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SURFACE ROUGHNESS OF MAGNESIUM ALLOY AZ91D IN HIGH SPEED MILLING

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Abstract

Magnesium alloy is a material with a high strength to weight ratio and is suitable for various applications such as in automotive, aerospace, electronics, industrial, biomedical and sports. Most end products require a mirror-like finish, therefore, this paper will present how a mirror-like finishing can be achieved using a high speed face milling that is equivalent to the manual polishing process. The high speed cutting regime for magnesium alloy was studied at the range of 900-1400 m/min, and the feed rate for finishing at 0.03-0.09 mm/tooth. The surface roughness found for this range of cutting parameters were between 0.061-0.133 µm, which is less than the 0.5µm that can be obtained by manual polishing. Furthermore, from the S/N ratio plots, the optimum cutting condition for the surface roughness can be achieved at a cutting speed of 1100 m/min, feed rate 0.03 mm/tooth, axial depth of cut of 0.20 mm and radial depth of cut of 10 mm. From the experimental result the lowest surface roughness of 0.061µm was obtained at 900 m/min with the same conditions for other cutting parameters. This study revealed that by milling AZ91D at a high speed cutting, it is possible to eliminate the polishing process to achieve a mirror-like finishing.

Keywords: High speed machining; AZ91D; surface roughness

Abstrak

Aloi magnesium adalah bahan dengan kekuatan tinggi kepada nisbah berat dan ianya sesuai untuk pelbagai aplikasi seperti dalam sektor automotif, aeroangkasa, elektronik, industri, bioperubatan dan sukan. Kebanyakan produk akhir memerlukan permukaan kemasan seperti cermin, Oleh itu kertas kerja ini akan membentangkan bagaimana permukaan seperti cermin boleh dicapai dengan menggunakan process pemesinan kisar muka tinggi yang menyamai dengan proses gilap manual. Julat Laju tinggi bagi aloi magnesium telah dikaji dalam lingkungan 900-1400 m/min, dan kadar suapan untuk kemasan diantara 0.03-0.09 mm/gigi. Hasil Kekasaran permukaan diperolehi di antara 0.061-0.133 µm, iaitu kurang daripada 0.5µm yang boleh diperolehi dengan menggilap manual. Tambahan pula, dari S/N nisbah plot, keadaan pemotongan optimum untuk kekasaran permukaan boleh dicapai pada laju pemotongan 1100 m/min, kadar suapan 0.03 mm/gigi, kedalaman potongan 0.20 mm dan dalam pemotonganjejari10 mm.Daripada keputusan eksperimen, kemasan permukaan 0.061 µm paling rendah diperolehi pada 900 m/min dengan keadaan parameter pemotongan yang lain adalah sama.Kajian ini mendapati dengan memesin AZ91D pada laju yang tinggi, ianya berupaya untuk menghapuskan proses gilap secara manual bagi mencapai kemasan seperti cermin.

Kata kunci: Proses pemesinan berkelajuan tinggi; AZ91D; Kemasan permukaan

1.0 INTRODUCTION

Today's interest is focused on the growing demand for more fuel-efficient vehicles to reduce energy consumption and air pollution. Addressing this concern has become a challenge for the current automotive industry. Magnesium alloy is one of the lightest materials and it is rapidly gaining more acceptances in various applications, such as in the automotive, aerospace, electronics, industrial biomedical and sports industries. Due to its lightness and durability, there was an increase of usage of magnesium in the automotive industry in parallel with the advancement in the new frontier technology [1].Most lightweight materials, such as magnesium, are widely used in the automotive and truck manufacturing industries [2]. In terms of fuel efficiency and for economic reasons, magnesium alloy is the best choice since it has a relatively low density compared to other materials. However, magnesium alloy exhibited poor machining at low temperatures due to its hexagonal closed-packed crystal structure, consequently requiring it to be processed at elevated temperatures. Its high affinity to oxygen leads to easy oxidation [3].Support and cover in drive train parts are examples made using AZ91D [4].

Machining magnesium die-cast offers a definite advantage over aluminium because magnesium machines dry up due to the natural lubricate and rapid heat dissipation [4]. The cutting forces for magnesium alloy are extremely small compared to those for aluminium alloy. From the recent studies and researches about the machining of magnesium alloy, researchers found that magnesium has better machinability than other materials [5, 6].

Surface roughness is commonly considered an important aspect to measure because it greatly influences the product quality. Kim and Lee [7] researched the magnesium alloy AZ31B using dry milling and found that surface roughness increases with the increasing of the feed rate per tooth and the increasing number of inserts in the cutting tool. The study of magnesium alloy done by Tönshoff and Winkler [8] was about the interaction between the tool material and tool coating under magnesium machining. Since surface roughness plays an important role for qualifying the product quality, this research aims to study the surface roughness obtained during the high speed cutting regime of the magnesium alloy AZ91D in a face milling process using a non-coated cemented carbide insert.

2.0 METHODOLOGY

In this study the magnesium alloy AZ91D used was provided by Sellwell Industries Group Limited. The size of the work piece had a dimension of 150mm length, 150mm width and 50mm height. The chemical composition of this material is shown in Table 1.

Table 1 Chemical composition of work material of AZ91D

Chemical composition (%)						
Al	Zn	Mn	Fe	Si	Cu	Ni
8.73	0.65	0.2	0.0028	0.012	0.0019	0.0004

The cutting tool used was the WALTER SDGT 09T3-AEN-688 and the cutting tool holder Walter F2233.B.050.204.05 with a diameter of 50mm and with the chemical composition as shown in Table 2.

Table 2 Chemical composition of carbide cutting tool

Chemical composition (%)						
WC	TiC	TaC	Cr3C2	Co	Ni	ISO Grade
92.7	-	1.0	0.3	6.0	-	N(K10)

The experiment was performed with a high speed milling regime. The Taguchi L9 (3^4) orthogonal array was utilized to accommodate the experimental run as shown in Table 3.

Table 3 Factors and levels used in the experimental work

Factor/Level	0	1	2
Cutting Speed Vc (m/min)	900	1100	1400
Feed Fz (mm/tooth)	0.03	0.06	0.09
Axial depth -Ap (mm)	0.2	0.25	0.3
Radial depth - Ae (mm)	10	35	50

The cutting speed (Vc), feed rate (Fz), axial (Ap) and radial depth of cut (Ae) were included in an experiment design that was suitable for a high speed machining regime of magnesium alloy. The cutting speed (Vc) was in the range of 900-1400m/min. The feed rate was 0.03-0.09 mm/tooth which is suitable for the finishing cut. The axial depth of cut was less than 0.5 mm, which is also suitable for the finishing cut. The challenge in cutting the magnesium alloy at a very small depth of cut was due to the spark generated during the cutting. The machine used was the Spinner VC450 Machining Centre with a capacity of 5.6 kW power and 23 Nm torque. The machining was carried out in a dry condition. A Mitutoyo Surftest SJ-310 surface roughness tester was used for measuring the roughness values of the machined surface. The measurement was taken after the milling was performed and was repeated 5 times to find the average and standard deviation values.

3.0 RESULTS AND DISCUSSION

The main aim of this study is to evaluate the factors affecting the measured surface roughness, as well as to determine the optimum cutting parameters for the surface roughness. The smallest axial depth of cut was used to observe any occurrence of spark. From nine trial runs, spark was only observed with trial run No. 4, as shown in Figure 1. In most previous studies, a high depth of cut was used to avoid the occurrence of sparks in the machining of magnesium alloy [8] since the chip formed needs to be kept large to reduce any fire hazard potential and to avoid damaging the machine tool components by polluting sensitive areas under dry machining conditions. In this study, although a small axial depth of cut of less than 0.5 mm was used, the occurrence of spark was observed only once.

Figure 1 Spark and flying chips observed in run trial 4

Table 4 shows that the lowest surface roughness of 0.061µm was achieved in trial run 1 using the cutting speed of 900 m/min, with a feed rate of 0.030 mm/tooth and a depth of cut of 0.2mm. This study shows the worst measurement of surface roughness was 0.133µm from trial run 8 at a cutting speed of 1400 m/min, with a feed rate of 0.06 mm/tooth and a 0.2 mm depth of cut. This is probably due to the interaction between the tool material and tool coating under magnesium machining at very high cutting speed [8]. Due to this low cutting speed of 900 m/min is preferable. But the S/N ratio analysis was found that the combination of moderate cutting speed of 1100 m/min, low feed rate of 0.03 mm/tooth, and low radial and axial depth of cut of 0.2 mm and 10 mm respectively will produce a good surface finish. At this condition it is expected that the Ra is lower than 0.061µm.But,all the results obtained for the surface roughness was less than 0.5µm, which means it is better than manual polishing [9, 10].

In order to analyse in detail the factors that affect the surface roughness, an ANOVA and S/N ratio were performed on the experimental results. These were analysed using options that were available in the Minitab 11 software. The characteristics chosen for the surface roughness was smaller the better for the S/N ratio.

Table 4 L9 (3^4) Orthogonal Array with experiment

	Factor				Response
Run	Vc (rev/min)	Fz (mm/tooth)	Ap (mm)	Ae (mm)	RA (µm)
1	900	0.03	0.2	10	0.061
2	900	0.06	0.25	35	0.096
3	900	0.09	0.3	50	0.129
4	1100	0.03	0.25	50	0.080
5	1100	0.06	0.3	10	0.076
6	1100	0.09	0.2	35	0.109
7	1400	0.03	0.3	35	0.099
8	1400	0.06	0.2	50	0.133
9	1400	0.09	0.25	10	0.120

Table 5 shows the ANOVA for the response surface linear model of the results analysed. From Table 5 it can be seen that the feed rate and radial depth are significant factors that influence the surface roughness values. The effect of the feed rate on the surface roughness in this study was similarly observed by other researchers [11-14]. Even though the cutting speed was found to be not significant, the P value was more by only 0.01, whereas the axial depth of cut was found to be not significant with a high P value of 0.9732.

Table 5 ANOVA for response surface linear model

Source	Sum of Squares	df	Mean	F Value	p-value Prob> F	
Model	0.004402623	4	0.001100656	8.444218248	**0.0313**	**significant**
A-Vc	0.000881289	1	0.000881289	6.761242997	0.0600	
B-fz	0.002320667	1	0.002320667	17.80412874	**0.0135**	
C-Ap	1.66667E-07	1	1.66667E-07	0.001278665	0.9732	
D-Ae	0.0012005	1	0.0012005	9.210222589	**0.0386**	
Residual	0.000521377	4	0.000130344			
Cor Total	0.004924	8				

The ranking of the factors that affect the surface roughness from the response table for means are the feed rate, cutting speed, axial depth and radial depth of cut respectively as shown in Table 6. The results in Table 6 and Figure 2 are similar. From Figure 2, the feed rate is the most significant factor that affects the surface roughness, followed by radial depth of cut, cutting speed and depth of cut. The effect of feed rate on surface roughness in this study was similarly found by Kim and Lee [7]. They found that surface roughness increases with the increasing of the feed rate per tooth when dry milling magnesium alloy AZ31B.The plots clearly show that the optimum cutting condition for surface roughness is at a cutting speed of 900 m/min, feed rate of 0.03 mm/tooth, axial depth of cut of 0.2 mm and radial depth of cut of 10 mm. But the result obtained in Table 4; shows that the Ra value of 0.061µm is achieved when machining at cutting speed of 900 m/min, feed rate on 0.03 mm, axial depth of cut of 0.2 mm and radial depth of cut of 10 mm.

Table 6 Response Table for means (smaller is better)

Level	Vc (rev/min)	Fz(mm/tooth)	Ap (mm)	Ae (mm)
1	0.09533	0.08000	0.10100	0.08567
2	0.08833	0.10167	0.09867	0.10133
3	0.11733	0.11933	0.10133	0.11400
Delta	0.02900	0.03933	0.00267	0.02833
Rank	2	1	4	3

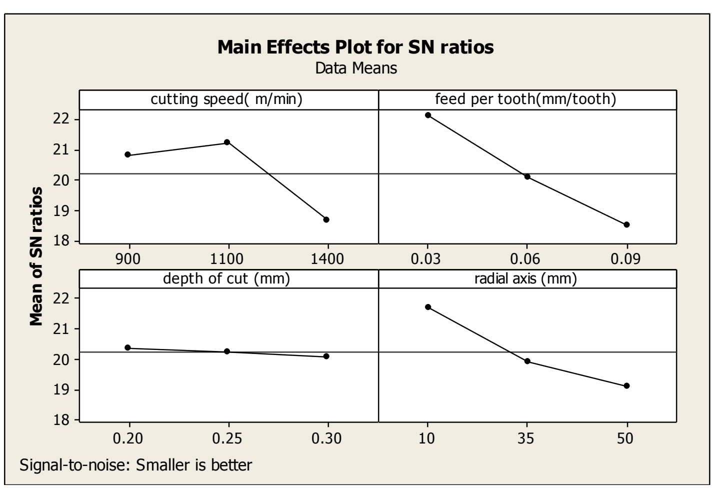

Figure 2 Main Effect plot for SN Ratio

4.0 CONCLUSION

From the study conducted, it was found that good surface roughness was achieved in the range of 0.061-0.133 µm, which is less than 0.5µm as can be obtained by manual polishing. Further, from the S/N ratio plots, the optimum cutting condition for surface roughness can be achieved at a cutting speed of 900 m/min, feed rate 0.03 mm/tooth, axial depth of cut of 0.20 mm and radial depth of cut of 10 mm. This study revealed that high speed cutting is able to eliminate the polishing process to achieve a mirror-like finishing in the face milling of magnesium alloy. Furthermore, no spark was observed except for trial run No. 4, although a small axial depth of cut of less than 0.5 mm was used in this study.

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