Research Article

Analysis and Optimization of Delamination Factor for Microwaved Cured Pineapple Leaf Fiber Polymer Composite through ANOVA Analysis

Manabendra Saha* and Hari Singh
Department of Mechanical Engineering, National Institute of Technology, Kurukshetra, Haryana, India

Vivek Srivastava
Department of Mechanical Engineering, SGT University, Gurugram, Haryana, India

Manoj Kumar Singh
Natural Composites Research Group Lab, Department of Materials and Production Engineering, The Sirindhorn International Thai-German Graduate School of Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

* Corresponding author. E-mail: sahamanab2003@gmail.com DOI: 10.14416/j.asep.2024.08.010
Received: 12 April 2024; Revised: 5 June 2024; Accepted: 1 August 2024; Published online: 22 August 2024

Abstract
Natural fiber-reinforced composites are quickly replacing other materials as the material of choice for various engineering applications because of their high specific strength, low weight, and affordability. Additionally, natural composites come in various forms and are environmentally benign. In particular, the composite needs to be drilled to put the pieces together. The entry and exit levels of the holes are prone to damage during the drilling process. In the present work, Low-density polyethylene (LDPE) was combined with pineapple leaf fiber (PALF) mat after first undergoing a chemical treatment in this investigation. Microwave curing was applied for fabricating the natural fiber composite with the three specified process parameters i.e., microwave power, % of NaOH solution, and weight percentage of treated fiber. After fabrication, the composite delamination factor and modified delamination factor were determined for evaluating the crack propagation after the drilling operation. At constant speed, the feed and diameter of the drill were used for making the drill in different samples. A CNC drilling machine was used to drill the constructed structure at various input parameters. Using the Taguchi approach, the entire work was analyzed. A tensile test was conducted to estimate the strength of the samples with specific parameters. The tensile strength increases up to 24.34 MPa. ANOVA analysis was used to find the best combination and affecting factors. It was observed that the weight percentage of the treated fiber mat has a maximum contribution percentage of 61 % for the processing of natural fiber polymer composite.

Keywords: Delamination, Low-density polyethylene, Microwave, Natural fiber, Pineapple leaf fiber

1 Introduction

The eco-friendly environment is one of the biggest challenges in the country and the government rules and regulations affect for searching better eco-friendly materials to secure the environmental condition. In some important sectors like automotive, defense, and aerospace technology, composite materials especially natural fiber composite materials are replacing the materials quickly. Due to the structural properties, low cost, comparative high strength, and easily available researchers are very keenly interested in the implementation of natural fiber composite where the load-bearing capacity is to be implemented [1]–[3]. Nowadays the term "Green Composite" is very well known because natural fibers like banana, kenaf, pineapple, hemp, abaca, and jute are reinforced with polymer matrix and become alternative and competitive materials [4], [5]. Fabrication of natural fiber polymer composite is a big challenge because of the temperature difference and properties balance.

There are many techniques available for fabricating the composite i.e., hand layup, pultrusion, injection molding process, etc., [6], [7]. Microwave curing is becoming a novel fabrication technique for fabricating the natural fiber polymer composite due to the uniform heating and better process capabilities [8]. Due to the faster curing time and better process methodology, microwave curing is a process used in various industries, particularly in materials science and manufacturing, to cure or harden materials using microwave radiation [9]. Curing refers to the process of setting or hardening a material, often through the application of heat, chemicals, or other means. In the case of microwave curing, electromagnetic waves in the microwave frequency range are utilized to induce heat and initiate the curing process. Microwave curing is often used in the manufacturing of composite materials, such as fiber-reinforced polymer composites. The microwave energy accelerates the curing of the resin, reducing processing times. Researchers are very interested in this technology and many fabrication processes have been done with the help of this technique [10]–[12]. Recently some papers have been published with different types of natural fiber along with polymer and the paper indicates a lot of improvement in the composite properties like drilling behaviors [13]. After the fabrication of the composite, making a hole is a big challenge because of the anisotropic nature of fabricated composites. In most cases, the holes are damaged on the surrounding of the recommended hole area during drilling. Technically, it is called as delamination factor. The delamination factor shows the hole's damaged region and based on this decision of acceptance and rejection of the entire composite occurs [8].

The delamination factor indicates the affected area of the hole and it has recommended the rejection of the whole composite [14]. An experimental analysis has been done on the unidirectional glass fiber composite. Using various drill bits, holes were made on Abaka fiber-reinforced polymer and the deliver-reinforced epoxy polymer-based composite. The rotating speed and feed were considered process parameters. It was observed that rotational speed is less important in determining axial force than tool feed. Different types of drill tools drilled abaka-fiber-reinforced polymer and deliver-reinforced epoxy polymer-based composite. Feed and rotational speed were taken as process parameters. It was seen that tool feed contributes more to axial force than rotational speed [15]. The hole properties of a composite made of sisal and Growpia optical fibers were studied. The thrust force, axial force, and torque of the hole were found to be influenced by the drill bit's geometry, cutting speed, and tool feed. According to reports, the drill's geometry has a greater impact on thrust force during drilling [10]. An investigation was conducted on the hole characteristics of sisal–grewia optiva fiber-based composite. It was examined that the geometry of the drill bit, cutting speed, and tool feed influence the thrust force, axial force, and torque of the hole. It has been reported that the geometry of the drill influences more on thrust force during the drilling process [16]. Another experiment was carried out on sisal fiber with PP composite for estimating the thrust force and cutting force. It was observed that the cutting force is significantly affected by the selection of drilling point geometry and the thrust force is significantly low as compared with twist drill during the drilling operation [17]. Another experiment was done on the sandwich structure of hemp and glass and it was observed that when the hole was being prepared, cutting speed and minimal tool feed influenced the damage of the hole at the maximum level [18].

With the help of the hand layup process sisal and aloe vera fiber -epoxy-based composite was prepared and a drilling process was applied to it. Surface roughness and delamination factor were determined. L27 orthogonal array was applied for making the drill hole. It was observed that less delamination and surface roughness were predicted when the feed and speed were at a higher rate [19]. To minimize the number of experiments, the Taguchi method was applied to drilling the hole. A total of 16 experiments were conducted where the point angle was between 1180 to 1350 [20]. For optimizing the process parameters for the drilling operation, glass fiber was used and various machinability test was observed. An 8 mm drill bit was chosen for conducting the drilling experiment. Spindle speed and feed rate were taken as process parameters. GRA methods were also applied to minimize the thrust force, surface roughness, and delamination factor [21]. Taguchi orthogonal array was applied for optimizing the process parameter to determine the burr height of the drilling hole. L27 orthogonal array was applied for experimenting. drill rate, tool feed, and nose angle were chosen as process variables. It was observed that low feed rate, minimum drill rate, and maximum nose angle imply less burr length and surface evenness.

ANOVA analysis was also applied to identify the percentage of contribution of the process parameter [22]. L18 orthogonal array was taken for Taguchi analysis with process parameters with their levels. The selected process parameters were tool feed, cutting speed, and tool type. Temperature measurements in the drill bit were chosen as response parameters for the study [23]. Glass fiber-reinforced polymer composite was drilled to optimize the experimental parameters. L9 orthogonal array was applied for the drilling operation. Cutting speed, chisel edge width and point angle parameters were taken as process parameters. It was found that cutting speed was the most significant factor affecting the torque [24].

In the present research work the natural fiber polymer composite was fabricated and the delamination factor was examined. Pineapple leaf fiber was taken as reinforcement and low-density polyethylene (LDPE) was taken as matrix material.

2 Materials and Methods

2.1 *Materials*

Pineapple leaf fiber (PALF) was procured from RUKSA Composite, Hyderabad. Granular-shaped LDPE was supplied by Mumbai-based Reliance Chemicals. Alumina mold was purchased from ANTS Ceramic Pvt. Ltd., Maharashtra. The alumina mold was as per the ASTM standard. A microwave with a power of 900 W was utilized to fabricate the PALF/LDPE composite. The chemical and mechanical characteristics of pineapple leaf fiber (PALF) are tabulated in Tables 1 and 2 [1].

Table 1: Chemical and mechanical properties of Pineapple leaf fiber (PALF) [1].

Sl.No	Chemical Composition	Proportion (%)
1	Cellulose	67.12 – 82
2	Hemicellulose	9.45 – 18.80
3	Fat and Wax	3.2 – 4.2
4	Lignin	4.4 – 15.4
5	Pectin	1.2 – 3

Table 2: Mechanical properties of Pineapple leaf fiber (PALF) [1].

S.No	Properties	Value
1	Density g/cm^3	1.7
2	Elongation (%)	2.2
3	Tensile Strength (MPa)	126.60
4	Young's Modulus (GPa)	6250

2.2 *Chemical treatment*

Chemical treatment of raw fiber was performed to reduce the hydrophilic nature of the natural fiber. To enhance the surface treatment property, alkali treatment was done. At a predetermined duration and with a varied proportion, the raw fiber mat was submerged in the NaOH solution. For approximately 6 h, the fiber was submerged in the alkali bath. Litmus paper was used while washing after alkali treatment to ensure the neutrality of the treated fiber. After being treated, the fiber was dried using a hot air oven. The mat was cut into the appropriate dimensions for composite manufacturing after getting dried.

2.3 *Design of experiments (DOE)*

Following the fabrication of the natural fiber composite, a CNC router (Suresh Indu Lasers Private Limited, Pune, Maharashtra) having a specification of 3 KW capacity with 0 to 24000 rpm spindle speed was used to drill the composite samples. Three parameters; drill bit diameter, feed, and spindle speed were chosen to conduct the drilling trials. The response parameter was used to calculate the updated delamination factor. These particular input parameters were selected because they had a direct impact on finishing, and optimized parameters might affect the hole condition. The control factor and its level for conducting the drilling experiment in compliance with Taguchi's experiment design are shown tabulated in Table 3. Overall, L27 orthogonal trials were conducted. The experimental work in this study uses the Taguchi method to determine the optimal set of process parameters. This method was used to calculate the signal-to-noise ratio for each experiment to determine the impact of each variable on the outcome. The S/N ratio was used to analyze using three main groupings of quality characteristics i.e., higher is preferable, nominal is ideal, and lower is preferred. The trials in these investigations were conducted using three parameters: drill bit diameter, feed rate, and drill speed. The "Lower the better" formula was used to calculate the responses. Equation (1) shows the formula for lower the better for calculating the S/N ratio. MINITAB 22 software was used to analyze every trial.

$$\text{S/N Ratio} = -10\ \text{Log}\left[\frac{1}{n}\sum_{i=1}^{n} yi^2\right] \qquad (1)$$

Table 3: Level and parameters for the experiment.

Symbol	Factors	Unit	Level 1	Level 2	Level 3
A	Power	W	540	720	900
B	% of NaOH	Wt. %	6	12	18
C	Fiber weight Percentage	gm	25	38	50

2.4 *Composite fabrication*

The natural fiber composite (PALF/LDPE) was fabricated by a domestic microwave. Some adjustments were made to ensure that the system operated as intended. The alumina mold (Al_2O_3) was bought from Ants Ceramic, Mumbai with ASTM specification (D3039). As alumina has special characteristics including microwave transparency, chemical inertness, and superior surface smoothness, it was chosen as mold material. Low-density polypropylene (LDPE) granules were layered for fabricating the LDPE sheet and it was stacked and placed into the mold alternatively with a treated fiber mat. After applying the microwave power at different levels, the composite was fabricated. Before the fabrication of natural fiber composites, the design of the experiment was applied for conducting the experiments. The Taguchi technique was applied for sample preparation. After applying the full factorial, 27 samples were prepared using 3 different factors at 3 different levels. As an input parameter, 3 factors of microwave power; % of chemically treated fiber mat, and weight % of the mat were taken. An initial dimension of the mold was taken as 98 × 25 × 2 mm^3 and after stacking fiber and LDPE matrix, the dimension was measured as 98 × 25 × 2.5 mm^3. The temperature of the microwave curing was maintained around 180 °C because of the degradation of natural fiber at higher temperatures. Figure 1 shows the schematic of stages used during natural fiber composite manufacturing.

2.5 *Mechanical testing*

Truemet Electro-Mechanical Servo Control Universal Testing Machine (Double Column) with a 10 KN capacity was used to conduct tensile test as per the D3039 ASTM standard. The crosshead speed of 10 mm/min was used for the tensile test. The thickness and length of the tensile specimen were 2.5 mm and 98 mm, respectively. Figure 2 depicts the tensile testing procedure of the PALF/LDPE composite sample.

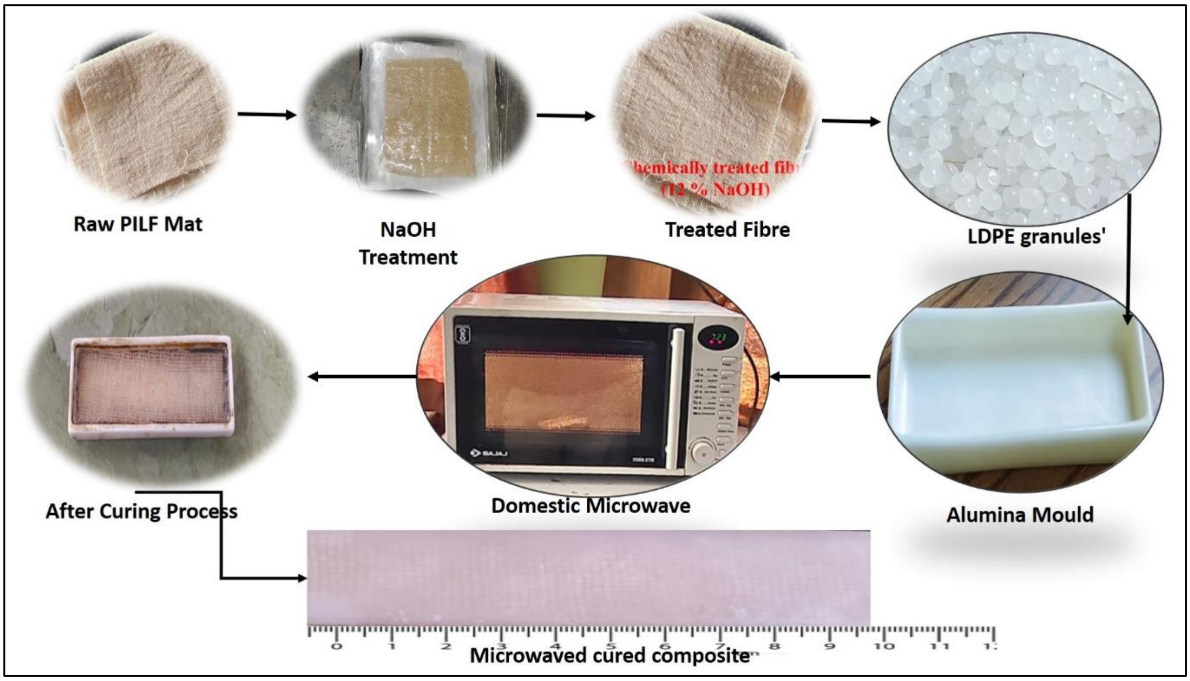


Figure 1: The process methodology of the microwave curing process of PALF -LDPE natural fiber composite.

Figure 2: Tensile testing setup performing tensile testing of PALF/LDPE composite.

2.6 *Delamination factor*

During the drilling operation, delamination of fiber-reinforced composite takes place. The delamination contains breaks and cracks at the hole entry and exit. Two diameters are presented on the structure. Firstly, the diameter of the hole to be produced is represented by D_o. Secondly, the maximum diameter of the crack hole produced is represented by D_{max}. Therefore, the delamination factor can be represented by Equation (2).

$$F_d = \frac{\mathrm{Dmax}}{Do} \tag{2}$$

Figure 3(a)–(c), and Figure 4 represent the delamination affected area and Critical Cases when drilling carbon fiber-reinforced carbon (CFRC) with a uniform damage area [1].

It has been observed that the conventional method for identifying the delamination factor is not satisfactory due to the estimate of the size of the crack, which represents the damage magnitude. Therefore, a novel approach has been proposed for identifying the actual delamination factor, namely the adjusted delamination factor (F_{da}), and calculated using Equation (3). This equation has two segments. The first segment of Equation (3) represents the identification of the delamination factor (Fd) and the second segment identifies the damage area contribution [25].

$$F_{da} = \alpha \frac{\mathrm{Dmax}}{Do} + \beta \frac{\mathrm{Dmax}}{Do} \tag{3}$$

Where A_{max} is the area related to the maximum diameter of the delamination zone (D_{max}) and A_0 is the area of the nominal hole (D_0). The parameters α and β are used as weights in the parts of Equation (3). Therefore

$$A_{max} = \frac{\pi}{4} D^2{}_{max} \tag{4}$$

$$A_0 = \frac{\pi}{4} Do^2 \tag{5}$$

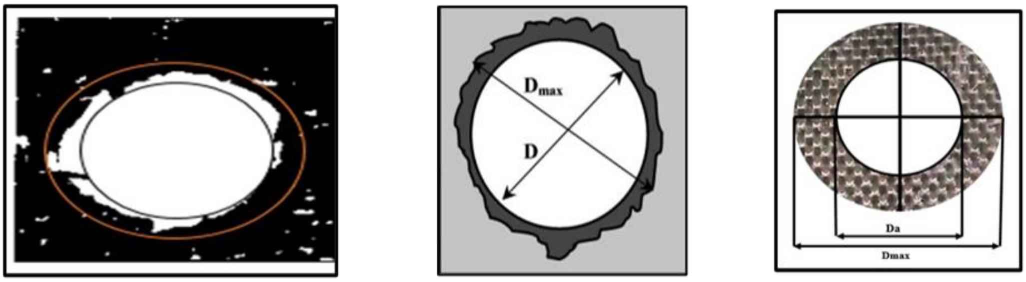
Replacing Equations (4) and (5) to the Equation (3).

$$F_{da} = \alpha F_d + \beta\, F_d^2 \tag{6}$$

In this work, β is considered as the ratio of the damaged area (A_d) to the area corresponding to D_{max} (A_{max}) minus the nominal hole area (A_0). The parameter α is the complement o , i.e., $\alpha = 1-\beta$. Therefore, Equation (6) can be rewritten as Equations (7) and (8):

$$F_{da} = (1-\beta)F_d + \beta\, F_d^2 \tag{7}$$

$$F_{da} = Fd + \frac{A_{max}}{(A_{max}-A_0)} (F_d^2 - F_d) \tag{8}$$



(a) (b) (c)

Figure 3: (a) Delamination development on CFRC (b) Delamination factor of CFRC (c) Critical case when drilling with uniform damage area.

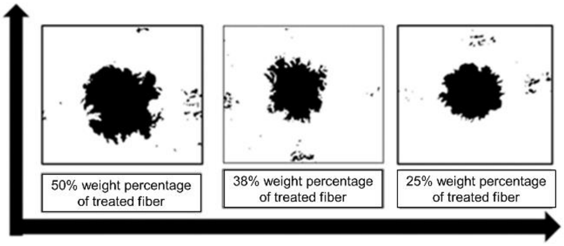


Figure 4: The changes in the dimension of the drilled hole with different weight percentages of treated fiber.

2.7 *Behavior of drilled composites*

For observing the drilling behavior, a CNC router machine was used for the drilling process. Microwaved cured polymer composite with approximate 2.5 mm thickness was used for the drilling. In most of the cases, the material of the drill bit is used as high-speed steel for obtaining the material properties [26]. A 5 mm drill bit diameter with a K20 helical drill was used as a cutting tool. An appropriate clamping system was employed to fix the specimen. Table 4 shows the drilling parameters (Speed, feed, and diameter of the drill) for the experiment. All experiments were conducted twice to ensure the repeatability of the data.

Table 4: Drilling parameters used while drilling with CNC Router.

Sl. No.	Parameters	Value
1	Speed	2400 rpm
2	Feed	50 mm
3	Diameter of drill	5 mm

A resulting scanner of 600 dpi was used for analyzing the drilled hole measurement. The damaged area was obtained through image digitalization and processing. Figure 4 shows the progress of the drill hole and the damaged area. The drilled hole was examined by Image J 1.34 public domain software (National Institute of Health, USA).

To obtain an image with acceptable quality, a series of parameters was selected appropriately, such as brightness, intensity, noise suppression image enhancement, and edge detection.

Table 5: Result of Effect of speed, feed, and diameter of drill bit on delamination and modified delamination factor on microwave-cured polymer composite.

Sl. No.	Power (Watt)	% of NAOH (gm)	Weight Percentage (%)	F_d (Delamination)	F_{da} (Modified Delamination)	S/N Ratio of mod. Delamination
1	900	6	25	1.690	1.730	–4.76092
2	900	6	38	1.811	1.910	–5.62067
3	900	6	50	1.982	2.010	–6.06392
4	900	12	25	1.711	1.779	–5.00352
5	900	12	38	1.286	1.931	–5.71565
6	900	12	50	1.810	2.072	–6.32780
7	900	18	25	1.424	1.782	–5.01815
8	900	18	38	1.512	1.816	–5.18232
9	900	18	50	1.762	1.942	–5.76498
10	720	6	25	1.653	1.744	–4.83093
11	720	6	38	1.672	1.882	–5.49239
12	720	6	50	1.672	1.992	–5.98579
13	720	12	25	1.674	1.722	–4.72066
14	720	12	38	1.711	1.802	–5.11510
15	720	12	50	1.982	2.004	–6.03795
16	720	18	25	1.745	1.740	–4.81098
17	720	18	38	1.675	1.842	–5.30579
18	720	18	50	1.882	2.031	–6.15420
19	540	6	25	1.452	1.591	–4.03340
20	540	6	38	1.672	1.743	–4.82595
21	540	6	50	1.760	1.810	–5.15357
22	540	12	25	1.556	1.631	–4.24908
23	540	12	38	1.672	1.715	–4.68528
24	540	12	50	1.792	1.842	–5.30579
25	540	18	25	1.581	1.692	–4.56801
26	540	18	38	1.621	1.717	–4.69541
27	540	18	50	1.687	1.782	–5.01815

3 Result and Discussion

3.1 *Delamination Factors*

Based on the Taguchi method the composite fabrication was performed using microwave curing. 27 specimens were prepared and all specimen was drilled by considering three parameters i.e., speed, feed, and diameter of the drill. Speed and feed are the most significant factors for hole accuracy [27]. Table 4 shows the parameters with their level. The delamination and modified delamination factors were calculated and tabulated in Table 5.

The delamination factor (F_d) and modified delamination (F_{da}) are calculated by the application of image J software (public domain software, USA). From the literature review, it was stated that the performance of the components is directly dependent on the geometry accuracy of the surface produced during manufacturing [28]. Table 5 shows the major two types of delamination factors i.e. conventional delamination and modified delamination factor. It was observed that the conventional delamination and modified delamination are closer when the damaged area (A_d) is small. However, the difference in hole size (area) increases with the damage area.

Figure 5 shows the progress of the delamination factor with power. It was observed that the conventional delamination is at its highest point when the power is at 540 W, but the modified delamination has increased progress with changes in microwave power correspondingly. Similarly, Figure 6 shows the changes in hole progress when the parameter of fiber weight percentage is changed from lower to higher. It is seen that the impact of the percentage of fiber directly impacts the progress of the fiber. The maximum modified delamination was observed near about 1.9. Several research are available based on chemical treatment for surface modification towards the improvement of the mechanical properties [29], [30]. When the percentage of NaOH solution is used for chemical treatment the fiber condition is changed. Similarly, Figure 7 shows the drilling behavior in the different percentages of NaOH solution. It was observed that a low percentage of NaOH solution has no such kind of impact on drill progress but when the amount of NaOH increases then the drilling factors like delamination change at the higher side. Modified delamination is near about at a constant level with changes in the percentage of NaOH (Figure 8).

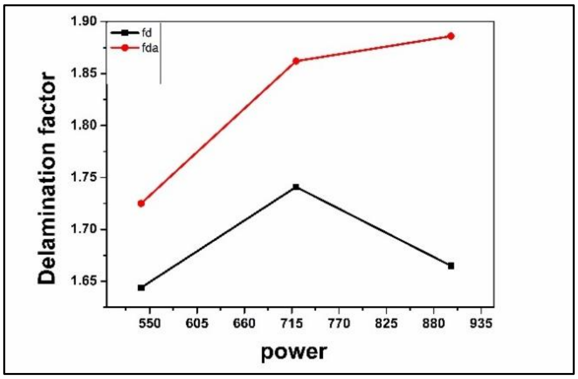


Figure 5: Effect of delamination factors of drilling hole with a variation of drilling hole with power.

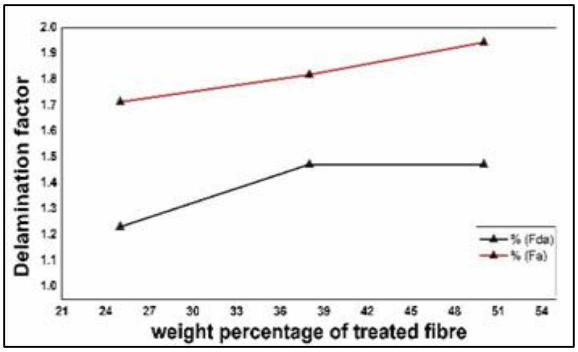


Figure 6: Effect of delamination factors of drilling hole with a variation of weight percentage of the mat.

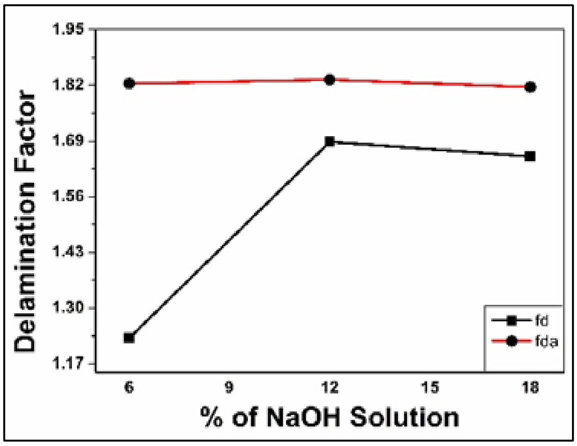


Figure 7: Effect of delamination factors of drilling hole with a variation of NaOH solution.

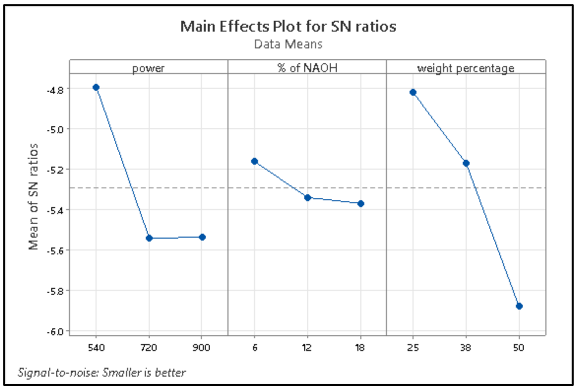


Figure 8: Taguchi response graph for modified delamination factor (DF).

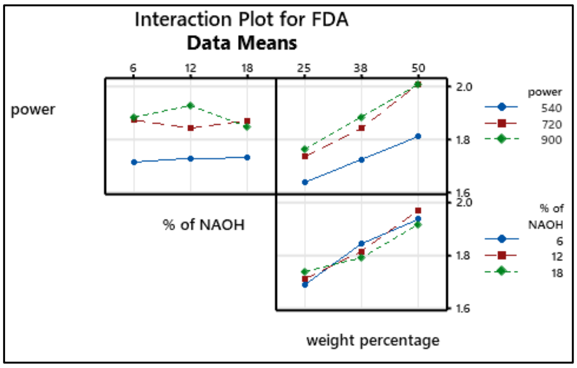


Figure 9: Interaction plot between the process parameters.

3.2 *Taguchi analysis for modified delamination Factor*

Table 5 displays the experimental results for the delamination factor, modified delamination factor, and modified delamination factor's S/N ratio. Figure 8 shows the major effect plot for the S/N ratio. It is observed that a composite construction performs better when the delamination factor is smaller. The response table of the mean S/N ratio is used to analyze the impact of the control factors (microwave power, percentage of NaOH, and weight percentage of treated fiber) on the response. The signal-to-noise ratio results are shown in Table 6. Figure 9 shows the interaction between all parameters.

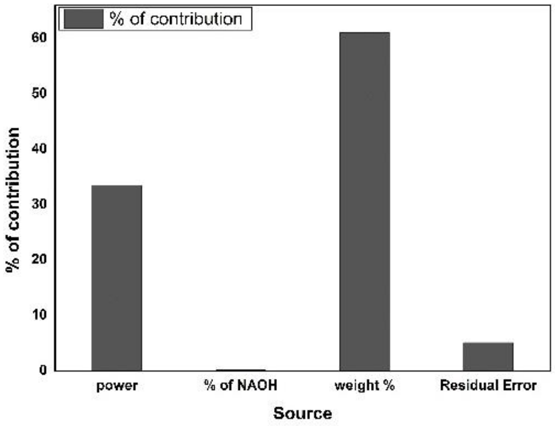


Figure 10: The Percentage of the contribution of process parameter.

Analysis of variance (ANOVA) was used to ascertain the process parameter's percentage contribution. The ANOVA table with the percentage of contribution is displayed in Table 7. After the data was confirmed, it was noted that the F ratio was greater than the value in the table. Thus, it was established that the microwave power process parameter and the fiber weight percentage were important. In a similar manner, the NaOH proportion was negligible. Additionally, it was shown that the weight of the treated fiber had the greatest influence, accounting for 61.12% of the total percentage as shown in Figure 10. The microwave power parameter was the next most important element, contributing 33.52%. It was also observed that the materials of the drill bit served the best quality of the drill hole with specific spindle speed and feed rate [31], [32]. ANOVA analysis gives the research analysis for finding the percentage of contribution of process parameters [32].

Table 6: Analysis of S/N Ratio for drilling behavior.

Level	Power (W)	% of NaOH (wt%)	Wt. (%)
1	–4.726	–5.196	–4.666
2	–5.384	–5.240	–5.182
3	–5.495	–5.169	–5.757
Delta	0.769	0.071	1.091
Rank	2	3	1

Table 7: Analysis of Variance (ANOVA) for SN ratios.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of Contribution
Power (Watt)	2	3.116	3.110	1.555	40.16	0.0010	33.522
% of NAOH (gm)	2	0.023	0.023	0.011	0.3	0.7430	0.250
weight percentage	2	5.682	5.682	2.679	69.19	0.0011	61.127
Residual Error	20	0.474	0.774	0.038			5.099
Total	26	9.295					100

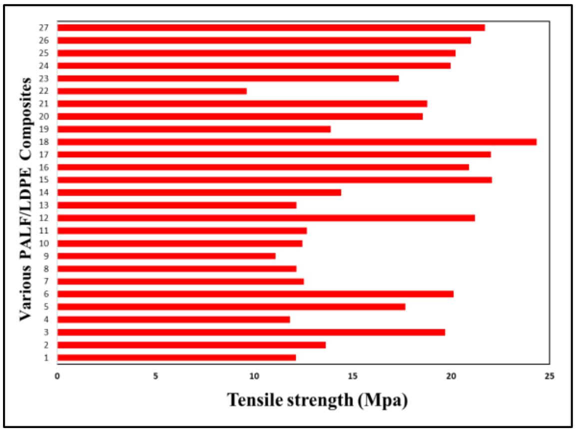


Figure 11: Tensile strength of different natural fiber PALF/LDPE polymer composite specimens.

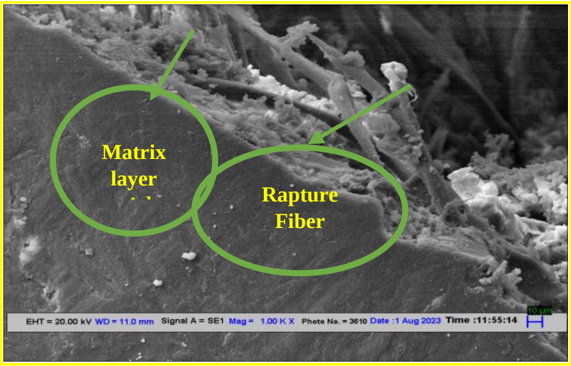


Figure 12: Microstructural analysis of drilling hole and fiber rapture progress.

4 Mechanical Testing

4.1 *Ultimate tensile test*

The mechanical properties of PALF/LDPE composites are dependent on the weight percentage of the fiber reinforcement, aspect ratio, the effectiveness of stress transfer at the interface, and fiber-matrix adhesion [33]. For better properties of PALF/LDPE natural fiber composite, process parameters i.e. microwave power, weight %, and chemical treatment are optimized. It was observed that the tensile strength directly affects the interfacial bonding between the fiber and matrix. The tensile strength of different PALF/LDPE composite specimens manufactured using different combinations of process parameters are shown in Figure 11. Tensile strength is measured in the range of 9.62 MPa to 24.34 MPa. Because of the improved interfacial bonding between the fiber and matrix, specimen number 18 exhibits the maximum tensile strength. The process variables are crucial in determining the maximum tensile strength. Exhibiting the greatest tensile strength when a higher degree of power, chemical treatment, and weight % are applied depends significantly on the process factors. The fiber-matrix region's temperature rises as a result of the highest power, resulting in maximal curing.

5 Microstructural Analysis

Figure 12 shows the SEM analysis of the delaminated area after fracture propagation in the surrounding of the hole. After analysis, it is confirmed that the fiber mat has a strong bond with the matrix. But due to the progress of the hole, the fiber is tried to pull out from the matrix.

6 Conclusions

One of the cutting-edge techniques that shows the fiber mat and matrix has strong interfacial bonding on curing with the help of microwave curing. The average tensile strength was 16.82 MPa. There was a minimum of 9.62 MPa and a maximum of 24.34 MPa tensile strength obtained. The maximum delamination factor was recorded at 2.072 MPa, while the delamination factor was seen at 1.982 due to the drilling process. It was observed that one significant component that has a direct impact on the delamination factor is the weight percentage. The results of an ANOVA study indicate that microwave power has the highest significant contribution. The interfacial bonding between the pineapple fiber and matrix is ensured using scanning electron microscopy.

Author Contributions

M.S., H.S. Conceptualization, original draft, Methodology, Formal Analysis, resources, validation software; M.K.S, V.S. writing – review & editing, project administration, resources, validation. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Reference

[1] R. Phiri, S. M. Rangappa, S. Siengchin, and D. Marinkovic, "Agro-waste natural fiber sample

preparation techniques for bio-composites development: Methodological insights," *Facta Universitatis, Series: Mechanical Engineering*, vol. 21, no. 4, p. 631, Dec. 2023, doi: 10.22190/Fume230905046p.

[2] A. K. Sinha, H. K. Narang, and S. Bhattacharya, "Mechanical properties of natural fiber polymer composites," *Journal of Polymer Engineering*, vol. 37, no. 9, pp. 879–895, Nov. 2017, doi: 10.1515/polyeng-2016-0362.

[3] S. M. Rangappa, S. Siengchin, and H. N. Dhakal, "Green-composites: Ecofriendly and sustainability," *Applied Science and Engineering Progress*, vol. 13, no. 3, pp. 183–184, Jul. 01, 2020, doi: 10.14416/j.asep.2020.06.001.

[4] M. K. Singh, R. Tewari, S. Zafar, S. M. Rangappa, and S. Siengchin, "A comprehensive review of various factors for application feasibility of natural fiber-reinforced polymer composites," *Results in Materials*, vol. 17, Mar. 2023, Art. no. 100355, doi: 10.1016/j.rinma.2022.100355.

[5] B. V. Ramnath, V. M. Manickavasagam, C. Elanchezhian, C. V. Krishna, S. Karthik, and K. Saravanan, "Determination of mechanical properties of intra-layer abaca-jute-glass fiber reinforced composite," *Materials & Design*, vol. 60, pp. 643–652, 2014, doi: 10.1016/j.matdes.2014.03.061.

[6] E. Zini and M. Scandola, "Green composites: An overview," *Polymer Composites*, vol. 32, no. 12. pp. 1905–1915, Dec. 2011. doi: 10.1002/pc.21224.

[7] M. K. Singh, N. Verma, and S. Zafar, "Conventional processing of polymer matrix composites," in *Lightweight Polymer Composite Structures: Design and Manufacturing Techniques*. Florida: CRC Press, pp. 21–66, 2020.

[8] S. Alsubari, M. Y. M. Zuhri, S. M. Sapuan, M. R. Ishak, R. A. Ilyas, and M. R. M. Asyraf, "Potential of natural fiber reinforced polymer composites in sandwich structures: A review on its mechanical properties," *Polymers*, vol. 13, no. 3, pp. 1–20, 2021, doi: 10.3390/polym13030423.

[9] S. Zafar, M. K. Singh, and N. Verma, "Method for manufacturing thermoplastic composite rom microwave-assisted compression molding," *Official Journal of the Patent Office*, vol. 33, 2020, Art. no. 31228.

[10] G. Arora, "Microwave irradiation manufacturing of polymer composites," in *Sustainable Advanced Manufacturing and Materials Processing*. Florida: CRC Press, pp. 9–32, 2022, doi: 10.1201/9781003269298-2.

[11] M. K. Singh and S. Zafar, "Influence of microwave power on mechanical properties of microwave-cured polyethylene/coir composites," *Journal of Natural Fibers*, vol. 17, no. 6, 2018, doi: 10.1080/15440478.2018.1534192.

[12] M. K. Singh and S. Zafar, "Development and mechanical characterization of microwave-cured thermoplastic based natural fibre reinforced composites," *Journal of Thermoplastic Composite Materials*, vol. 32, no. 10, pp. 1427–1442, 2019, doi: 10.1177/0892705718799832.

[13] S. Rao and R. Rao, "Cure studies on bifunctional epoxy matrices using a domestic microwave oven," *Polymer Testing*, vol. 27, no. 5, pp. 645–652, 2008, doi: 10.1016/j.polymertesting.2008.04.005.

[14] Rampal, G. Kumar, S. M. Rangappa, S. Siengchin, and S. Zafar, "A review of recent advancements in drilling of fiber-reinforced polymer composites," *Composites Part C: Open Access*, vol. 9, 2022, Art. no. 100312, doi: 10.1016/j.jcomc.2022.100312.

[15] I. Paul, T. Rajakumar, P. Hariharan, and L. Vijayaraghavan, "Drilling of carbon fiber reinforced plastic (CFRP) composites-A review," *International Journal of Materials and Product Technology*, vol. 43, pp. 43–67, 2012, doi: 10.1016/j.jmrt.2022.08.161.

[16] A. M. Kumar, R. Rajasekar, P. M. Kumar, R. Parameshwaran, A. Karthick, and M. Muhibbullah, "Comparative analysis of drilling behaviour of synthetic and natural Fiber-Based composites," *Advances in Materials Science and Engineering*, vol. 2021, pp. 1–13, 2021, doi: 10.1155/2021/9019334.

[17] P. K. Bajpai and I. Singh, "Drilling behavior of sisal fiber-reinforced polypropylene composite laminates," *Journal of Reinforced Plastics and Composites*, vol. 32, no. 20, pp. 1569–1576, 2013, doi: 10.1177/0731684413492866.

[18] K. Patel, P. P. Gohil, and V. Chaudhary, "Investigations on drilling of hemp/glass hybrid composites," *Materials and Manufacturing Processes*, vol. 33, no. 15, pp. 1714–1725, 2018, doi: 10.1080/10426914.2018.1453150.

[19] P. N. E. Naveen, "Experimental investigation of drilling parameters on composite materials," *Journal of Mechanical and Civil Engineering*, vol. 2, pp. 30–37, 2012, doi: 10.9790/1684-0233037.

[20] A. S. J. Sekaran and K. P. Kumar, "Study on drilling of woven sisal and aloevera natural fibre polymer composite," *Materials Today: Proceedings*, vol. 16, pp. 640–646, 2019, doi: 10.1016/j.matpr.2019.05.140.

[21] E. Kilickap, "Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite," *Expert Systems with Applications*, vol. 37, no. 8, pp. 6116–6122, 2010, doi: 10.1016/j.eswa.2010.02.023.

[22] K. Palanikumar, "Experimental investigation and optimization in drilling of GFRP composites," *Measurement*, vol. 44, no. 10, pp. 2138–2148, 2011, doi: 10.1016/j.measurement.2011.07.023.

[23] E. Kilickap, "Modeling and optimization of burr height in drilling of Al-7075 using Taguchi method and response surface methodology," *The International Journal of Advanced Manufacturing Technology*, vol. 49, pp. 911–923, 2010, doi: 10.1007/s00170-009-2469-x.

[24] R. Çakıroğlu and A. Acır, "Optimization of cutting parameters on drill bit temperature in drilling by Taguchi method," *Measurement*, vol. 46, no. 9, pp. 3525–3531, 2013, doi: 10.1016/j.measurement.2013.06.046.

[25] V. K. Vankanti and V. Ganta, "Optimization of process parameters in drilling of GFRP composite using Taguchi method," *Journal of Materials Research and Technology*, vol. 3, no. 1, pp. 35–41, 2014, doi: 10.1016/j.jmrt.2013.10.007.

[26] J. Arputhabalan, S. Prabhu, K. Palanikumar, S. Venkatesh, and K. Vijay, "Assay of machining attributes in drilling of natural hybrid fiber reinforced polymer composite," *Materials Today: Proceedings*, vol. 16, pp. 1097–1105, 2019, doi: 10.1016/j.matpr.2019.05.201.

[27] S. N. Fayzimatov, Y. Y. Xusanov, and D. A. Valixonov, "Optimization conditions of drilling polymeric composite materials," *The American Journal of Engineering and Technology*, vol. 3, no. 02, pp. 22–30, 2021, doi: 10.37547/tajet/Volume03Issue02-04.

[28] Y. Kaynak, T. Lu, and I. S. Jawahir, "Cryogenic machining-induced surface integrity: A review and comparison with dry, MQL, and flood-cooled machining," *Machining Science and Technology*, vol. 18, no. 2, pp. 149–198, 2014, doi: 10.1080/10910344.2014.897836.

[29] L. Prasad, S. Kumar, R. V. Patel, A. Yadav, V. Kumar, and J. Winczek, "Physical and mechanical behaviour of sugarcane bagasse fibre-reinforced epoxy bio-composites," *Materials*, vol. 13, no. 23, 2020, Art. no. 5387, doi: 10.3390/ma13235387.

[30] R. V. Patel, A. Yadav, and J. Winczek, "Physical, mechanical, and thermal properties of natural Fiber-Reinforced epoxy composites for construction and automotive applications," *Applied Sciences*, vol. 13, no. 8, p. 5126, 2023, doi: 10.3390/app13085126.

[31] T. Raja, Y. Devarajan, G. Dhanraj, S. Pandiaraj, M. Rahaman, and M. Thiruvengadam, "Delamination analysis of drilling parameters on neem/banyan fiber–reinforced sawdust particulates hybrid polymer composite," *Biomass Conversion and Biorefinery*, vol. 14, no. 9, pp. 10747–10757, 2024, doi: 10.1007/s13399-023-04951-x.

[32] J. Davim, J. Rubio, and A. Abrao, "A novel approach based on digital image analysis to evaluate the delamination factor after drilling composite laminates," *Composites Science and Technology*, vol. 67, no. 9, pp. 1939–1945, 2007, doi: 10.1016/j.compscitech.2006.10.009.

[33] R. Benyettou, S. Amroune, M. Slamani, Y. Seki, A. Dufresne, M. Jawaid and S. Alamery, "Assessment of induced delamination drilling of natural fiber reinforced composites: A statistical analysis," *Journal of Materials Research and Technology*, vol. 21, pp. 131–152, 2022, doi: 10.1016/j.jmrt.2022.08.161.