IOP Conf. Series: Materials Science and Engineering **248** (2017) 012010 doi:10.1088/1757-899X/248/1/012010

Edge Trimming Analysis for Surface Quality of Hybrid Composite - CFRP/Al2024

J Ismail[1], S B Mohamed[1], M Mohamad[1], W N F Mohamad[1], A S Mohamed[2] and A Mohd[3]

[1]Universiti Sultan Zainal Abidin, 21300 Kuala Terengganu, Terengganu, Malaysia
[2]Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal, Melaka, Malaysia
[3]TATi University College, 24000 Kemaman, Terengganu, Malaysia

Abstract. The application of hybrid composite materials has increased due to their strength and light weight ratio. Edge trimming of these materials was extremely difficult due to the anisotropic and non-homogeneous structures of CFRP and ductile nature of aluminium. This research was focused on edge trimming process via down milling operation. Three cutting parameters were examined namely spindle speed, feed rate and depth of cut. The extension of two level full factorial design, Centre Composite Design (CCD) was used to plan systematic experimental methodology. The analysis of the influence and the interaction factors associated to surface quality was studied. The objective was to obtain machined surface quality of CFRP/Al2024 between 0.4 µm to 0.6 µm. The depth of cut was the most significant factor for Al2014 and meanwhile the spindle speed and feed rate were significant factors of CFRP. The validation experiment was conducted at optimum level of recommendation control factors setting to compare the deviation of predicted value from actual/measured value. Surface roughness of CFRP was found to be at 0.594 micron at the setting of spindle speed, 11750 rpm, feed rate, 750 mm/min and depth of cut, 0.255 mm. For Al2024, the surface roughness was found to be at 0.32 micron.

1. Introduction

The use of hybrid composite materials has significantly increased especially in aerospace, naval and automotive industries due to their strength and light weight ratio [1, 2]. Trimming the edges is the first step to be carried out after the composite parts are taken out from the mold. This is normally done by conventional machining [3, 4] with the aims to satisfy the surface integrity requirement. Hence, investigations on the significant factors of machining parameters had been performed by some researchers which associated with machined surface of drilling [5], turning [6], milling [7] and trimming [8-11].

This research project described the edges trimming process of CFRP/Al2024 via down milling operation. The objectives of this study is to optimize cutting parameters in achieving surface quality of below 1 μm. The down milling method for trimming operation where the feeding direction of specimen is in the direction of cutting tool rotation was carried out to achieve optimum surface quality. This is to prevent the cutting edges form rubbing and burnishing against the surface of the specimen before engaging the cut. Every trimming operation was carried out randomly to avoid any systematic errors.

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2. Material preparation and experimental set-up

The stacking of 16 layers of Carbon Fibre Reinforced Plastic (CFRP) with 4.0mm thickness and Aluminium alloy 2024 (Al2024) with a thickness of 1.2 mm was used. The edge trimming operation was carried out on Mori Seiki NV4000 DCG CNC milling machine using KENNAMETAL Burr-Style Routers Helix 15^0, KCN05 of 10mm in diameter as shown in figure 1. The value of control parameters was set according to the table 1.

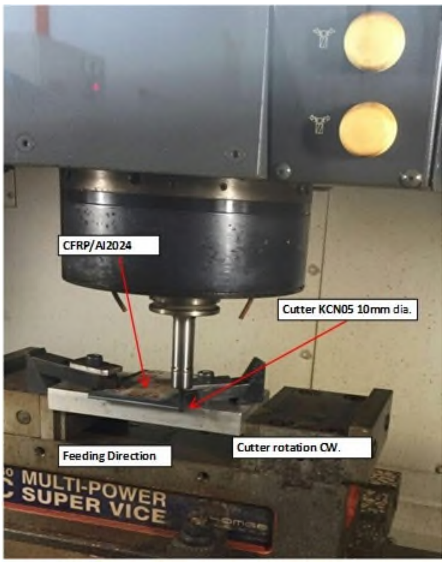

Figure 1. Experimental set-up for edge trimming process applying down milling approach.

Table 1. Cutting Parameters (control factors) for Trimming Process.

Cutting Parameters (Control Factors)	Unit	Min Value	Max Value
Spindle Speed	N (rpm)	1000	13500
Feed Rate	F_r (mm/min)	500	1000
Depth of Cut	d_c (mm)	0.01	0.5

The surface roughness for both CFRP and Al2024 was measured separately using Mitutoyo SJ-301. Five readings of 100 mm length machined surface were measured, averaged and recorded in order to encounter for unknown error. Because of composition of the composite specimen consists of metal and non-metal, therefore the machined surfaces were treated and recorded as two separate responses. By doing this, it is more convenient to observe and analyze each response individually. Moreover understanding and identifying of the interaction and the influential factors can be easily done statistically hence, the optimal formulation of the controlled factors can be predicted and formulated.

3. Results and discussion

Design-Expert V9 software was used to predict the cutting parameters. The results of the previous two level full factorial design ($2^3 = 8$ experiments) showed a significant lack of fit in the design. It was found that addition of curvature terms in the model would improve the model significantly. The software suggested to do replication of the current design (8 experiments x 2 = 16 experiments). Adding of 3 centre points was recommended in order to detect the present of any curvature in the response in the experiment. Thus, the total of 19 experiments were conducted using two level full factorial design. Table 2 shows the surface roughness (Ra) of CFRP and Al2024.

The analysis of variance (ANOVA) was performed to analyse the factors that affect the surface roughness of CFRP and Al2024 separately due to their different responses. Statistically, the quadratic model F-value of 6.29 implied that the model was significant. P-value is less than 0.05, which indicated that the model was significant. In this case A, B, and BC were significant model terms. The analysis showed that spindle speed and feed rate have a significant effect on surface roughness of CFRP. The depth of cut has no significant effect, but there was a significant interaction effect between feed rate and depth of cut as shown in table 3.

Table 2. Experimental Results of Surface Roughness (Ra) of CFRP and Al2024.

Experiment No.	Spindle Speed, *N* (rpm)	Feed Rate, f_r (mm/min)	Depth of Cut, d_c (mm)	Surface Roughness, *Ra* (μm) CFRP	Al2024
1	13500	1000	0.5	0.56	0.34
2	10000	500	0.5	0.66	0.35
3	10000	1000	0.5	0.73	0.54
4	11750	750	0.25	0.49	0.22
5	13500	500	0.01	0.45	0.34
6	10000	1000	0.01	1.04	0.21
7	13500	500	0.5	0.42	0.73
8	10000	500	0.01	0.44	0.28
9	11750	750	0.25	0.49	0.22
10	13500	1000	0.01	0.89	2.02
11	11750	750	0.25	0.50	0.20
12	11750	1000	0.25	1.03	0.55
13	11750	750	0.25	0.75	0.37
14	11750	750	0.5	0.54	0.26
15	11750	500	0.25	0.50	0.42
16	11750	750	0.01	0.43	0.47
17	13500	750	0.25	0.53	0.80
18	11750	750	0.25	0.74	0.36
19	10000	750	0.25	0.82	0.74

Table 3. ANOVA for Surface Roughness of CFRP.

Source of Variation	Sum of Square (SS)	Degree of Freedom (d.o.f)	Mean Square = SS/d.o.f	F Value	P Value	Remarks
Model	0.063	9	0.070	6.29	0.0182	Significant
A-Spindle Speed, *N*	0.091	1	0.091	8.19	0.0287	Significant
B-Feed Rate, f_r	0.25	1	0.25	22.72	0.0031	Significant
C-Depth of Cut, d_c	0.055	1	0.055	4.99	0.0669	
AB	1.513E-003	1	1.513E-003	0.14	0.7243	
AC	0.017	1	0.017	1.49	0.7243	
BC	0.11	1	0.11	9.74	0.0206	Significant
Residual	0.066	6	0.011			
Lack of Fit	0.066	4	0.017	497.29	0.0020	Significant

Table 4 showed the quality of surface roughness of Al2024 was influenced by the interaction between A-spindle speed and B-feed rate. The results of the model P-Value of 0.0384 and lack of fit of 0.0088 are significant. C-depth of cut of 0.0114 has a significant effect on surface roughness of Al2024 but A-spindle speed of 0.1068 and B-feed rate of 0.2531 are not significant.

Table 4. ANOVA for Surface Roughness of Al2024.

Source of Variation	Sum of Square (SS)	Degree of Freedom (d.o.f)	Mean Square = SS/d.o.f	F Value	P Value	Remarks
Model	0.42	9	0.046	4.60	0.0384	Significant
A-Spindle Speed, *N*	0.036	1	0.036	3.59	0.1068	
B-Feed Rate, f_r	0.016	1	0.016	1.60	0.2531	
C-Depth of Cut, d_c	0.13	1	0.13	12.94	0.0114	Significant
AB	0.061	1	0.061	6.11	0.0484	Significant
AC	3.966E-004	1	3.966E-004	0.040	0.8489	
BC	4.561E-004	1	4.561E-004	0.045	0.8382	
Residual	0.060	6	0.010			
Lack of Fit	0.060	4	0.015	112.32	0.0088	Significant

4. Optimization of Edge Trimming Parameters

Design expert allows criteria setting for all variables including factors and desired responses. So in this case the researcher left the setting of spindle speed, feed rate and depth of cut without any changes. The target value response criteria was set to below 1 μm for both. Since the responses of the experiment involved two responses, thus the setting of numerical criteria optimization was done separately.

For CFRP, the setting for lower and upper bound were 0.42 and 1.04 respectively. Meanwhile, for Al2024, the settings for the lower and upper bound were 0.2 and 0.8 respectively. These limits indicated that it was the most desirable range to achieve the targeted value of less than 1 μm. The design expert provided optimal designs with the different desirability factors ranging the least desirable to the most desirable (0 to 1). The goal of optimization is to obtain a secure set of conditions that will satisfy all the goals. The program randomly picked a set of conditions from which to begin its search for desirable outcomes. After grinding through cycles of optimization, Design Expert sorted the results as shown in table 5.

Table 5. Experimental Results of Surface Roughness (Ra) of CFRP and Al2024.

No	Spindle speed	Feed Rate	Depth of cut	Ra CFRP	Ra Al2024	Desirability
1	11750.001	750.000	0.255	0.607	0.335	0.771
2	11775.572	750.011	0.255	0.606	0.336	0.769
3	11749.985	758.312	0.255	0.612	0.334	0767
4	11717.068	750.005	0.254	0.609	0.334	0.767
5	11749.981	762.408	0.255	0.615	0.333	0.767

The validation experiment conducted at optimum level of predicted control factors setting. The deviation of predicted value from the actual (measured) value is 3.11% for CFRP and 3.43% of Al2024.

5. Conclusion

Edges trimming analysis for surface quality of hybrid composite using Design of Experiment methodology, two level full factorial design has beed carried out. The influence and interaction of cutting parameters namely, spindle speed, feed rate and depth of cut on machined surface quality of

CFRP/Al2024 has been experimentally studied via trimming process. The surface quality of CFRP was influenced by the interaction effect between feed rate and depth of cut. The spindle speed and feed rate were the most significant parameters on surface quality of Al2024.

6. References

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Acknowledgement

The authors would like to thank Universiti Sultan Zainal Abidin for funding of this research project (UniSZA/2015/DPU/29) and TATi University College for allowing us to utilize equipment and laboratory.