e-ISSN:2582-7219

INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING AND TECHNOLOGY

Volume 7, Issue 5, May 2024

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.521

6381 907 438 6381 907 438 ijmrset@gmail.com www.ijmrset.com

| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 7.521| Monthly Peer Reviewed & Referred Journal |

| Volume 7, Issue 5, May 2024 |

| DOI:10.15680/IJMRSET.2024.0705020 |

Optimization of Process Parameters for Drilling Sisal Fiber-Reinforced Polyester Composites

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ABSTRACT: Natural fiber-reinforced composites, such as composites consisting of 20 wt.% sisal and 80% polyester, pose challenges in terms of machinability when compared to traditional materials. The complexity arises from the inherent heterogeneity within their internal structure, prompting numerous researchers to delve into the exploration of optimal machining parameters. Achieving precision in drilling is imperative for effectively joining diverse components crafted from natural fiber composites. Hence, a comprehensive comprehension of the interplay between various adjustable parameters is essential to pinpoint the key factors influencing drilling quality. The primary objective of this investigation is to scrutinize the impact of operational parameters - namely spindle speed of 750, 1000, and 1250 rpm, feed rate range of 50, 75, and 100 mm/min, and drill diameter of 9 mm - on torque (N), thrust force (N), and tangential force (N) during the drilling process of 20 wt.% sisal and 80% polyester composites. The experimentation entailed the utilization of an automated drilling apparatus along with High-Speed Steel (HSS) twist drill bits. Employing the L9 orthogonal array, the study harnessed the response surface methodology (RSM) to optimize the operational parameters.

KEYWORDS: Natural fiber ,drilling ,Polyester resin ,process parameter ,RSM ,optimization

I. INTRODUCTION

In recent years, concern regarding the impact of human activities on the environment, this has prompted a transition towards more sustainable and environmentally friendly practices across various applications. In the field of composite materials is one such industry that has witnessed a notable surge in the utilization of natural fibers as reinforcing materials. The natural fibers such as sisal, jute, flax, hemp, and kenaf have garnered interest due to their eco-friendly characteristics and high mechanical properties, positioning them as a feasible alternative to synthetic fibers. The incorporation of natural fibers in composite materials is not a novel concept and has historical roots.

Natural fibers have been utilized for centuries in traditional materials like mud bricks and thatched roofs. However, because of technological advancements and the need for sustainable materials, natural fibers have now entered the domain of composites. A key driver behind the escalating interest in natural fibers is their eco-friendly attributes. In contrast to synthetic fibers sourced from non-renewable origins such as petroleum, natural fibers are sourced from renewable plant-based origins. This renders them biodegradable and diminishes their carbon footprint, rendering them a more sustainable choice.

Moreover, the creation of natural fibers utilizes a reduced amount of energy and generates fewer greenhouse gases when contrasted with synthetic fibers, thereby positioning them as a more environmentally conscious alternative. In addition, natural fibers have displayed outstanding mechanical properties, thus making them appropriate for integration into composite materials. These fibers display significant tensile strength, stiffness, and impact resistance, making them ideal for reinforcement in various applications. For instance, flax fibers exhibit a notable strength-to-weight ratio, rendering them eligible for use in the aerospace domain. Similarly, jute fibers exhibit commendable impact resistance, making them a fitting option for automotive components. An additional advantage of natural fibers lies in their cost-effectiveness when compared to synthetic fibers. The integration of natural fibers in composite materials has also created opportunities for local communities. Given that natural fibers can be produced on a small scale, there exists potential for job creation and economic growth, particularly in rural regions where these fibers are cultivated.

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II. LITERATURE REVIEW

1) Experimental investigation and optimization in drilling of GFRP composites, Authors-Palanikumar K, Performed optimization of drilling parameters with multiple performance characteristics with Taguchi's method with grey relational analysis.
2) Mechanical properties of green coconut fiber reinforced HDPE polymer composite, Authors-Syed Altaf Hussain, Pandurangadu V, and Palanikumar K, Worked to determine the mechanical properties namely tensile strength, flexural strength and impact strength of green coconut fiber reinforced HDPE (High Density Poly-ethylene) polymer composite material.
3) Application of Sisal, Bamboo, Coir and Jute Natural Composites in Structural Up gradation, Authors-Tara sen and Jagannatha Reddy, Attempted to study the possibilities of reusing the sisal fibers, bamboo fibers, coir fibers and jute fibers. The authors reviewed these fibers in origin, growth, physical and chemical properties, advantages and disadvantages and their applications in various fields
4) Application of grey fuzzy logic for the optimization of drilling parameters for CFRP composites with multiple performance characteristics, Authors-Krishnamoorthy A, Rajendra Boopathi S, palanikumar K and Paulo Davim J, performed drilling operation on CFRP composite plates. They had chosen the optimal combination of drilling parameters using GRA to improve the quality of the holes drilled. The authors used the Analysis of variance (ANOVA) to find the percentage contribution of the drilling parameters.

III. METHODOLOGY

3.1 HAND LAY-UP PROCESS

In this process resins are impregnated by hand into fibers which are in the form of woven, knitted, stitched or bonded fabrics. Hand lay up process usually accomplished by rollers or brushes. An increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates then, are left to cure under standard atmospheric conditions

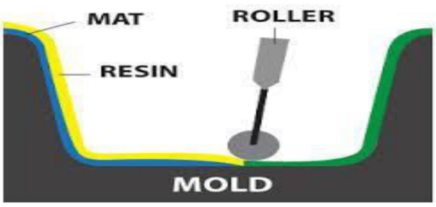

Figure 3.1.Hand lay-up process

The work piece material used in the present research work is Glass fibre reinforced polymer composite. Due to their excellent properties such as high physical strength, high shock absorption property, low temperature respond, resist to degradation in chemicals, nuclear radiation and good dimensional stability. Dimensions: 100mm * 75mm*8mm.

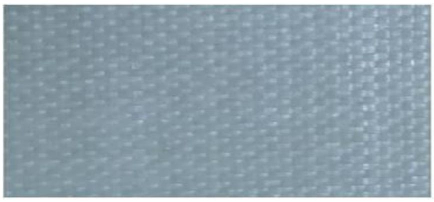

Figure 3.2. work piece

3.2 HIGH SPEED STEEL

Drill bit used high speed steel with 6 mm diameter.

Figure 3.3 High Speed steel tool

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High-speed steel (HSS or HS) is a subset of tool steels, commonly used in tool bits and tools. When used in machining vs. carbide cutting tools it actually cuts the material rather than shearing it. This property allows HSS to cut faster than high carbon steel, hence the name high-speed steel. At room temperature, in their generally recommended heat treatment, HSS grades generally display high hardness (above HRC60) and abrasion resistance compared with common carbon and tool steels.

3.3 EXPERIMENTAL WORK

Drilling experiment was conducted in vertical machining center. Drilling is an operation that produces holes of desired diameter on a plate. The quality of holes differs based on the work material and the tool used for drilling.

Figure 3.4 Vertical Machining Center

3.3.1 CONVENTIONAL DRILLING

Convention drilling conducted by (VMC-LY 45) drilling machine without vibratory setup. Drilling is a cutting process that uses a drill bit to cut or enlarge a hole of circular cross-section in solid materials. The drill bit is a rotary cutting tool, often multipoint. The bit is pressed against the workpiece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the workpiece, cutting off chips (swarf) from the hole as it is drilled.

STROKE	X AXIS	450
	Y AXIS	300
	Z AXIS	300
	DISTANCE FROM SPINDLE NOSE TO TABLE TOP	200-550mm
TABLE	TABLE WORKING SURFACER	600*350mm
	NO.OF T-SLOTS X PITCH	3*125
	MAX.LOAD ON TABLE	200 Kgs
SPINDLE	SPINDLE BORE TAPER	BT – 40 TYPE
	SPINDLE SPEED	8000 rpm
	SPINDLE MOTOR POWER	5.5/3.7 Kw
FEED	CUTTING FEED RATE	10m/min
	RAPID TRANSVERSE RATE RATE-X/Y	36/36m/min
	RAPID TRANSVERSE RATE RATE –Z	24m/min
CNC SYSTEM	CONTROLLER	FANUC

Table 4.1 specifications of conventional vertical machining center (VMC-LY 45)

3.3.2 VIBRATION ASSISTED DRILLING

vibration assisted drilling conducted by (VMC-LY 45) drilling machine with vibratory set up. The first works on vibration drilling began in the 1950s (Pr. V.N. Poduraev, Moscow Bauman University). The main principle consists in generating axial vibrations or oscillations in addition to the feed movement of the drill so that chips could be fractionated and easily removed from the cutting zone.

One can find two main technologies of vibration drilling: self-maintained vibrations systems and forced vibrations systems. Most vibration drilling technologies are still at a research stage. It is the case of the self-maintained vibrations

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drilling: the eigen frequency of the tool is used in order to make it naturally vibrate while cutting; vibrations are self-maintained by a mass-spring system included in the tool holder. Other works use a piezoelectric system to generate and control the vibrations. These systems allow high vibration frequencies (up to 2 kHz) for small magnitude (about a few micrometres); they particularly fit drilling of small holes. Finally vibrations can be generated by mechanical systems: the frequency is given by the combination of the rotation speed and the number of oscillation per rotation (a few oscillations per rotation), the magnitude is about 0.1 mm.generally two type frequency applied in the tool or workpiece. One type is longitudinal and another one transverse . longitudinal type vibration assisted drilling frequency applied in longitudinal to the tool axis. Transverse type vibration assisted drilling frequency applied in transverse direction in the tool axis.

STROKE	X AXIS	450
	Y AXIS	300
	Z AXIS	300
	DISTANCE FROM SPINDLE NOSE TO TABLE TOP	200-550mm
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	RAPID TRANSVERSE RATE RATE –Z	24m/min
CNC SYSTEM	CONTROLLER	FANUC
AMPLITUDE	X AXIS Y AXIS Z AXIS	0 – 9 µm

Table 4.2 specifications of vibration assisted vertical machining center(VMC-LY 45)

The experiments are planned based on the design of experiments using Taguchi's approach (Taguchi and Konishi, 1987). The orthogonal array is used to study the entire parameter space with less number of experiments. Taguchi's L_9 orthogonal array for three factors, three level experiments, needs 9 runs with 8 degrees of freedom (DOF). The study of interaction between the main factors is expressed by means of regression equations.

3.4 DRILLING PARAMETERS

The drilling parameters identified are process parameters that include spindle speed and feed rate and tool parameters that include tool geometry and the tool material. The drilling parameters chosen for this experimentation is spindle speed, feed rate and Amplitude for vibration assisted drilling. spindle speed, feed rate for conventional drilling.

3.4.1 AMPLITUDE

The maximum displacement of a vibrating particle or body from its position of rest. Amplitude apply in workpiece or tool. In this experiment amplitude applied in a workpiece in the range of 3µm, 6µm, 9 µm.

3.4.2 SPINDLE SPEED

The spindle speed is the rotational frequency of the spindle of the machine, measured in revolutions per minute (RPM).speed choose 500 rpm, 1000 rpm, and 1500 rpm.

3.4.3 FEED RATE

The speed with which the drill tool is pushed down towards the work piece is called the feed rate. Higher feed rates will result in increased thrust force and a rough surface finish whereas lower feed rates will result in more heat generated in

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the workpiece and lower material removal rate. Hence a reasonable feed rate is preferred in drilling of Glass fiber reinforced polymer composites. The feed rate chosen for the present work is 0.1 mm/rev, 0.15 mm/rev and 0.2 mm/rev.

3.5 RESPONSES

In this work concentrated to analyze the response in the Delamination Factor. Delamination measured by using profile projector.

Figure 3.5 Profile projector

A profile projector is an optical measurement tool that magnifies a sample's surface features to allow measurement on a linear/circular scale. A profile projector is also referred to as an optical comparator, or even known as a shadowgraph. A profile projector projects a magnified profile image of an area or feature of a work piece onto a screen most commonly using diascopic illumination. Dimensions can be measured directly on the screen or compared to a standard reference at the correct magnification. For accuracy, it is important that the magnification does not change with perspective, i.e. its position or the viewpoint of the operator. Telecentric lenses are, therefore, highly desirable. The screen often has a grid and this grid can often be rotated through 360 degrees to align with an edge as displayed on the screen. Point positions, measurements, and calculations may also be performed using a simple digital readout device. A computer may be added to a profile projector system for edge detection, thereby eliminating some human error.

Profile Projector stepwise procedures

1. Switch on the optical profile projector.
2. Place the clean work piece on the glass of the table.
3. Focus it properly by moving the focusing wheel and moving the work table to obtain the correct magnified image of the object.
4. Horizontal (x axis) measurement can be taken by the right hand side micrometer and the vertical measurement can be taken from the front side micrometer.

IV. RESULT AND DISCUSSION

Composite materials anisotropy and inhomogeneity. During drilling of composites, materials are prone to various types of damages such as fiber separated from composite, peel-up delamination, and push-out delamination. To reduce these defects and to investigate the suitability for many applications,a study of drilling of composite structures is required.

4.1 EXPERIMENTAL RESULTS

The experiment was conducted in conventional and vibration assisted drilling. The experiments are repeated once for each set of input combinations and the average values of the responses are tabulated in order to reduce the error in the experimentation.

4.2 DESIGN OF EXPERIMENTS

Design of experiments (DOE) is a systematic, rigorous approach to engineering problem-solving that applies principles and techniques at the data collection stage so as to ensure the generation of valid, defensible, and supportable engineering conclusions.

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4.2.1 DESIGN OF EXPERIMENTS IN VIBRATION ASSISTED DRILLING

Test No.	Level 1	Level 2	Level 3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 4.1 Taguchi orthogonal arrays in vibration assisted drilling

Taguchi orthogonal arrays in vibration assisted drilling shown in Table 4.1.The table helpful for conducting experiments in different combinations of process parameters. The process parameters include amplitude, spindle speed, feed rate.

4.3 RESPONSE SURFACE METHODOLOGY (RSM)

The Response surface methodology (RSM) is a compilation of analytical, scientific, and numerical approaches employed for establishing, remodeling, and enhancing variable response models. The ANOVA using Design Expert 13 tool based outcomes for the yield strength, tensile strength, percentage of elongation are mentioned in below Table 4.1. This test successfully carried out a 5% level of importance and a 95% level of certainty. The importance of control factors in ANOVA was decided by correlating the F values of each & every control factor. Since the range of the individual process parameters is large, an adjustable focal composite design of second order was observed to be one of the utmost effective mechanisms in the RSM for establishing the numerical and statistical relationships for the surface of response, employing a modest number of trials without any loss in their accuracy.

Factor	Name	Units	Minimum	Maximum	Coded Low	Coded High
A	Tool Diameter	mm	5.00	9.00	-1 ↔ 5.00	+1 ↔ 10.00
B	Feed	mm/min	750.00	1250.00	-1 ↔ 600.00	+1 ↔ 1200.00
C	Speed	rpm	50.00	100.00	-1 ↔ 30.00	+1 ↔ 90.00

Table 4.1 Factors

Response	Name	Units	Observations	Minimum	Maximum
R1	Delamination Factor		9.00	1.112	1.198

Table 4.2 Response

Ex.N0.	Drill Dia. (mm)	Speed (rpm)	Feed Rate (mm/rev)	Delamination Factor (DF)
1	5	750	50	1.198
2	7	750	75	1.162
3	9	750	100	1.157
4	7	1000	50	1.163
5	9	1000	75	1.148

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6	5	1000	100	1.112
7	9	1250	50	1.136
8	5	1250	75	1.136
9	7	1250	100	1.129

Table 4.3 Factors and response

Response 1: Delamination Factor

Fit Summary

Source	Sequential p-value	Adjusted R^2	Predicted R^2	
Linear	0.0398	0.6573	0.1305	
2FI	**0.0300**	**0.9828**	**0.7333**	**Suggested**
Quadratic				**Aliased**

Fit Statistics

Std. Dev.	0.0033	**R^2**	0.9957
Mean	1.15	**Adjusted R^2**	0.9828
C.V. %	0.2836	**Predicted R^2**	0.7333
		Adeq Precision	29.5435

The Predicted R^2 of 0.7333 is not as close to the Adjusted R^2 of 0.9828 as one might normally expect; i.e. the difference is more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. All empirical models should be tested by doing confirmation runs.

Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 29.543 indicates an adequate signal. This model can be used to navigate the design space.

ANOVA for 2FI model Response of Delamination Factor

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0049	6	0.0008	77.17	0.0128	significant
A-Tool Diameter	0.0001	1	0.0001	7.42	0.1125	
B-FEED	0.0001	1	0.0001	8.74	0.0979	
C-SPEED	0.0001	1	0.0001	12.61	0.0710	
AB	8.595E-06	1	8.595E-06	0.8094	0.4632	
AC	0.0004	1	0.0004	40.26	0.0239	
BC	0.0000	1	0.0000	1.63	0.3294	
Residual	0.0000	2	0.0000			
Cor Total	0.0049	8				

The Model F-value of 77.17 implies the model is significant. There is only a 1.28% chance that an F-value this large could occur due to noise.

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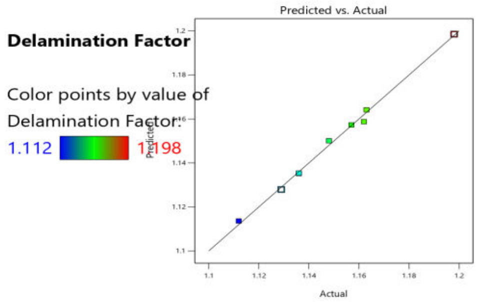
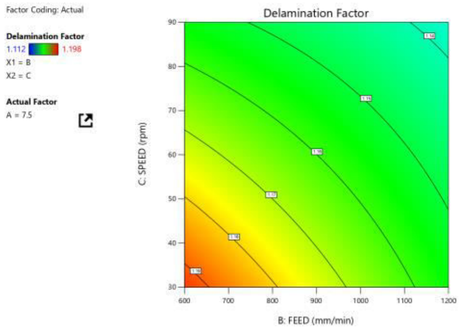
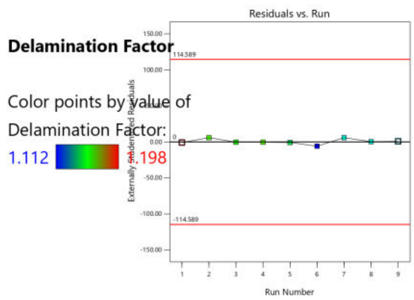
P-values less than 0.0500 indicate model terms are significant. In this case AC is a significant model term. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

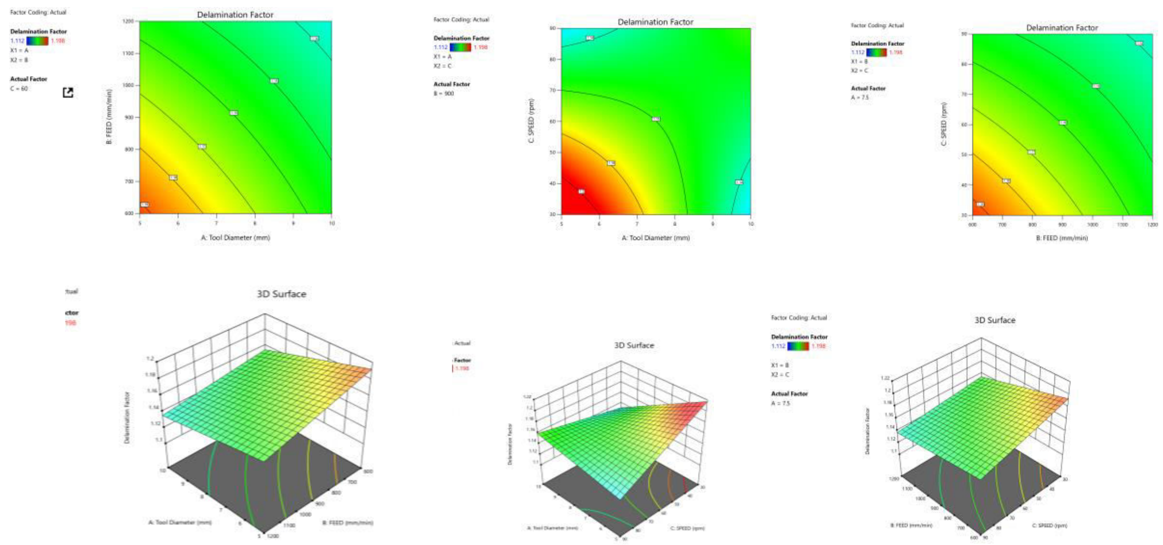


The predicted values versus the actual experimental values for the responses of the developed regression equations are graphically illustrated in the graphs. The predicted values versus the actual experimental values for the responses of the developed regression equations are graphically illustrated in the graphs.





The graphs reveal the presence of an exceptional interrelationship between the predicted value of the generated responses and the actual experimental values.



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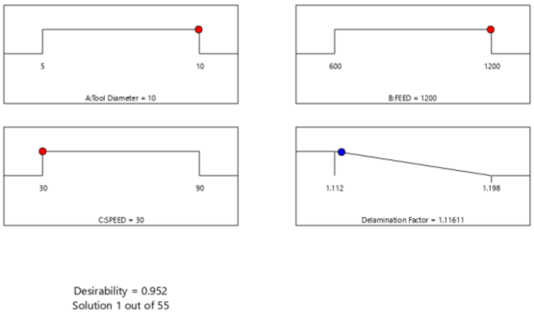

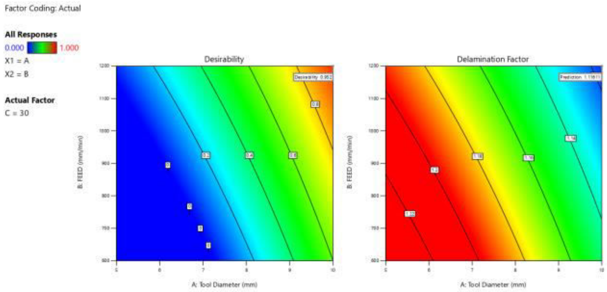

Based on the desirability of delamination value minimum the other factors to be optimized based on the input factors. N= 55 Solutions found

Number	Tool Diameter	FEED	SPEED	Delamination Factor	Desirability	
1	9.000	1199.998	30.000	1.116	0.952	Selected
2	10.000	1195.209	30.000	1.116	0.949	
3	10.000	1192.709	30.000	1.116	0.948	
4	10.000	1199.999	30.582	1.116	0.948	
5	10.000	1197.837	30.449	1.117	0.947	
6	10.000	1190.241	30.000	1.117	0.947	
7	9.965	1199.998	30.064	1.117	0.945	
8	10.000	1187.589	30.006	1.117	0.945	
9	10.000	1199.999	30.966	1.117	0.945	
10	10.000	1199.997	31.068	1.117	0.944	
11	9.963	1190.698	30.000	1.117	0.940	
12	10.000	1171.298	30.000	1.118	0.935	
13	9.900	1200.000	30.000	1.118	0.934	
14	10.000	1200.000	33.143	1.118	0.928	
15	9.956	1171.362	30.000	1.118	0.927	
16	10.000	1156.331	30.000	1.118	0.927	
17	9.858	1199.999	30.000	1.118	0.927	
18	10.000	1151.320	30.000	1.119	0.924	
19	10.000	1147.179	30.177	1.119	0.920	
20	5.000	1200.000	90.000	1.119	0.916	
21	5.000	1196.620	90.000	1.119	0.915	
22	5.022	1199.998	89.993	1.119	0.914	
23	5.043	1199.997	90.000	1.120	0.913	
24	5.000	1191.276	90.000	1.120	0.912	
25	9.776	1200.000	30.000	1.120	0.912	
26	5.000	1199.999	89.605	1.120	0.910	
27	10.000	1200.000	35.469	1.120	0.910	
28	9.756	1200.000	30.001	1.120	0.908	
29	10.000	1123.950	30.000	1.120	0.908	
30	5.000	1199.998	89.287	1.120	0.906	
31	5.034	1200.000	89.465	1.120	0.906	
32	5.000	1169.853	90.000	1.120	0.902	
33	5.000	1199.996	88.866	1.121	0.900	
34	10.000	1098.695	30.000	1.121	0.893	

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35	5.000	1199.987	88.377	1.121	0.893	
36	9.670	1199.998	30.000	1.121	0.892	
37	5.000	1143.215	90.000	1.122	0.889	
38	5.000	1130.727	90.000	1.122	0.883	
39	5.408	1200.000	90.000	1.122	0.881	
40	10.000	1199.999	39.279	1.122	0.880	
41	5.000	1098.849	90.000	1.123	0.868	
42	5.000	1086.433	90.000	1.124	0.863	
43	9.999	1046.830	30.000	1.124	0.862	
44	5.725	1200.000	90.000	1.125	0.854	
45	9.659	1199.999	35.985	1.125	0.853	
46	10.000	1200.000	43.186	1.125	0.850	
47	10.000	1022.144	30.000	1.125	0.848	
48	5.000	1002.292	90.000	1.127	0.823	
49	5.000	929.845	90.000	1.130	0.789	
50	10.000	912.129	30.000	1.131	0.783	
51	6.733	1200.000	90.000	1.132	0.768	
52	6.698	1199.998	89.101	1.132	0.764	
53	10.000	1118.439	50.951	1.133	0.754	
54	7.946	1199.986	90.000	1.141	0.664	
55	10.000	600.010	48.027	1.152	0.538	

Table 4. Design Experts “N” different solutions

The minimum delamination recommended by the design of the expert tool is taken into consideration and the confirmation test was made by the same setup and the minimum delamination factor value of 1.214 is obtained. They were shown in the table

	Tool Diameter	FEED	SPEED	Delamination Factor
Predicted Value	9	1199.998	30.000	1.116
Confirmation Test Value	9	1200	30	1.214

V. CONCLUSION

The objective of this investigation was to examine the impact of cutting parameters and fiber alignment on delamination and surface quality when drilling unidirectional fiber alignment composites. Two cutting parameters (speed and feed rate) at three different levels were examined with three different tool diameters, and the conclusions were made based on the RSM results obtained:

- Visual and microscopic evaluations of cross-sections of drilled holes indicated that it is advisable to avoid higher cutting speed in conjunction with increased feed rate, as they result in inferior surface quality.
- ANOVA findings indicated that feed rate and speed are the primary influential factors on delamination, while feed rate and drill diameter significantly affect the surface quality of unidirectional sisal fiber composites.
- Optimal parameters identified were: 1200 rpm speed, 30 mm/rev feed rate, and 9 mm drill diameter and the minimum delamination value is obtained 1.214.
- In both composite scenarios, intermediate speed, moderate drill diameter, and reduced feed rate resulted in improved delamination characteristics and surface quality of drilled holes.
- Both samples were assessed under identical drilling conditions and parameters. Therefore, the selection of their engineering applications should be based on their respective responses to this damage.

The predicted values versus the actual experimental values for the responses of the developed regression equations are graphically illustrated in the graphs.

| ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 7.521| Monthly Peer Reviewed & Referred Journal |

| Volume 7, Issue 5, May 2024 |

| DOI:10.15680/IJMRSET.2024.0705020 |

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