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A central composite design based fuzzy logic for optimization of drilling parameters on natural fiber reinforced composite †

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Abstract

Machining of polymeric composite is inevitable during assembly of components. In view of making holes on structural composites, drilling is essential and a study to optimize the machining parameters is very important. The present study has been made to investigate the defaces and cutting forces associated during drilling of natural fiber reinforced plastics. Plastic composite has been manufactured using chemically treated *vetiveria zizanioides* as the reinforcement and polyester as the matrix. The composite has been drilled several times on the basis of central composite design. Speed and feed rate of the spindle, point angle and diameter of the tool are considered as the input parameters. Deface of each hole during entry and exit, thrust force and torque have been measured as the output parameters. A fuzzy model has been created and a comparative study between the central composite design and fuzzy model is made. The design has been optimized with the objective of minimizing the output parameters and a set of confirmatory experiments have been conducted. The central composite model has been validated by comparing it with the fuzzy model and confirmatory runs. The comparison presented only a minimal error and hence the modeling by central composite design and fuzzy are consummate.

Keywords: Central composite design; Fuzzy; Delamination; Thrust force; Torque; Optimization

1. Introduction

Fiber reinforced plastics is a classification of composite material which are primarily aimed to work as structural components. These composites may be custom made to the requirements of users as their characteristics have been decided well in advance. In earlier stages, fiber reinforced plastics have been fabricated using man-made reinforcements like carbon, glass, aramid etc. Nowadays, man-made reinforcements are completely replaced by bio-materials in order to enhance the mechanical characteristics and to cope with the bio-degradability [1, 2]. Composites are fabricated by different methods like hand layup, compression moulding, filament winding, etc. Composite after fabrication requires machining for achieving the dimensional accuracy and thus assist for assembly of components [3].

Drilling is inevitable during assembly of structural components. Drilling induces thrust force in the machining region and also the inner wall surface roughness get affected during hole making. A research work reported that, the feed rate of the spindle and diameter of the drill has more influence on the thrust force. On the other hand, feed rate and speed of the spindle dominantly affects the wall roughness [4]. Drilling ability depends not only on the drilling parameters, but also depends upon the selection of matrix and reinforcement materials. The forces induced during drilling a thermoplastic composite material will be smaller than that of the thermoset composite material [5]. In the same way, a thermoplastic composite develops continuous chips and a thermoset composite develops discontinuous chips during hole making [6].

During the process of hole making, the region around the hole at the top and bottom surface of the composite is subjected to damage. The damage is otherwise called as delamination or deface. Among the various drilling parameters, the spindle rotational speed and feed rate plays a vital role in deciding the hole defaces [7]. The quantum of hole deface depends on the magnitude of the thrust force developed during drilling [8]. Machinability studies on composite made of artificial reinforcements has been extensively done by many researchers. The present day research works are focused on natural fiber reinforced composites. The composites once manufactured are subjected to testing of its characteristics and followed by machining studies [9]. Although many natural reinforcements are utilized in the recent past, there is always

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Table 1. Composite properties.

Property	Value
Tensile strength (MPa)	35.17
Flexural strength (MPa)	58.92
Compressive strength (MPa)	45.23
Impact energy (J)	4
Strain at break (%)	7.5

a need develop new composite which may give improved performance during mechanical testing and machining.

The present research is focused on development of new composites by using chemically treated *vetiveria zizanioides* as the reinforcement and polyester as the matrix resin. The characteristics of this composite have been tested and drilling analysis is carried out on the basis of central composite design. Although there are several output parameters like deface, thrust force, torque, surface roughness, metal removal rate, temperature etc., the hole deface at the entrance and exit, thrust force and torque have been majorly concentrated in majority of the research studies [10-12]. The reason being that, the ease of drilling a hole depends on the finish of the hole profile. When the hole profile is made without any damage, then the hole making process is said to be accurate. Also, the thrust force and torque plays a vital role in deciding the deface produced during hole making. Hence, the deface of hole at the entrance and exit, thrust force and torque are considered as output parameters in this study and the inner wall roughness has been investigated using surface morphology study. A fuzzy model has been created and used as a comparison tool for central composite design. The machining conditions have been optimized and confirmatory trials are conducted for validation.

2. Experimental methods

2.1 Composite fabrication and testing

Vetiveria zizanioides (vetiver) roots have been supplied by a local vendor. The fiber has been washed in distilled water and treated with benzoyl chloride solution for 3 hours. The fiber is then dried in sunlight and heated in furnace at 50 °C for an hour. During this treatment, the undesirable celluloses are removed and the surface roughness of the fiber gets elevated. Thus it improves the adhesive bonding of fibers with the matrix [13]. Composite has been fabricated using compression moulding method during which, a fiber to resin composition of 25:75 by weight has been maintained. The composite has been made in the form of a square plate of side 300 mm and with a thickness of 5 mm. Mechanical properties have been tested according to ASTM standards as presented in Table 1.

2.2 Experimental setup

Holes have been drilled on the composite using a vertical machining center of Bharat Frietz Werner make. The center has a maximum speed of 6000 rpm and a tool traverse of 510 mm x 410 mm x 46 mm. The composite has been cut in the size of 100 mm x 50 mm in order to accommodate easily in the vice. The machining setup has been presented in the Fig. 1. A set of three HSS 8 mm drill, 10 mm drill and 12 mm drills have been purchased and their point angles are modified to 60°, 90° and 120° in each of the 8 mm, 10 mm and 12 mm tools. The input factors and levels are presented in Table 2. The largest damaged diameter of the each hole at entrance and exit have been measured using a Mitutoyo tool makers microscope. The output factors namely, entrance deface (D_i) and exit deface (D_o) are calculated by using the formula [7, 10] presented in Eq. (1).

Table 2. Input factors.

S. No.	Factors	Level 1	Level 2	Level 3
1	Speed N (rpm)	1000	2000	3000
2	Feed f (mm/rev)	0.2	0.4	0.6
3	Point angle θ (degree)	60	90	120
4	Tool diameter d (mm)	8	10	12

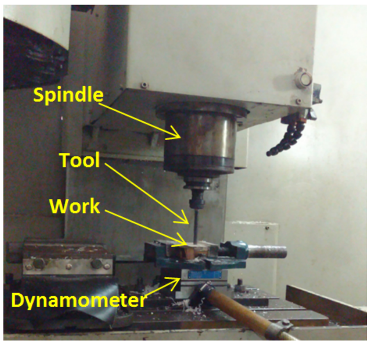

Fig. 1. Schematic of machining zone.

$$Deface = \frac{d_{max}}{d} \tag{1}$$

where d_{max} denotes the largest diameter of damaged hole and d denotes the nominal diameter. The thrust force and torque have been recorded by using a Kistler make dynamometer which has been placed in between the table and vice as shown in the Fig. 1.

3. Statistical design and fuzzy modeling

3.1 Central composite design

Central composite design (CCD) is a method of response surface analysis which has been built on the basis of two level factorial designs with addition of few central and star points [14]. This analysis helps to model and optimize the output responses whose behavior depends upon the multiple independent variables [15]. Its gives three dimensional surface

Table 3. Experimental trials and comparison.

Trial No.	Speed	Feed	Point angle	Tool size	Experimental				Fuzzy				Regression			
					D_i	D_o	F_t	T	D_i	D_o	F_t	T	D_i	D_o	F_t	T
1	1000	0.2	60	8	1.02	1.15	62	5.5	1.02	1.14	63	5.8	1.02	1.16	64	5.7
2	3000	0.2	60	8	1.03	1.03	89	5.89	1.03	1.03	88	6.0	1.02	1.03	90	5.9
3	1000	0.6	60	8	1.1	1.2	73	6.67	1.1	1.2	73	6.58	1.1	1.22	74	6.75
4	3000	0.6	60	8	1.09	1.04	95	7.14	1.08	1.04	96	7.0	1.1	1.03	95	7.23
5	1000	0.2	120	8	1.07	1.19	63	5.7	1.07	1.17	65	5.9	1.07	1.19	64	5.88
6	3000	0.2	120	8	1.06	1.04	96	7.11	1.04	1.04	94	7.0	1.07	1.05	97	7.2
7	1000	0.6	120	8	1.14	1.21	75	6.68	1.13	1.2	75	6.51	1.15	1.23	75	6.7
8	3000	0.6	120	8	1.15	1.08	98	7.15	1.15	1.08	96	7.28	1.14	1.076	97	7.18
9	1000	0.2	60	12	1.02	1.12	64	5.53	1.02	1.1	65	5.5	1.03	1.12	63	5.57
10	3000	0.2	60	12	1.03	1.02	91	5.88	1.03	1.02	90	5.7	1.03	1.02	90	5.79
11	1000	0.6	60	12	1.1	1.2	74	6.68	1.1	1.2	77	6.78	1.1	1.2	76	6.63
12	3000	0.6	60	12	1.11	1.04	97	7.13	1.11	1.04	94	7.16	1.1	1.04	98	7.09
13	1000	0.2	120	12	1.07	1.18	65	5.7	1.07	1.18	64	5.7	1.06	1.2	67	5.6
14	3000	0.2	120	12	1.03	1.02	98	7.12	1.04	1.02	100	7.01	1.06	1.02	96	7.1
15	1000	0.6	120	12	1.12	1.21	77	6.67	1.12	1.18	76	6.57	1.13	1.2	75	6.58
16	3000	0.6	120	12	1.13	1.08	100	7.15	1.09	1.07	98	7.02	1.13	1.08	99	7.18
17	1000	0.4	90	10	1.09	1.19	66	6.5	1.09	1.1	66	6.6	1.09	1.19	67	6.8
18	3000	0.4	90	10	1.09	1.05	92	6.77	1.09	1.05	92	6.9	1.09	1.04	90	6.58
19	2000	0.2	90	10	1.05	1.06	82	5.67	1.06	1.07	84	5.48	1.05	1.08	83	5.78
20	2000	0.6	90	10	1.13	1.1	89	7.13	1.09	1.11	90	7.03	1.12	1.1	88	7.06
21	2000	0.4	60	10	1.07	1.08	83	6.77	1.09	1.12	80	7.4	1.061.	1.08	82	6.7
22	2000	0.4	120	10	1.1	1.09	86	6.73	1.09	1.09	85	6.72	1.1	1.09	87	6.8
23	2000	0.4	90	8	1.09	1.08	84	6.8	1.09	1.08	83	6.9	1.09	1.08	85	6.7
24	2000	0.4	90	12	1.09	1.09	84	6.8	1.09	1.09	83	6.7	1.08	1.09	85	6.8
25	2000	0.4	90	10	1.09	1.1	84	6.8	1.08	1.09	83	6.7	1.09	1.08	83	6.7
26	2000	0.4	90	10	1.08	1.09	84	6.8	1.08	1.09	83	6.7	1.09	1.08	83	6.7
27	2000	0.4	90	10	1.09	1.09	84	6.8	1.08	1.09	83	6.7	1.09	1.08	83	6.7
28	2000	0.4	90	10	1.08	1.08	84	6.8	1.08	1.09	83	6.7	1.09	1.08	83	6.7
29	2000	0.4	90	10	1.09	1.09	84	6.8	1.08	1.09	83	6.7	1.09	1.08	83	6.7
30	2000	0.4	90	10	1.08	1.07	84	6.8	1.08	1.09	83	6.7	1.09	1.08	83	6.7

% Error b/w Exp and fuzzy: D_i = 0.35, D_o = 0.29, F_t = 0.38, T = 0.075; % Error b/w Exp and Regression: D_i = -3.46, D_o = -2.36, F_t = 0.72, T = 1.2

plots and contour plots through which, the relationship between the output and input factors could be analyzed effectively. It also gives regression equations through which, response prediction could be effectively done for any input value [16]. A general form of regression equation has been presented in Eq. (2).

$$z = a_0 + a_1 y_1 + a_2 y_2 + a_3 y_3 + a_{12} y_1 y_2 + a_{13} y_1 y_3 + a_{23} y_2 y_3 + a_{11} y_1^2 + a_{23} y_2^2 + a_{133} y_3^2 \quad (2)$$

where z denotes the output response, y_1, y_2 etc denotes the input variables, a_0, a_1, etc denotes the constants. Among the CCD types, the present study uses face centered CCD in which the star points are located at the center of all faces of the factorial space, hence $\alpha = \pm 1$. The advantage of using this method is that, it will minimize the number of trials thus reduces the experimentation time and cost. The present investigation uses four input factors viz., spindle speed, spindle feed rate, point angle and tool diameter each at 3 levels. Hence, this design will be a 3^4 central composite design containing 30 trial runs as listed in Table 3. The drilling experiments have been conducted and the entrance and exit defaces are measured for the 30 runs.

3.2 Fuzzy modeling

Fuzzy logic was first evolved during the mid-1960 s. It is used to model the problems containing imprecise data or problems in which the inference rules are made in a general way to make use of the diffuse categories hence it is also known as diffuse logic. Fuzzy logic does not take only two alternatives,

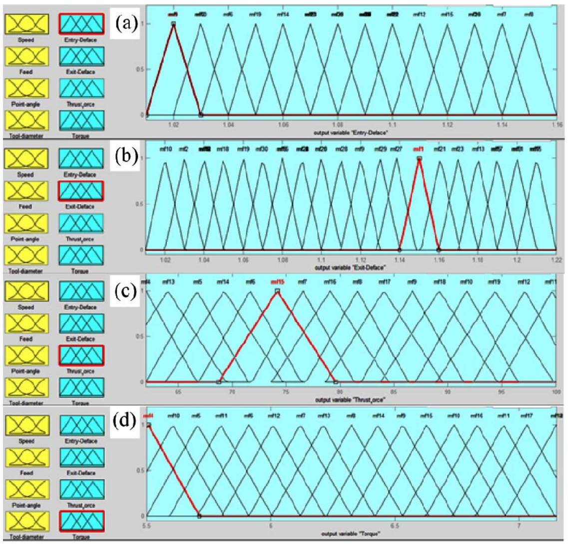

Fig. 2. Membership definitions: (a) D_i; (b) D_0; (c) F_t; (d) T.

instead it considers the whole metric space of truth values for logical propositions. This system permits the middle values to ascertain between conventional logics like, high or low, yes or no and true or false etc. [17]. There are three stages in fuzzy modeling. The first stage is the fuzzification process during which, each factor is treated as a well-defined numeric value. This is done with the help of membership definitions. A triangular membership function takes has been used to define the factors by assigning three numerical values. The second stage of fuzzy is the rule framing process. During this process rules are framed by with a combination of input parameters using logical operators like 'AND' and 'OR'. In the third stage of fuzzy, the outputs of the framed rules are consolidated [18]. Finally, all the membership degrees are made in to a quantifiable value. This process is known as the defuzzification. The membership definitions for output factors are presented in Fig. 2. The fuzzy predictions for all 30 runs have been noted as shown in the Table 3. The difference between the experimental value and fuzzy value has been measured as an average error percentage. It has been observed that the error is only 0.35 % and 0.29 % respectively for entrance and exit deface hence, the fuzzy predictions closely follows the experimental ones.

4. Discussions

The influence of different factor on the output is analyzed using ANOVA study as presented in Table 4. The significance of the model is studied by comparing the model, lack of fit and the pure error. Another way of doing this is by observing the closeness of R^2 and adjusted R^2 to unity. Always the model should be adequate for predicting the responses and this is analyzed by the value of adequate precision (AP). A value greater than 4 indicates that the model is highly adequate. In the present analysis, R^2 and adjusted R^2 are 0.955 and 0.948 for entry deface. In the same way, they are 0.91 and 0.895 for exit deface, 0.997 and 0.994 for thrust force and 0.923 and 0.86 for torque. All these values are very closer. The AP values of 37.12, 26.047, 40.426 and 15.479 for entry deface, exit deface, thrust force and torque respectively are well above 4. Considering the entry deface, the F-value of 132.82 for the model and 2.13 for lack of fit confirms that the model is sig-

Table 4. ANOVA study for responses.

Source	Sum of squares	Degree of freedom	Mean square	F-value	p-value
Entry deface (D_i)	$R^2 = 0.955$, Adj $R^2 = 0.948$, AP = 37.12				
Model	0.03	4	0.007	132.82	< 0.0001
Speed-N	2.22E-5	1	2.22E-5	0.39	0.5381
Feed-f	0.024	1	0.024	424.4	< 0.0001
Angle-θ	0.00605	1	0.00605	106.1	< 0.0001
Tool dia-d	2.22E-5	1	2.22E-5	0.39	0.5381
Residual	0.0014	25	5.7E-5	-	-
Lack of fit	0.00127	20	6.38E-5	2.13	0.206
Pure error	1.5E-4	5	3E-5	-	-
Total	0.032	29	-	-	-
Exit deface (D_o)	$R^2 = 0.91$, Adj $R^2 = 0.895$, AP = 26.047				
Model	0.093	4	0.023	63.16	< 0.0001
Speed-N	0.084	1	0.084	227.38	< 0.0001
Feed-f	0.00605	1	0.00605	16.37	0.0004
Angle- θ	0.0032	1	0.0032	8.66	0.0069
Tool dia-d	8.9E-5	1	8.9E-5	0.24	0.628
Residual	0.0092	25	3.69E-4	-	-
Lack of fit	0.0087	20	4.35E-4	4.08	0.0625
Pure error	5.33E-4	5	1.06E-4	-	-
Total	0.1	29	-	-	-
Thrust force (F_t)	$R^2 = 0.96$, Adj $R^2 = 0.955$, AP = 40.426				
Model	3439.89	4	859.97	154.88	< 0.0001
Speed-N	3120.5	1	3120.5	562.00	< 0.0001
Feed-f	256.89	1	256.89	46.27	< 0.0001
Angle-θ	50.00	1	50.00	9.01	0.006
Tool dia-d	12.50	1	12.50	2.25	0.146
Residual	138.81	25	5.55	-	-
Lack of fit	138.81	20	6.94	-	-
Pure error	0.00	5	0.00	-	-
Total	3587.70	29	-	-	-
Torque (T)	$R^2 = 0.735$, Adj $R^2 = 0.692$, AP = 15.479				
Model	6.08	4	1.52	17.32	< 0.0001
Speed-N	1.81	1	1.81	20.64	0.0001
Feed-f	3.83	1	3.83	43.60	< 0.0001
Angle- θ	0.44	1	0.44	5.03	0.034
Tool dia-d	2.22E-5	1	2.22E-5	2.53E-4	0.9874
Residual	2.19	25	0.088	-	-
Lack of fit	2.19	20	0.11	-	-
Pure error	0.00	5	0.00	-	-
Total	8.27	29	-	-	-

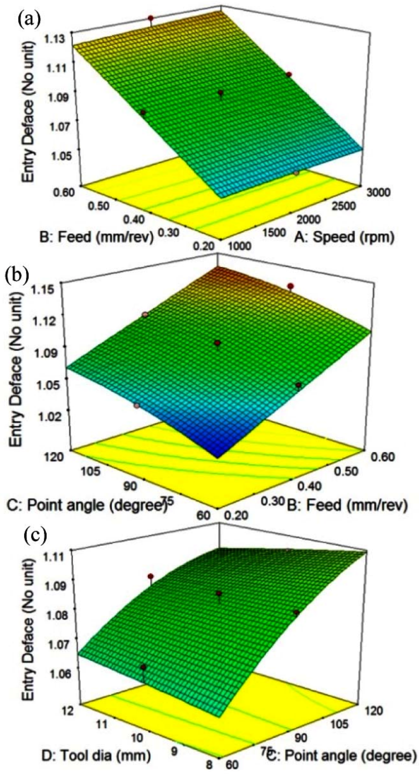

Fig. 3. Response plot: (a) N & f V D_i; (b) f & eV D_i; (c) e & d V D_i.

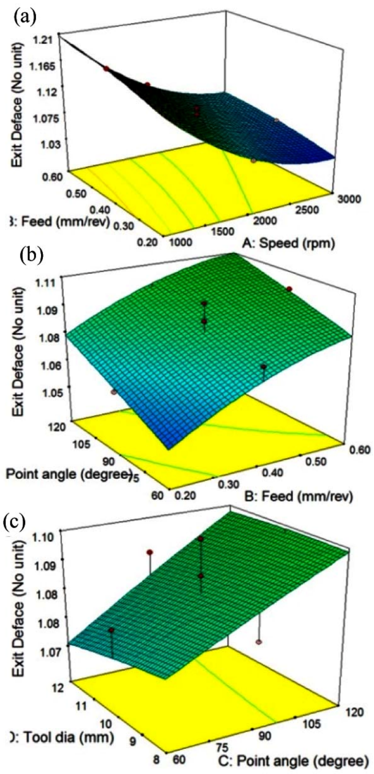

Fig. 4. Response plot: (a) N & f V D_0; (b) f & eV D_0; (c) e & d V D_0.

nificant and the lack of fit is insignificant with respect to pure error. In the same way, models are significant and the lack of fit is insignificant for all the output responses as seen from Table 4.

4.1 Entry deface

Among the input factors, speed and tool diameter does not have any influence on the entry deface. This is known from the p-value of the ANOVA study. A p-value less than 0.05 denote highly influencing factors. Feed and point angle plays a dominant influence on the entry deface. Speed and tool diameter have no influence on the entry deface. The response surface plot of entry deface are presented in Fig. 3. Variation in speed does not causes any change in the entry deface whereas with the elevation of feed rate, the entry deface increases tremendously. Increase in the feed rate practically denotes the increase in the velocity of tool penetrating the work surface. As the penetrating velocity increases, the damage of the profile also increases thus increasing the entry deface [19]. As the point angle is elevated, the entry deface goes up notably. This is because, as the point angle increases, the contact of the cutting edge with the work surface also increases and thus during tool rotation the tool tries to remove more material. This elevates the torque requirement and increases the hole damage. With the hike in the tool diameter, there is no notable change in the entry deface as seen from Fig. 3(c). Hence, the tool size does not affect the damage of the hole. The regression equation for entry deface is presented in Eq. (3).

$$\begin{aligned} D_i = {} & 0.84 - 2.84X10^{-6}N + 0.226f + 2.46X10^{-3}\theta + \\ & 6.39X10^{-3}d + 6.25X10^{-6}Nf - 4.17X10^{-8}N\theta + \\ & 6.25X10^{-7}Nd - 2.08X10^{-4}f\theta - 3.13X10^{-3}fd - \\ & 6.25X10^{-5}\theta d - 2.63X10^{-10}N^2 - 6.587X10^{-3}f^2 - \\ & 5.85X10^{-6}\theta^2 - 6.58X10^{-5}d^2 \ . \end{aligned} \tag{3}$$

4.2 Exit deface

Among the input factors, speed, feed and point angle predominantly affects the exit deface. Tool diameter does not affects the exit deface. Unlike the entry deface, the spindle speed has a dominant influence on the exit deface. An elevation in speed decreases the exit deface as seen from Fig. 4(a). This happens because, as the drill tool reaches near the bottom surface at high speed, the torque required to remove the material gets decreased. This reduces the damage and hence declines the exit deface. The elevation of feed tremendously increases the exit deface and this is similar to the trend observed with entry deface. The reason being that, as the tool moves with an increased velocity near the exit surface, it damages the skin layer of the composite thus elevating the exit deface. As the point angle goes up, the exit deface increases and this behavior is similar to that of the entry deface and happens due to the same reason. A hike in the tool diameter declines the exit deface as seen from Fig. 4(c). This behavior

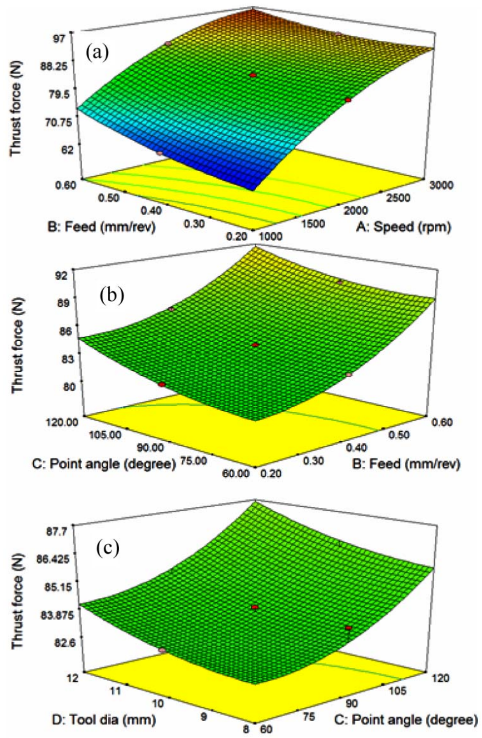

Fig. 5. Response plot: (a) N & f V F_t; (b) f & e V F_t; (c) e & d V F_t.

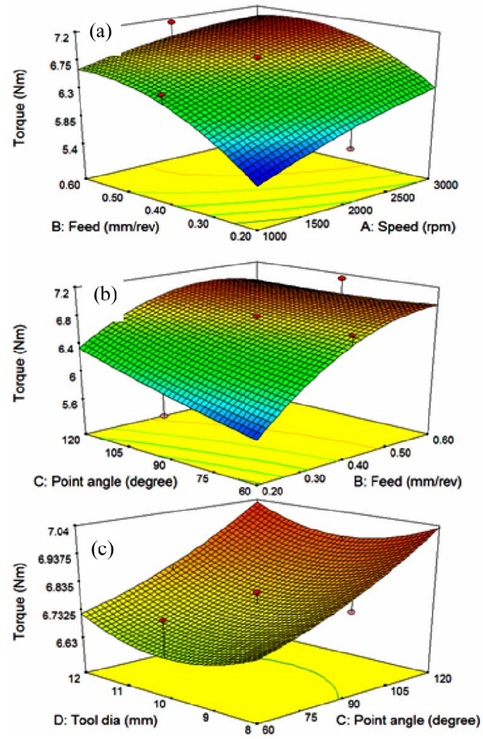

Fig. 6. Response plot: (a) N & f V T; (b) f & e V T; (c) e & d V T.

is not observed with the entry deface where, the change in tool diameter does not affects the deface. The regression equation for exit deface is presented in Eq. (4).

$$\begin{aligned} D_0 = {} & 1.3 - 2.05X10^{-4}N + 0.19f + 3.86X10^{-4}\theta - \\ & 6.73X10^{-3}d - 2.19X10^{-5}Nf - 2.08X10^{-8}N\theta + \\ & 9.38X10^{-7}Nd - 3.13X10^{-4}f\theta + 7.81X10^{-3}fd + \\ & 3.13X10^{-5}\theta d + 3.46X10^{-8}N^2 - 0.14f^2 - \\ & 4.87X10^{-7}\theta^2 - 1.09X10^{-4}d^2 \,. \end{aligned} \tag{4}$$

4.3 Thrust force

It has been noticed that, among the input factors speed, feed rate and point angle significantly affects the thrust force whereas the tool diameter does not affects the thrust force. An elevation in the spindle speed increases the thrust force to a greater extent as shown in Fig. 5. This behavior is quite different from a previous research on drilling of hybrid composites which concluded that, an elevation in speed has no effect on the thrust force [9]. Hence, all natural fiber composites do not behave in a similar way and the machinability directly depends on the property of reinforcement present in the composite. A hike in the feed rate also elevates the thrust force because, as the rate at which the tool enters the work elevates it increases the axial force developed and hence the thrust force. As the point angle is elevated, thrust force goes up because increase in the point angle covers more area on the work during hole making and applies more thrust force. As the tool size is elevated, there is no much change in the thrust force hence the tool diameter has no much influence on the thrust force. The regression model for thrust force is presented in Eq. (5).

$$\begin{aligned} F_t = {} & 43.42 + 0.0326N + 5.89f - 0.162\theta - 1.52d - \\ & 9.06X10^{-3}Nf + 2.71X10^{-5}N\theta + 3.125X10^{-5}Nd - \\ & 0.052f\theta - 0.156fd + 1.04\theta d - 4.63X10^{-6}N^2 + \\ & 46.71f^2 + 9.65X10^{-4}\theta^2 + 0.091d^2 \,. \end{aligned} \tag{5}$$

4.4 Torque

Among the four input factors, speed and feed are majorly affecting the torque as seen from Table 4. The response surface plot is presented in Fig. 6. Elevation in speed makes a hike in the torque. This mechanism happens because, as the speed is elevated, the drill tool tries to remove the material at a faster rate. At the same time, the work material offers resistance to the tool rotation and hence elevates the torque requirement. A hike in the feed rate also elevates the torque because at feed rate, more axial force is applied and consequently more resistance is offered by the work material thus causing an elevation in torque. As the point angle is hiked, torque is elevated and this behavior happens because at high point angle, the tool covers more area and elevates the torque as discussed in Sec. 4.1. This phenomenon is quite different from a previous research on hybrid composites where an elevation in point angle declines the torque [20]. Hence, the mechanism by which a response behaves is not similar in all cases; it depends on the constituents of work material and working conditions. The influence of tool diameter on the torque does not show a clear trend. Torque requirement is high at low and high drill size whereas it is minium at a medium drill size. The regression model for torque is presented in Eq. (6).

$$\begin{aligned} T = {} & 4.76 + 4.72X10^{-4}N + 12.392f + 1.63X10^{-3}\theta - \\ & 0.41d - 5.31X10^{-4}Nf + 4.41X10^{-6}N\theta - 1.25X10^{-6}Nd - \\ & 0.029f\theta - 6.25X10^{-3}fd - 2.083X10^{-5}\theta d - \\ & 8.18X10^{-8}N^2 - 7.92f^2 + 3.684X10^{-5}\theta^2 + 0.02d^2 \ . \end{aligned} \tag{6}$$

4.5 Sub-surface investigations

The surface morphology of hole walls has been studied using SEM analysis as presented in Fig. 7. It has been observed that at a high speed of 3000 rpm, the surface seems to be smooth but as feed is increased from 0.2 mm/rev to 0.6 mm/rev, the fineness of the surface decreases. This shows that the surface roughness of the inner walls increases with increase in the feed rate. As compared to the images presented for speed at 3000 rpm, the images at 2000 rpm seem to be rough with few pits and fiber pullouts spread over the region. As the feed rate is elevated, the quantum of pits increases and this shows that feed rate has a dominant effect on the wall surface roughness. In comparison to the morphologies at 2000 rpm and at 3000 rpm, the images at 1000 rpm show more deep pits, cracks and cavities. The quantum of these defects increases with increase in the feed rate. This clearly shows that, feed rate of the spindle is the dominant in increasing the sub-surface roughness of the hole. The second dominant factor is the spindle speed and the sub-surface roughness goes down whilst elevating the spindle speed [21, 22]. This is attributed mainly due to two reasons. Firstly, as the spindle speed is elevated, the cutting edge of the tool makes a polishing action on the wall surface. Due to this, the tool clears the micro level chips present on the inner walls and thus reduces the surface roughness of the wall. Secondly, as the natural fibers are dispersed evenly in matrix, the heat absorption by the matrix is eliminated thus preventing the softening of the matrix. Hence the surface finish has been good at high spindle speeds.

5. Optimization, confirmation and comparison

Multiple response optimization has been made by setting the input factors within the range and the objectives as minimization of responses. A desirability based approach has been followed in which the condition with a maximum desirability is taken as the optimum [23]. A spindle speed of 1450 rpm, a feed rate of 0.2 mm/rev, a point angle of 60^0 and a tool diameter of 10 mm are observed as the optimum input condition with 1.03, 1.11, 71.23 N, 5.49 Nm as the optimum output parameters . Confirmatory run has been made for this condition and repeated five times as presented in Table 5. Each time the responses have been measured and the average of five readings has been calculated. The fuzzy prediction for the optimum condition is also noted to be 1.02, 1.11, 70.9 N and 5.44 Nm for D_i, D_0, F_t and T respectively. A comparative analysis among, the CCD, fuzzy and confirmatory is made. The error between the CCD and fuzzy is found to be -0.97 %, 0.9 %, 0.46 % and 0.91 % for D_i, D_0, F_t and T respectively.

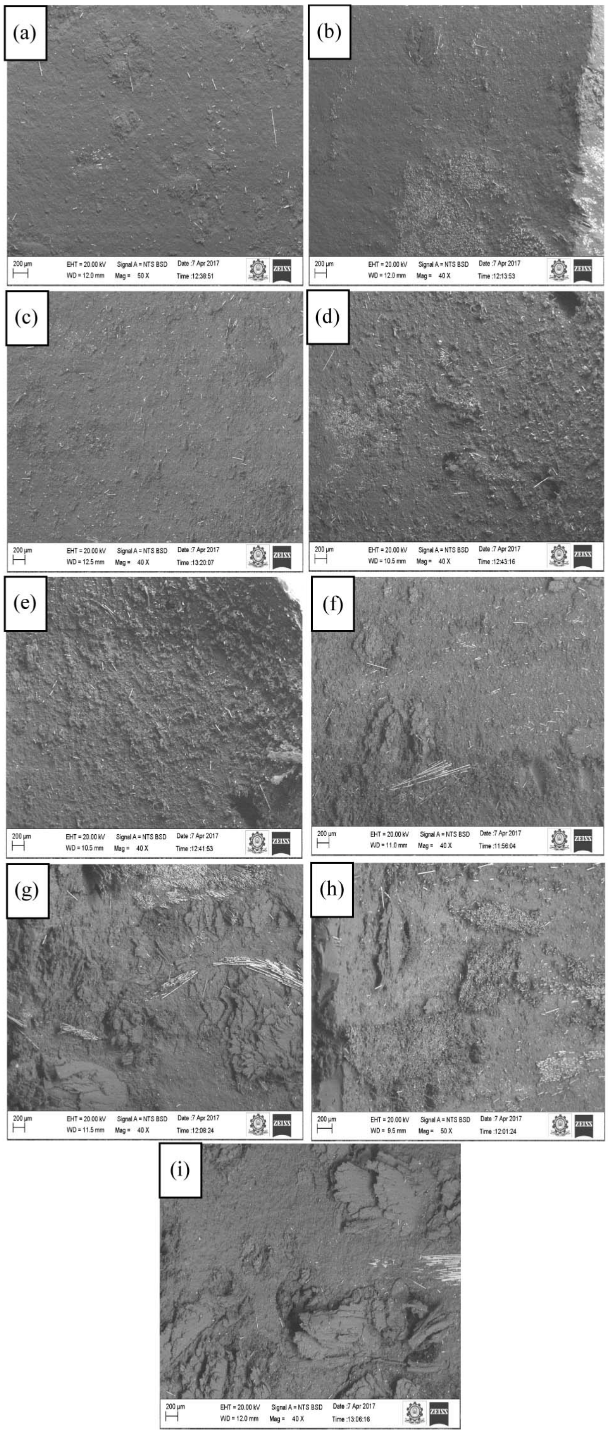

Fig. 7. SEM image of hole at (a) 3000 rpm, 0.2 mm/rev; (b) 3000 rpm, 0.4 mm/rev; (c) 3000 rpm, 0.6 mm/rev; (d) 2000 rpm, 0.2 mm/rev; (e) 2000 rpm, 0.4 mm/rev; (f) 2000 rpm, 0.6 mm/rev; (g) 1000 rpm, 0.2 mm/rev; (h) 2000 rpm, 0.4 mm/rev; (i) 1000 rpm, 0.6 mm/rev.

Table 5. Confirmatory experimentation.

Run No.	Model				Confirmatory			
	N	F	θ	d	D_i	D_0	F_t	T
1	1450	0..2	60	10	1.02	1.03	70.89	5.47
2					1.03	1.04	71.5	5.5
3					1.02	1.02	70.96	5.52
4					1.02	1.02	71.5	5.46
5					1.03	1.03	70.58	5.4

The error between CCD and confirmatory is observed to be 0.58 %, 0.36 %, 0.2 % and 0.36 % for D_i, D_0, F_t and T, respectively. In the same way, the error between fuzzy and confirmatory is observed as -0.39 %, -0.54 %, -0.26 and -0.55 % D_i, D_0, F_t and T, respectively. The error values are found to be negligible between the models and hence the model optimization is consummate. A regression analysis has been made by manually calculating the values of output parameters from the models given from Eqs. (3)-(6) and presented in Table 3. A comparison between the experimental and regression model shows an error of -3.46 %, -2.36 %, 0.72 % and 1.2 %, respectively for D_i, D_0, F_t and T. As the error is meager, it is clear that experimental data closely follows the regression data. In the same way, the results predicted by regression model for optimum conditions are also calculated and found to be 1.025, 1.087, 70.9 N and 5.4 Nm, respectively for D_i, D_0, F_t and T. These data are very close to both the model and confirmatory; hence the model is highly satisfactory.

6. Conclusion

New composite has been prepared by using chemically treated vetiver as reinforcement. Mechanical properties have been investigated and subjected to drilling on the basis of central composite design. The entrance and exit defaces, thrust force and torque have been measured as the output responses. A fuzzy model has been developed and a comparative analysis between the central composite design and fuzzy for all the trial is found to be satisfactory. Feed and point angle are dominantly affecting the entry deface whereas speed has no influence on the entry deface. Speed, feed and point angle are majorly affecting the exit deface. In both the defaces, tool diameter has very less significance. Except the tool diameter, all the input parameters are majorly affecting the thrust force. In the same way speed and feed rate are dominating the torque. The damage of hole walls has been investigated using surface morphology studies. It has been observed that, a high speed drilling produces very less damage on the walls but an elevation in the feed rate increases the damages under all spindle speeds. A multi-response optimization has been made by considering response minimization and desirability approach. It has been observed that a speed of 1450 rpm, a feed of 0.2 mm/rev, a point angle of 60° and a tool diameter of 10 mm are found to the optimum conditions for drilling. Confirmatory runs has been conducted and repeated five times. It is compared with the CCD model and fuzzy. The average error between each comparison is found to be very less and hence, the optimization by using central composite design based fuzzy is highly consummate. Machining under the optimized condition eliminates the wastage in terms of resources, man power and time in a manufacturing sector. At the same time, considering the natural fiber composites each natural fiber has its own properties and they directly have an impact on the machinability. Hence, the optimum conditions are not similar for all composites; they must be selected after careful experimentaion.

Nomenclature

N : Spindle speed
f : Spindle feed
ϴ : Point angle
d : Tool diameter
F_t : Thrust force
T : Torque

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