Journal of Manufacturing Engineering, March 2011, Vol. 6, Issue 1, pp 5-9

OPTIMIZATION OF TURNING PARAMETERS OF IN-SITU METAL MATRIX COMPOSITE FOR SURFACE ROUGHNESS USING TAGUCHI METHOD

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ABSTRACT

In-situ metal matrix composites have a potential for structural applications because of the presence of fine, small size and uniform distribution of reinforcements. An in-situ synthesized reinforcement particle yields better interface strength between the matrix and reinforcement than the composites fabricated by ex-situ technology. As a result, the mechanical properties, such as strength, stiffness and creep resistance are improved. The objective of the paper is to analyze the influence of machining parameters on surface roughness in turning of in-situ metal matrix composite using Taguchi method. The experiments are carried out by using L_{27} (3^{13}) orthogonal array. Analysis of variance (ANOVA) is carried out to identify the significant machining parameters affecting the surface roughness. The result indicates that feed rate is the more significant parameter than others. In order to correlate process parameters and measured surface roughness, a mathematical model has been developed by regression analysis.

Keywords: *In-situ Composites, Surface Roughness,* L_{27} (3^{13}) *Orthogonal Array*.

1. Introduction

Automotive and aircraft industries are seeking high performance materials in order to minimize the weight and improving the fuel economy. Aluminum matrix composite is suitable candidate material with which the improvement has been made not only in the decrease in density but also increase the strength and stiffness of the materials [1-3]. Many limitations are observed in processing the composite by ex-situ technology. Presence of large size reinforcements, poor wetting and thermodynamic instability leads to a limited improvement in mechanical properties [4]. Fabrication of composite by in-situ route can overcome these limitations. In-situ metal matrix composites are called as multiphase materials where the reinforcing phase is synthesized in a metallic matrix during the composite fabrication. The most important advantage among many is that the reinforcements so formed by in situ reaction are finer in size, and their distribution is more uniform, resulting in better mechanical properties of composites [5]. Machining the metal matrix composite material is difficult, because of the presence reinforcements in the soft matrix [6]. Selecting the optimal cutting parameter for the particular operation is a crucial task in order to serve competitiveness and increasing demand of quality product in the market. [7]. Surface roughness is the most critical quality measure for the mechanical components. Taguchi method is usually appreciated for its distribution-free and orthogonal array design and considerable reduction in time. This method is used to determine the important factors which are affecting operations with simultaneous improvement of quality and cost of manufacturing [8].Many researchers applying taguchi technique to optimize the machining parameters in machining ex-situ aluminum matrix composites. Davim [9] established a correlation between the cutting velocity, feed and cutting time with tool wear, power and surface roughness in turning of A356/20/SiC_p metal matrix composite. Taguchi technique, orthogonal array and analysis of variance are employed to investigate the cutting characteristics. Manna et al.[10] applied taguchi method to optimize the flank wear during turning of Al-20%SiC metal matrix composite. Zhang et al. [11] presented a study of the Taguchi design application to optimize surface quality in a CNC face milling operation. Confirmation tests verified that the Taguchi design was successful in optimizing milling parameters for surface roughness. Shetty et al. [12] reported a taguchi based experimental investigation to optimize the cutting force and cutting temperature in turning of Al6061/15/SiC composite. Navensait et al.[13] used taguchi method for predicting the surface roughness, cutting force; flank wear and crater wear as well as finding the optimal process parameter in machining of aluminum - glass fiber

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reinforced composite. Palanikumar and Karthikeyan [14] studied the influence of machining parameters on the surface finish obtained in turning of LM25 Al/SiC particulate composites. The experiments are conducted based on Taguchi's experimental design technique. The results and discussion shows that the developed model can be effectively used to predict the surface roughness on the machining of Al/SiC-MMC composites with 95% confidence intervals. However, there is no work addresses the optimization of the machining parameters for in-situ composites. Therefore, an attempt has been made to study the effect of machining parameters on the surface roughness in machining of Al-ZrB_2 in-situ metal matrix composite. Optimum machining conditions for minimizing the surface roughness is determined by using Taguchi method.

2. Experimental Work

In-situ Al-ZrB_2 metal matrix composite specimen has aluminum alloy 6061 as matrix and containing 6 % volume of ZrB_2 particles. The specimen is fabricated by flex assisted synthesis by reacting KBF_4 and K_2ZrF_6 salts. Figure 1 shows the EDAX pattern of the Al6061-6%ZrB_2 in-situ composite. The presence of ZrB_2 is confirmed by from the EDAX pattern. Silicon element from Al6061 also detected in the pattern. Fine, oxide free and uniform distributions of reinforcements are observed from figure2. Turn master -35 lathe (Kirloskar make) is used to carry out machining test (Figure 3.) and surf test SJ-210(Mitutoya, Japan) instrument is used to measure the surface roughness. The specification of insert and tool holder is given in Table1 The turning parameters namely cutting speed, feed rate and depth of cut each at three levels are considered in this work and the details are presented in the Table 2.

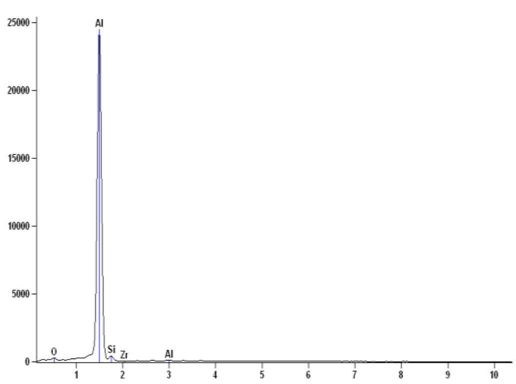

Fig. 1 EDAX Pattern of Al6061-6% ZrB_2 In-Situ Metal Matrix Composite

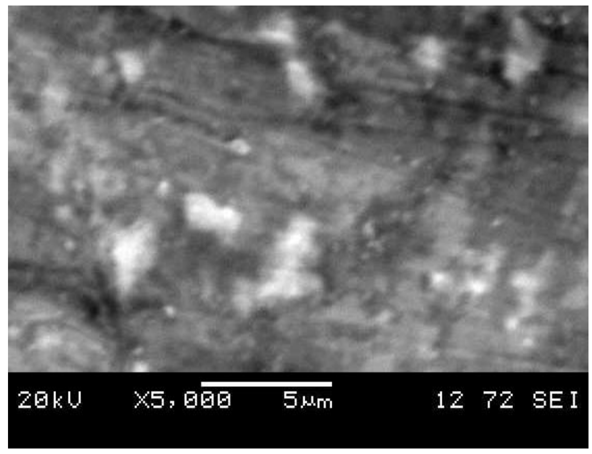

Fig. 2 Micrograph of Al6061-6% ZrB_2 In-Situ Metal Matrix Composite

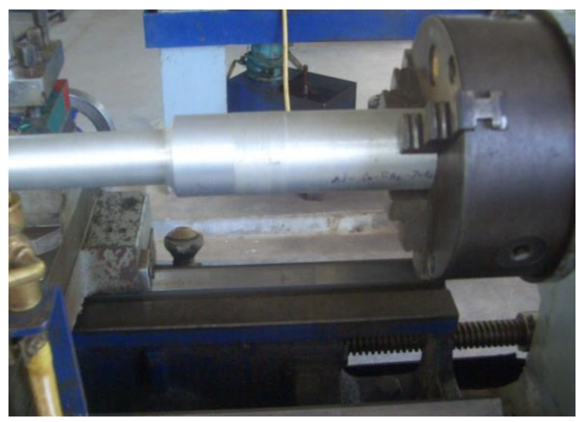

Fig. 3 Photographic View of Experimental Setup

Table 1: Experimental Conditions

Experimental conditions	
Cutting tool	Uncoated tungsten carbide
Cutting tool specification	SNMG120408 MTTT5100
Tool holder specification	PSBNR-2525M12
Clearance angle in °	7
Cutting edge angle in °	75
Nose radius (mm)	0.8
Reinforcement ratio (wt %)	6
Cutting condition	Dry

L_{27} (3^{13}) orthogonal array is selected to carry out the experimentation. There are three types of quality characteristics are available in taguchi method namely smaller-better, nominal -better and larger- better. This research work is aimed to produce the minimum surface roughness of the machined components. Therefore, a smaller-better characteristic is applied in this study. The surface roughness value for each experiment is evaluated as per L_{27} (3^{13}) orthogonal array shown in Table 3.

Table 2: Factors and Levels of Experimental Work

Factor Notation	Factor	1	2	3
A	Cutting speed (m/min)	100	125	150
B	Feed rate (mm/rev)	0.05	0.1	0.2
C	Depth of cut (mm)	0.5	1	1.5

Table 3: L27 (313) Orthogonal Array Table

Trail No.	Levels		
	A	B	C
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

3. Analysis of Results

Generally lowest surface roughness value is desired for setting optimal parameters. Response table (Table 4) and graph (Figure 4) for given experiment layout was generated by using Minitab 14 package. Response table for surface roughness is generated by grouping the responses by factor level for each column in the orthogonal array and taking average of them. Table 4 shows the difference between maximum and minimum value is more for feed rate followed by cutting speed. These values indicate that feed arte has strongest effect on surface roughness characteristics then other parameters. Increase in cutting speed will reduce the chip tool contact length, which reduce the friction in the machining interface, and build up edge formation. Therefore fracture and pulling of reinforcement particle as well as the deposition of buildup edge on the machined surface is minimized. This may be reason for good surface finish at higher cutting speed. Increase in feed rate will increase the area of cut and generated more feed force, when compared to lower feed rate. Hence pulling and fracture of reinforcement particle has increased. This will result high roughness at higher feed rate. Excessive depth of cut will increase the area of contact, temperature, build up edge formation, friction in the machining interface and radial force of cutting. Due to these reasons, surface roughness is increased when increasing the depth of cut. Response graph which was drawn from the table 4 which shows A_3, B_1 and C_1 have lowest response values. Therefore optimal level of parameters in turning of Al6061-ZrB_2 in-situ metal matrix composite for attaining good surface finish can be given as A_3, B_1 and C_1.

Table 4: Response Table for S/N Ratio for Surface Roughness and Significant Interaction

Parameters Level	A	B	C	AB	BC	AC
	Speed	feed	DOC	Speed-Feed	Feed-DOC	Speed-DOC
1	3.139	2.695	2.794	2.891	2.898	2.911
2	2.776	2.908	2.959	2.887	2.891	2.884
3	2.774	3.085	2.935	2.91	2.898	2.893
Delta	0.365	0.39	0.165	0.022	0.007	0.028
Rank	2	1	3	5	6	4

4. Analysis of Variance

Analysis of variance is performed to determine the level of significance of influencing factors by using Minitab-14 package and tabulated in Table 5. Fig 5 shows the percentage contribution of factors and their interactions on surface roughness. It is observed from

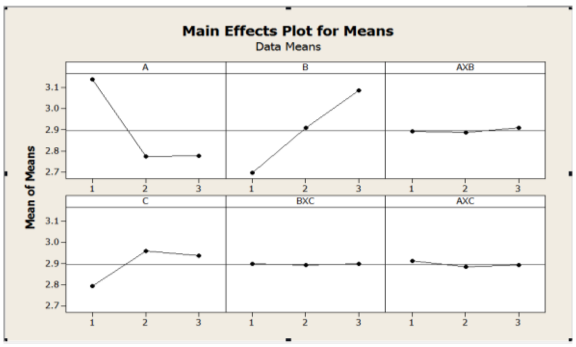

Fig. 4 Main Effects of Plot and Interaction Plot for Average Response (Surface Roughness)

fig 5 the feed rate (38.8 %) is the most significant factor followed by cutting speed (33.24 %). It can be observed from Tables 4 and 5 the order of importance (B > A >C AC > AB > BC) for the factors are in same sequence, which reveals the accuracy of the Taguchi method.

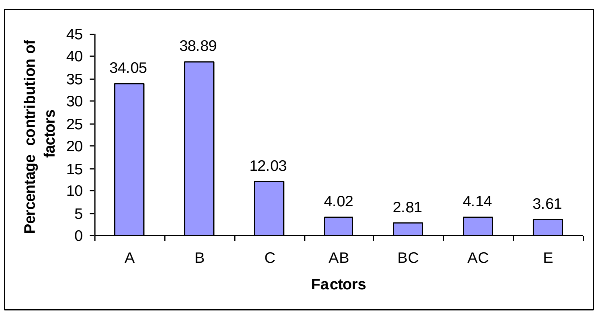

Fig. 5 Percentage Contribution of Factors

Table 5: Result of ANOVA

Factor notation	Control factor	DOF	Seq SS	Adj SS	Adj MS	F	P
A	Speed	2	0.253	0.253	0.127	11.8	**34**
B	Feed	2	0.291	0.291	0.146	13.6	**38.8**
C	DOC	2	0.09	0.042	0.021	1.96	**12**
AB	Speed-Feed	2	0.03	0.001	0	0.04	**4.02**
BC	Feed – DOC	2	0.021	0	0	0	**2.81**
AC	Speed-DOC	2	0.031	0.001	0.001	0.06	**4.14**
Error		14	0.027	0.15	0.011	1	**3.61**

5. Correlation

Correlation between the cutting speed, feed rate and depth of cut and measured value of surface roughness was obtained by multiple liner regression from Minitab14 package. At the optimal setting condition, the surface roughness equation obtained was as follows.

$$Ra = 2.73-0.182A+0.195B+0.0706C+0.0092AB-0.0004BC-0.0095AC \quad (1)$$

6. Confirmative Test

Confirmative test was conducted to verify the improvement of performance characteristics at the optimal levels of selected turning parameters. The optimum machining parameter for the turning operation was set, and two trials were conducted. Table 6 shows that 1.58 % error is observed between the predicted value (2.53 µm) and experimental value (2.49µm) of the optimum parameters. There is a 4.5 % improvement in surface roughness is achieved by setting optimal parameter (2.49 µm) when compared to initial machining parameters (2.64µm). Therefore, Equation. 1 correlates the evaluation surface roughness with a reasonable degree of approximation.

Table 6: Result of Confirmative Test

Level	**Initial**	**Optimal machining parameters**	
	Machining parameters	**Prediction (Eqn. 1)**	**Experiment (Average value of trail 1 &2)**
Setting level	$A_1 B_1 C_1$	$A_3 B_1 C_1$	$A_3 B_1 C_1$
Surface roughness	2.64 µm	2.53 µm	2.49 µm

7. Conclusion

The optimal level of machining parameters to obtain the good surface finish in turning of Al-6061-6% ZrB_2 in-situ metal matrix composite is A_3(cutting speed of 150 m/min),B_1 (Feed rate of 0.05 mm/rev) and C_1(Depth of cut of 0.5mm). The difference between the maximum and minimum value of surface roughness obtained from response table shows that the cutting speed has greater influence of surface roughness. Analysis of variance also confirmed that feed rate has the significant influence on surface roughness with 38 % contribution followed by cutting speed 34 % and the depth of cut 12 %. It is observed from the confirmation run, there is a good agreement between the estimated value and experimental value of the surface roughness. Thus linear regression model may employ successfully for designing process parameters in turning of Al-6061-6% ZrB_2 in-situ metal matrix composite.

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