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ORIGINAL ARTICLE

Machinability And Surface Quality Of Hybrid Composite CFRP/Al2024

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Abstract

The use of hybrid composite has increased due to their special mechanical and physical properties. However, machining of composite materials is extremely difficult due to non-homogeneous, anisotropic and highly abrasive characteristics. The performance of machined surface quality of CFRP/Al2024 was described using two level full factorial methodology. Trimming test was performed under dry conditions using 6mm diameter of burr tools end mills. The factors investigated were spindle speed(N), feed rate(fr) and depth of cut(dc), furthermore Ra CFRP and Ra Al2024 were the response variables. This work aims to minimize the machined surface quality of CFRP/Al2024 between 1µm to 2µm. The finding of this empirical study has shown that, the best estimated value of fr should be 500 mm/min to 530 mm/min, N is between and 2313.870 rpm to 2336.042 rpm. For both response spindle speed is the most significant effect followed by Feed rate and Depth of Cut.

Keywords: CFRP/Al2024; DoE; Surface roughness; Trimming.

Introduction

Carbon fibre reinforced plastics (CFRP) and Fibre metal laminates (FMLs) are often used in various application of aircraft components and structures due to high mechanical properties material. Both of these materials are widely adopted and superior substitutes when compared to conventional materials that required a lighter structural aircraft thereby improving fuel efficiency but still retaining the integrity of the structure. That is why advanced materials made of FMLs are highly recommended in aircraft manufacturing. However, machining of advanced materials severely challenging due to non-homogeneous, anisotropic and highly abrasive characteristic. All those characteristics produced poor surface quality, geometry defects and work piece damage that normally found in metal cutting. This phenomena may cause the long-term performance of this kind of materials degraded (Rahim et al., 2014; Savage, 2010; Zitoune et al., 2010). Aluminium grade 2024 and 7075 are normally used as a core or skin material of FMLs.

Moreover, the nature of aluminum alloy is easy to form and have excellent machinability compared to carbon fibers itself. According to Shyha and Nooraini et al., predominant damage has occurred while machine through composite and titanium rather than aluminium (Noorani et al., 2010; Shyha et al., 2010). As a result of these properties and potential applications, there is a need of investigations to understand the behaviour towards the machinability of these materials by establishing the models of composite laminates to increase machining efficiency of composite laminates with minimum of waste and defects. Usually composites for aircraft components are made to near net shape. On the other hand assembly of the components requires a secondary process since the excess of material occurs at the end of the moulding. Trimming and drilling are needed as the primary operation in most of the secondary machining for aircraft components (Rajmohan et al., 2012; Zenia et al., 2014).

Once the machining operation is done, surface finish of machined components are major concerns of the quality of the product. Previous studies suggest that the need of surface finish is very important in controlling the final form of the product quality (Castanié, 2013; Janardhan et al., 2006). Selection of cutting parameters will determine whether the machined surface meets the requirements or not, since it greatly influence the functionality of mechanical parts as well as satisfying the customer needs. Considering of investigation in composite trimming is not much studied, thus this motivates researchers to conduct this research to expand the gap in trimming of composite materials. In this work, factorial design technique was used to design a set of experimental investigation.

Factorial design is a popular technique in design of experiment (DoE). DoE technique can reduce the number of experiments, time, overall process cost and to obtain a better response. Many authors applied factorial designs for optimal conditions of parameters control in various applications (Butler, 2008; Gottipati and Mishra, 2010; Mohamed et al., 2015). A statistical analysis of variance (ANOVA) is employed to indicate the impact of cutting parameters on surface roughness. After each series of experiments, surface roughness tester was applied to check the roughness of machined surface. Trimming process is done to accomplish several objectives. The first objective is to analyze the influence and interaction of cutting parameters to a surface quality of CFRP/Al2024 composite graphically and statistically. Secondly, to find the optimal cutting conditions in order to minimize the surface texture quality of CFRP/Al2024 between 1µm to 2µm.

Methodology

In this work, the two level factorial design was applied and analysis was carried out in Design Expert software using statistical technique, ANOVA. This work examined how the mechanisms of the processes of composite machining. Carbon prepreg of 16 layers and 4.0mm thickness have been used. According to a journal article in composite structure written by (Zitoune et al., 2010), the lay up sequence of the unidirectional CFRP prepregs [90/-45/0/45/90/-45/0/45] was adopted to get a symmetric stacking. Aluminum alloy 2024 of 1.2 thicknesses was used to form a hybrid stack. An experiment was conducted under dry cutting conditions for trimming operation on Mori Seiki NV4000 DCG milling machine. Two Kennametal burr tool of 6 mm diameter was used to carry out the full experimental design. In this work, up milling method has been chosen to achieve the optimal parameter setting in order to produce a minimum surface roughness.

The roughness has been measured 5 times and averaged since the result of roughness are depends mainly on the stylus with respect to the direction of the fibers (Palanikumar, 2004). The surface roughness was measured using Mitutoyo SJ-301 with a sampling length (cut off) of 0.8mm. From the journal reviews, spindle speed, feed rate and depth of cut were identified as the dominant cutting parameters involved in composite machining. Machining condition and their levels used for carrying out trimming operations on CFRP/Al 2024 composite are given in Table 1. The layout of the design matrix are given in Table 2. In the table, the first 3 coloums indicate the main factors, which are set at different levels, and the remaining coloums indicate the surface roughness measurement. In the current work, analysis of variance (ANOVA) were produced to determine the significance effect factors and interactions of main effect between the factors were performed. It can be seen clearly from the interaction plot in order to provide a better understanding regarding influences and interaction between variables.

Table 1. Machining condition and their levels used for carrying out trimming operations on CFRP/Al 2024 composite

Factors	**units**	**min**	**max**
Spindle speed	*rpm*	1000	3500
Feed rate	mm/min	500	1000
Depth of cut	**mm**	**0.01**	**0.5**

Table 2. Layout of The Design Matrix

Run	**Spindle** speed [rpm]	**Feed** rate [mm/min]	**Depth of** cut [mm]	**Surface roughness, Ra** [µm] CFRP	Al2024
1	3500	500	0.01	0.68	0.74
2	3500	1000	0.01	0.88	0.77
3	1000	500	0.50	3.68	4.50
4	3500	500	0.50	1.45	1.67
5	1000	500	0.01	2.48	3.40
6	1000	1000	0.01	3.49	4.23
7	1000	1000	0.50	5.21	6.70
8	3500	1000	0.50	1.82	2.52

Results and Discussion

Analysis of variance(ANOVA)

After estimating the main effect, the interacting factors affecting the surface roughness were determined by performing the analysis of variance ANOVA. These results were input into the Design Expert software for further analysis. Without performing any transformation on the response, examination of the Fit Summary output revealed that the linear model is statistically significant for both responses and therefore it will be used for further analysis. As shown in Table 3. The main and interaction effects of each factor having P values <0.05 are considered as potentially significant.

Table 3. The main and interaction effects of each factor having P values <0.05

	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
CFRP						
Model	17.15	5	3.43	99.57	0.0100	significant
A-Spindle speed	*12.60*	*1*	*12.60*	*365.75*	*0.0027*	
B-Feed rate	*1.22*	*1*	*1.22*	*35.32*	*0.0272*	
C-Depth of cut	*2.67*	*1*	*2.67*	*77.45*	*0.0127*	
AB	*0.48*	*1*	*0.48*	*13.94*	*0.0648*	
AC	*0.19*	*1*	*0.19*	*5.40*	*0.1457*	

Residual	0.069	2	0.034			
Std. Dev. = 0.12; Mean = 2.46; R-squared =0.9960; Pred R-squared = 0.9860; Adj. R-squared = 0.9360						
Al2024						
Model	29.49	5	5.90	86.75	0.0114	significant
A-Spindle speed	*21.52*	*1*	*21.52*	*316.42*	*0.0031*	
B-Feed rate	*1.90*	*1*	*1.90*	*27.96*	*0.0340*	
C-Depth of cut	*4.90*	*1*	*4.90*	*72.04*	*0.0136*	
AB	*0.58*	*1*	*0.58*	*8.58*	*0.0995*	
BC	*0.59*	*1*	*0.59*	*8.74*	*0.0979*	
Residual	0.14	2	0.068			
Std. Dev. = 0.26; Mean = 3.07; R-squared =0.9954; Pred R-squared =0.9266; Adj. R-squared = 0.9839						

Regression Analysis

Based on ANOVA, a mathematical model was developed to estimate the optimal trimming parameters for optimization purpose. Final equation actual factors can be used to make predictions about response for given levels of each factors. The prediction equation for CFRP and Al2024 are presented as:

$$Ra_{CFRP} = +1.34422-2.89020E\text{-}004 * \text{Spindle speed}+3.32400E\text{-}003 * \text{Feed rate} +3.47755 * \text{Depth of cut}-7.84000E\text{-}007 * \text{Spindle speed} * \text{Feed rate} -4.97959E\text{-}004 * \text{Spindle speed} * \text{Depth of cut}$$

$$Ra_{Al2024} = +3.13543-6.64000E\text{-}004 * \text{Spindle speed}+2.75951E\text{-}003 * \text{Feed rate}-0.14286 * \text{Depth of cut}-8.64000E\text{-}007 * \text{Spindle speed} * \text{Feed rate}+4.44898E\text{-}003 * \text{Feed rate} * \text{Depth of cut}$$

Interaction plot

An interaction occurs when the response is different depending on the settings of two factors. Plots make it easy to interpret two factor interactions. They will appear with two non-parallel lines, indicating that the effect of one factor depends on the level of the other. The default "I beam" range symbols on the interaction plots are the result of least significant difference (LSD) calculations. If the plotted points fall outside the range, the differences are unlikely to be caused by error alone and can be attributed to the factor effects. If the I beams overlap there is not a significant difference (95% confidence is the default) between the two points. Figure 1 shows the interaction of A and C, with feed rate is at 750mm/min. From the AC interaction, the roughness effect is minimized when the depth of cut is at low level (black line) and maximum when the depth of cut is at high level (red line).

The best results are obtained at low depth of cut(C) and a maximum spindle speed (A). The interaction of A and B on CFRP is shown in Figure 2 with the depth of cut of 0.22mm. The combination of high feed rate and minimum spindle speed will produce maximum surface roughness. In contrary, the minimum of Ra CFRP would appear to be obtained when the feed rate at low level and spindle speed at the high level. Notice that the effect of surface roughness depends on level of feed rate. When feed rate is at a high level at low level spindle speed, the change in roughness goes very bad (maximum).

This is much clearer when graphed (see Figure 3) shows the interaction of A and B, with depth of cut is at 0.22mm. Moreover the effects of roughness depend on the level of

Depth of cut, represented by two lines on the graph (see Figure 4). On the low level of depth of cut the line is flat, which indicates that the system is unaffected by feed rate (B). But when the depth of cut goes high (C), the line angles go upward, indicating a negative effect due to the increase of feed rate. Here the LSD bars do not overlap indicates that the effect of feed rate is significant.

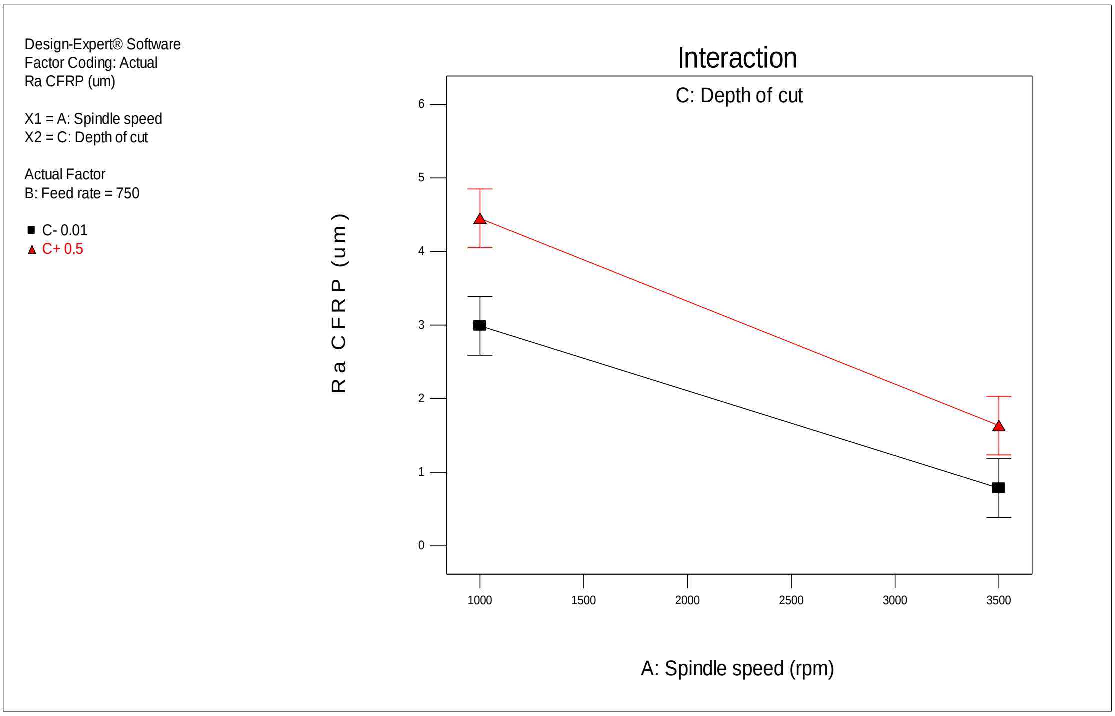

Figure 1. Interaction of Sindle speed (A) versus Depth of cut (C) on Ra CFRP

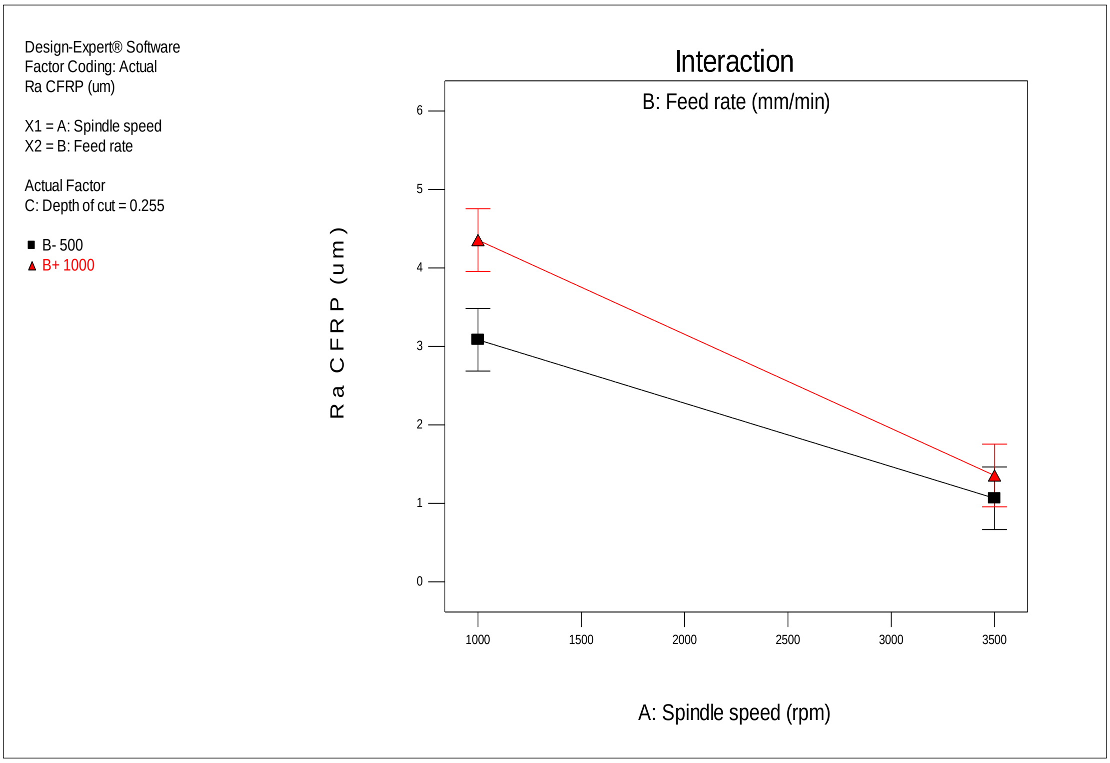

Figure 2. Interaction of Spindle speed (A) versus Feed rate (B) on Ra CFRP

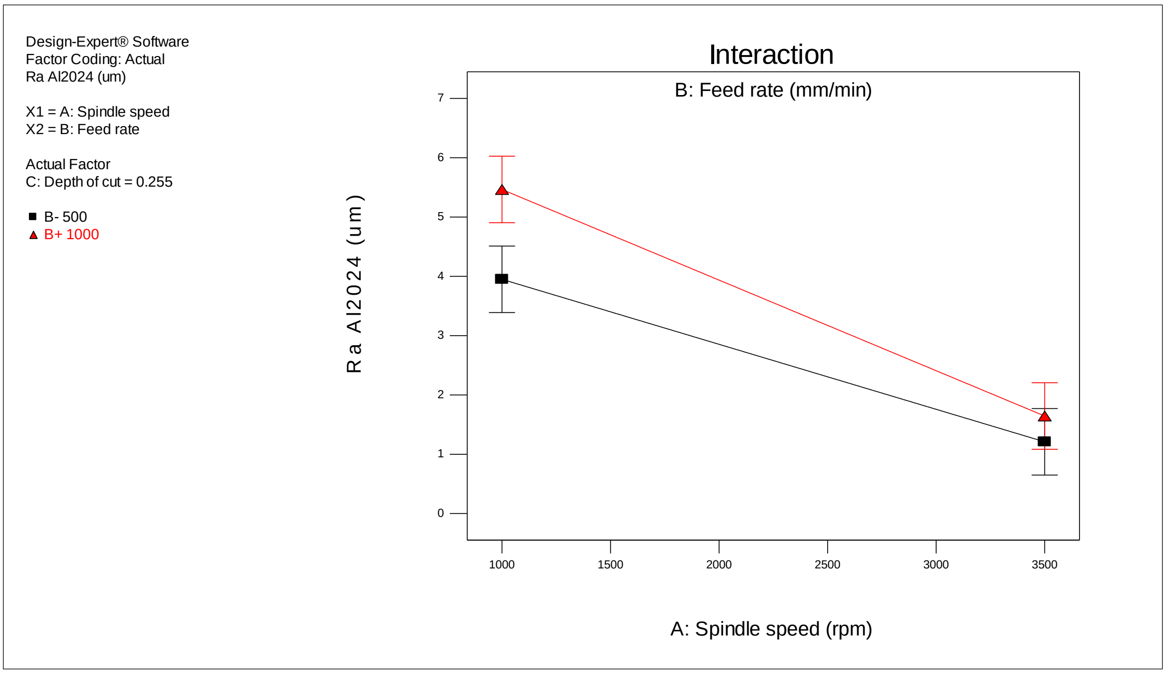

Figure 3. Interaction of Spindle speed(A) versus Feed rate(B) on Ra Al2024

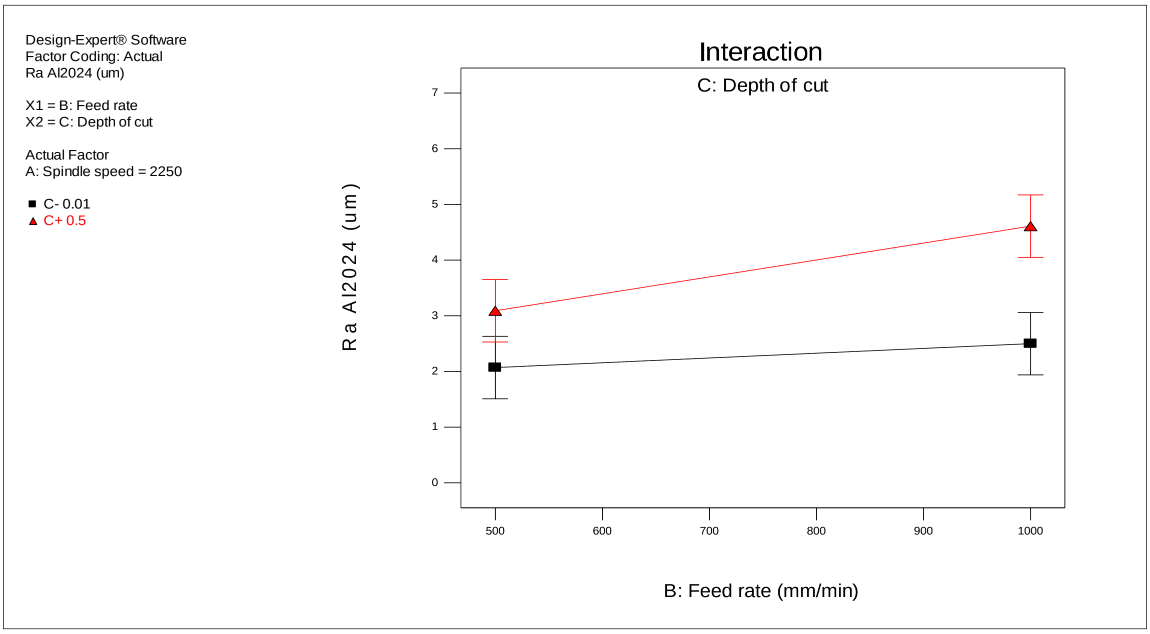

Figure 4. Interaction of feed rate(B) versus Depth of cut(C) on Ra Al2024

Optimal region

The design Expert provides optimal designs with the different desirability factors. Figure 5 shows the optimal region under consideration with the range of surface roughness between 1μm to 2 μm. The overlay plot provides graphical overview of the proposed factor settings with shaded area (yellow) that meeting the range of responses. The shaded region defines the allowable values of the factors (Spindle Speed and Feed Rate) with 0.01 depth of cut by determining the boundaries of the surface roughness desired.

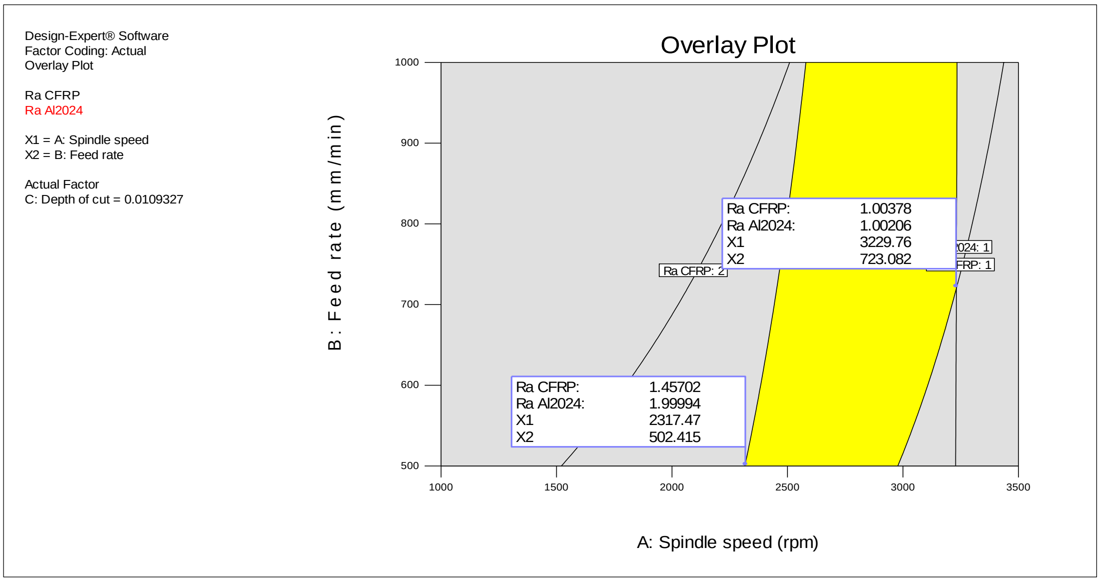

Figure 5. Overlay plot

Thus, the range of Feed rate and spindle speed for a presetting surface roughness value should be 500 mm/min to 1000 mm/min and 2317 rpm to 3229 rpm. The alternative solutions are shown in Table 4.

Table 4. Optimal Solutions

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:Spindle speed	is in range	1000	3500	1	1	3
B:Feed rate	is in range	500	1000	1	1	3
C:Depth of cut	is in range	0.01	0.5	1	1	3
Ra CFRP	is in range	1	2	1	1	3
Ra Al2024	is in range	1	2	1	1	3

Number	Spindle speed	Feed rate	Depth of cut	Ra CFRP	Ra Al2024	Desirability
1	2313.870	500.001	0.010	1.454	2.000	0.949
2	2315.789	502.619	0.010	1.456	2.000	0.947
3	2318.057	505.728	0.010	1.459	2.000	0.946
4	2323.655	500.000	0.015	1.459	2.000	0.941
5	2327.410	505.630	0.015	1.464	2.000	0.938
6	2329.720	500.616	0.010	1.444	1.983	0.936
7	2330.454	522.996	0.010	1.477	2.000	0.936
8	2333.599	527.448	0.010	1.481	2.000	0.933
9	2335.606	530.298	0.010	1.484	2.000	0.932
10	2336.042	500.000	0.022	1.465	2.000	0.931

Conclusions

An investigation of surface roughness of CFRP and Al2024 has been presented. Analysis of results was carried out by using two level full factorial design. Three factors were investigated, including spindle speed, feed rate and depth of cut. The results shown that, the spindle speed (A) has the most significant effect of both surface roughness of CFRP and Al2024, followed by the depth of cut, feed rate, interaction between spindle speed and feed rate(AB) as well as interaction between spindle speed and depth of cut (AC).

Surface roughness is the most crucial requirement on machined surface integrity. Generally, surface roughness increased with the increasing of spindle speed at lower of feed rate, however depth of cut only shows a small role (Nurhaniza et al., 2014; Hocheng et al,. 1993). Thus, the combination of high level of spindle speed and low level of feed rate is bad for surface roughness. The reason is simple, the productivity rate would decrease if the low level of feed rate used.

Moreover, if the high level of feed rate used it would affect the quality of machined surface and the cutting tools become dull due to heat generated occurred between cutting tool and workpiece. Therefore, optimization is a technique which was adopted as the best solution in order to control the system on how to optimise the combination between of cutting parameters while minimizing the machined surface defects. Furthermore, CFRP/Al2024 hybrid material can be applied to enhance the integrity of modern aircraft due to their unique properties.

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References

Butler, N. A. (2008). Defining equations for two-level factorial designs. *Journal of Statistical Planning and Inference*, 138(10): 3157–3163.

Castanié, H. and R. Z. F. E. B. (2013). Machinability and surface quality during high speed trimming of multi directional CFRP Madjid. *International Journal of Machinability of Materials*, 13:

Gottipati, R., & Mishra, S. (2010). Process optimization of adsorption of Cr (VI) on activated carbons prepared from plant precursors by a two-level full factorial design. *Chemical Engineering Journal*, 160(1): 99–107.

Hocheng, H., Puw, H. Y., & Huang, Y. (1993). Preliminary study on milling of unidirectional carbon fibre-reinforced plastics. *Composites Manufacturing*, 4(2): 103–108.

Janardhan, P., Sheikh-Ahmad, J., & Cheraghi, H. (2006). Edge trimming of CFRP with diamond interlocking tools. Aerospace Manufacturing and Automated Fastening Conference, (724).

Mohamed, S. B., Mohamad, W. N. F. W., Kasim, M. S., Ibrahim, Z., & Musanih, R. (2015). Machining Parameters Optimization for Trimming Operation in A Milling Machine Using Two Level Factorial Design. *Applied Mechanics, Materials Journal*, 789-790 (2015): 105–110.

Noorani, R., Farooque, Y., & Ioi, T. (2010). Improving Surface Roughness of CNC Milling Machined Aluminum Samples Due to Process Parameter Variation, 1–7.

Nurhaniza, M., Ariffin, M. K. A., Mustapha, F., & Baharudin, B. T. H. T. (2014). A review of machining process for composite materials. Regional Conference on Mechanical and Manufacturing Engineering, (October).

Palanikumar, K. (2004). Optimizing the machining parameters for minimum surface roughness in turning of GFRP composites using the design of experiments. *Cailiao Kexue Yu Jishu Journal*, 20(4): 373–378.

Rahim, E. A., Mohid, Z., Hamzah, M. R., Yusuf, A. F., & Rahman, N. . (2014). Performance of Tools Design when Helical Milling on Carbon Fiber. *Applied Mechanics, Materials Journal*, 466: 1075–1079.

Rajmohan, T., Palanikumar, K., & Kathirvel, M. (2012). Optimization of machining parameters in drilling hybrid aluminium metal matrix composites. *Transactions of Nonferrous Metals Society of China*, 22(6): 1286–1297.

Savage, G. (2010). Formula 1 Composites Engineering. *Engineering Failure Analysis*, 17(1): 92–115.

Shyha, I., Soo, S. L., Aspinwall, D. K., Bradley, S., Dawson, S., & Pretorius, C. J. (2010). Drilling of Titanium / CFRP / Aluminium Stacks. Key Engineering Materials, 448, 624–633. Zenia, S., Ben Ayed, L., Nouari, M., & Delamézière, a. (2014). Numerical analysis of the interaction between the cutting forces, induced cutting damage, and machining parameters of CFRP composites. *The International Journal of Advanced Manufacturing Technology*.

Zitoune, R., Krishnaraj, V., & Collombet, F. (2010). Study of drilling of composite material and aluminium stack. *Composite Structures*, 92(5): 1246–1255.

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