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Kumar, Anil
G. B. Pant DSEU Okhla-I Campus

Kumar, Sushil
Deen BandhuChotu Ram University of Science and Technology

Jindal, Sandeep
Guru Jambheshwar University of Science and Technology

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Enhancing Composite Material Fabrication through Optimization: Employing Fruit Peel or Shell Powder as Reinforcements using Taguchi-GRA-PCA Methodology

Anil Kumar[1,*], Sushil Kumar[2], Sandeep Jindal[3]
[1]G. B. Pant DSEU Okhla-I Campus, New Delhi, 110020, India
[2]Deen BandhuChotu Ram University of Science and Technology, Sonipat-131001, India
[3]Guru Jambheshwar University of Science and Technology, Hisar, 125001, India

*Author to whom correspondence should be addressed:
E-mail:anilapmae@gmail.com

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Abstract: The characteristics of composite fiberboard are influenced by various design factors including the type and properties of the reinforcement material, the matrix material and its proportion, curing conditions, processing methods and moisture content etc. The disposal of fruit sheel or peel wastes is a very big issue. This research focuses on three key factors: the type of reinforcement material, its weight percentage in combination with epoxy and the curing time for fabricating the composite fiberboard. The reinforcement materials utilized consist of Citrus limetta peel powder (CLP), pomegranate peel powder (PPP), and Walnut Shell Powder (WSP). These materials are incorporated at weight percentages of 30%, 40%, and 50%. The curing time, representing the third factor, varies across three levels: 24, 36, and 48 hours. As a result, nine composite fiberboard samples were manufactured based on the configurations outlined by the L9 Orthogonal Array obtained from Taguchi Design. To evaluate the material's properties, the fabricated samples underwent Tensile, Flexural and Compressive strength tests. The results of these tests were then subjected to Taguchi Analysis to determine the optimal design parameters and validated through PCA (Principal Component Analysis) aided Grey Relation Analysis. The analysis yielded the most suitable design parameters i.e. Reinforcement Material WSP, with a weight percentage of 30%, coupled with a curing time of 48 hours for creating composite fiberboard. Notably, the mechanical properties of composite fiberboard made from Walnut Shell Powder outperformed those of other agricultural waste materials that were examined.

Keywords: Composite Fiberboard; Tensile Strength; Flexural Strength; Compressive Strength;Taguchi-GRA-PCA

1. Introduction

In the last twenty years, there has been a notable global inclination towards using natural filler substances for producing composite materials. Composite materials made from waste agricultural materials or fruit peels are a promising area of research and development in the field of sustainable materials. They have become an increasingly important aspect of present day's materials because of their numerous advantages such as light weight, corrosion resistance etc. [1)]. Natural fiber composites are increasingly seen as a feasible substitute for synthetic composites [2-3)]. Due to their affordability, low weight, high durability, biodegradability, and advantageous characteristics, natural fibers are gaining increased utilization in the composites industry [4-6)]. Fruit peel waste can be utilized as a potential reinforcement material in the fabrication of composite fiberboards, contributing to sustainable resource utilization and reducing waste. Citrus peels, rich in natural fibers and bioactive compounds, can be processed and integrated into composite fiberboards. The fibers from citrus peels can enhance the mechanical properties of the board, while their natural compounds may provide added durability and resistance to decay. Incorporating waste materials like Citrus limetta peel Powder into the production of Food Waste filler-based Epoxy Polymer composites not only decrease the reliance on petroleum-based Epoxy Polymer products but also enhance the potential for eco-friendly disposal of this fruit residue, thus promoting green manufacturing practices [7-8)].Pomegranate peels, with their fibrous content and antioxidants, can be integrated into composite fiberboards. The fibers can improve the board's mechanical properties, and the antioxidants may offer protection against environmental degradation. Incorporating walnut shell powder into composite fiberboard fabrication can result in sustainable, lightweight, and potentially aesthetically appealing materials suitable for various applications [9-11].

With the escalating environmental issues and increasing global energy requirements, there is a rising emphasis on integrating natural fibers into diverse sectors [12]. Because of the adverse effects of synthetic fibers in both production and disposal of end products, natural fibers are favored over them in engineering industries. Natural composites surpass manufactured composites in terms of their positive environmental impact [13-14]. They result in less reliance on nonrenewable resources, lower greenhouse gas emissions and increased energy restoration [15]. These increased environmental achievements are a key factor in improving the "Natural Fiber Composite" practice in the future. Natural fibers such as Bagasse, Pineapple, Ramie, Coir, Sisal, Bamboo, Banana and others are easily available and all the countries have focused on the development of “Natural Fiber Composite” to create value-added jobs [16]. Researching polymer composites with natural fibers is an important and pertinent field of study, given its potential to yield favorable mechanical properties [17-18]. Moreover, composites fabricated from natural fibers are eco-friendly and recyclable, rendering them well-suited for recovery and subsequent utilization [19-20].

Studies have compared different fillers, such as coconut shell, rice husk and teakwood, in lingo-cellulosic flour/epoxy composites, revealing that higher filler content increases the stiffness of the composite, while the volume content of fillers affects its elasticity [21]. Various agricultural wastes, including bagasse, walnut shell powder and chicken feathers, can be utilized to develop composites using epoxy or polyester [22-23].

Annually, approximately 1.3 billion tons of food are wasted globally during the food life cycle, including fruits, fresh vegetables, dairy products, and bakery items. With population growth, the volume of FW is expected to increase further in the next 30 years. Currently, the predominant method of disposing of used waste is through landfill dumping. However, the rapid development of production, population growth, waste accumulation and environmental pollution have created hazardous conditions for human life and contributed to global climate change. As a result, there is a need to reevaluate production and consumption models, including household waste management. This involves revising management approaches and exploring methods such as processing waste to obtain new materials and useful products (e.g., compost) and utilizing physical, chemical and biological means to convert waste into fuel and energy. Some countries, like Sweden, have achieved significant success in this regard, with less than 1% of household waste being sent to landfills [24-25]. The production of bio-plastic from orange waste opens up exciting possibilities for creating innovative materials that have the potential to replace traditional plastics. Incorporation of PVC in concrete leads to reduced workability, enhanced strength and recycling potential [29-30].Moreover, these bio-plastics are environmentally friendly biomaterials, presenting an excellent solution to the issues posed by fruit waste disposal and the need for its effective utilization [26].

These materials, often referred to as bio-composites, offer several advantages such as reduced environmental impact, utilization of waste materials, and potential biodegradability. Fruit peels, such as those from citrus fruits, can be dried, ground, and mixed with a suitable binder to form composites. These composites can be used for packaging materials, disposable cutlery, or even as additives in other composite materials. Agricultural residues and fruit peels can also be used as raw materials for manufacturing particleboard and fiberboard. These engineered wood products find applications in furniture, construction and interior design industries.

The specific process for creating composites from waste agricultural materials or fruit peels may vary depending on the desired properties and applications. Researchers and manufacturers are continually exploring new techniques and formulations to optimize the performance and sustainability of these materials.

In today's context of increasing environmental concerns and the need for sustainable waste management solutions, the efficient utilization of fruit peel waste has gained significant attention. Fruit peels, such as those from Citrus limetta, pomegranate and walnut shell, possess valuable bioactive compounds and have the potential for various applications, including biofuels, animal feed supplements and natural additives. However, the selection of the most suitable and superior fruit peel waste for a specific application involves multiple interdependent factors, including chemical composition, physical properties, and economic feasibility.

This research work seeks to address the challenge of identifying the suitable fruit peel waste among Citrus limetta, pomegranate and walnut shell, for fabrication of a composite fiberboard for higher flexural, impact strength and compressive strength, by mixing the waste fruit peel powder with epoxy using a novel hybrid approach combining the Taguchi experimental design, Grey Relational Analysis (GRA) and Principal Component Analysis (PCA). Taguchi-GRA-PCA Approach is the advanced and best technique for computational analysis [31-32]. By combining these methodologies, this study aims to:

1. Design a comprehensive set of experiments using the Taguchi method to investigate the influence of key parameters such as peel waste type, weight

percentage and curing time.

2. Apply PCA assisted GRA to determine the optimal peel waste type that exhibits the highest potential for the desired application, considering multiple performances attributes simultaneously.
3. Develop a hybrid decision-making framework that integrates the outcomes of Taguchi, GRA and PCA to recommend the most appropriate fruit peel waste type for specific applications.
4. Develop a hybrid decision-making framework that integrates the outcomes of Taguchi, GRA and PCA to recommend the most appropriate fruit peel waste type focusing on identifying the suitable fruit peel waste among Citrus limetta, pomegranate and walnut shell, for fabrication of a composite fiberboard for higher flexural and impact strength.

The successful implementation of this research will contribute to the optimal utilization of fruit peel waste, reducing environmental impact and promoting sustainable practices.

2. Materials and Methods

2.1 Production of Particles from fruit peels waste

Consistent source conditions were upheld by procuring Citrus limetta, pomegranate and walnut from the nearby market in Delhi, India. Then these waste materials were exposed to the natural environment to aid in the dehydration procedure. Once thoroughly dried, they were crushed to acquire a powdered consistency. Figure 1 show the images of different types of peel/ shell powders.

Fig. 1: Different peel powders

2.2 Taguchi Design

Taguchi design and analysis is a robust methodology used for optimizing and improving the quality of products and processes. It's particularly useful in engineering and manufacturing fields. The main goal of Taguchi design and analysis is to identify the optimal set of factors and their levels that would result in the best possible outcome with minimal variation. This methodology involves systematically planning and conducting experiments to understand how different factors or variables impact the final result. Key steps in Taguchi design and analysis include:

1. **Identifying Factors and Levels:** Determine the factors (variables) that might influence the outcome and the various levels at which each factor can be set.
2. **Creating an Experimental Matrix:** Design a matrix of experiments using combinations of factor levels. Taguchi uses orthogonal arrays, which ensure a balanced and efficient allocation of experiments.
3. **Conducting Experiments:** Run the experiments as per the designed matrix. These experiments are often conducted in a controlled environment to minimize external influences.
4. **Collecting Data:** Record the outcomes of each experiment. This data includes both the mean (average) and the variation of the results.
5. **Analyzing Data:** Use statistical methods to analyze the data. Taguchi emphasizes the use of signal-to-noise ratios (SNR) to determine how variations in factors affect the outcome and to identify which factors have the most significant impact on the desired result.
6. **Determining Optimal Settings:** Based on the analysis, identify the factor levels that lead to the best result with the least sensitivity to variation.
7. **Validation:** Confirm the results by conducting further experiments using the identified optimal settings.

Utilizing Taguchi Design within Minitab 18, an L_9 Orthogonal Array (OA) has been formulated to systematically investigate these permutations in a resource-efficient manner. Table 1 shows the L_9 OA obtained from Taguchi design.

Table 1. L_9 Orthogonal Array Design Matrix

S. N.	Reinforcement Material	Weight %	Curing Time (H)
1	CLP	30	24
2	CLP	40	36
3	CLP	50	48
4	PPP	30	36
5	PPP	40	48
6	PPP	50	24
7	WSP	30	48

8	WSP	40	24
9	WSP	50	36

2.3 Fabrication of composites for testing

Creating a composite using peel/shell powder and epoxy involves mixing the two materials together to form a homogeneous mixture, which is then applied and cured to create the desired shape or structure. It involves-

1. **Preparation of Peel/Shell Powder**: The peels/shells need to be processed into a fine powder. This can be done by grinding or milling the shells until they reach the desired particle size. The finer the powder, the better it will integrate with the epoxy resin.
2. **Preparation of Epoxy Resin**: Epoxy resin typically comes in two parts: the resin and the hardener. These two components need to be mixed together according to the manufacturer's instructions. This usually involves mixing them in specific ratios to ensure proper curing.
3. **Mixing Shell Powder with Epoxy**: Once the epoxy resin and hardener are mixed together, the shell powder is gradually added to the mixture. The amount of shell powder added can vary depending on the desired properties of the composite. More powder typically results in a stronger, more durable composite, while less powder may result in a smoother finish.
4. **Homogenization of the Mixture**: It's important to thoroughly mix the shell powder with the epoxy resin to ensure that the particles are evenly distributed throughout the mixture. This can be done using mechanical stirring equipment or by hand mixing, depending on the scale of the project.
5. **Application and Curing**: Once the mixture is homogenized, it can be applied to the desired surface or mold. The composite should be allowed to cure according to the manufacturer's recommendations. This typically involves allowing the epoxy to cure at room temperature or applying heat to expedite the curing process.
6. **Finishing**: After the composite has cured, it can be sanded, polished, or otherwise finished to achieve the desired appearance and surface texture.

Nine composite fiberboard samples were created according to the L_9 Orthogonal Array configurations, using the casting method. Novolac resin epoxy was chosen for its excellent resistance to chemicals and high-temperature stability. To initiate the curing process, a hardener and accelerator were added during the fabrication of the composite plate. The epoxy resin and hardener were mixed in a weight ratio of 10:1 and stirred thoroughly to prevent the formation of voids. These well-prepared mixtures of different configurations were poured onto the clean surfaces, maintaining the desired width, breadth, and thickness to form the composite fiberboards as per Taguchi design Requirements.

For the mechanical characterization of the fabricated composite, the following tests will be performed on the different specimens-

1. Tensile Strength
2. Flexural Strength Test
3. Compressive Strength Test

2.3.1 Tensile Strength Test

The tensile strength test (ASTM D3039), also known as the tension test, is a common mechanical test used to determine the strength of a material when subjected to a stretching or pulling force. It helps in understanding how a material behaves under axial loading and provides valuable information about its mechanical properties.

A specimen of the material, usually in the form of a standardized shape (such as a cylindrical or rectangular bar), is prepared with precise dimensions. The prepared specimen is placed in a universal testing machine (UTM). This machine is capable of applying a controlled force to the specimen while simultaneously measuring the applied force and the resulting deformation. The UTM applies a gradually increasing tensile force to the specimen.

Tensile strength testing provides valuable information about a material's mechanical properties, including its yield strength, ultimate tensile strength, elongation at break, and more. These properties are crucial for designing and engineering materials for various applications, from structural components to consumer products.

2.3.2 Flexural Strength Test

The flexural strength test (ASTM D790), also known as bending strength test, is commonly used to determine the ability of a material to withstand bending forces. In the case of composite fiberboard, this test helps assess the material's ability to resist deformation and fracture when subjected to bending loads. This test is performed on a Universal Testing Machine. This machine applies a controlled bending force to the test specimen until it fractures. The machine measures the maximum load applied and the corresponding deflection of the specimen. To perform the test rectangular samples of the composite fiberboard are prepared according to specific dimensions and guidelines.

The dimensions of the specimen, including length, width, and thickness, should adhere to relevant standards or testing protocols.

The Flexural strength is calculated using the following formula:

$$\text{Flexural Strength } (\sigma) = 3FL/2wd^2 \qquad \text{……. (1)}$$

Where:

F=Load at fracture is the maximum load applied to the specimen before it fractures.
L=Span is the distance between the supports.
w=Width is the width of the specimen.
d=Thickness is the thickness of the specimen.

2.3.3 Compressive Strength Test

The compression strength test (ASTM C365) is a mechanical test conducted to determine the ability of a material to withstand axial loads, pushing or crushing forces without collapsing or failing. In conducting a compression test on a composite fiberboard using a Universal Testing Machine (UTM), the initial step involves preparing a representative specimen of the fiberboard with dimensions complying with applicable standards. Once the UTM is set up and calibrated, the specimen is carefully installed on the machine's platen, ensuring proper alignment. Testing parameters, such as the rate of loading, are adjusted, and the test is initiated, applying compressive forces until the fiberboard fails. During the test, the UTM records the load and corresponding deformation data. The ultimate compressive strength and failure modes are identified post-test. The obtained data is then analyzed to assess the material's performance under compressive forces

2.4 PCA assisted GRA

The combination of Principal Component Analysis (PCA) and Grey Relational Analysis (GRA) involves a detailed method that aims to enhance the effectiveness of analyzing relationships between variables in a dataset with limited information.

PCA transforms the original variables into a set of new variables (principal components) that are linear combinations of the originals. These components are ordered by the amount of variance they explain. Choose the top principal components that capture a significant portion of the total variance (e.g., 95%).

GRA is based on the concept of "grey relational degree," which measures the similarity or correlation between sequences of data. It's used to analyze the relationship between a reference sequence and other sequences.The integration of PCA with GRA allows for a more effective exploration of relationships in the dataset. PCA reduces the dimensionality, making it easier to handle the data, and GRA provides insights into the correlations among sequences. This combined approach is especially valuable when dealing with complex and limited data situations [27].

3. Results and Discussion

This research focuses on three key factors: the type of reinforcement material, its weight percentage in combination with epoxy and the curing time for fabricating the composite fiberboard. Each factor has been tested at three different levels. Reinforcement materials used for this research are Citrus Limetta Peels Powder (CLP), Pomegranate Peels Powder (PPP) and Walnut Shell Powder (WSP). The composite panel with a ratio of 60:40 groundnut shell particles to epoxy resin exhibited the highest tensile, bending, and impact strengths [28]. Also most of the researchers considered that the weight percentage of the reinforcement material from 25 to 50 percentage for their research. So keeping this in mind the three levels of weight percentage have been considered as 30, 40 and 50. The curing time is the third factor having duration 24, 36 and 48 Hour. This time duration is considered as per the data sheet of the epoxy resin used.

3.1 Tensile Strength Test

The tensile strength test is conducted to determine the maximum amount of tensile stress the composite can withstand before fracturing or breaking. A composite sample, in the form of a standardized shape (e.g., dog bone shape), is subjected to an axial force that gradually increases until the material fails. The applied force and the resulting elongation of the sample are carefully measured. By analyzing the force-displacement data, the tensile strength of the composite can be calculated. The tensile test has been performed on all the nine fabricated samples using tensile testing machine. The test set for one of the specimen is shown in the Fig. 2.

Fig 2: Tensile Test Set up

The Tensile strength of all nine specimens have been calculated and tabulated as shown in the Table 2 below. The tensile strengths of the specimens vary across the different configurations. Configuration 7 exhibits the highest tensile strength of 29.80 MPa, indicating it is the strongest among the tested specimens. Configuration 3 has the lowest tensile strength of 17.31 MPa, suggesting it is the weakest specimen in terms of tensile properties. Configurations 1, 4, 5, and 8 also show relatively high tensile strengths, ranging from 21.12 MPa to 26.28 MPa. Configurations 2, 6, and 9 have intermediate tensile strengths compared to the other configurations.

Overall, the tensile test results demonstrate variations in the mechanical properties of the composite sandwich panels across different configurations. Factors such as the composition of the materials, processing techniques and structural design may influence the observed tensile strengths.

Table 2. Tensile Strength for 9 Specimens

Configuration No.	Tensile Strength (MPa)
1	24.31
2	21.72
3	17.31
4	23.28
5	24.64
6	19.47
7	29.80
8	26.28
9	21.12

3.3 Flexural Strength Test

The test method evaluates the flexural properties of the composites following the guidelines of ASTM D790. Flexural test was conducted using a Universal Testing Machine, with a constant loading rate of 2 mm/min. The specimen was prepared with dimensions of 191×12 mm² and a depth of 12 mm. The setup for this experiment is shown in Fig. 3.

Fig 3: Flexural Strength Test Setup

The Flexural strength of all nine specimens have been calculated and tabulated as shown in the Table 3.

Table 3. Flexural Strength for 9 Specimens

Configuration No.	Flexural Strength (MPa)
1	35.23
2	33.15
3	29.31
4	31.52
5	34.44
6	29.27
7	40.25
8	34.53
9	31.47

During the testing of different specimens, it was observed that the presence of voids within specific fiberboards resulted in a decrease in mechanical integrity and increased susceptibility to failure. These voids contributed to inadequate distribution of loads, thereby reducing the overall flexural strength of the composite. To enhance the composite's flexural strength, it is recommended to minimize voids and enhance the adhesion between the walnut shell particles and the polymer matrix.

3.4 Compressive Strength Test

A Universal Testing Machine was employed to conduct the compressive strength test, aiming to determine the compressive strength of the composite fiberboards. The specimens underwent precise cutting and shaping before alignment and support throughout the testing process being tested on the machine, ensuring accurate, as illustrated in Fig. 4.

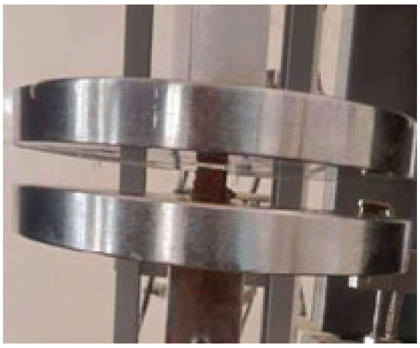

Fig 4: Compressive Strength Test Setup

The Compressive strength of all nine specimens have been calculated and tabulated as shown in the Table 4 below. The different specimens show good compressive strength.

Table 4. Compressive Strength for 9 Specimens

Configuration No.	Compressive Strength (MPa)
1	46.52
2	46.38
3	50.31
4	50.94
5	52.85
6	49.01
7	54.48
8	48.82
9	50.11

3.5 Taguchi Analysis

The primary purpose of Taguchi Analysis is to optimize processes, products, and systems by identifying the factors that have the most significant impact on performance and quality while minimizing the effects of variation. All the calculated values of the two different responses have been placed against the different configurations of the L_9 OA as shown in Table 5.

Table 5. Different configurations as per Taguchi L_9 array and their responses

S. N.	Reinf. Mat.	Weight %	Time (H)	TS	FS	CS
1	CLP	30	24	24.31	35.23	46.52
2	CLP	40	36	21.72	33.15	46.38
3	CLP	50	48	17.31	29.31	50.31
4	PPP	30	36	23.28	31.52	50.94
5	PPP	40	48	24.64	34.44	52.85
6	PPP	50	24	19.47	29.27	49.01
7	WSP	30	48	29.80	40.25	54.48
8	WSP	40	24	26.28	34.53	48.82
9	WSP	50	36	21.12	31.47	50.11

a. Taguchi Analysis for Tensile Strength

To identify the Superior Agricultural Waste Powder as Reinforcement Material, Taguchi analysis has been performed on the calculated Tensile strength of all nine configurations. As the main requirement for designing a composite fiberboard is its higher Tensile strength, so "*Larger is Better*" option has been selected to identify the Superior Agricultural Waste Powder as Reinforcement Material. Table 6 shows the Response Table for Signal to Noise Ratios after Taguchi analysis.

Table 6. Response Table for S/N Ratio for Tensile Strength (Larger is better)

Level	RM	WP	CT
1	26.41	28.18	27.30
2	26.99	27.65	26.86
3	28.12	25.68	27.36
Delta	1.72	2.50	0.50
Rank	2	1	3

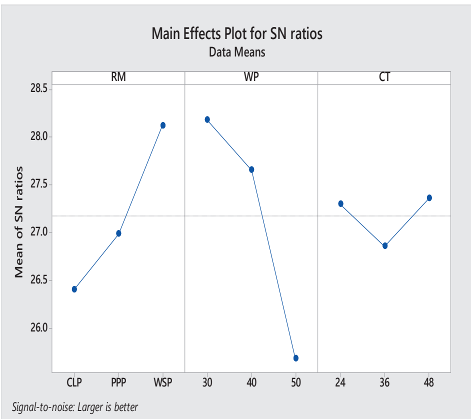

Fig 5: Main Effect plot for S/N Ratios for Tensile Strength

The Fig. 5 shows that the highest tensile strength has been achieved at configuration for Walnut shell powder, weight percentage of 30 and at a curing time of 48 hours.

b. Taguchi Analysis for Flexural Strength

Taguchi analysis was conducted to determine the superior agricultural waste powder for reinforcing composite fiberboard. The analysis focused on the calculated Flexural strength of nine different configurations. Since the primary goal in designing the composite fiberboard is to achieve higher flexural strength, the criterion of "Larger is Better" has been opted. This approach aimed to identify the optimal agricultural waste powder as a reinforcement material. The results of the Taguchi analysis, presented in Table 7, display the Response Table for Signal to Noise Ratios, showing results of Taguchi analysis.

Table 7. Response Table for S/N Ratio for Flexural Strength (Larger is better)

Level	RM	WP	CT
1	30.23	31.00	30.34
2	30.01	30.64	30.11
3	30.94	29.54	30.73
Delta	0.93	1.46	0.61
Rank	2	1	3

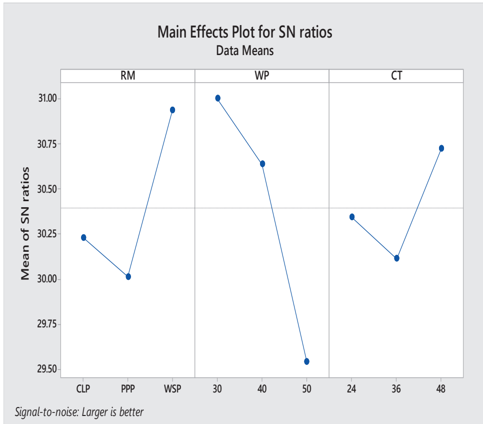

Fig 6: Main Effect plot for S/N Ratios for Flexural Strength

The Fig. 6 illustrates that the highest Flexural strength was attained under the conditions of utilizing walnut shell powder at a weight percentage of 30% and subjecting it to a curing period of 48 hours.

c. Taguchi Analysis for Compressive Strength

In the pursuit of identifying the optimal agricultural waste powder as a reinforcement material, Taguchi analysis was employed to assess the calculated compressive strength across nine configurations. Given that the primary criterion for designing a composite fiberboard is achieving higher compressive strength, the "Larger is Better" criterion was chosen. The outcomes of the Taguchi analysis, specifically the Signal-to-Noise Ratios, are presented in Table 8, illustrating the performance of various configurations in relation to the desired compressive strength.

Table 8. Response Table for S/N Ratio for Compressive Strength (Larger is better)

Level	RM	WP	CT
1	33.57	34.07	33.64
2	34.14	33.85	33.82
3	34.17	33.95	34.41
Delta	0.59	0.22	0.76
Rank	2	3	1

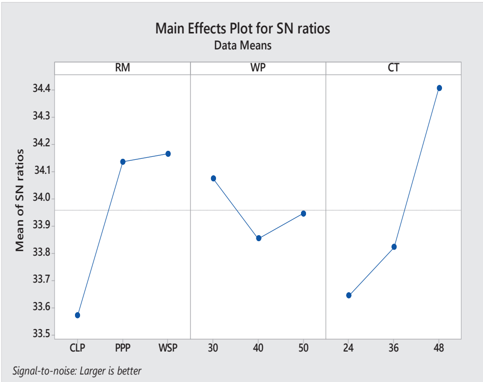

Fig 7: Main Effect plot for S/N Ratios for Compressive Strength

Figure 7 demonstrates that the maximum compressive strength was achieved when employing walnut shell powder at a concentration of 30%, coupled with a curing duration of 48 hours.

d. Taguchi Analysis for Tensile, Flexural and Compressive Strength Taken Together

Also one more Taguchi Analysis has been conducted considering together all the responses. Table 9 shows the Response Table for Signal to Noise Ratios for both the responses taken together for "Larger is Better" option.

Table 9. Response Table for for S/N Ratio all responses taken together (Larger is better)

Level	RM	WP	CT
1	29.09	30.44	29.67
2	29.47	30.00	29.39
3	30.40	28.51	29.90
Delta	1.31	1.93	0.51

Figure 8 illustrates that the most effective combination, yielding the highest values for all responses, entails the utilization of walnut shell powder at a weight percentage of 30% and employing a curing duration of 48 hours.

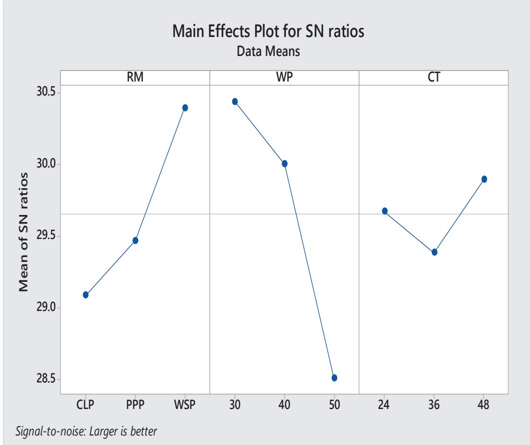

Fig 8: Main Effect plot for S/N Ratios for all responses taken together

According to the Taguchi analysis, it is evident that the configuration featuring walnut shell powder at a weight percentage of 30% and a curing duration of 48 hours exhibits the most favorable mechanical properties.

3.5 PCA Assisted GRA

Taguchi's approach is suitable for determining the optimal configurations of process variables for a single response. However, for the optimization of multiple responses, the widely adopted method is Grey Relational Analysis (GRA). To validate the outcomes of the Taguchi analysis in this study, GRA has been employed. GRA involves the normalization of values to calculate "Grey Relational Coefficients (GRC)" and "Grey Relation Grade (GRG)." In this research, both Tensile and Flexural responses, both of which fall under the "Larger-is-better" category, have been chosen. Initially, normalized values were derived for both responses, followed by the computation of Deviation Sequences, as presented in Table 10.

Table 10. Responses and their Normalized value

RESPONSES				NORMALIZED VALUES		
S N	TS	FS	CS	TS	FS	CS
1	24.31	35.23	46.52	0.560	0.543	0.017
2	21.72	33.15	46.38	0.353	0.353	0.000
3	17.31	29.31	50.31	0.000	0.004	0.485
4	23.28	31.52	50.94	0.478	0.205	0.563
5	24.64	34.44	52.85	0.587	0.471	0.799
6	19.47	29.27	49.01	0.173	0.000	0.325
7	29.8	40.25	54.48	1.000	1.000	1.000
8	26.28	34.53	48.82	0.718	0.479	0.301
9	21.12	31.47	50.11	0.305	0.200	0.460

Following the computation of the deviation sequences, the Grey relation coefficients for the two responses have been determined, as presented in Table 11.

Table 11**.** Deviation Sequences and Grey Relational Coefficients (GRC)

SN	Deviation Sequences			Grey Relational Coefficients		
	TS	FS	CS	TS	FS	CS
1	0.440	0.457	0.983	0.532	0.522	0.337
2	0.647	0.647	1.000	0.436	0.436	0.333
3	1.000	0.996	0.515	0.333	0.334	0.493
4	0.522	0.795	0.437	0.489	0.386	0.534
5	0.413	0.529	0.201	0.548	0.486	0.713
6	0.827	1.000	0.675	0.377	0.333	0.425
7	0.000	0.000	0.000	1.000	1.000	1.000
8	0.282	0.521	0.699	0.640	0.490	0.417
9	0.695	0.800	0.540	0.418	0.385	0.481

Principal Component Analysis (PCA) has been integrated into Grey Relational Analysis (GRA) to determine the importance of each performance characteristic. The weighted values for each performance characteristic were established through the application of PCA. The various performance characteristics exhibiting Grey Relational Coefficients (GRCs) were entered into Minitab 18. Subsequently, Minitab 18 generated the corresponding Eigen-values, which are documented in Table 12. Additionally, the Eigen-vectors corresponding to these Eigen-values were generated through MINITAB and are presented in Table 13. Utilizing these Eigen-vectors for Principal Components, the weighting contribution of each performance characteristic was calculated, as detailed in Table 14. The individual contributions of performance characteristics, such as Tensile and Flexural Strength, are outlined in Table 12.

Table 12. Eigen analysis of the Correlation Matrix

Eigen value	2.202	0.737	0.060
Proportion	0.734	0.246	0.020
Cumulative	0.734	0.980	1.000

Table 13. Eigen vectors

Variable	PC1	PC2	PC3
TS	0.644	-0.274	0.714
FS	0.637	-0.326	-0.699

Table 14. Contribution of the used performance characteristic for the principal components

Performance characteristic	Weighted value
Tensile Strength	$(0.644)^2 = .415$
Flexural Strength	$(0.637)^2 = .405$
Compressive Strength	$(0.424)^2 = .180$

As indicated in Table 15, the Grey Relation Grades (GR Grades) were computed using Principal Component Analysis (PCA) and the weighted values of all the responses. An illustration of the sample analysis for Grey Relation Grade (GRG) for Configuration No. 1 is provided below:

(GRG)=1(k) =(1/3*(0.415*TS+0.405*FS+0.18*CS)) ..(2)

Table 15**.** Grey relation grades (GRG)

PCA assisted GR Grades
0.164
0.139
0.121
0.152
0.184
0.123
0.333
0.180
0.139

To determine the optimal levels of various process factors, the mean GRG value was assessed for each factor level, and the highest GRG value was selected for each factor.

In Table 16, the bold dark values of GRG depict the largest value for the different levels of each process factor and *these values correspond to* Reinforcement Material *WSP,* Weight percentage of 30% and Curing Time 48 Hours *for optimum response characteristics.*

Table 16. Grey Relation Grade Values Analogous to Different Levels of Input Process Factors

Level	Reinforcement Material	Weight %	Curing Time
1	0.1414	**0.2165**	0.1555
2	0.1529	0.1676	0.1432
3	**0.2172**	0.1274	**0.2127**

The GRA confirms that the optimum design is available for *Reinforcement Material WSP, Weight % of 30% and Curing Time 48 Hours.*

Confirmatory Test

The provided Table 16 effectively demonstrates that the outcomes of the Grey Relational Analysis (GRA) of response characteristics align entirely with the conclusions drawn from the Taguchi Analysis. Furthermore, it was noted that the optimal design corresponds to the utilization of Reinforcement Material WSP, with a weight percentage of 30%, coupled with a curing time of 48 hours as shown in table 17.

Table 17. Comparison of the results of Taguchi and

GRA

Input Factors	Taguchi Optimal Level	GRA Optimal Level	Value
Reinforcement Material	3	3	WSP
Weight %	1	1	30%
Curing Time	3	3	48 Hr.

4. Conclusion

In conclusion, this research aimed to investigate the influence of three crucial factors on the fabrication of composite fiberboards: the type of reinforcement material, its weight percentage in conjunction with epoxy, and the curing time. Employing the Taguchi Design methodology within Minitab 18, a comprehensive exploration of these factor combinations was efficiently conducted through the utilization of a L_9 Orthogonal Array. Through the fabrication of nine composite fiberboard samples based on the L_9 Orthogonal Array configurations, the material's properties were rigorously evaluated using Tensile and Flexural Strength tests. Subsequent Taguchi Analysis enabled the identification of optimal design parameters by analyzing the results from these tests. To reinforce the validity of these findings, a Principal Component Analysis (PCA) assisted Grey Relation Analysis was applied to the output responses.

The synthesized findings consistently highlighted that the most favorable configuration for composite fiberboard fabrication involved the application of Reinforcement Material WSP, incorporating a weight percentage of 30%, and subjected to a curing time of 48 hours. This amalgamation of factors yielded composite fiberboards with superior mechanical properties, as indicated by the Tensile and Flexural Strength tests. These findings contribute to the advancement of composite material fabrication techniques and offer valuable insights for industries seeking to enhance the performance and durability of fiberboard-based products.

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Nomenclature

CLP	Citrus lemiita Powder
PPP	Pomegranate Peel Powder
WSP	Walnut shell powder
GRA	Grey Relation Analysis
GRG	Grey Relation Grade
PCA	Principal Component Analysis
SNR	Signal to Noise Ratio
L_9 OA	L_9 Orthogonal Array
ASTM	American Society for testing and Materials

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