	33.55	33.22
3	31.87	31.87	34.83
Delta	2.82	2.81	2.79
Rank	1	2	3

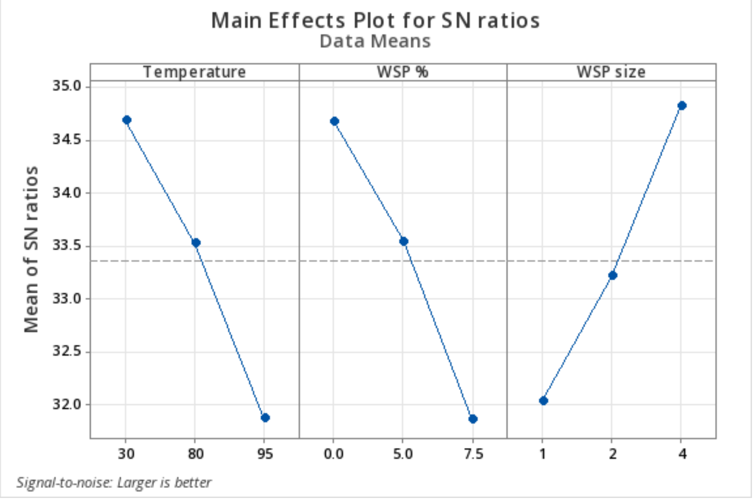

Fig. 6. Signal-to-noise ratio graph for flexural strength

Jute fibre has been shown to provide high flexural strength when heated to 30°C or left at room temperature. Composites with 0% WSP that is, composites made entirely of gypsum have stronger tensile strength. Combining these observations as shown in the below fig 6,

WSP size has less of an impact on improving the mechanical properties of the composite than temperature and WSP %.

4.3 Regression Equation for water absorption (%)

Water absorption rate = 25.1 + 0.112 temp + 0.36 wsp % - 0.31 wsp size

Table 10. ANOVA table for water absorption rates

Source	DF	Adj SS	Adj MS	F	P	Percentage
temp	2	117.04	58.52	1.88	0.347	18.07
wsp %	2	292.43	146.22	4.70	0.175	44.99
wsp size	2	178.27	89.14	2.87	0.259	27.42
Residual Error	2	62.21	31.11			9.5
Total	8	649.96				

The amount of walnut shell powder present has the greatest impact as shown in the above table 10 on the composite's capacity to absorb water; this is followed by the powder's size and the jute fiber's temperature. Given the modest residual error, the majority of the variation in water absorption can be explained by the model.

4.3.1 Response table for water absorption rates

Table 11. Response table for signal to noise ratio of water absorption rates (smaller is better)

Level	Temperature	WSP %	WSP size
1	-30.65	-28.12	-29.12
2	-30.01	-28.86	-31.33
3	-29.66	-33.35	-29.87
Delta	0.98	5.23	2.21
Rank	3	1	2

The percentage of walnut shell powder (WSP%) is the most important parameter, according to the response table analysis as shown in the table 11 for water absorption rates. In particular, the most significant factor is variations in WSP %, which results in the most variances in water absorption rates. More so than the WSP %, the size of the powdered walnut shell has a major effect on the rates of water absorption. Improving the WSP % is essential to improving the water absorption capabilities of the composite. Furthermore, it has been discovered that jute fibre can support a reduced rate of water absorption by fiber being heated to 95°C or kept at ambient temperature. When combined with 2.5% gypsum and 7.5% WSP, composite show reduced water absorption as shown in the fig 7. When these observations are combined, it becomes clear that minimizing the composite's water absorption qualities requires careful attention to the WSP percentage content.

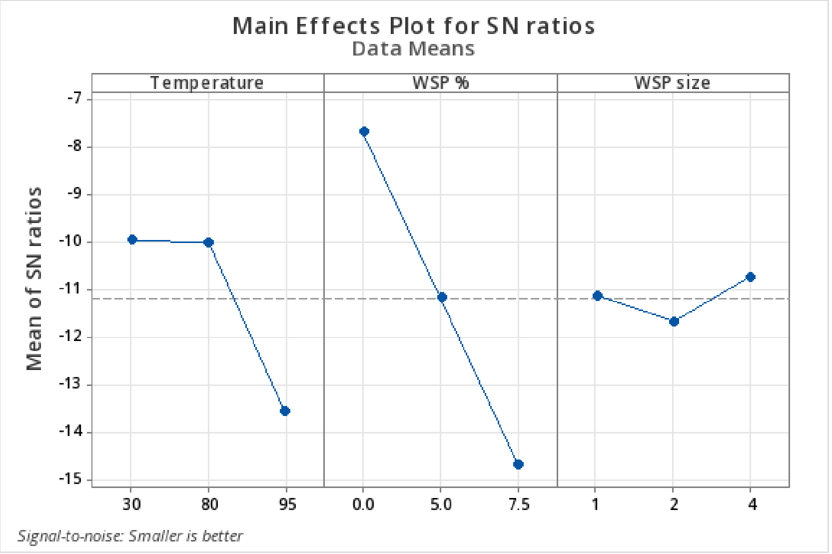

Fig. 7. Signal-to-noise ratio graph for water absorption rates

4.4 Regression Equation for Thickness swelling rate (%)

Thickness swelling rate = 0.98 + 0.0237 temp + 0.409 wsp % - 0.156 wsp size

Table 12. ANOVA table for Thickness swelling rates

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage
Regression	3	18.9174	6.3058	3.10	0.128	65.01
temp	1	3.9101	3.9101	1.92	0.224	13.437
wsp %	1	14.6678	14.6678	7.20	0.044	50.40
wsp size	1	0.3395	0.3395	0.17	0.700	1.166
Error	5	10.1808	2.0362			34.98
Total	8	29.0982				

The primary factor affecting the composite's propensity to swell in thickness is the amount of powdered walnut shell. To a lesser degree, the temperature of the jute fibre also plays a significant role. The residual error suggests that there are more factors influencing thickness swelling that were not taken into account in the research as shown in the table 12, and the size of the powdered walnut shell has very little effect.

4.1.1 Response table for Thickness swelling rates

Table 13. Response table for signal to noise ratio of thickness swelling rates (smaller is better)

Level	Temperature	WSP %	WSP size
1	-9.957	-7.679	-11.132
2	-10.007	-11.170	-11.671
3	-13.573	-14.687	-10.734
Delta	3.616	7.008	0.937
Rank	2	1	3

The most important factor, according to the response table analysis shown in the table 13 for thickness swelling rates, is the proportion of walnut shell powder (WSP%). In particular, the most significant factor is differences in WSP %, which results in the most variances in thickness swelling rates. For thickness swelling rates to be decreased, WSP percentage optimisation is essential. Additionally, maintaining jute fibre to room temperature or 30°C can result in lesser thickness swelling. Combinations in which there is no walnut shell powder proportion shown in the fig 8 and 10% gypsum in the composite show less swelling in terms of thickness. By combining these insights, concentrating on the WSP %, and putting the ideal conditions into practice, thickness swelling in the composites can be effectively reduced.

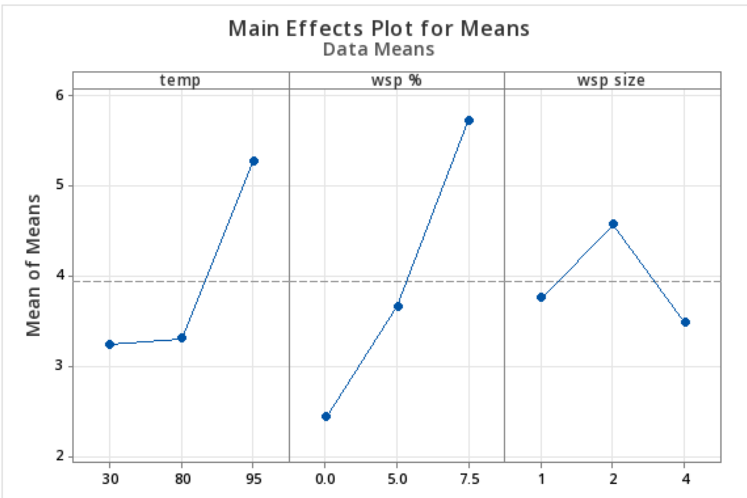

Fig. 8. Signal-to-noise ratio graph for thickness swelling rates

5 Conclusion

Using the Taguchi L9 orthogonal array, the number of composite samples needed for the investigation was reduced. Hand layup was the method used to create these composites. Tests for tensile strength, flexural strength, impact strength, water absorption, and thickness swelling were performed on each of the nine composites. For every test, regression equations were created to simulate the connections between the factors and the results. Furthermore, Minitab was utilised to conduct response tables and ANOVA (analysis of Variance) study in order to determine the major factors impacting each property.

- The tensile strength of composites declines as the amount of walnut shell powder (WSP) increases, the higher tensile strength of 25.89Mpa was obtained at combination of 30^0C of jute fiber temperature, 10% of gypsum content. The response table analysis indicates that the percentage content of the powdered walnut shell has a greater impact on tensile strength. For greatest tensile strength, 95°C, 0% WSP (with 10% gypsum), are the ideal values.
- Flexural strength is constant at 30°C for all WSP percentages; at higher temperatures (80°C and 95°C), flexural strength is enhanced by 5% WSP, but declines with 7.5% WSP, the higher flexural strength of 57.12Mpa was obtained at combination of 80^0C of jute fiber temperature, 5% of gypsum and also WSP content and 4mm size of walnut shell powder Flexural strength is not always impacted by the size of the powdered walnut shell. The response table analysis indicates that temperature has the greatest impact on

flexural strength, with WSP percentage coming in second. Flexural strength is best achieved at 30°C with 0% WSP.

- The impact strength of all nine composite combinations remained constant at two joules, unaffected by changes in size, temperature, or walnut shell powder proportion. This suggests that impact strength is less sensitive to these variables compared to tensile and flexural strengths, potentially requiring further investigation for a comprehensive understanding.
- Higher percentages of walnut shell powder (WSP) result in increased water absorption; the lowest absorption rates are observed at 95°C and 5% WSP of 1mm. The lowest mean water absorption is seen in walnut shell sizes of 1 mm. The size of the powdered walnut shell also had a significant effect, but WSP% is the most significant factor, according to the response table analysis. The best circumstances to reduce water absorption are to use 7.5% WSP, 2.5% gypsum and heat the jute fibre to 95^0C temperature.
- Higher temperature and percentage of walnut shell powder (WSP) cause thickness swelling, the lowest thickness swelling can be found at 80^0C of fiber temperature, 0% walnut shell powder content where 10% is of gypsum powder. The lowest mean swelling rate is seen in walnut shell sizes less than 1 mm. The response table analysis indicates that WSP% is the main factor affecting thickness swelling. The best circumstances to reduce thickness swelling are to maintain jute fibre to room temperature or 30°C, use 10% gypsum and 0% WSP.

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