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Multi Criteria selection of Optimal CFRP composites drilling Process Parameters

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Abstract

Common Industrial practices suggests to use material with more strength but at the same time the weight needs to be least as possible, this requirements takes our attention towards (CFRP) Carbon Fiber-Reinforced Polymer which is well known for its light weight and durability. In this paper we took spindle speed, point angle, feed rate as input parameter whereas thrust, torque, delamination and eccentricity as our output parameters. From our analysis we got the best results from our 19th experimental combination (84.23 N of thrust, 0.39 Nm torque, 1.4287 delamination component at entrance, 1.41 delamination component at exit point and eccentricity of 0.0156mm) whereas the least favourable output was yielded by our 6th experimental combination (310.4667 N of thrust, 1.37 Nm torque, 1.5211 delamination component at entrance, 1.4137 delamination component at exit point and eccentricity of 0.0619mm). This study will require an analysis which will guide us while choosing methods for less energy consumption while maintaining product quality. (MCDM) Multi-criteria decision making (MCDM) will be most suitable for us to resolve conflicting conditions.

Keywords- Drilling, CFRP, thrust force, torque, point angle, delamination, eccentricity

1. Introduction

This polymer made of carbon linkages makes it free from corrosion problems. To enhance strength and durability of the polymer, glass or aluminum is often added with carbon. Characteristic properties of the CFRP can be adjusted according to its usage and requirement, it depends on the additives we provide, density of the fibers and the structure. This customizable property of the fibre makes it a versatile option for aerospace components, sporting goods and many more. The only practical drawback so far experienced with this material is low fatigue resistance which has to be kept in mind to prevent any premature failure. Drilling process is dependent on provided Feed rate, Drill dia, Spindle speed, Layers of composites. Within these parameters , feed rate is observed to affect the quality more dominantly than other three. Product quality reduces for higher feed rates and gets better quality for low feed rate. By observation of the experiments we achieved better quality with low feed rate in combination with high spindle speed. The cause for the difference in product quality is the force distribution, When the tool rotates with a high speed, the cutting edge pierces precisely but at slow speed the force gets distributed in surrounding area and the cut is not accurate whereas at high feed rate the contact surface of the tool and product increases resulting in unexpected deformation The better results yielding from drilling CFRP composite being our purpose, application of thrust is found to be almost linear to the delivered feed rate, which is approved with the industrial practice. Where spindle speed is inversely proportional to thrust, ie more the speed less the thrust required. If the speed is kept constant while we observe the relation between thrust and diameter ratio, it is clear that greater diameter generates higher thrust, but also this variation in thrust caused by the diameter ratio decreases at higher spindle speed [4]. As the results from table .1 gives us, minimum thrust force is required at lesser point angle, the deviation in results from angle 118 º and 135 º are not much noticeable unless the spindle speed is increased to 2000 and 3000 rpm whereas the 100 º point angle results are appreciably better than others. The increase of thrust with increase of feed rate is also noticed at every set of speed and point angle kept constant whereas if the spindle speed is increased the thrust experienced by the product keeps getting low. at high spindle speeds, preferential removal of work piece takes place, which in turn produces smooth surface; whereas, at low spindle speeds due to slow penetration of the tool in The work piece produce more delamination. Other advantages of high spindle speed is the instant removal of chips so they don't stick to the tool and also the heat produced helps in better penetration. Three sets of spindle speed are taken 1000, 2000, 3000 rpm with varying point angle and feed rate. Our motive is to get least thrust, delamination component s, torque and eccentricity. All these factors are clearly inversely proportional to the speed. The orientation while drilling a product plays a major role as the point angle affects the quality of the machining process and for analyzing this factor experiments at different point angles are carried out. The increase of point angle in the drill bit increases the delamination and vice-versa [12]. the results from the table supports the relation between point angle and drilling quality, delamination , thrust, torque and eccentricity increases with increase of point angle. The best set of results are yielded by the 100 º point angle with minimum feed rate and maximum speed. Feed rate is found to be proportional to the output factors, the results from table .1 clearly states that less feed rate tends to give less delamination, torque, thrust and eccentricity for any set of speed and point angle. Torque gives the measure of safe and efficient chip load for particular drill diameter, which prevents the drill from any permanent breakage [2]. The knowledge about the amount of torque and thrust the work-piece experiences is important for deciding the method and other designing factors while production. [4]. Thrust force and torque depended on the ratio of the cutting speed to the feed rate with a local minimum being observed between 900 and 1500 for different drill point geometries to calculate thrust and torque we integrate the cutting pressure over the cutting edge [6]. To optimize the drilling process we expect minimum torque generation. From table .1 the results of higher spindle speed are better than that of lower ones whereas the values of torque are higher for higher feed rates and point angle. We can deduce the best result must be the one with maximum speed and minimum feed rate and point angle and the results supports the same. The delamination caused at exit surface is known by 'Push-out at exit' and the delamination caused on the entrance is known as 'peel-up at entrance'. This delamination component was examined by Chen[14] using empirical relations are developed for this purpose in relation with drilling parameters such as feed rate, spindle speed ie the delamination component increases with the increasing feed rate and reduces if the spindle speed is reduced. While analyzing the drilling process, most important factor is delamination which is also physically tested on microscopic level. Table .1 gives the analysis of entry and exit delamination component ie analyzing both side of the hole. Achieving least delamination by trying different combinations of input parameter is our purpose. In drill regrinding, the point of the twist drill can deviate from the centerline generating eccentricity of the drill point. The eccentric twist drill will cause scatter and enlarge the hole in drilling, while the delamination damage in drilling composite materials becomes more serious. The critical thrust force that will produce delamination decreases with increasing point eccentricity x. The results agree with industrial experience. The need for control of drill eccentricity during drill regrinding has been proved analytically by the proposed models. A comprehensive analysis of the delamination caused by the eccentricity in twist and candle stick drills [11].

2. Materials and Methods

The process has 3 input parameters and 5 output parameters—thrust force, torque, delamination at the entry and exit and eccentricity. The objective is to find optimal combinations of process parameters that produce minimum thrust force, torque, delamination at the entry and exit and eccentricity. Keeping this in mind, 3 scenarios are tested. Scenario 1: All 5 output parameters are considered. Scenario 2: Only thrust force, torque, and eccentricity minimization is considered. Scenario 3: Only delamination at the entry and exit is considered. In all the three scenarios, the weightage (or importance of the output parameters) is considered as equal. Weighted sum method is said to be a versatile option for analyzing parameter which are inter-related in complicated manner. The outputs for particular parameter combinations are arranged in a way that best quality output comes at higher place and the worst quality at the bottom, from which the normalized matrix can be formed by dividing each value by the sum of all outputs. After which the total score of each experiment is multiplied by its weight. The experiment with best and most optimized result is the highest total score among all other alternatives.

3. Results & Discussion

Scenario 1 – from table 2, the best combination of inputs parameters, where 3000rpm spindle speed , 100^o point angle and 100 mm/min feed rate which gives us 84.23 N of thrust, 0.39 Nm torque , 1.4287 delamination component at entrance,1.41 delamination component at exit point and eccentricity of 0.0156mm followed by the combination of 3000rpm spindle speed, 118 ^{o} point angle and 100 mm/min feed rate which gave us 130.6167 N of thrust, 0.4 Nm torque , 1.4347 delamination component at entrance,1.3534 delamination component at exit point and eccentricity of 0.0308mm. the least optimized combination in this scenario is 6th combination which ranked 27th in the ranking of various alternatives with 1000rpm spindle speed, 118 ^{o} point angle and 500 mm/min feed rate which gave us 310.4467 N of thrust, 1.37 Nm torque , 1.5211 delamination component at entrance,1.4137 delamination component at exit point and eccentricity of 0.0619mm. the combination at 26th position in ranking of various alternatives is the 18th experiment with spindle speed, point angle and feed rate 2000rpm ,135 ^{o} and 500 mm/min which gave us 299.1833 N of thrust, 0.95 Nm torque , 1.411 delamination component at entrance,1.45 delamination component at exit point and eccentricity of 0.0671mm

Table 1: Input variables and experimental responses

Exp. No.	Spindle speed(rpm)	Point angle	Feed rate (mm/min)	Thrust force(N)	Torque (Nm)	Entry-delamination factor	Exit-delamination factor	Eccentricity (mm)
1	1000	100	100	99.69	0.73	1.3418	1.4378	0.0728
2	1000	100	300	165.2033	0.84	1.3759	1.6373	0.0619
3	1000	100	500	198.3633	1.12	1.4368	1.541	0.0609
4	1000	118	100	156.25	0.99	1.3921	1.2628	0.0517
5	1000	118	300	253.2933	1.34	1.44	1.4658	0.0431
6	1000	118	500	310.4667	1.37	1.5211	1.4137	0.0619
7	1000	135	100	155.4333	1.37	1.3398	1.1851	0.0437
8	1000	135	300	261.23	1.52	1.3587	1.3692	0.0302
9	1000	135	500	310.06	1.87	1.4756	1.2739	0.0251
10	2000	100	100	92.3667	0.48	1.39	1.4455	0.0623
11	2000	100	300	154.01	0.68	1.3439	1.51	0.0815
12	2000	100	500	192.8733	0.87	1.3817	1.3607	0.1113
13	2000	118	100	140.1767	0.57	1.4287	1.4	0.0652
14	2000	118	300	231.5233	0.92	1.43	1.4562	0.0821
15	2000	118	500	271.81	0.93	1.4474	1.3794	0.0799

16	2000	135	100	150.7533	0.64	1.4021	1.3296	0.0671
17	2000	135	300	234.78	0.94	1.3798	1.3585	0.0655
18	2000	135	500	299.1833	0.95	1.411	1.45	0.0671
19	3000	100	100	84.23	0.39	1.4287	1.41	0.0156
20	3000	100	300	152.3867	0.47	1.3974	1.3807	0.0322
21	3000	100	500	165.8133	0.6	1.36	1.1688	0.0588
22	3000	118	100	130.6167	0.4	1.4347	1.3534	0.0308
23	3000	118	300	191.8567	0.54	1.4098	1.51	0.0342
24	3000	118	500	270.3867	0.7	1.4224	1.4	0.0411
25	3000	135	100	143.6367	0.48	1.4601	1.44	0.0448
26	3000	135	300	226.0333	0.55	1.4264	1.51	0.0601
27	3000	135	500	283	0.78	1.4018	1.4774	0.077

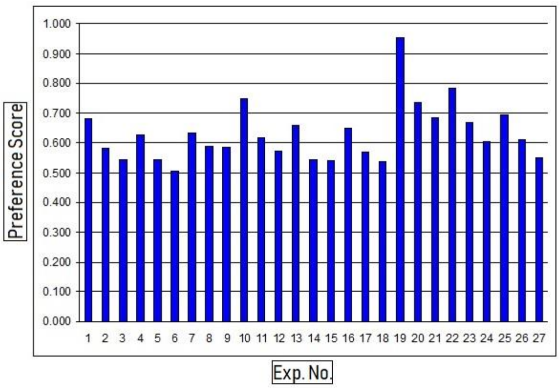
Scenario 2 – 19th combination of inputs parameters was most optimized , where 3000rpm spindle speed , 100º point angle and 100 mm/min feed rate which gives us 84.23 N of thrust, 0.39 Nm torque , 1.4287 delamination component at entrance,1.41 delamination component at exit point and eccentricity of 0.0156mm. The 22nd combination to be the second best with 3000rpm spindle speed, 118 º point angle and 100 mm/min feed rate which gave us 130.6167 N of thrust, 0.4 Nm torque , 1.4347 delamination component at entrance,1.3534 delamination component at exit point and eccentricity of 0.0308mm. the least optimized combination in this scenario is 6th combination which ranked 27th in the ranking of various alternatives with with 1000rpm spindle speed, 118 º point angle and 500 mm/min feed rate which gave us 310.4467 N of thrust, 1.37 Nm torque , 1.5211 delamination component at entrance,1.4137 delamination component at exit point and eccentricity of 0.0619mm. the combination at 26th position in ranking of various alternatives is the 15th experiment with 2000rpm spindle speed, 118 º point angle and 500 mm/min feed rate which gave us 271.81 N of thrust, 0.93 Nm torque , 1.4474 delamination component at entrance,1.3794 delamination component at exit point and eccentricity of 0.0799mm. Scenario 3 – most optimized combination in this scenario is the 7th experiment, where 1000rpm spindle speed , 135º point angle and 100 mm/min feed rate which gives us 155.4333 N of thrust, 1.37 Nm torque , 1.3398 delamination component at entrance,1.1851 delamination component at exit point and eccentricity of 0.0437mm. The 21nd combination to be the second best with 3000rpm spindle speed, 100 º point angle and 500 mm/min feed rate which gave us 165.8133 N of thrust, 0.6 Nm torque , 1.36 delamination component at entrance,1.1688 delamination component at exit point and eccentricity of 0.0588mm. the least optimized combination in this scenario is 2nd combination which ranked 27th in the ranking of various alternatives with with 1000rpm spindle speed, 100 º point angle and 300 mm/min feed rate which gave us 165.2033N of thrust, 0.84 Nm torque , 1.3759 delamination component at entrance,1.6373 delamination component at exit point and eccentricity of 0.0619mm. the combination at 26th position in ranking of various alternatives is the 3rd experiment with 1000rpm spindle speed, 100 º point angle and 500 mm/min feed rate which gave us 198.3633 N of thrust, 1.12 Nm torque , 1.4368 delamination component at entrance,1.541 delamination component at exit point and eccentricity of 0.0609mm

Table 2: Ranking of various alternatives

Exp. No.	Rank		
	Scenario 1	Scenario 2	Scenario 3
1	7	7	9
2	18	15	27
3	22	19	26
4	12	14	3
5	24	23	22
6	27	27	25
7	11	16	1
8	16	18	4
9	17	17	8
10	3	3	15
11	13	12	16
12	19	20	7
13	9	8	14
14	23	24	20
15	25	26	13
16	10	10	5

17	20	21	6
18	26	25	18
19	1	1	17
20	4	4	10
21	6	9	2
22	2	2	11
23	8	6	23
24	15	13	12
25	5	5	21
26	14	11	24
27	21	22	19

From the ranking of various alternatives the combination, where 3000rpm spindle speed , 100º point angle and 100 mm/min feed rate gives the best results in first as well as second scenario and gives acceptable results for third scenario where as the combination with 3000rpm spindle speed, 118 º point angle and 100 mm/min feed rate gives second best results in both first and second scenarios and its results for 3rd scenario is better than that of previous mentioned combination. In spite of comparison in last result the fact of giving best results in two of the scenarios matters the most, making 84.23 N of thrust, 0.39 Nm torque, 1.4287 delamination component at entrance, 1.41 delamination component at exit point and eccentricity of 0.0156mm most optimized result. On the other hand the making 310.4667 N of thrust, 1.37 Nm torque , 1.5211 delamination component at entrance,1.4137 delamination component at exit point and eccentricity of 0.0619mm was noted as the worst results in two of the scenario and non-acceptable result in the last one, making it the least optimized combination



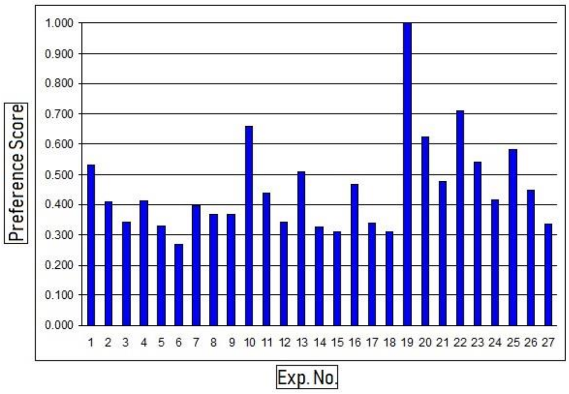


Fig. 1. Preference scores of various alternatives for scenario 1. Fig. 2. Preference scores of various alternatives for scenario 2.

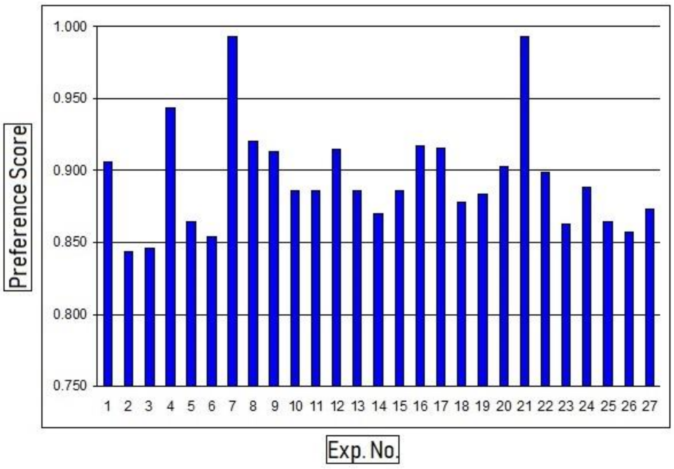


Fig. 3. Preference scores of various alternatives for scenario 3.

4. Conclusion

Machining of CFRP composites needs careful planning and estimation of adequate process parameters as it is substantially different from conventional machining of metallic materials .After determining the evaluation criteria and alternatives, WSM process integrates entropy and MCDM methods to rank the priority , In order to determine the importance of each criterion. From table .2 we obtain two combinations with favourable outcomes ie 19th (rate which gives us 84.23 N of thrust, 0.39 Nm torque , 1.4287 delamination component at entrance,1.41 delamination component at exit point and eccentricity of 0.0156mm.) and 22nd experiment (which gave 130.6167 N of thrust, 0.4 Nm torque , 1.4347 delamination component at entrance,1.3534 delamination component at exit point and eccentricity of 0.0308mm) . In first and second scenario the 19th combination gave us best result and 22nd combination second best while in case of third scenario 22nd combination yielded some degree of better results than that of 19th combination.

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