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Study the Impact of Drilling Process Parameters on Natural Fiber Reinforced Herringbone Epoxy Composites

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ABSTRACT

Common fiber composite overlays are attractive for a few applications, (for example, aviation and flying machine auxiliary parts) because of their predominant properties and bio-degradable. Typically, mechanical drilling process parameters are significant effect final machining process outcomes. It covers drilling performance like convectional drilling, grinding, vibration-influence twist drilling, and rapid boring, drilling apparatus geometry and materials, drilling actuated delamination and its smothering methodologies, thrust power, and wear rate. This paper aimed to address the effect and ranking of process parameters on trust force, torque, and delamination at both entry and exit of the hole sisal fabric herringbone reinforced epoxy composites. The herringbone woven sisal fabric reinforced epoxy composite is fabricated using conventional compression molding technique. The result shows that at higher speed and feed rate delamination at both entrance and exit, thrust force, and toque decreases. Optimum drill diameter found from 6 to 10 mm to obtain minimum responses. As four output parameters are deciding quality of drilled hole, further grey regression analysis is used to study the ranking of output responses. Form grey regression analysis it is found that for 2700 rpm spindle speed, 60 mm/min feed and 8 mm diameter exhibit minimum effort.

1. INTRODUCTION

In recent times, composite materials have gained a lot of recognition because of their superior properties due to which they find their application in a number of fields [1, 2]. They are additionally utilized in hardware, building development, furniture, control industry, oil industry, restorative industry and in numerous other mechanical items, for example, oxygen tanks, control transmission shafts and so on [3, 4]. But with these applications, the composites need to be properly selected to avoid burning and delamination can be overcome chemical treatment [5, 6].

There were many advantages in composites such as good strength to weight ratio, high creep resistance, high wear resistance, corrosion-resistant, anisotropic and many more that is why it has strong future potential and prospects. It also depends on the composites being used, whether matrix or fiber, chemical treatments [7]. In addition to that, natural fiber-reinforced composite is eco-friendly [8-10]. There were various drawbacks in using of composites such as material costs, manufacturing difficulties, difficult to repair, inspection and testing more complex and also difficult to achieve required property in required direction [11, 12]. There were various machining processes such as drilling, milling, trimming, grinding, etc. which were used to reduce the raw materials to the desired shape and while machining, it was possible that the properties of the composite may get impaired. Among the different machining operations, drilling was one of the most prominent operations for the joining of composites to structures [13]. It is defined as an operation in which a drill bit is used to make a circular hole in a workpiece. While drilling, the fiber particles come in contact with the drill bit in an intermittent fashion, thus causing delamination of the composite material. Factors such as material thickness, drill bit diameter, spindle speed, feed rate, thrust force, torque and several other factors play a pivotal role in the drilling of reinforced composites. [14, 15]

The epoxy resin was most demanding matrix material, which is used during the preparation of composites. Epoxy was a thermosetting polymer that possesses unique mechanical and resistance properties. Epoxy resins were first commercialized in 1946 and are widely used in industry as protective coatings and for structural applications, such as laminates and composites, tooling, molding, casting, bonding and adhesives, and others [16-18]. Nagamadhu et al. also worked on dynamic mechanical analysis of composites and found that bonding strength between epoxy to sisal fabric was better even at higher temperature [12]. Saba et al. worked on thermal and dynamic mechanical properties of cellulose nanofibers reinforced epoxy composites and observed that reinforcement enhanced the thermal and dynamic mechanical properties [19]. Mohan et al. observed the water barrier properties of nano clay filled sisal fiber reinforced epoxy composites and found that mechanical properties are enhanced by adding nano clay [20]. Fiore et al. observed that mechanical properties enhanced with adding Arundo Donax fillers in epoxy [21]. It was found from the literatures that mechanical and thermo-mechanical properties were enhanced by reinforcement. But machining of natural fiber epoxy composite was major limitation due to its processing

parameters. Karthikeyan et al. studied the effect of drilling process parameters of natural fiber chaired epoxy composite with polyurethane foam as core material [22]. These literatures revels that need to understand the effect of drilling process parameters on sisal fabric reinforced composites.

Taguchi technique method was implemented for the design of systems with improved quality [23, 24]. With the help of Taguchi technique, the performance characteristics can be optimized for the sensitivity of the source of the design parameters [25]. This technique can be used to improve the quality of the hole produced. The drilling processes are analyzed using statistical techniques in order to determine the effect of thrust force and torque on the geometry of the bit. Ranking and finding the most optimal solution for the problem is done using this technique.

Grey relation finds its use in different fields. With the help of these method operations with multiple performance characteristics were solved effectively. This method was used to solve problems having limited information. The model made using GRA is able to handle incomplete as well as inaccurate information [26]. It was widely used in real-world applications due to its ability to find the most optimum solution for the designed problem. Management, Engineering and many other domains make use of this method. After careful analysis, it can be said that the quality of the drilled hole depends on parameters such as delamination, torque, thrust force and many more of the drilling process. Since there has been limited research done multi responses using grey relation analysis, hence this paper aims to improve the process parameters like spindle speed, bit diameter and feed rate on drilling of herringbone epoxy composites for the output characteristics like thrust force, torque and delamination.

2. MATERIAL AND METHODS

2.1 Materials

Herringbone woven type fabric shown in Figure 1(a) is prepared from the extracted sisal fiber in M/s. OM Textile Industries, Bangalore the basic properties of which are shown in Table 1. The composite is prepared by first preparing a mixture of ARALDITE LY 556 unfilled non-modified epoxy resin of low viscosity (5000-8000 MPa. s at 20°C) and pot life of ½ to 1 hours (at 20°C) and hardener HY 951 in the ratio 10:1. Once the mixture is ready it is stirred using a conventional stirrer at 50rpm to prepare the composite. The Araldite resin LY 556 with hardener HY 951 is supplied by M/s. Zenith Industrial Suppliers, Bangalore shown in Figure 1(a).

The Yarn crimp of Herringbone woven fabrics measured according to ASTM: D3883. Yarn size (linear density, yarn count) measured according to ASTM: D1907. Fabric density (number of yarns) measured according to ASTM: D3775, fabric weight (GSM) according to ASTM: D3776 and fabric thickness measured as per ASTM: D1777.

2.2 Composite fabrication

Epoxy composites are prepared using herringbone type sisal fabrics by maintaining suitable orientation with warp and weft directions 60% weight fraction of fiber. The resin is mixed with nearly 100ml of HY 951 hardener for about 5 min. Convectional compression molding technique is used to make the composite sheets shown in Figure 1(b). The trapped air bubbles are carefully removed with the help of a roller after which the mold is closed. It is then cured at room temperature for 8 hours and then post cured at 80°C for 4 hours Figure 1(b).

Table 1. Textile properties of fabric

Sl. No	Woven type	Fabric Thickness in mm	GSM	Cover factor (%)		Yarn Count in Tex		Number of yarns per cm	
				Warp (P)	Weft (T)	Warp (P)	Weft (T)	Warp (P)	Weft (T)
1	Herringbone (SH)	1.43	402	88.6	93.8	242.1	273.1	11	12
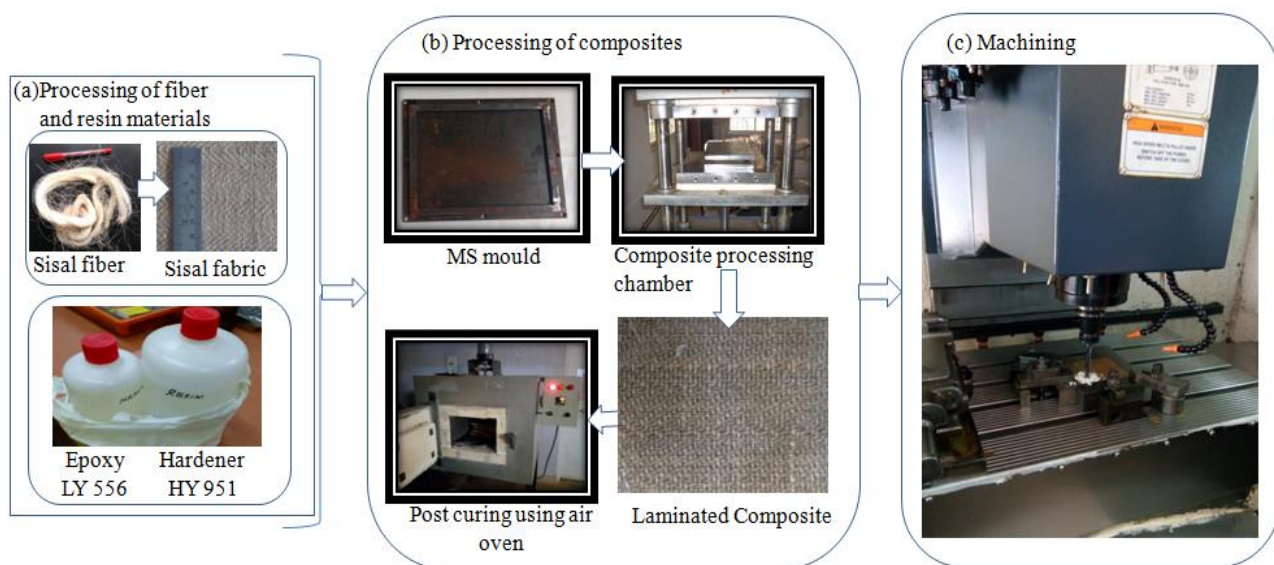
Figure 1. Schematic of processing of composites

3. DRILLING OF COMPOSITE SPECIMEN

The prepared herringbone epoxy composite is machined using VMC drilling machine by varying process parameters shown in Figure 1(c). To minimize the defects due to vibrations during machining the composite should be properly clamped using suitable fixtures. All precautions must be taken such as proper clamping, suitable coolant etc. to avoid the loss of properties of the composite. The VMC is programmed to follow a particular path by considering drilling bit diameter. A high-speed steel twist drill of a specific diameter is used and the composite material is subjected to drilling. Parameters such as drill diameter, spindle speed and feed rate are varied during its operation and it is tabulated in the Table 2 [27, 28].

Table 2. Levels of operational parameters

Levels	Spindle speed (RPM)	Feed rate (mm/min)	Drill diameter(mm)
Lowest	450	30	4
Lower	852	40	6
Medium	1260	50	8
Higher	1860	60	10
Highest	2700	70	12

The torque and thrust force are noted from the VMC controller. The delamination measured at the entry as well as the exit of the drilled hole, as it is a one of the important and significant characteristics. The extent of delamination of the composite directly relays the quality hole. At the entry delamination occurs due to the peeling action whereas at the exit it is due to push out action of the drill bit. The delamination factor plays an important role in the process and it can be found as

$$F_d = D_{max}/D_o \qquad (1)$$

where,
D_{max} = Affected zone of maximum diameter;
D_o = Drilled hole diameter of Actual size.

The parameters such as bit diameter, spindle speed and feed rate are varied. Five different values are considered for the study. The factors with their corresponding values for different variations is tabulated. The torque and thrust force acting on the drill bit is evaluated. The process is then optimized using Taguchi's technique using Minitab 18.

In composite materials the input parameters should be chosen optimally since it affects the machining and geometrical characteristics of drilling operation. Grey relation theory has an easier computing technique and less processing time compared to other optimizing techniques. Using grey relation technique, the responses can be understood effectively in a problem. It provides significant data about the relationship among the sequences. With minimum data the relationship with the sequences can be studied. The results of the experiments based on Taguchi's L_{25} orthogonal array is shown in Table 3.

To optimize several parameters using Grey relation technique, the following steps are stated below [28].
1. The sequence of performance characteristics is preprocessed.
2. From the preprocessed data deviation sequences are evaluated.
3. Grey relation co-efficient is obtained from the deviational sequence data.
4. The average Grey relation co-efficient.
5. ANOVA analysis for GRG values.

During the Grey relation technique, the variation in multiple output characteristics are preprocessed to a comparable data within 0-1. After the analysis the output parameters such as thrust force, delamination and torque are standardized by using given formula shown in Eq. (2).

Table 3. Taguchi L_{25} orthogonal array

Sl no	Spindle speed (rpm)	Feed rate (mm/min)	Drill diameter (mm)	Delamination factor (Fd) Entry	Delamination factor (Fd) Exit	Thrust force (N)	Torque (N-m)
1	450	30	4	1.003	1.010	453.06	1.10
2	450	40	6	1.008	0.998	604.08	2.20
3	450	50	8	1.006	1.000	339.80	1.65
4	450	60	10	1.005	0.999	271.84	1.65
5	450	70	12	1.009	1.013	302.04	2.20
6	852	30	6	1.017	0.997	239.29	0.87
7	852	40	8	1.004	0.999	239.29	1.16
8	852	50	10	1.009	1.001	191.43	1.16
9	852	60	12	1.012	1.012	159.53	1.16
10	852	70	4	1.008	1.015	358.94	0.87
11	1260	30	8	1.000	1.000	323.62	1.57
12	1260	40	10	1.010	1.000	258.89	1.57
13	1260	50	12	1.004	1.009	242.71	1.77
14	1260	60	4	1.005	1.010	728.13	1.77
15	1260	70	6	1.013	1.000	431.49	1.57
16	1860	30	10	1.006	0.999	175.38	1.06
17	1860	40	12	1.008	1.011	146.15	1.06
18	1860	50	4	1.005	1.013	438.45	1.06
19	1860	60	6	1.008	0.998	292.30	1.06
20	1860	70	8	1.005	1.001	219.22	1.06
21	2700	30	12	1.034	1.017	88.10	0.64
22	2700	40	4	1.010	1.003	264.29	0.64
23	2700	50	6	1.007	1.002	176.19	0.64
24	2700	60	8	1.003	1.000	132.14	0.64
25	2700	70	10	1.011	1.002	120.82	0.73

Table 4. Sequence of performance for Normalizing of data

Sl no	Normalizing/preprocessing				Deviation sequence data			
	Thrust force	Torque	Delamination		Thrust force	Torque	Delamination	
			Entry	Exit			Entry	Exit
1	0.43	0.71	0.93	0.33	0.57	0.29	0.07	0.67
2	0.19	0.00	0.76	0.92	0.81	1.00	0.24	0.08
3	0.61	0.35	0.82	0.83	0.39	0.65	0.18	0.17
4	0.71	0.35	0.85	0.88	0.29	0.65	0.15	0.12
5	0.67	0.00	0.73	0.21	0.33	1.00	0.27	0.79
6	0.76	0.85	0.51	1.00	0.24	0.15	0.49	0.00
7	0.76	0.67	0.89	0.90	0.24	0.33	0.11	0.10
8	0.84	0.67	0.74	0.78	0.16	0.33	0.26	0.22
9	0.89	0.67	0.66	0.25	0.11	0.33	0.34	0.75
10	0.58	0.85	0.78	0.08	0.42	0.15	0.22	0.92
11	0.63	0.40	1.00	0.83	0.37	0.60	0.00	0.17
12	0.73	0.40	0.71	0.83	0.27	0.60	0.29	0.17
13	0.76	0.28	0.88	0.38	0.24	0.72	0.12	0.62
14	0.00	0.28	0.85	0.33	1.00	0.72	0.15	0.67
15	0.46	0.40	0.61	0.83	0.54	0.60	0.39	0.17
16	0.86	0.73	0.82	0.88	0.14	0.27	0.18	0.12
17	0.91	0.73	0.78	0.29	0.09	0.27	0.22	0.71
18	0.45	0.73	0.85	0.21	0.55	0.27	0.15	0.79
19	0.68	0.73	0.76	0.92	0.32	0.27	0.24	0.08
20	0.80	0.73	0.85	0.77	0.20	0.27	0.15	0.23
21	1.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00
22	0.72	1.00	0.71	0.71	0.28	0.00	0.29	0.29
23	0.86	1.00	0.80	0.75	0.14	0.00	0.20	0.25
24	0.93	1.00	0.93	0.83	0.07	0.00	0.07	0.17
25	0.95	0.94	0.68	0.73	0.05	0.06	0.32	0.27

Table 5. Calculated Grey relational coefficient, grade and rank

Sl no	Grey relational coefficient				Grey Relational Grade	Rank/order
	Thrust force	Torque	Delamination			
			Entry	Exit		
1	0.467	0.630	0.872	0.429	0.599	18
2	0.383	0.333	0.672	0.857	0.561	23
3	0.560	0.436	0.732	0.750	0.619	16
4	0.635	0.436	0.774	0.811	0.664	13
5	0.599	0.333	0.651	0.387	0.493	24
6	0.679	0.772	0.506	1.000	0.739	5
7	0.679	0.600	0.820	0.828	0.732	6
8	0.756	0.600	0.655	0.698	0.677	11
9	0.818	0.600	0.594	0.400	0.603	17
10	0.542	0.772	0.695	0.353	0.590	19
11	0.576	0.456	1.000	0.750	0.695	10
12	0.652	0.456	0.631	0.750	0.622	15
13	0.674	0.409	0.804	0.444	0.583	20
14	0.333	0.409	0.774	0.429	0.486	25
15	0.482	0.456	0.562	0.750	0.562	22
16	0.786	0.648	0.740	0.811	0.746	4
17	0.846	0.648	0.695	0.414	0.651	14
18	0.477	0.648	0.774	0.387	0.572	21
19	0.610	0.648	0.672	0.857	0.697	9
20	0.709	0.648	0.774	0.686	0.704	8
21	1.000	1.000	0.333	0.333	0.667	12
22	0.645	1.000	0.631	0.632	0.727	7
23	0.784	1.000	0.719	0.667	0.793	2
24	0.879	1.000	0.872	0.750	0.875	1
25	0.907	0.895	0.608	0.652	0.766	3

$$y_i^*(p) = \frac{maxy_i^0(p) - y_i^0(p)}{maxy_i^0(p) - miny_i^0(p)} \qquad (2)$$

where,

$y_i^0(p)$ = Sequence of original value;

$y_i^*(p)$ = the sequence value after data-preprocessing;

$maxy_i^*(p)$ = the maximum value of $y_i^0(p)$;

$miny_i^*(p)$ = the maximum value of $y_i^0(p)$;

y^0 = the desired value.

Eq. (2) shows the original responses for "lesser-the better" characteristics are preprocessed and tabulated in Table 4. The variation of sequence data can be calculated from the preprocessed data to a comparable value within 0-1. Δ_{max} is considered as 1 and Δ_{min} is considered as 0. The Grey coefficient ξ(p) can be determined by the below mentioned equation:

$$\xi(p) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{oi}(p) + \xi\Delta_{max}} \quad (3)$$

where,

Δ_{oi} = The absolute difference between $y_i^0(p)$ and $y_i^*(p)$, in other words called as deviation sequence. ξ coefficient used, if the ξ has a larger value. But in common the value of ξ is considered as 0.5.

$$\Delta_{oi} = ||y_0^*(p) - y_i^0(p)|| \quad (4)$$

$$\Delta_{min} = \left(\begin{smallmatrix}min\\\forall j \in i\end{smallmatrix}\right)\left(\begin{smallmatrix}min\\\forall p\end{smallmatrix}\right)||y_0^*(p) - y_j^*(p)|| \quad (5)$$

$$\Delta_{max} = \left(\begin{smallmatrix}max\\\forall j \in i\end{smallmatrix}\right)\left(\begin{smallmatrix}max\\\forall p\end{smallmatrix}\right)||y_0^*(p) - y_j^*(p)|| \quad (6)$$

Grey relation grade is the average of grey relational coefficient of each sequence. It is calculated from Eq. (7) as shown below:

$$\gamma_i = \frac{1}{n}\sum_{p=1}^{n}\xi i(p) \quad (7)$$

It is quite possible that the significant factors in the real world may change according to their circumstance of unequal weight for various factors. Hence the GRG value can be calculated using Eq. (8):

$$\gamma_i = \frac{1}{n}\sum_{p=1}^{n} w_p \xi_i(p) \quad (8)$$

where, w_p = normalized weight of factor p, when, w_p is considered as equal for all the factors in the problem. The grey coefficient was determined using the Eq. (3) and GRG value by Eq. (8) and is tabulated in Table 5.

## 4. RESULTS AND DISCUSSION

4.1 Grey regression analysis

The drilling operation was conducted and 25 holes were drilled with varying input process parameters. It was observed that input parameters such as feed rate, spindle speed and drill diameter affected the quality of the drilled hole. By varying the parameters, different values for thrust force and torque were obtained while drilling the specimen. One of the major factors affecting the quality of the drilled hole was the delamination factor which is dependent on the input process parameters. Hence different output values are obtained for the 25 drilled holes having varying input parameters, which are tabulated in Table 3 using Taguchi's L 25 orthogonal array.
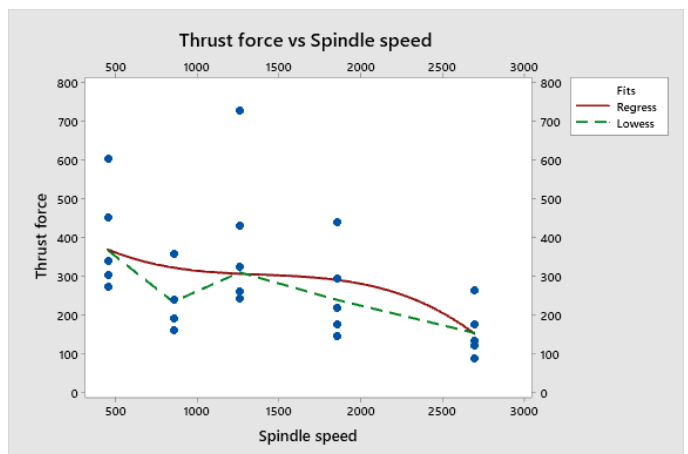
The 25 trials are listed according to their ranks. The grey relation coefficient and grey relation grade was first calculated for all 25 trials by using the values from Table 3 and set of formulas from Eqns. (2)-(8), the values of which have been shown in Table 5. The trial having the greatest grey relational grade is ranked 1. The trial having the second greatest value is ranked 2 and the procedure is followed for all 25 trials.

The value of grey relational grade is higher for trial 24 and the values corresponding to it are the optimal values for improving the quality of the drilled hole. It is found that the maximum value of grey relational grade is 0.875 for which the spindle speed is 2700 rpm, feed rate is 60mm/min and the drill diameter is 8mm. Thus, selecting these optimal input values will reduce the parameters affecting the quality of the drilled hole thereby achieving a drilled hole of improved quality and also enhancing the life of the tool [29].

The influences of input variables on output responses are analyzed and only few graphs are plotted here to show the significance. Figure 2(a) to 2(d) shows the significantly varied input variable and output response. Figure 1(a) shows the variation of delamination factor at exit of hole over a range of drill diameter. It is found that drill diameter is from 6 to 10 mm exhibit lesser defect at exit of the hole. This may due to following (a) drill diameter is less then 6mm and more then 10mm will tears the fiber during drilling and forms delamination as fiber yarns are herringbone pattern [30, 31], (b) gram per square meter of the fabric is high, (c) yarn crimp of the fabric is higher, (d) yarn linear density of the fabric (e) yarn count of the fabric. Figure 2(b) shows the variations of thrust force on spindle speed, found that as spindle speed increased the thrust force decreases. Figure 2(c) variations of thrust force on drill diameter and found that as drill diameter increases thrust force decreases. Figure (d) shows the variations of torque on spindle speed and found as the spindle speed increases torque decreases [32, 33].
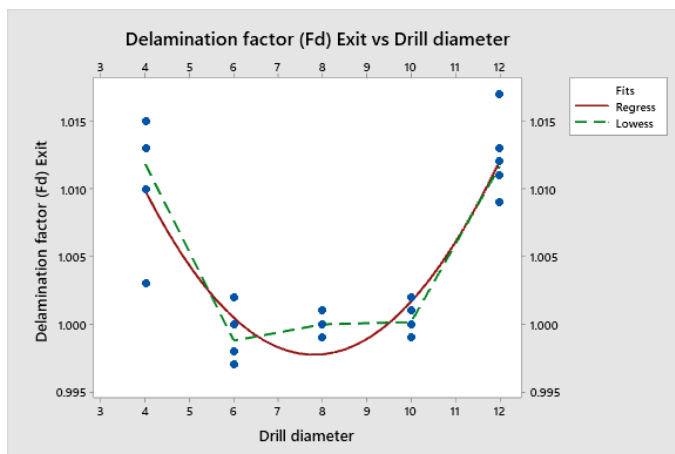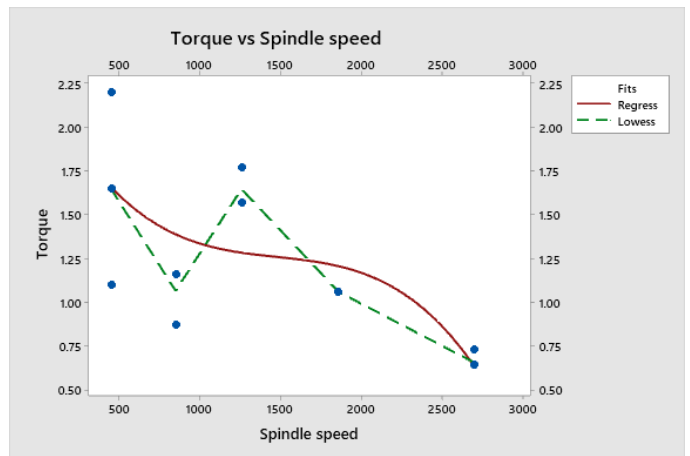

(a) Influence of drill diameter on delamination factor at exit of hole　　　(b) Influence of thrust force on Spindle speed
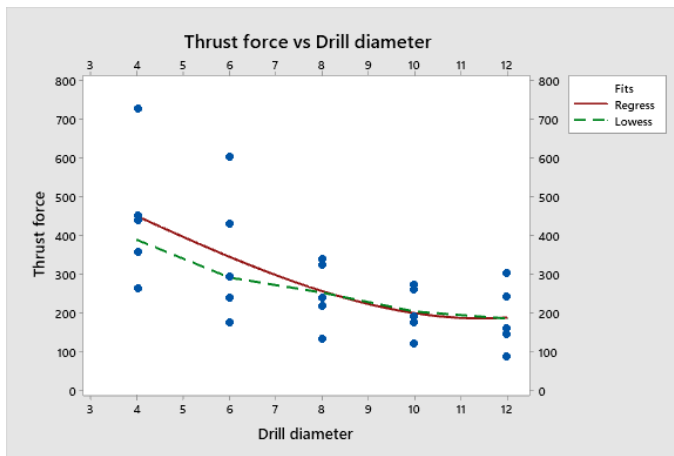
(c) Influence of thrust force on drill diameter

(d) Influence of spindle torque on spindle speed

Figure 2. Influence of operational parameters on drilling performance

5. CONCLUSION

The experiment on drilling of sisal fiber reinforced herringbone epoxy composite material is conducted, the delamination factor is analyzed and the following conclusions are drawn:

1. By varying the cutting parameters, the delamination factor for sisal fiber reinforced herringbone epoxy composite material is observed and analyzed.
2. The result obtained indicates that the value of output characteristics decreases with increasing spindle speed, increasing feed rate and selecting a slightly larger drill bit diameter.
3. The optimum drill diameter was found from 6mm to 10mm to reduce the delamination at both entrance and exit of the hole
4. The decrease of drill diameter increases the delamination due to the increase of Thrust Force developed on the drill bit during drilling. Thus, it is suggested to use a slightly bigger drill bit for this fiber.
5. The spindle speed is having only limited effect on drilling of sisal fiber reinforced chaired epoxy composite materials in which higher spindle speed is preferred to reduce the delamination.

Hence, from the entire experiment, it is found that spindle speed of 2700 rpm, feed rate of 60mm/min and drill diameter of 8mm are the optimal values for the drilling of sisal fiber reinforced herringbone epoxy composite material.

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