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RESEARCH ARTICLE

Milling of Magnesium Alloy with Micro Cutting Tools

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HIGHLIGHTS

> It is seen that the Taguchi optimisation technique is a useful technique in the design of the workability test of AZ91 magnesium alloy material, optimisation of parameters, and obtaining the desired rates of response values.

> The results obtained from the experimental study with the analysis of variance (ANOVA) are as follows; the most effective factor in creation of cutting forces was a rotation with 73.83%, and the second most effective factor in creation of cutting force was feed rate with 18.25%.

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ABSTRACT

Micromachining is a method of manufacturing micro-scale products with three-dimensional and complex geometry by using engineering materials with narrow tolerances and high precision. In this study, the effects of feed, cutting speed and chip depth on milling of magnesium alloy material by micro-milling cutting tools were investigated. Taguchi method was used in the test design. By this means, time and cost were saved. The data obtained from the experiments were optimised. The effect of each parameter on the obtained results was determined by using analysis of variance (ANOVA). It is seen from the results of the experimental study obtained by the analysis of variance (ANOVA) that the most effective factor on the formation of cutting force is the revolution with 73,83%. In this study where the Taguchi method was used, the cutting force was minimized. The performance was increased, and the quality of the end product was improved. In this study, it was tried to determine the optimal workability of magnesium material with micro micro-finger milling machining.

Contents

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1. Introduction

At present, micro-scale products are needed and required in many industries such as aeronautics and space, medical and healthcare, electronics, optics and biotechnology. Although other methods are used in the manufacture of micro-sized parts, there are restrictions such as not being able to apply them to every workpiece, high cost and low productivity. Therefore, micro-machining methods (micro turning, micro milling, micro drilling and micro surface and hole grinding) are widely used. With these methods, a large number of engineering materials, micro parts and complex surfaces of moulded micro parts in the mould can be easily machined [1–4].

Although the micro-machining in the form of micro-milling is a technique similar to macro-milling, the significant difference between the two machining methods is that the tool sizes are small in micro-machining (Figure 1) [5].

Figure 1 Ø6 tool used in micro-machining and Ø1, Ø0.6, Ø0.5, Ø0.3 and Ø0.15 micro-tools used in micro-machining seen respectively in the picture.

In this kind of machining, mostly 100-999 μm diameter micro end milling cutters are used. The small diameter shaft of micro end milling cutters causes some drawbacks. This decreases the tool life. If the machining parameters are not appropriately selected, the micro end mills will soon break. This increases the number of changing tools and stops machining. Therefore, the machining time increases and the quality of the machined surface deteriorates. In order to prevent this problem, machining conditions such as revolutions per minute, feed rate, chips height, properties of the cutting tool, tool fixing length should be appropriately selected for micro-milling [6].

Proper machining conditions prevent tool breakage. The effect of micro-milling conditions applied to different materials was investigated in the literature. Rahman and ark. have investigated the effects of cutting speed, chips height and helix angle on tool wear in micro-machining of copper material [7].

Foy and his friends have examined the effect of cutter's angle of inclination and the feed rate on surface roughness in micro-milling [8]. Wu and ark. have investigated the effect of nano-crystal diamond coating applied to micro-tool on chip formation, cutting forces and surface roughness in micro milling of aluminium 6061 material [9].

Wu and ark. have examined the effects of rake angle, helix angle and cutting corner radius on cutting forces and temperature in micro milling cutters utilising simulation [10].

In this study; magnesium was used as the experimental material because it is the sixth metal and the eighth element found most widely, has a density of 1.74 g/cm^3 and is very light. Magnesium is a silver coloured and shiny metal. When contacted with air, it is covered with an oxide layer. It is a refractory and easily formable material. It is 36% lighter than aluminium and 78% lighter than steel. The automotive industry resorted reducing weight to manufacture environment-friendly vehicles and minimise energy consumption. A lightweight vehicle ensures fuel saving and prevents air pollution. In this sense, magnesium is preferable as it is relatively light. Revolution, feed rate and chip depth are used as machining parameters. The sufficient amount of progress in ANOVA analysis.

2. Material and Method

2.1. Material

AM50, AM60 and AZ91 are the most commonly used magnesium alloys. AZ91 is highly resistant and pourable. The material used in the research is the AZ91 series of magnesium alloy. Components of the material are shown in Table 1.

2.2. The Experimental Setup

It is necessary to work at high speeds and with micro-cutting tools for micro-milling. For these tests, Nikken brand spindle speeder was adapted to CNC machining centre on the JOHNFORD VMC-850/550+APC CNC Fanuc 0T x-y-z axial milling machine. The test arrangement are shown Figure 2.

Table 1 Magnesium alloys and their chemical compositions

Alloy Element	AZ91
Get	8.5-9.5
Zn	0.45-
Mn	0.17-
Si (max)	0.05
Fe (max)	0.004
Cu	0.025
Ni (max)	0.001
Be	-
Other	0.01
Mg	Remaining

Dimensions of the magnesium alloy used are (150*150*10) are mm.

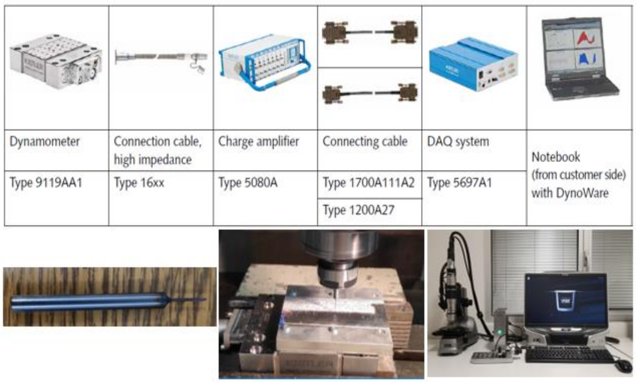

Figure 2 Test arrangement

2.3. The Experiment Design

Parameters such as material properties, revolutions per minute, feed rate and chip depth constitute the cutting conditions. Taguchi method reduces the number of experiment and decreases test and production costs [11].

Experiments were designed with the Taguchi complies with SK10 norm. In order to use the micro tools, collet complying with SK10 were used. The diameter of the microtools used in the test is 1 mm in diameter, as indicated with d1 in the below figure.

To measure the cutting force in micro-milling of the magnesium alloy KISTLER 9265B dynamometer and KISTLER 5019b load amplifier were used, and DynoWare software was used for analysis. The figure showing adaptation of cutting tool, spindle speeder, CNC machining centre, dynamometer and computer is given below (Figure 2).

Method. First of all, the control factor and levels were determined. Then the matrix was selected, and levels were transferred to the matrix. The variables have three different levels according to the index of L9. A total of 9 different tests were made.

The variables and levels in this research are given in Table 2.

Table 2 Variables and levels

Variables	Symbol	Unit	Code	Levels		
				1	2	3
Rotation	n	m/min	A	10.000	11.000	12.000
Feed rate	f	mm/min	B	170	200	230
Chip depth	d	mm	C	0.1	0.2	0.3

Below is a list of experiments designed according to the Taguchi method in Table 3. Tests were repeated for 1 mm cutting tool. The total number of tests was 9.

Table 3 Test design

Test No	Variables	Cutting speed (m/min)	Progression (mm/rev)	Depth of cut (mm)	Cutting force (N)
1	A1B1C1	1	1	1	47.61
2	A1B2C2	1	2	2	20.69
3	A1B3C3	1	3	3	42.11
4	A2B1C2	2	1	2	25.63
5	A2B2C3	2	2	3	16.02
6	A2B3C1	2	3	1	16.94
7	A3B1C3	3	1	3	14.95
8	A3B2C1	3	2	1	18.31
9	A3B3C2	3	3	2	14.65

3. Results and Discussion

3.1. Signal / Noise Ratios and Optimal Levels

The results obtained with Taguchi design are converted to signal/noise (S/N) ratios and expressed in decibels (dB). The signal value represents the real value given by the system to be measured; the noise factor represents the share of unwanted factors within the measured value [11]. As the goal of our study was obtaining the best surface quality, the equation we have used for Signal / Noise ratio was the smallest best equation [11]. S/N ratio is given in Figure 3.

$$\frac{S}{N} = 10x\, log.\left(\frac{1}{n}\sum_{i=1}^{n} y_{i^2}\right) \qquad (1)$$

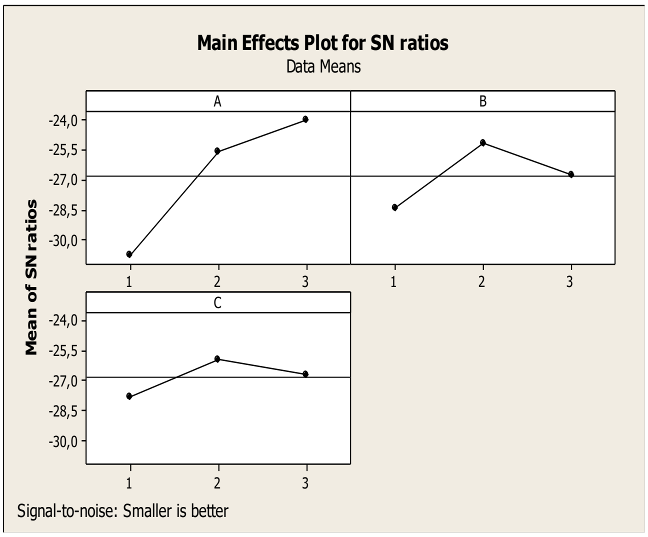

Figure 3 S/N ratio

3.2. Evaluation of Cutting Force Results

The results obtained with cutting force measurement taken by using Kistler dynamometer has become determinative to understand the impact of cutting parameters on cutting forces. From among the cutting force results obtained in the experimental study, only maximum cutting forces were taken into consideration. Accurate determination of cutting forces is essential for both the workpiece and the cutting tool. Because cutting forces affect both the workpiece and the cutting tool. In general, the resulting cutting force values were between 14.95-47.61 N. S/N ratios of cutting force value in proportion to machining parameters are presented in Table 4 and Figure 3 below. As seen in Table 4, when the impacts of machining parameters in proportion to S/N ratios obtained in nine tests are examined; it is understood that the smallest cutting force is obtained when feed is 200 mm/min, revolution is 10.000 rpm, and chip depth is 0.2 mm. However, as this test machining was not included in the tests, verification tests were made. It is understood that the change in cutting force was affected by the feed rate, rotation and chip depth.

Verification tests were performed, and it is understood that the difference was approximately 3 N (Table 5).

Table 4 Max. S/ N ratios of cutting force values

Level	A Rotation (rpm)	B (Feed Rate mm/min)	C (Chip Depth mm)
1	-30.79	-28.41	-27.80
2	-25.62	-25.22	-25.94
3	-24.02	-26.79	-26.69
Delta	6.76	3.19	1.86
Rank	1	2	3

Table 5 Optimal Results for Force

	Estimation	Verification Test
Level	$A_1B_2C_3$	$A_1B_2C_3$
Cutting Force Values (N)	31.30 N	34.1 N

The effects of the parameters used in experimental studies on cutting forces are shown in Figure 4 and Figure 5.

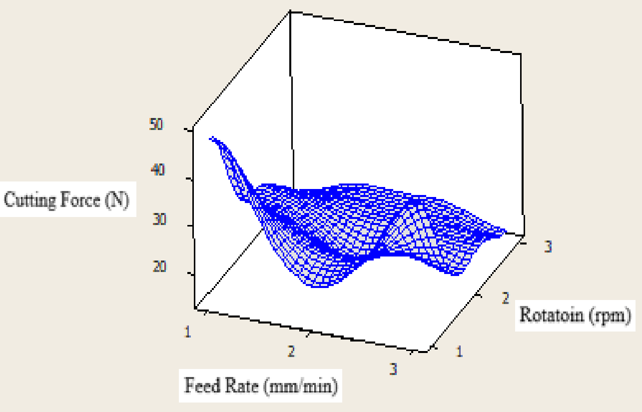

Figure 4 Effects of Feed Rate and Rotation on Cutting Force

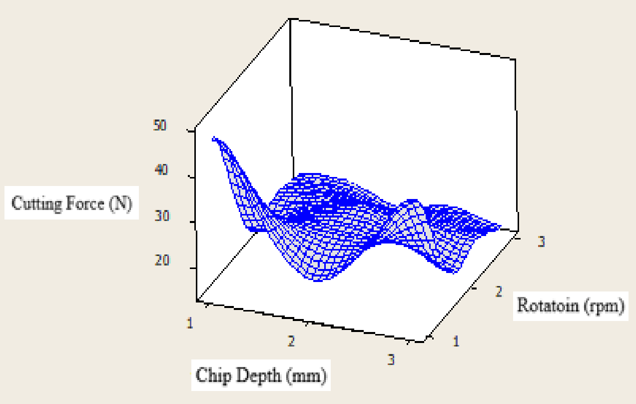

Figure 5 Effects of Chip Depth and Rotation on Cutting Force

3.3. Evaluation of Parameters with ANOVA Method

Nine tests were made by using three different factors at three different levels for micro-milling of magnesium alloy material and different cutting force response values were measured in each test. Variance analysis was applied to clarify whether these differences were random or caused by the factors and the effects of each factor on the response. The results of the variance analysis of average surface roughness and cutting force values are shown in Table 6. As it can be seen from the table, the most effective factor in the formation of roughness on the machined surface as a result of machining the AZ91 magnesium alloy material with DLC coated cutting tools is the revolution with 73.83%. The revolution is being the effective parameter matches with the literature.

Table 6 ANOVA results according to cutting force values

Notations	Degree of Freedom	Sum of Squares	Variables	F rate	Percentage Rate (%)
A	2	745.1	372.5	3.64	73.83
B	2	184.4	92.2	0.90	18.25
C	2	80.2	40.1	0.39	7.91
Error (e)	2	204.6	102.3		0.01
Total	8	1214.2			100

4. Conclusions

In this study on the workability of AZ91 magnesium alloy material with DLC coated bits, useful conclusions were reached. The criterion examined for workability was the surface roughness. Three control factors (rotation, feed rate and chip depth), which are considered to be useful in the realisation of this criterion under ideal conditions, were chosen at three different levels and applied in the experimental study. The results are summarised below.

- All three control factors (rotation, feed rate and chip depth) were active on the formation of cutting force when AZ91 magnesium alloy material was machined with DLC coated cutting tools. Ideal cutting force value was reached when rpm was 10.000, the feed rate was 200 mm/min, and chip depth was 0.3 mm.
- It is seen that the Taguchi optimisation technique is a useful technique in the design of the workability test of AZ91 magnesium alloy material, optimisation of parameters, and obtaining the desired rates of response values.
- The results obtained from the experimental study with the analysis of variance (ANOVA) are as follows; the most effective factor in creation of cutting forces was a rotation with 73.83%, and the second most effective factor in creation of cutting force was feed rate with 18.25%.

When the results are evaluated in consideration of the literature, it is found out that DLC coatings contribute positively to the workability of AZ91 magnesium alloy material and mainly accelerates the improvement in the performance of the cutting tool.

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