Analysis of the Bending Strength of OSB Made from Palm Leaves and Fronds Using Taguchi Orthogonal Array

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Abstract- This study focuses on the bending strength of the Oriented Strand Board (OSB) manufactured from palm leaves and fronds where the Taguchi orthogonal array method is used for optimal parameter determination. The three key factors such as temperature, pressure, and moisture are changed systematically to measure their effect on the final quality of OSB. Our findings point to moisture content as a key factor in the bending strength with its ability to correlate positively with better performance. In contrast to the previous point, temperature and pressure have relatively little impact on the OSB quality. Exploitation of Taguchi methodologies can assist in understanding the process parameters that will be followed by making the product better and more efficient based on the field of sustainable construction materials. One of the future research directions is to improve the model about other factors involved, more complex material characterizations, and environmental impact assessment. This research is adding to the expanding mass knowledge of sustainable materials and process optimization; thus, the findings are beneficial for industrial practitioners and researchers who are at the forefront of eco-friendly construction methods and materials.

Index Terms- Palm Leaves, Fronds, Bending Strength, Taguchi Orthogonal Array

I. INTRODUCTION

Palms, which have their crown in the tropics, are underestimated and can be used in many ways in manufacturing and recycling instead of being used just for one purpose. Against the backdrop of advancing environmental issues and the need for Green solutions, researching other sources of construction materials has turned into a top priority. Engineered wood products, including Oriented Strand Board (OSB), have recently been identified as the leaders in their class by many construction experts for their structural strength, versatility, and cost-effectiveness for various uses [2]. Through the use of palm leaves and fronds as the main stocks of OSB, not only can we ease the pressure on traditional wood supplies, but we can also take the road to sustainability in the construction sector [2, 3]. The bending strength of OSB is the most important performance indicator that will be critical in assessing the OSB's suitability for structural applications. Recognition and improvement of the parameters affecting the bending strength are critical things for boosting the efficiency and the durability of OSB panels [4-6]. This study applies the Taguchi orthogonal array methodology, a powerful statistical method, to systematically explore the effect of different process variables on the bending strength of OSB derived from palm stems and leaves [7]. By determining the right combination of settings, we intend to optimize the mechanical features of palm-based OSB at the same time, we would like to cut down the resource waste and production costs. Figure 1 shows the palm leaves which is used as a raw material for the manufacturing of OSB.

a) Raw material (palm leaves) b) Finished product

Figure 1. a) Raw material b) Finished product (OSB board)

The parametric optimization method is a key optimization technique that is primarily applied to manufacturing processes and goes across the entire industry. Among these techniques, the orthogonal array methodology designed by Taguchi is a breakthrough in its systematical way of improving the process parameters and ensuring high product quality. The Taguchi method systematically changes the level of control factors and runs a few experiments to pinpoint the most critical parameters and their optimal levels. By doing so, researchers can minimize the time and effort on optimization [8, 9]. With the situation of PALMOSB, made from palm leaves and fronds as an engineered wood product, Taguchi optimization serves as a structured approach so that bending strength can be improved at the same time as the waste and production costs can be minimized [10]. Utilizing Taguchi orthogonal arrays, this research is doing its best to realize the large potential of palm-based OSB as an environment-friendly construction material [11].

This research supports the growing area of sustainable materials through the provision of findings relevant to the mechanical properties of OSB derived from palm leaves and fronds. Through the establishment of the connection between the process parameters and bending strength, we give the most appropriate advice on the way of the improvement of the process and the level of its performance. In the last analysis, our research findings could facilitate the industry's green building revolution, which will involve the transition to renewable and eco-friendly supplies and the reduction of the dependence on non-renewable resources.

II. LITERATURE REVIEW

The conversion of agricultural residues and biomass to engineered wood products has been on the rise while researchers and the industry are at the forefront of the search for more sustainable materials replacements [12]. The palm leaves and fronds, which are cheap abound in nature, and have beneficial strength properties, can be used as the base material for the development of eco-friendly products [13, 14]. The results of this study have shown the possibility of using palm-based fibers and integrating them into composite materials, such as OSB, that have mechanical properties that are comparable to the current ones in use and can be used in the construction industry [15-17].

Asyraf et al. (2022) investigated olein phenolic fibers of oil palm frond which are considered to be an improvement instrument in mechanical features and constructional viability [18]. In the same way, studies of the use of date palm fronds as main components for OSB have given positive results so far, and Taguchi optimization techniques have been useful in making the OSB stronger [19, 20]. These studies hence show that palm leaves and fronds are not only viable but also can be used as a substitute for conventional wood fibers in engineered wood products.

The area of parametric optimization for wood composites has a range of ways of performing the product in terms of performance and efficiency. The Taguchi method, that is orthogonal array technique, has been applied widely due to its ability to systematically evaluate the effects of multiple factors on the quality of products and process performance

[21-23]. Moreover, techniques like composite desirability functions and regression analysis may act as complementary rather than competitive methods toward optimization. The defined weighting of the composite desirability functions allows for researchers to achieve the optimization of several responses concurrently, by calculating a single index of desirability [24-26]. Regression analysis is in contrast with this in the areas of modeling and predictions of product properties from the experimental data. This helps in the decision-making process during the optimization.

Although existing literature has been quite beneficial in the aspect of mechanical properties assessment of palm-based composites, there is still a significant space that needs to be filled in terms of identifying the optimum operating condition using Taguchi orthogonal array methodology, with special consideration of bending strength. This research is aimed at providing the fill the gap that exists by examining the effects of the numerous process parameters on the bending strength of OSB produced from the palm leaves and fronds. Through the use of Taguchi optimization methods in the manufacturing course, we intend to improve the mechanical features and structural resistance of the palm-based OSB, which in turn promotes sustainable materials development in the construction domain.

III. EXPERIMENTAL DESIGN

In this study, the Taguchi signal-to-noise ratio (S/N) has been used for the experimental design.

Taguchi Signal to Noise Ratio (S/N)

S/N or the Signal Noise Ratio is one of the main ideas in the study of the Taguchi method, which is the method used to evaluate the performance of a product or a process by quantifying the variation of the performance characteristics [21, 27]. In this study, we utilize the "higher the better" S/N ratio for OSB made of palm leaves and fronds to establish the optimal bending strength of the OSB. Through employing this S/N ratio, the objective is cleared to upscale the response variable to the greatest level possible, in this case, bending strength, to lead to the improved structural strength and durability of the composite wood product.

Calculation of S/N Ratio

The Taguchi signal-noise ratio (S/N) can be calculated by dividing the mean value of a performance characteristic by the noise or variation associated with it [27, 28]. In this example of the "larger the better" S/N ratio, the formula for finding S/N is the same — to get the response variable as big as possible. Mathematically, the S/N ratio is expressed as equation (1) below:

$$\frac{S}{N} = -10log_{10}\left[\frac{1}{n}\left(\sum_{i=1}^{n} 1/y_i^2\right)\right] \quad (1)$$

When n is the number of times of the ith experimental repeated and Yi represents the individual response variable. In our present investigation the n=1.

Through S/N ratio evaluation, the most optimum combination of process parameters can be pinpointed to ensure the flattest bending strength value for palm-based OSB, which will in turn improve product performance and quality.

Taguchi Orthogonal Array Design

Taguchi Orthogonal Array Design is a rigorous experimental method for a systemic analysis of the impacts of several factors on a response variable, which knots down the number of experiments required [29]. To detect Taguchi orthogonal arrays experiment design for the fabrication process of OSB made from palm fronds and leaves is used in this study. The experimental design gets the job done by choosing from suitable orthogonal arrays which makes the efficient utilization of resources possible and facilitates the most significant process parameters to be identified affecting the bending strength. The orthogonal array design methodology offers an avenue for the systematic analysis of the role played by various factors on the bending strength of palm-based OSB. This, in turn, leads to informed decision-making and process optimization. Table 1 demonstrates the orthogonal L8 array, which was generated with Minitab 21.

Table 1. Taguchi orthogonal L8 array

Temperature (°C)	Pressure (N/mm^2)	Moisture (%)
1	1	1
1	1	2
1	2	1
1	2	2
2	1	1
2	1	2
2	2	1
2	2	2

In this study, three process parameters to improve the OSB (Oriented strand board) manufacture from palm fronds and leaves are selected (Table 2): These determinants, as well as their respective levels, systematically will be changed to analyze their contribution to the bending strength of the designed wood product. Firstly, temperature (°C) is explored at two distinct levels: 185 and 205. They exhibit variations of the heat applied during production, and the higher temperatures may be beneficial to the OSB, thus enhancing the bonding and mechanical properties of the OSB. Secondly, pressure (N/mm2) is examined across two tiers: 0.1 MN/mm2 and 2.5 MN/mm2. This study is concerned with the examination of the effect of compression force on OSB density and compaction which are the main factors determining mechanical strength. Finally, moisture content (% for 3% and 5% levels) is monitored to reflect the variation in the moisture content of raw materials. The water content may be responsible for better gluing and cohesion action during pressing and dry-curing. The study aims to achieve this goal through the process of systematic parameters and statistics manipulations while detecting the best combination for peak OSB bending strength. Thus, the exploration of this emerging technology is a promising venture for enhancing manufacturing processes and increasing the quality of products thus furthering sustainable construction materials.

Table 2. Parameters and their levels

S.No	Factor	Level 1	Level 2
1	Temperature (°C)	185	205
2	Pressure (N/mm^2)	0.1	2.5
3	Moisture (%)	3	5

The data of the eight experiments are shown in Table 3, which were conducted to determine the bending strength of OSB (Oriented Strand Board) produced from the palm fronds and leaves. Each experiment was designed on the orthogonal Taguchi array based on the temperature (°C), pressure (N/mm^2), and moisture content (%) levels. Bending strength values (N/mm^2) reflecting the mechanical behavior of the OSB boards for different production parameters were measured.

Table 3. Experimental Results for Bending Strength of OSB

Experiment	Temperature (°C)	Pressure (N/mm^2)	Moisture (%)	Bending Strength (N/mm^2)
1	185	0.1	3	22.648
2	185	0.1	5	27.896
3	185	2.5	3	22.475
4	185	2.5	5	23.434
5	205	0.1	3	21.79
6	205	0.1	5	22.429
7	205	2.5	3	24.788
8	205	2.5	5	26.648

The data obtained from these tests reveal the impact of factors such as temperature, pressure, moisture content, and bending strength between palm leaves and frond-based OSB. Extended examination of these data will enable us to discover the best mix of factors in which the largest bending strength is achieved, and hence improvement of the manufacturing process for sustainable construction materials is possible. Table 4, which is presented below, gives the S/N ratios for the "bending strength" response variable at different levels of temperature, pressure, and moisture content. The S/N ratios are obtained through the "bigger is better" principle that involves the larger values for higher performance. The delta shows the S/N (signal-to-noise) ratio difference between two levels and the rank is the index of performance of each level within the corresponding factor.

Consequently, this study indicates that the most decisive factor influencing the bending strength is the moisture content, the pressure is ranked second, and temperature has the third rank. The rank ordering of the parameters indicates the relative importance of each factor to the optimization of the OSB produced from palm leaves and fronds. In addition, it also provides a basis for the development of other strategies for improving the processes of production for this type of material.

Table 4. Response for Signal to Noise Ratios "Larger is better"

Level	Temperature (°C)	Pressure (N/mm^2)	Moisture (%)
1	27.61	27.45	27.2
2	27.54	27.71	27.96
Delta	0.07	0.26	0.76
Rank	3	2	1

The main effect plot for the S/N ratio of Figure 2 depicts the evolution of the mean ± standard error of S/N ratios in response to changes in temperature, pressure, and moisture levels, which are all major factors that impact process or system quality. This graph demonstrates how the change of each factor influences the mean S/N ratio, so it provides informative data on process optimization and quality monitoring. The x-axis marks Temperature ranging from 170 to 200°C; Pressure varying from 0 to 3 N/mm²; Moisture fluctuations lie between 3% and 5%. The y-axis shows the values of the S/N ratio as the mean. These range from 27.1 to 28.0 approximately. Notably, the plot reveals distinct trends for each factor: T/P, on the other hand, are more stable, moving in the same direction with only small fluctuations in the S/N ratio across their respective levels. However, M/H is comparable to T/P with a pronounced increase in the S/N ratio as moisture content rises from 3% to 5%. This means that as the value of moisture increases, the likelihood of the S/N ratio being positive will rise, which is a good indicator of a higher process or system quality.

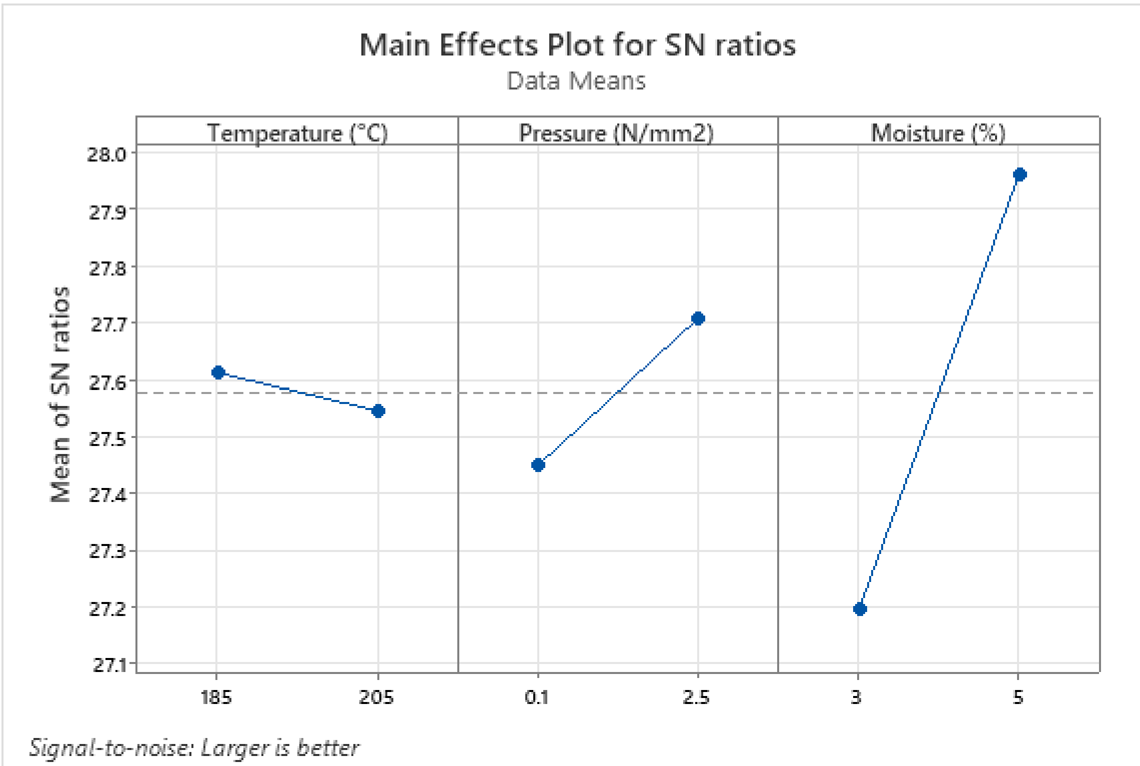

Figure 2. Main effects plot for SN ratios

Table 5 displays the mean values for the response variable, bending strength, under different levels of temperature, pressure, and moisture content. The delta represents the difference in mean values between the two levels, while the rank indicates the relative performance of each level within its respective factor. The analysis suggests that the moisture content has the greatest impact on the bending strength than the pressure and temperature, so it is ranked first followed by pressure with rank 2 and temperature rank 3.

Table 5. Response for Means

Level	Temperature (°C)	Pressure (N/mm^2)	Moisture (%)
1	24.11	23.69	22.93
2	23.91	24.34	25.1
Delta	0.2	0.65	2.18
Rank	3	2	1

The main effects plot for means shown in Figure 3 provides a detailed examination of how different factors—Temperature, Pressure, and Moisture—affect the mean response (average outcome) in a statistical experiment. The graph illustrates the relationship between each factor and the mean response, shedding light on their respective impacts. Across the x-axis, each factor is varied within specified levels: Temperature ranges from 185 to 205°C, Pressure varies from 0.1 to 2.5 N/mm^2, and Moisture fluctuates between 3% and 5%. The y-axis represents the mean of means, indicating the average response across all experimental conditions. Notably, the plot reveals distinct trends for each factor. While changes in Temperature exhibit a slight decrease in the mean of means as temperature rises, suggesting a potential negative impact on the response, variations in Pressure lead to a modest increase in the mean of means with higher pressure levels. However, the most significant effect is observed for Moisture, where an increase from 3% to 5% results in a sharp rise in the mean of means, indicating a positive influence on the response variable.

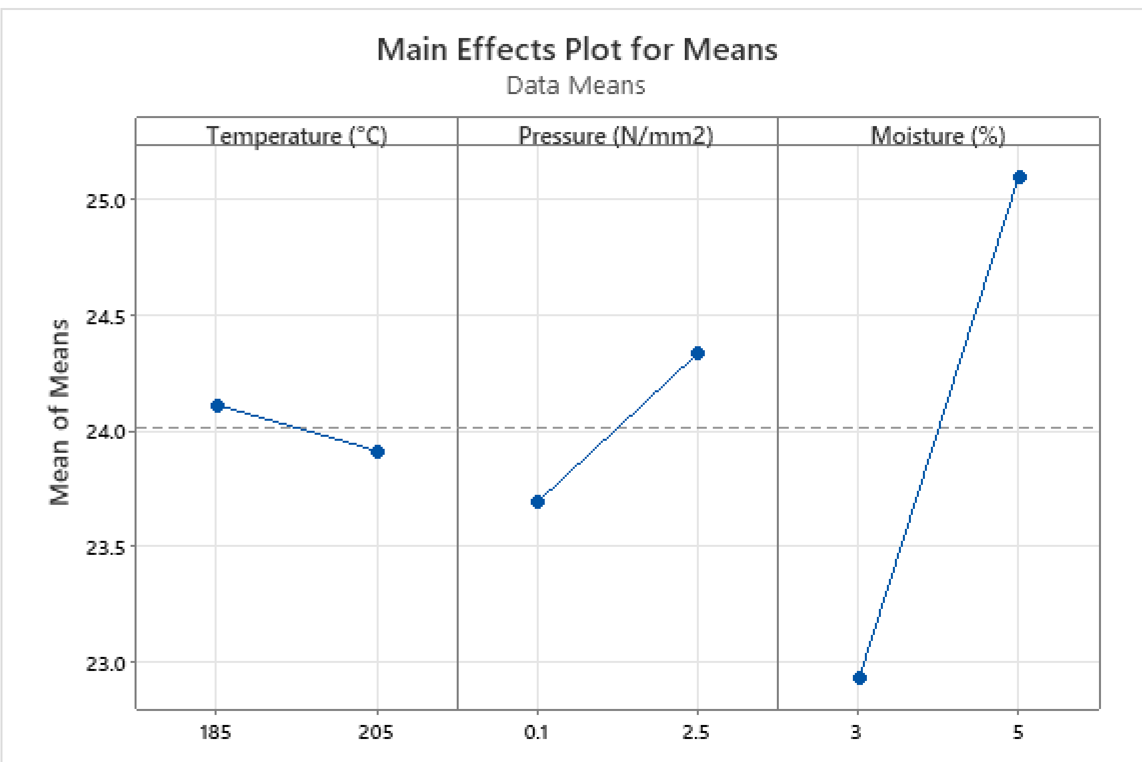

Figure 3. Main effects plot for means

IV. CONCLUSION

This study investigated the bending strength of OSB manufactured from palm leaves and fronds, applying Taguchi orthogonal array methodology for parameter optimization. Our findings highlight the significant impact of moisture content on OSB quality, with higher moisture levels correlating with improved bending strength. While temperature and pressure exhibited minor effects, moisture emerged as a crucial factor in OSB performance. Leveraging Taguchi methodologies, we elucidated key insights into process parameters, paving the way for enhanced product quality and efficiency in sustainable construction materials. This research contributes to the ongoing discourse on sustainable materials and process optimization, providing valuable insights for industry practitioners and researchers alike. As the quest for eco-friendly building solutions continues, the findings from this study offer practical strategies for advancing sustainable practices in the construction sector, fostering a more resilient and environmentally conscious built environment. This study is limited to the analysis of three parameters i.e. temperature, pressure, and moisture, and one response variable i.e., bending strength. Future studies can include additional parameters such as adhesive type and content, strand orientation, and pressing time could lead to enhanced OSB quality and performance. Advanced material characterization techniques, including scanning electron microscopy (SEM) and Fourier-transform infrared spectroscopy (FTIR), could provide deeper insights into the microstructure and bonding mechanisms of palm-based OSB. Environmental impact assessments using life cycle assessment (LCA) methods could quantify the sustainability of OSB production, informing strategies for reducing environmental burdens.

V. REFERENCES

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