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Fuzzy based optimization of thrust force and torque during drilling of natural hybrid composites

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Abstract: This investigation was done to study machinability during drilling on sandwichlaminates. Vetiver and jute were used as natural fibers and glass was used as synthetic fibers in vinyl ester matrixin the form oflaminatesby varying the fiber content in each laminate.The laminateswere drilled during which spindle speed, spindle feed rate, tool point angle and sample laminate weremodified using D-optimal design technique. During drilling of each hole, thrust force impressed and torque developedwere noted as outputs.The outputswere optimized to observe best drilling conditions.A fuzzy model was created and its predictions for trialconditionswere noted. A comparison between trial values, regression values and fuzzy values was made. Confirmatory trialswere madefor optimumset of runs and outputswere again noted.The percentage of error between the model, confirmatory trials and fuzzy were found to be meagre and hence concluded that the optimization was satisfactory.

Introduction

During ultrasonic drilling on glass fiber epoxy plastics, it was reported that hole surface roughness increases when power rating and grain size were increased. Also, maximumhole surface roughness was observed at entrance side than at exit side[1]. In another research, sandwich laminates were prepared by using sisal and glass as reinforcements in vinyl ester matrix. Drilling experiments on the developed samples reported that feed rate has the predominant influence on the delamination [2]. A drilling study was done on medium density fiber boards and concluded that feed rate and drill size are predominantly affecting the thrust force and this happened due to increase in shear area at high feed and drill size conditions [3]. A research work has been carried out on milling of jute fibers composites and concluded that thrust force and torque were majorly affected by input factors like spindle speed, spindle feed rate and depth of cut [4]. In presentinvestigation,sandwich laminateswere preparedby using natural as well as synthetic reinforcements.The laminateswere subjected to a drilling in accordance withD-optimal design technique.Two outputs namely thrust force and torque developed were noted and optimized.

Experimental

Composite laminateswere made by using hand layup techniquein the size of 350 x 350 x 12 mm. Vetiverwas pre-treated in sodium hydroxide in order to remove the cellulosic substances. After this treatment, the fibers wereheated in furnace in order to enhance its bonding ability with resin[5]. The proportions of vetiver, jute and glass were varied and maintained as 34 % put together whereas the resincontent was maintained as 66 % in all laminates. Laminate I was made with 17 % of vetiver and 17 % of jute, Laminate II was made with 13 % of vetiver, 13 % of jute and 8 % of glass and laminate III was made with 10 % of vetiver, 10 % of jute and 14 % of glass.

Drilling operations were done by using computer numerical machining center. Four high speed steel drill tools of 10 mm diameter were purchased and their point angles were modified to 60^0, 90^0, 120^0 and 150^0. A Kistler make force dynamometer was used to measure the thrust force and torque during drilling. Speed, feed rate andpoint angle were selected as 4-level numerical input factors and sample laminatewas selected as a 3-level categorical input factor. Thus, selected model was a D-optimal model with mixed levels. The identification of input factors was basedon the previous literatures done in the field of drilling [6-8]. The numerical values for speed (n) were assigned as 500 rpm, 1000 rpm, 1500 rpm and 2000 rpm,feed rate (f) were assigned as 0.1 mm/rev, 0.2 mm/rev, 0.3 mm/rev and 0.4 mm/rev, point angle were assigned as mentioned earlier. The categorical factor for sample laminate (D) was assigned as I, II and III levels.

Table 3. Experimental trial runs and measured outputs

Run	Speed (rpm)	Feed (mm/rev)	Point angle (degree)	laminate	Experimental		Regression		Fuzzy	
					Thrust force F (N)	Torque T (Nm)	Thrust force F (N)	Torque T (Nm)	Thrust force F (N)	Torque T (Nm)
1	500	0.2	60	III	102.1	6.27	103.2	6.83	100.6	6.3
2	500	0.1	60	II	90.3	5.21	89.45	5.45	91.2	5.3
3	1000	0.4	150	I	94.8	4.72	95.1	4.66	95.3	4.8
4	1000	0.1	120	II	94.1	4.9	94	5.03	93.5	5
5	2000	0.1	90	III	99.3	5.73	99.18	6.1	98.8	5.2
6	2000	0.3	90	I	86.3	4.94	85.27	5.8	86.1	5.1
7	500	0.4	150	III	120.4	6.49	121.2	5.58	121	6.5
8	1500	0.1	60	I	82.7	4.32	83.91	4.23	83.1	4.2
9	500	0.3	150	II	99.3	4.11	100.1	4.1	99	4.2
10	2000	0.1	150	I	89.5	4.81	90.2	5.08	88.9	5
11	2000	0.4	60	III	111.4	7.08	110.5	7.1	110.7	7.1
12	2000	0.4	150	II	105.5	5.6	106.11	5.67	105.9	5.2
13	2000	0.1	60	II	91.6	5.19	90.51	5.2	92.9	5.2
14	500	0.1	120	I	88.7	4.02	89	4.04	87.2	4
15	2000	0.2	150	III	109	6.02	109.2	6.05	108.7	6
16	500	0.1	150	III	107.6	5.48	108.02	5.1	106.9	5.5
17	500	0.4	60	II	102.5	5.89	103.6	5.23	103.1	5.4
18	500	0.4	60	I	90.9	5.1	90.76	5	91	5
19	1500	0.3	60	II	96.3	5.48	95.89	5.11	97.2	5.1
20	1000	0.4	90	III	114.5	6.7	114.19	6.79	113.2	6.2
21	2000	0.3	150	I	90.4	4.56	89.2	4.34	91	4.4
22	2000	0.2	120	II	91.5	5.39	92.34	5.33	92	5.3
23	2000	0.4	120	III	115.3	6.54	114.27	6.31	114.7	6.3
24	500	0.1	120	I	87.2	4.01	86.4	4	86.7	4
25	2000	0.4	150	II	106.4	5.5	106.82	5.6	106	5.1
26	500	0.4	60	I	91.5	4.18	90.12	4.19	92	4.2
27	500	0.1	150	III	108.3	5.5	108.45	5.56	107.6	5.6
28	2000	0.4	60	III	110.3	7.1	110.22	7.14	110.5	7.2
Error between Experimental and Regression: F = 0.81%, T = 0.73 %, Error between Experimental and Fuzzy: F = 0.7%, T = 0.6%										

Design of Experiment

Thisresearch work utilizes D-optimal model for design and optimization. D-optimal modelwould be effectively used when the output is influenced by a mixture of numerical and categorical factors. It also effectively optimizes the output influenced by input factors with unequal levels. Analysis of variance was used to study the predominance of input factors on the output. The experimental trials followed and observed outputs were shown in Table 3.

Discussions

Thrust force (F). The combined ANOVA analysiswasshown in Table. 4. The F-values of model and lack of fit show that the model is significant. Adequacy of the model was verified by the closeness of R^2 and adj R^2 values. As they are very closer, the model was adequate for predicting the outputs.The contribution values as presented shows thatthe sample laminate, feed rate and tool angle were majorly influencingthe thrust force. A maximum contribution of 55.24 % was noticed with sample laminate. This clearlyshows that the proportions of fibers in laminate plays avital role in deciding the thrust force.

Table 4. ConsolidatedANOVA Table

Entity/Factor	Square sum	DOF	Mean square	F-value	p-value	Contribution %	R^2	Adj-R^2	Adequate precision (AP)
Thrust Force (F)									
Model	2803.5	17	164.91	115.6	<0.0001	Significant	0.995	0.986	38.5
Speed (n)	6.12	1	6.12	4.29	0.0651	0.22			
Feed (f)	408.03	1	408.03	286.2	<0.0001	14.5			
Tool angle (α)	130.82	1	130.82	91.77	<0.0001	4.64			
Work (D)	1556.5	2	778.22	545.8	<0.0001	55.24			
Lack of fit	11.7	5	2.34	4.57	0.0605	-			
Pure error	2.56	5	0.51	-	-	No			
Total	2817.7	27	-	-	-	-			
Torque (T)									
Model	20.82	17	1.22	13.16	<0.0001	Significant	0.95	0.9	12.2
Speed (n)	0.73	1	0.73	7.88	0.0185	3.35			
Feed (f)	2.02	1	2.02	21.7	0.0009	9.29			
Tool angle (α)	0.82	1	0.82	8.84	0.014	3.77			
Work (D)	12.04	2	6.02	64.64	<0.0001	55.35			
Lack of Fit	0.5	5	0.1	1.17	0.433	-			
Pure error	0.43	5	0.086	-	-	No Significance			
Total	21.75	27	-	-	-	-			

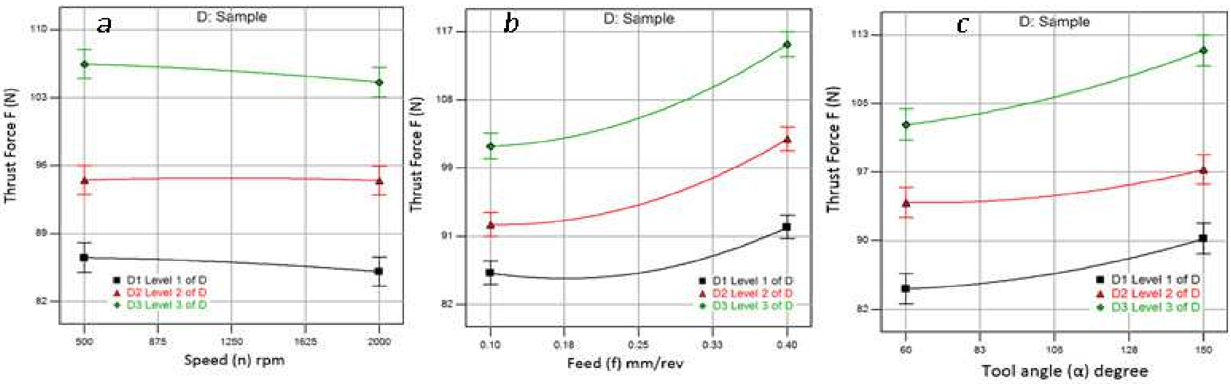

Figure 1: Interaction plots(a) F vs n (b) F vs f (b) F vs α and

Interaction plots for thrust force were presented in Fig. 1. Fig 1a clearly shows that speed has no much importance on thrust force as there was a meagre variation of thrust when speed was varied. When feed rate was increased, thrust force also increases for laminates II and III whereas for laminate I, thrust force shows slight decrease until 0.15 mm/rev thereafter there found to be an increase in thrust force. This increase in thrust force may be of the fact that at high feed rates, the rate of penetration of tool on laminate increases. This creates high thrust force on the laminate surface.When tool angle was increased, the area of contact of the tool with laminate surface increases thusboosting thrust force. The observedbehaviors were quite commonin all laminates but, laminate I show a minimum thrust force than laminate II and III. This clearly indicates that the presence of glass reinforcementraises thethrust force considerably [9]. Hence, laminate I was suitable for drilling under minimum thrust force.

Torque (T). The F-values of model and lack of fit shows that the model is significant from Table 4. As R^2 and adj R^2 values are very closer, the model was adequate for predicting the outputs.The contribution values as presented shows thatall the input factorswere majorly influencingthetorque. The laminates contribution of 55.35 % shows that the reinforcement content in laminate plays avital role in deciding the torque. Interaction plots for torque were shownin Fig. 2. Fig. 2a shows that increase in spindle speed increases the torque value for laminate I and II whereas laminate III show a constant torque value. Fig 2bshows that, increase in feed rate increases the torque value after a value nearer to 0.15 mm/rev. Fig 2c also shows that, increase in tool angle decreases the torquerapidly for laminates II and III whereas for laminate I there was only a meagre decrease in torque. A comparison between the laminates clearly infers that laminate I shows minimum torque under all conditions.Thus it may be concluded that natural reinforcements namely vetiver and jute as a replacement for glass made positive effect on machinability.A second order regression equations for outputs were developed and presented in Table 5.

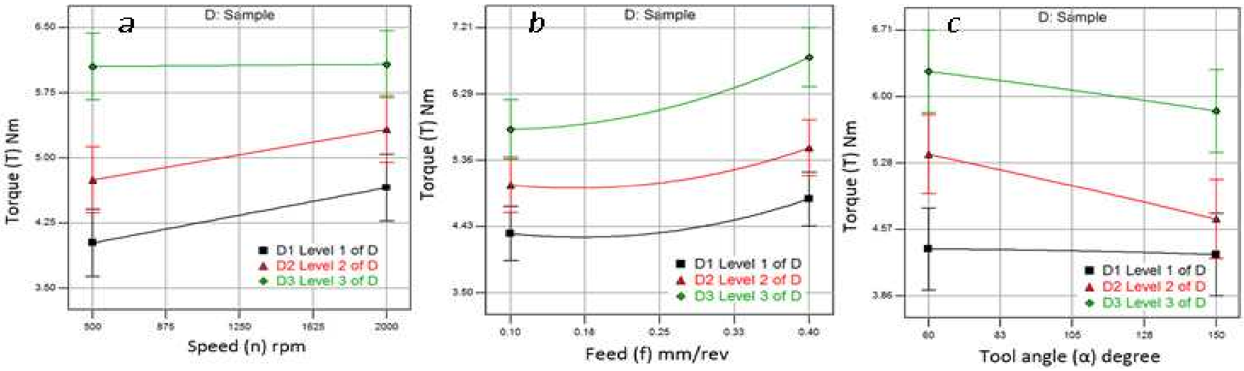

Figure 2: Interaction plots(a) Tvs n (b) Tvs f (b) Tvs α and

Table 5. Table of regression equations

Response	Equation
Thrust (F)	$F_I = 88.23 -7.2E\text{-}4n -36.68 f-0.042\alpha+4.42E\text{-}4nf+6.9E\text{-}6n\alpha-0.057f\alpha-4.26E\text{-}7n^2+129f^2+5.24E\text{-}4\alpha^2$
	$F_{II} = 94.11+2E\text{-}4n-22.8f-0.063\alpha+4.42E\text{-}4nf+6.9E\text{-}6n\alpha-0.057f\alpha-4.26E\text{-}7n^2+129F^2+5.24E\text{-}4\ \alpha^2$
	$F_{III} = 99.51-1.01E\text{-}3n-15.8f-0.012\alpha+4.42E\text{-}4nf+6.9E\text{-}6n\alpha-0.057f\alpha-4.26E\text{-}7n^2+129f^2+5.24E\text{-}4\alpha^2$
Torque (T)	$T_I = 4.3-5.6E\text{-}5n-2.38f-1.16E\text{-}3\alpha+2.51E\text{-}4nf+4.02E\text{-}6n\alpha-0.0134f\alpha-2E\text{-}9n^2+10.25f^2+5.26E\text{-}6\alpha^2$
	$T_{II} = 5.76-9.28E\text{-}5n-2.25f-8.24E\text{-}3\alpha+2.51E\text{-}4nf+4.02E\text{-}6n\alpha-0.0134f\alpha-2E\text{-}9n^2+10.25f^2+5.26E\text{-}6\alpha^2$
	$T_{III} = 6.52-4.64E\text{-}4n-0.64f- 5.2E\text{-}3\alpha+2.51E\text{-}4nf+4.02E\text{-}6n\alpha-0.0134f\alpha-2E\text{-}9n^2+10.25f^2+5.26E\text{-}6\alpha^2$

Optimization

A multiple optimization techniquewas donewith an objective of minimizing the outputs. The optimization technique was carried out on the basis of desirability approach. Using this approach, there found to be more than one optimum condition. These conditions would be selected based on the desirability values which are closer to unity. A set of seven optimum conditions were taken and confirmatory trials have beenconducted for these conditions.

Fuzzy modelling

Fuzzy modeling starts with fuzzification process during which membership functionswere created for input and output factors. A triangular type membership function [10] was made by taking three values namely low, medium and high as shown in Fig. 3. The next stepwas the de-fuzzification process in which membership functions were reduced in to a most representative value.During this stage, set of rules containing IF-THEN statements were framed based on the runsshown in Table 5. Fuzzy gives aprediction plot from which output responses could be predicted for input values. The developed model was validated by comparing the D-optimal values with confirmatory trials and with fuzzy predictions. Theerror between each analysis was calculated and shown Fig. 4. These error were found to be minimum for both thrust force and torque. Hence, the optimization was found be highly satisfactory.

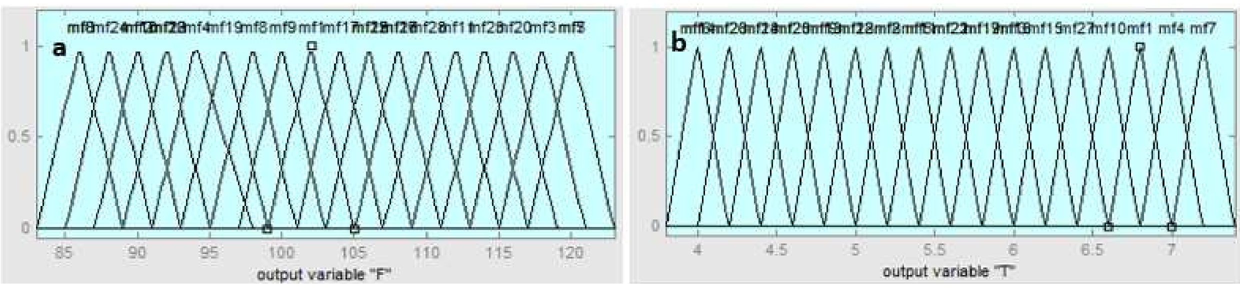

Figure. 3 Membership plot for (a) Thrust force (b) Torque

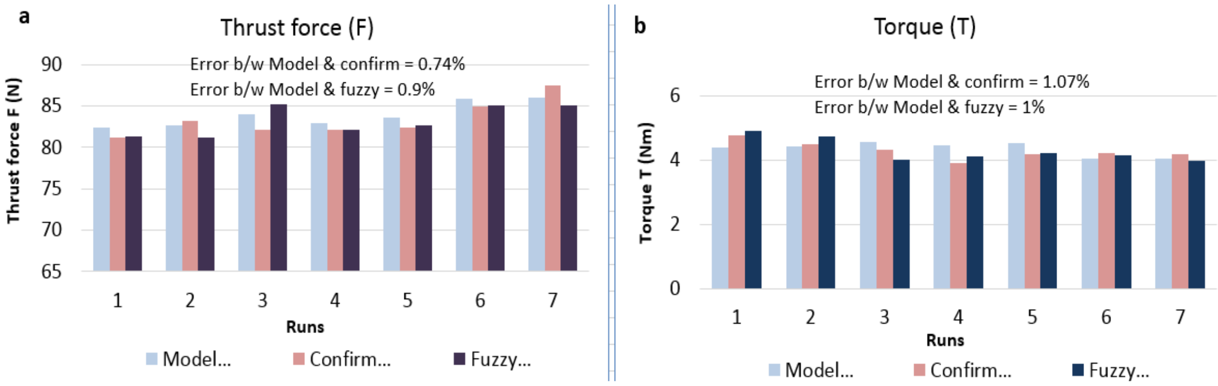

Figure 4: Comparison between Model, Confirmatory and Fuzzy models (a) Thrust (b) Torque

Conclusion

1. Sample laminate, feed rate and point angle were found to have major contribution on thrust force. All factors have major influence on torque.
2. There found to be a highest contribution of 55 % for sample laminate with thrust force and torque. This shows that the natural reinforcement content plays a vital role in deciding the thrust force and torque.Inclusion of glass fibers creates development of thrust force and torque. Hence, sample Icontaining only natural fibersimproved machinability.
3. The developed model shows good agreement with confirmatory runs and fuzzy values. Hence the optimization is highly satisfactory.

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