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Surface Roughness Optimization of Brass Reinforced Epoxy Composite Using CNC Milling Process

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ABSTRACT

This paper attempts to optimize the effect of cutting parameters on surface roughness of brass reinforced epoxy composite in CNC milling process. Practically, in milling operation, cutting parameters such as feedrate, spindle speed and depth of cut have greater effect on surface roughness. In this experiment, each parameter is determined by two machining levels. Thus, roughness analysis is carried out based on the L-4(2^3) Taguchi orthogonal array. Then, the effect of cutting parameters on surface roughness is evaluated by analysis of variance and also the optimal mixed-level array of the parameters is determined by using signal to noise ratio.

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INTRODUCTION

Recently, polymer matrix composites are utilized in various mechanical applications owing to their high quality characteristics like strength, stiffness and modulus (Narayana *et al*. 2011). In the field of advance material, several machining processes are carried out on polymer matrix composites to develop their applications. CNC milling is an advanced material removal process used for machining complex parts when high accuracy is required. For evaluating the milling process, Yih-fong and Ming-der (2005) aimed to improve high speed CNC milling process with dynamic quality characteristic. Davim *et al*. (2004) studied the milling process in two types of glass fiber reinforced polymer composites. Also, Davim and Reis (2005) in their research focused on damage and dimensional precision in milling process of carbon reinforced plastic composites.

In CNC machining, surface roughness is an important criterion for the quality of products and productivity of machining operations. Basically, in milling process, machining parameters such as feedrate, spindle speed, and depth of cut are the most effective parameters on the surface roughness. These parameters must be controlled to achieve desirable surface quality. In this regard, Fuh and Wu (1995) investigated the effect of the machining parameters on surface roughness of aluminum alloy (2014-T6). Sun and Guo (2009) conducted various milling conditions on titanium Ti–6Al–4V to achieve the minimum surface roughness. Azuddin and Abdullah (2011) studied burr formation and surface roughness on Aluminum 6061 during slot milling operation. However, minimizing the surface roughness is not an easy task and also it will increase the manufacturing costs. Meanwhile, a proper method must be used for evaluating the surface roughness. Thus, Benardos and Vosniakos (2003) presented different methodologies for prediction the surface roughness in machining processes. Ozcelik and Bayramoglu (2006) attempted to improve the statistical modeling for surface roughness in rapid end milling process. Omar *et al*. (2007) introduced the developed model which was applied to predict the 3D surface structure during milling process.

Taguchi design of experiment is a systematic technique which includes a set of procedures in order to study the effect of cutting parameters on surface roughness. Many researchers employed Taguchi design to improve the productivity in machining processes by optimizing the procedure. Ghani *et al*. (2004) applied Taguchi method to determine the optimal level of cutting parameters in milling process of hardened steel AISI H13. Gologlu and Sakarya (2008) also carried out this method to minimize the surface roughness in end milling of DIN 1.2738 mold steel. In Taguchi method, analysis of variance (ANOVA) is used to identify the effect of the cutting parameters on machined surface roughness. Also, signal to noise ratio (S/N) is employed to find the optimal combination of parameters. Wang *et al*. (2005) aimed to optimize the surface roughness in milling

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process of a brass workpiece using ANOVA method. Muthukrishnan and Davim (2009) conducted this method to optimize the machined surface of Al/SiC-MMC workpiece. Also, Zhang *et al*. (2007) employed both ANOVA analysis and signal to noise ratio to find the optimal mixed-level array of cutting parameters in CNC milling process. Therefore, in this study, we intend to minimize the surface roughness of brass reinforced epoxy composite by determining the optimal value of the cutting parameters in CNC milling operation by the use of Taguchi method.

MATERIALS AND METHODS

Preparation of Brass Reinforced Epoxy Composite:

Practically, the preparation of polymer matrix composites (PMCs) needs a strong knowledge of the matrix materials and fiber particles; which can be involved into shape, amount of material, and structural performance. Brass/epoxy composite is produced from combination of brass fibers in epoxy matrix. Brass particles were recycled from waste particles resulted from machining processes. Since they have various dimensions, they must be filtered out to get fine and uniform particles. Therefore, by using motorized sieve shaker (model SS 207/2-Technotest), the brass particles were filtered out from sieves with 600 μm dimensions. In the composite, as it is shown in Table 1, 70 grams of brass particles was combined with 80 grams of epoxy materials uniformly since epoxy itself was produced from 40.8 grams of resin and 39.2 grams of epichlorohydrin hardener.

In the following step, the mixtures were casted in rectangular Aluminum mold and heated in hot air oven by 63 ˚C during 8 hours. Finally, they were put in outside temperature during 12 hours to get stable form. It is necessary to note that, this temperature point is attained from the thermal characteristic of the epoxy material. Figure 1 shows a sample of brass/epoxy composite.

Table 1: Composition of the epoxy matrix and brass fibers.

EPOXY				BRASS	
Resin		Hardener			
volume fraction	weight (gms)	volume fraction	weight (gms)	volume fraction	weight (gms)
0.2720	40.8	0.2613	39.2	0.4667	70

Fig. 1: Brass reinforced epoxy composite.

Taguchi Design of Experiment:

1) Procedure of Taguchi Design:

Based on the objective of this study which is determining the optimal level of cutting parameters that leads to the lowest surface roughness, thus the main steps for Taguchi design in this experiment are listed as below.

1. Identify the objective function (surface roughness) to be optimized.
2. Identify the cutting parameters and their levels.
3. Selecting the proper orthogonal array according to the numbers of cutting parameters.
4. Carry out the experiment.
5. Analyze the data via ANOVA and S/N ratio.
6. Determining the optimum level of cutting parameters.

2) Taguchi Orthogonal Array (OA):

In this experiment Taguchi orthogonal array (OA) is used to make the design of experiment more applicable by reducing the number of the trials. In OA, each row shows the different mixed-level array of parameters combination in experiments. For experimental design, in this research each parameter was determined by two levels which are shown in Table 2.

Table 2: Machining levels of cutting parameters.

Factors	Cutting Parameters	Level 1	Level 2
A	Feedrate (mm/min)	10	20
B	Spindle speed (rpm)	1000	1500
C	Depth of cut (mm)	0.4	0.8

The selection of machining levels was attained by considering the nature of composite's components and running a sort of trial experiments before the main process to find the best machining levels which yielded to the lowest surface roughness. After selecting the level of cutting parameters, by the help of Minitab software, the proposed orthogonal array for 3 two-level parameters can be determined as L-4(2^3) array which is shown in the Table 3. As it can be seen, the 4 runs of experiments are different from each other. Therefore, it validates that the obtained result from each experiment would be different from the others.

Table 3: L-4(2^3) orthogonal array for experimental design.

Experimental run	Cutting factors and levels		
	A	B	C
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Experimental Set-up:

In this experiment, according to selected 4 mixed-level orthogonal array, the milling operation was processed via 3-axis CNC milling machine (OKUMA 45VX) using high strength substrate (HSS) 4-flute cutting tool with 6mm diameter. It is necessary to note that, this particular CNC machining was run under dry cutting condition because of the flexible nature of the materials which can absorb the coolant liquid that would cause changes in mechanical properties and surface texture of the machined workpiece.

Surface Roughness Evaluation:

3) Surface Roughness Tester:

In this work, perthometer S2 (MAHR) is used for measuring and documenting the surface roughness of each selected machined path in terms of R_a and R_z standards. It is necessary to explain that, for each of 4 machined paths, the measurement was carried out based on two points to attain more accurate results.

4) S/N Ratio Analysis:

Taguchi recommends the signal to noise ratio (S/N) method to study the effects of cutting parameters on surface roughness. The S/N ratio can be defined based on three main classifications which are labeled as smaller-the-better, larger-the-better and nominal-the-best characteristic. In this study, the smaller the better characteristic (S/N_s) is used since the minimum response (surface roughness) is desired. The calculation of S/Ns is shown as below.

$$S/N_S \text{ ratio} = -10 \log \frac{1}{N} [(\sum y_i{}^2)]$$

Where y_i is the individual measured roughness and N is the number of y_i.

5) Analysis of Variance (ANOVA):

In this investigation, the average roughness data attained from roughness tester are evaluated via ANOVA tables to study the effect of the cutting parameters on surface roughness of machined brass/epoxy composite.

RESULTS AND DISCUSSION

Experimental Results for Surface Roughness:

The obtained value of surface roughness measurement is shown in Table 4. In addition, Figure 2 displays one sample of the surface roughness measurement by perthometer S2 device. In this study, the calculations of S/N_s ratio are shown in Table 5 along with the values of $R_{average}$.

Table 4: Roughness value for the machined surface of brass/epoxy composite.

Experimental run	Feedrate (mm/min)	Spindle speed (rpm)	Depth of cut (mm)	R_a1 (μm)	R_a2 (μm)
1	10	1000	0.4	6.03	5.99
2	10	1500	0.8	8.32	7.71
3	20	1000	0.8	7.31	8.40
4	20	1500	0.4	8.54	8.06

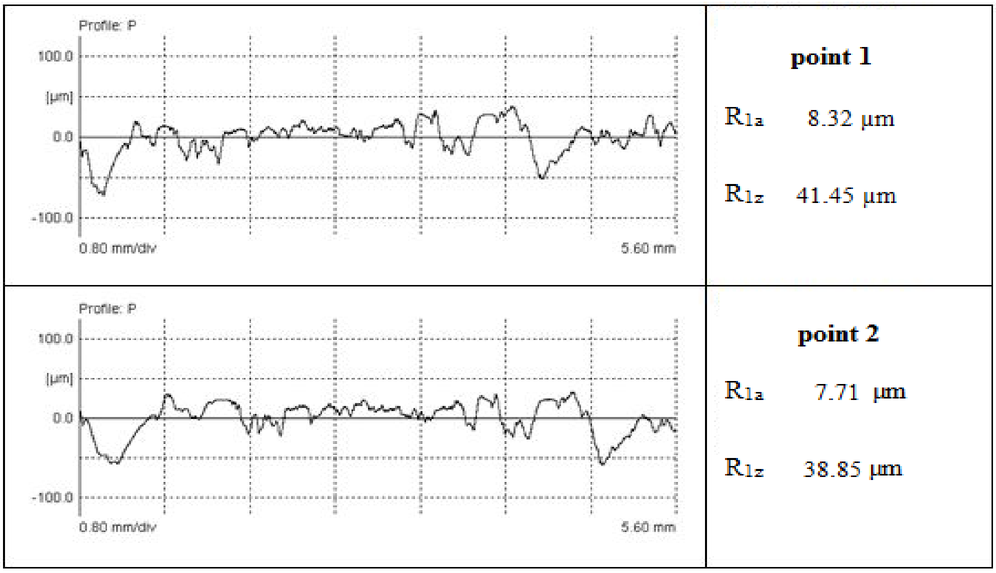

Fig. 2: Roughness graph for level 2 (A1, B2, C2).

Table 5: $R_{average}$ and S/N_s ratio response for surface roughness.

Experimental run	$R_{average}$ (µm)	S/N_s ratio
1	6.010	-15.577
2	8.015	-18.084
3	7.855	-17.924
4	8.300	-18.385

The Effect of Cutting Parameters on Surface Roughness Using ANOVA:

Based on the surface roughness data ($R_{average}$) and with the help of Minitab software, the ANOVA tables shown in Tables 6, 7 and 8 are created to investigate the effect of cutting parameters on surface roughness. These tables are designed by consideration the parameters degree of freedom, sum of square, mean of square (Variance), F-ratio (variance ratio) and P-value (probability value). Where the variance for each factor is the sum of square for each trial divided by the factor's degree of freedom and the variance ratio is defined as a variance of each trial divided by error variance.

Table 3: ANOVA analysis for the effect of feedrate on surface roughness.

Source	Degree of freedom	Sum of square	Mean square	F- ratio	P-value
Feedrate	1	1.134	1.134	1.080	0.409
Error	2	2.109	1.055		
Total	3	3.243			

Table 4: ANOVA analysis for the effect of spindle speed on surface roughness.

Source	Degree of freedom	Sum of square	Mean square	F- ratio	P-value
Spindle speed	1	1.5006	1.5006	1.720	0.320
Error	2	1.7426	0.8713		
Total	3	3.2433			

Table 5: ANOVA analysis for the effect of depth of cut on surface roughness.

Source	Degree of freedom	Sum of square	Mean square	F- ratio	P-value
Depth of cut	1	0.608	0.608	0.460	0.567
Error	2	2.635	1.317		
Total	3	3.243			

In order to assess the effect of each parameter on surface finish, it must be considered that factor with higher variance ratio or smaller P-value has larger effect on surface roughness. Therefore, in this experiment the spindle speed with the largest F-ratio (1.720) and smallest P-value (0.320) is determined as the most influential factor on surface roughness (Table 7). According to Tables 6 and 8, after spindle speed, between feedrate and depth of cut, the feedrate with 1.080 F-ratio and 0.409 P-value has larger effect on surface roughness rather than depth of cut with 0.460 F-ratio and 0.567 P-value. As a result of the three tables, it can be concluded that, the three cutting parameters have significant effect on surface roughness while difference of surface finish caused by varying spindle speed are higher than two other parameters.

Determination of Optimum Cutting Parameters with S/N Ratio:

The designed main effects plot of S/N_s ratio is shown in Figure 3. Practically, cutting parameters' set with the highest S/N_s ratio always produces the best surface quality. It means that the optimal level of each parameter can be defined as the level which contains the highest value of S/N_s. The graph shows that the variation of S/N_s plot in terms of spindle speed is higher than the other two factors. Therefore, spindle speed is determined as the most powerful factor that affects the surface finish as it was proven in ANOVA analysis. After spindle speed, between feedrate and depth of cut, the variation of S/N_s plot in the graph of feedrate is more than depth of cut, so it would cause more changes on surface finish.

According to Figure 3, in order to find the optimal cutting factors, feedrate of 10mm/min (A1) with the higher S/N_s ratio yields to the minimum surface roughness. Similarly, spindle speed at 1000 rpm (B1) and depth of cut at 0.4mm (C1) with larger S/N_s ratio lead to the minimum roughness. Thus, the optimal mixed-level array of cutting parameters which would result in minimum surface roughness in milling of brass/epoxy composite is defined as A1, B1 and C1. It means that, lower level of the parameters would cause to better surface quality. However, the parameters' setting of 20 mm/min feedrate, 1500 rpm spindle speed and 0.8 mm depth of cut (A2-B2-C2) with the lowest S/N_s ratio leads to the highest surface roughness. As a result of this study, it can be concluded that by increasing the machining level of the parameters, the surface roughness would be increased considerably.

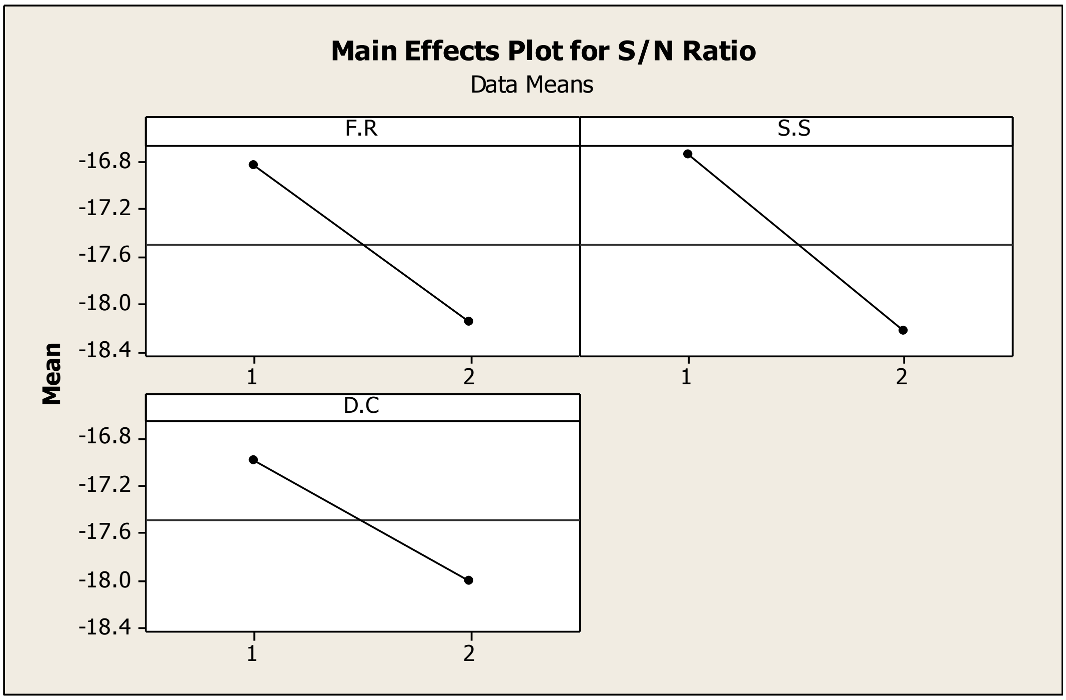

Fig. 3: Main effects plot for S/N ratio.

Conclusions:

This experimental investigation attempted to optimize the surface roughness of brass/epoxy composite by determining the optimal machining level of cutting parameters in CNC milling process. Thus, cutting parameters which are labeled as feedrate, spindle speed and depth of cut were determined by two machining levels. Then, the milling process and roughness analysis was carried out according to L-4(2^3) Taguchi orthogonal array. From ANOVA analysis, it was considered that each of three cutting parameters had significant effect on surface roughness. Among them, the spindle speed with the highest F-ratio (variance ratio) and smallest P-value (probability) was determined as the most effective parameter on the surface roughness. After spindle speed, feedrate and depth of cut also followed this pattern. In addition to ANOVA analysis, signal to noise ratio (S/N_s) technique was employed to identify the optimal mixed-level of machining parameters. The obtained results showed that the minimum surface roughness was attained at 10 mm/min feedrate, 1000 rpm spindle speed and 0.4 mm depth of cut (A1-B1-C1). While the maximum surface roughness was happened at the parameters' setting of 20 mm/min feedrate, 1500 rpm spindle speed and 0.8 mm depth of cut (A2-B2-C2). Overall, the result clarified that the better surface quality would be attained at the lower level of the parameters.

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