Proceedings of Malaysian International Tribology Conference 2015, pp. 259-260, November 2015

Surface roughness of AlSi/AlN metal matrix composite material using the Taguchi method

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Keywords: AlSi/AlN Metal Matrix Composite (MMC); optimum machining parameter; surface roughness

ABSTRACT – This paper presents the surface roughness of aluminum silicon alloy (AlSi) matrix composite reinforced with aluminum nitride (AlN) using three types of carbide inserts. Experiments were conducted at various cutting speeds, feed rates, and depths of cut, according to the Taguchi method, using a standard orthogonal array L_{27} (3^4). Signal-to-noise (S/N) ratio and ANOVA were applied to study the characteristic performance of cutting speed, feed rate, depth of cut, and tool types in measuring surface roughness during milling. The surface roughness of the machined surface were observed using Mitutoyo Formtracer CS-500. Analytical results using the Taguchi method showed that enhanced surface roughness could be obtained using low feed rate, medium depth of cut, low cutting speed, and TiB_2 insert. Optimal surface roughness was obtained under the following machining parameters: cutting speed, 230 m/min; feed rate, 0.4 mm/tooth; depth of cut, 0.5 mm, and TiB_2 insert.

1. INTRODUCTION

Metal matrix composites (MMCs) are composite materials widely used in aerospace, automotive, electronics, and medical industries. These materials possess outstanding properties such as high strength, low weight, high modules, low ductility, high wear resistance, high thermal conductivity, and low thermal expansion. These desirable properties are mainly manipulated by the matrix, reinforcement element, and interface [1]. MMCs exhibit poor machinability because of the hard and abrasive reinforcement used [2]. These materials are usually applied in bearings, automobile pistons, cylinder liners, and piston rings, connecting rods, sliding electrical contacts, turbo charger impellers, and space structures. The most popular reinforcements are silicon carbide (SiC) and alumina (Al_2O_3). Aluminum, titanium, and magnesium alloys are commonly used as the matrix phase [1]. MMCs possess the combined properties of metals and ceramics [3,4]. The structure and properties of MMCs are affected by the type and properties of the matrix, reinforcement, and interface [5]. Thus, these materials have been increasingly used to replace conventional materials in numerous applications [4]. Surface roughness has been given significant attention for many years [6], and has been considered in fatigue load, precision fits, fasteners hole, and aesthetic requirements. In addition to tolerance, surface roughness imposes one of the most critical aspects in selection of machine and cutting parameter in the planning process [6,7].

2. METHODOLOGY

2.1 Surface Roughness Measurement

Coated carbide cutting tools performed better than uncoated cutting tools in terms of surface finish. The surface roughness values using various cutting speeds, feed rate, depth of cut, and type of insert are shown in Table 1.

2.2 Materials and the Milling Process

AlN reinforced Al-Si alloy matrix composite was fabricated using the stir casting method, where Al-Si alloy ingot, called the matrix material, was reinforced with AlN particles of 10wt% reinforcement.

Table 1 The Taguchi L_{27} orthogonal array.

Test No	A	B	C	D	SR (µm)	S/N ratio for SR
1	0	0	0	0	0.63	4.01
2	0	0	1	1	0.74	2.61
3	0	0	2	2	0.49	6.20
4	0	1	0	1	0.70	3.10
5	0	1	1	2	0.41	7.74
6	0	1	2	0	0.86	1.31
7	0	2	0	2	0.41	7.74
8	0	2	1	0	0.82	1.72
9	0	2	2	1	0.88	1.11
10	1	0	0	1	0.59	4.58
11	1	0	1	2	0.55	5.19
12	1	0	2	0	0.60	4.43
13	1	1	0	2	0.94	0.54
14	1	1	1	0	0.60	4.44
15	1	1	2	1	0.94	0.54
16	1	2	0	0	0.84	1.51
17	1	2	1	1	1.10	-0.83
18	1	2	2	2	0.60	4.44
19	2	0	0	2	0.57	4.88
20	2	0	1	0	0.78	2.16
21	2	0	2	1	0.90	0.92
22	2	1	0	0	0.87	1.21
23	2	1	1	1	0.97	0.26
24	2	1	2	2	0.72	2.85
25	2	2	0	1	0.92	0.72
26	2	2	1	2	0.70	3.10
27	2	2	2	0	0.80	1.94

The experimental study was carried out in a CNC Vertical Milling Center Lagun-GVC1000 milling machine. Cutting inserts were attached to the tool with a body diameter of ∅20mm. The tool holder used was CoroMill R390-020C4-11L and the tool inserts was uncoated cemented carbide ISO catalogue no: R390-11T08E-NL, TiN coating development by SIRIM and a commercial tool insert, KC410M PVD TiB_2 coating. The experiment has three different cutting speeds (230,300 and 370 m/min) with constant feed rate (0.4, 0.6, 0.8 mm/rev) and depth of cut (0.3, 0.4 and 0.5mm) under dry cutting condition. The worked material was fabricated in the form of block 120mm length x 50mm width x 50mm thickness.

2.3 Taguchi Method

In this experiment, with four factors (each with three levels), the fractional factorial design used was a standard L_{27} (3^4) orthogonal array. The orthogonal array was chosen because of its minimum number of required experimental trials. Each row of the matrix represented one trial [8]. The optimization for surface roughness is using the smaller is better characteristics.

3. RESULT AND DISCUSSION

3.1 Surface Roughness and S/N Ratio

Surface roughness was analyzed based on the Taguchi method and S/N ratio as in Table 1. These ratios were generated according to Taguchi's smaller-is-better characteristic.

3.2 Optimization of Machining Conditions Using the Taguchi Method

This study was conducted to determine the optimum condition for surface roughness when AlSi/AlN is cut using three different cutting tools. One of the methods used to analyze data for process optimization considered S/N ratio. Fig. 1 shows the mean S/N ratio for the smaller-is-better characteristics of surface roughness obtained using Minitab 17. The slope of the graphs clearly show that insert type is the most significant factor, followed by the type of cutting speed, feed rate, and depth of cut. Based on Fig. 1, the optimum parameters for surface roughness is cutting speed of 230 m/min; feed rate of 0.4 mm/tooth; depth of cut of 0.3 mm; and TiB_2 tool insert.

4. CONCLUSION

The Taguchi method was applied in the experimental design to optimize multi response process parameters of end milling. The machining of AlSi/AlN MMC was optimized using an L27 orthogonal array. The results were drawn based on the experiments. The optimum machining parameters for surface roughness were as follows: cutting speed, 230 m/min; feed rate, 0.4 mm/tooth; depth of cut, 0.3 mm; and TiB_2 tool insert. These optimum parameters will facilitate the competitive machining operation from the economical and manufacturing perspective in the automotive industry.

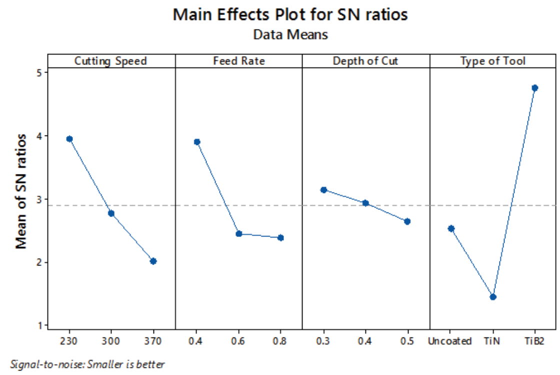

Figure 1 S/N ratio effects of machining parameters.

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