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Chip Morphology in Turning of AZ91D Magnesium Alloy under Different Machining Conditions

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Abstract: In recent years, there has been an increase in research into industrial applications, especially in the machining of lightweight metals. In this study, the effect of processing of AZ91D magnesium alloy in different parameters (machining medium, cutting speed, depth of cut, feed rate and cutting tool types) on the force, chip formation and cutting tool conditions were investigated. The experiments were designed using the L_{18} orthogonal array of the Taguchi method. Thanks to the Taguchi method, time and cost savings were achieved by reducing the number of tests required. Then, the effect of the turning parameters on the force values was obtained by analysis of variance. The most important parameters affecting the force values were the depth of cut and the feed rate. As a result, only the cutting speed has a significant effect on the chip type.

Farklı İşleme Koşullarında AZ91D Magnezyum Alaşımının Tornalanmasında Talaş Morfolojisi

Anahtar Kelimeler
Talaş oluşumu,
AZ91D,
Magnezyum alaşımı,
Tornalama işlemi

Özet: Son yıllarda, özellikle hafif metallerin işlenmesinde ve bu metallerin endüstride uygulamalarına yönelik araştırmalarda önemli ölçüde artış olmuştur. Bu çalışmada, AZ91D magnezyum alaşımı farklı parametrelerde (işleme ortamı, kesme hızı, kesme derinliği, ilerleme oranı ve kesici takım tiplerine) işlenmesi sonrasında kuvvet, talaş tipleri ve kesici takım durumları incelenmiştir. Deneyler, Taguchi metodunun L_{18} ortogonal dizini kullanılarak tasarlanmıştır. Taguchi metodu sayesinde yapılması gereken deney sayısı azaltılarak zaman ve maliyet tasarrufu sağlanmıştır. Ardından varyans analizi yapılarak tornalama parametrelerinin kuvvet değerlerine olan etkisi elde edilmiştir. Varyans analizi sonuçlarından kuvvet değerlerini etkileyen en önemli parametrelerin kesme derinliği ve ilerleme oranı olduğu belirlenmiştir. Sonuç olarak, yalnızca kesme hızının talaş tipinde önemli bir etkisinin olduğu görülmüştür.

1. Introduction

Magnesium is the lightest metal of all lightweight metal alloys and therefore is an excellent choice for engineering applications when weight is a critical design element [1, 2]. It is strong, has good heat dissipation, good damping and is readily available. Its properties make it easy to weldability, forging, castability or machinability [3, 4]. It can be alloyed with other metals, making them more beneficial and usable. The use of pure magnesium is rare due to its volatility at high temperatures and it is extremely corrosive in wet environments [5]. Therefore, the use of magnesium alloys when designing aerospace and automotive parts is critical [6].

Magnesium alloys are in use around the world in a variety of different applications [3, 7]. The most common applications are: aircraft and missile components; aircraft engine mounts, control hinges, fuel tanks, wings; automotive wheels, housings, transmission cases, engine blocks; bicycles and other sporting equipment; equipment for material handling; printing and textile machinery steering wheels and columns, seat frames [7, 8]. Magnesium alloys have also been used as a replacement for some engineering plastics due to their higher stiffness, high recycling capabilities and lower cost of production [9].

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It is an important influence on the type of chip produced and the machining process [10, 11]. During the cutting process, the formation of long chips may interfere with the machine tool, workpiece and tool, and may cause harmful effects in the material removal process and the quality of the part [12-14]. In machining processes where long and continuous chip formation is likely, such as turning operations, it is difficult to realize chip control. It is difficult to estimate the variations in chip breaking and chip breakability as a consequence of changes in the reasons for the lack of recommendations and methods [15, 16]. The chip type and chip formation have been investigated in many different materials. However, a limited number of studies are available in the literature for AZ91D magnesium alloy.

In this paper, an experimental study on chip morphology is carried out under different machining conditions. The influence of the machining medium with cutting speed, feed rate, depth of cut and tool type on chip morphology is analyzed in turning of AZ91D magnesium alloys.

2. Material and Methods

2.1. Experiments design

The Taguchi method is the best among different levels of different parameters is a widely used method in the manufacturing industry to determine the combination. Because, for every combination of each parameter, each level, a lot of experimental work has to be done. Nowadays, time and cost are very important in terms of competition in the manufacturing sector. Reducing the number of experiments with the Taguchi method is very beneficial to the manufacturer both in terms of time and cost. In this way, research and development works can be accelerated. The test results obtained in the Taguchi method are evaluated by converting them to the signal / noise (S/N) ratio. The signal/noise ratio value is calculated and analyzed in different approaches according to the value that “the small is better”, the larger is better, the nominal is better, and the quality value is targeted. In this study, L18 orthogonal array Taguchi method is used. The parameters and levels used in experiments are shown in Table 1 [17]. The orthogonal experimental design according to the Taguchi method is presented in Table 2 [17]. In the experiments, three different cutting speeds (500, 750 and 1000 m/min), three different cutting depths (0,5, 1 and 1,5 mm) and three different feed rates (0,05, 0,1 and 0,2 mm/rev) were used. The experiments were carried out in two different environments in dry and minimum quantity of lubrication (MQL). Also, uncoated DCGT, VCGT and CCGT carbide tools were used for the experiments. These cutting tools supplied from ISCAR firm.

Table 1. Process parameters and their limits

Codes	Cutting Parameters	Level 1	Level 2	Level 3
C	Machining medium	MQL	Dry	-
V	Cutting speed (m/min)	500	750	1000
D	Depth of cut (mm)	0.5	1	1.5
F	Feed rate (mm/rev)	0.05	0.1	0.2
T	Tool type	CCGT	DCGT	VCGT

Table 2. Orthogonal experimental design according to Taguchi method

	Machining medium	Cutting speed (m/min)	Depth of cut (mm)	Feed rate (rev/mm)	Tool type
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	3	3
11	2	1	2	1	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

2.2. Experimental investigation

AZ91D series of magnesium alloys are preferred as experimental work materials. Due to the low corrosion resistance of magnesium alloys, the materials have been supplied by Yuanhong Alloy Materials Co., Ltd from China, packed in special vacuum plastic bags. The materials were supplied in dimensions Ø60x300 mm. In the system designed for the experimental study, one material was used for each experiment. Three repetitive experiments were performed on each material. The chemical composition of AZ91D cast by the manufacturer with special casting methods is given in Table 3.

Machinability studies were performed on the YCM GT-200A CNC lathe as shown in Figure 1. In this study, the MQL system, which is frequently used as cooling system, has been used. The system delivers 0.0036 ml Werte 2000 cutting oil to each spray, 2 sprays per second and 5 - 6 bar cut point. For the experiment is used Force Measurement (Kistler 9257BA). The cutting force measurement, dynamometers which were mounted on the CNC lathe. In addition, chip morphology of the samples were examined using an optical stereo microscope (SteREO Discovery.V8; Zeiss, Jena, Germany).

3. Results and discussion

3.1. Cutting force

The analysis of the total cutting force (F) and its components is necessary for the physical and technological evaluation of the machining process. This analysis stems from the nature of the physical mechanism of the process, such as the directions of the machining movements, the geometry, the properties of the machined material, and the type of technological process [18]. High force values with cutting edge chipping lead to catastrophic wear. The cutting force (tangential) component Ft is a peak of the total cutting force (F) toward the main direction of motion, and the cutting rate is a determinant factor in shear. For this reason, the Ft cutting force is also called the main component of the total cutting force. The average results of the cutting force values obtained as a result of the experimental study (Table 4). The S/N ratios of the surface roughness values obtained in the experiments were calculated and the variation of the results according to the parameters is shown in Figure 2. When the results are examined, it is seen that the specific cutting energy required for machining of AZ91D magnesium alloy are much lower than the specific cutting energy generated during machining of materials such as aluminum, titanium, steel and super alloy [19-22].

3.2. Analysis of Variance (ANOVA)

The purpose of ANOVA is in order to obtain data such as degrees of freedom (DF), F-value, P-value, mean squares (MS), sum of squares (SS) and percent contribution. Using this analysis, it is determined how the factors examined affect the selected output values to measure the quality and how the different levels cause variability. According to the applied ANOVA in this study, it is observed that the machining medium (0.0006%), the cutting speed (0.02%), the depth of cut (58.2%), feed rate (35.1%), and tool type (0.0006%) play roles in minimizing the force (Table 5). After the tests applied to the AZ91D mg alloy workpiece, it turns out that the most notable factor affecting the force value is the depth of cut. The F-test was used to find out which turning parameters have a notable effect on the performance characteristic. Generally, the variation of the turning parameters has an important relationship between the numerical value of F and the performance features. The larger the F-value, the greater the effect of parameters on the result obtained. Considering the data in Table 5, it is seen that the depth of cut and feed rate parameter are the most dominant factor affecting the force. In ANOVA modelling the R^2 is found as 95.35%.

Figure 1. a) YCM GT-200A CNC lathe b) display of the dynamometer and cutting tool connected to the CNC machine

Table 3. Chemical composition of AZ91D magnesium alloy (wt. %)

Material	Al	Zn	Mn	Fe	Be	Si	Cu	Ni	Mg
AZ91D	9.21	0.45	0.17	0.0018	0.00084	0.016	0.002	0.00085	Balance

Table 4. The cutting force values obtained after the parameters used in the experiment

	Machining medium	Cutting speed (m/min)	Depth of cut (mm)	Feed rate (rev/mm)	Tool type	Force (N)	Standard Deviation	S/N ratio for force data
1	MQL	500	0.5	0.05	CCGT	19.95	0.72	-25,9989
2	MQL	500	1	0.1	DCGT	45.98	2.59	-33,2514
3	MQL	500	1.5	0.2	VCGT	113.66	3.41	-41,1122
4	MQL	750	0.5	0.05	DCGT	14.70	0.81	-23,3463
5	MQL	750	1	0.1	VCGT	48.54	1.48	-33,7220
6	MQL	750	1.5	0.2	CCGT	107.01	4.14	-40,5885
7	MQL	1000	0.5	0.1	VCGT	23.84	0.73	-27,5461
8	MQL	1000	1	0.2	CCGT	72.72	0.21	-37,2331
9	MQL	1000	1.5	0.05	DCGT	45.37	3.75	-33,1354
10	Dry	500	0.5	0.2	DCGT	45.61	2.61	-33,1812
11	Dry	500	1	0.05	VCGT	27.24	0.12	-28,7041
12	Dry	500	1.5	0.2	CCGT	120.61	1.20	-41,6277
13	Dry	750	0.5	0.1	CCGT	24.42	0.64	-27,7549
14	Dry	750	1	0.2	DCGT	80.95	1.48	-38,1643
15	Dry	750	1.5	0.05	VCGT	44.01	0.38	-32,8710
16	Dry	1000	0.5	0.1	VCGT	29.52	1.09	-29,4023
17	Dry	1000	1	0.05	CCGT	32.26	2.11	-30,1733
18	Dry	1000	1.5	0.2	DCGT	65.48	3.86	-36,3222

Table 5. ANOVA results for surface roughness

Parameters	DF	SS	MS	F-Value	P-Value	Contribution (%)
Machining medium	1	0.286	0.286	0.10	0.760	0.0006
Cutting speed (m/min)	2	9.077	4.539	1.58	0.263	0.02
Depth of cut (mm)	2	287.043	143.521	50.09	0.000	58.2
Feed rate (mm/rev)	2	173.348	86.674	30.25	0.000	35.1
Tool type	2	0.281	0.141	0.05	0.952	0.0006
Error	8	22.924	2.866			
Total	17	492.959				

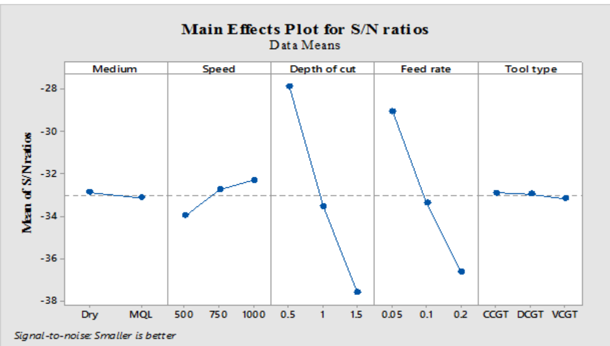


Figure 2. Change of force results to calculated S/N ratios

3.3. Chip formation

Chip morphology plays an important role in determining the machinability of alloys such as Magnesium, Titanium alloys. In addition, chip morphology significantly affects thermal behavior in the workpiece / tool interface, which affects tool life. In order to increase productivity and tool life in the machining of Mg alloys, it is necessary to study the chip formation and its effect on machinability. The types of chips obtained as experimental operating parameters are given in Figure 3. These chips are compared and categorized with ISO 3685 standards as shown in Figure 4 [23]. When these types of chips are examined, the undesirable and worst type of chip is seen in the image 1. This figure shows 500 m / min in case of chip type MQL conditions. MQL and Dry machining types are not very effective in chip formation. It is seen that the change of cutting thickness is a little effect on the types of chips formed. In other words, as the chip depth increases, it approaches the ideal chip type. It has been seen that the feed rate is not very effective in the chip type. It has been found that the preferred chips for machining of magnesium alloys and the chip breaking tools used in the experimental work are not significantly ethical in the types of chips that are formed. As a result, cutting speed is important for chip formation. Chip types can be evaluated from three angles. Process health (cutting health and operator safety), surface quality of processed material and regarding of the cutting force evaluation for shape of chips. In terms of process health, short chips are safer. Because long chips are not only endangering operator health but also disrupting the surface quality of the material.

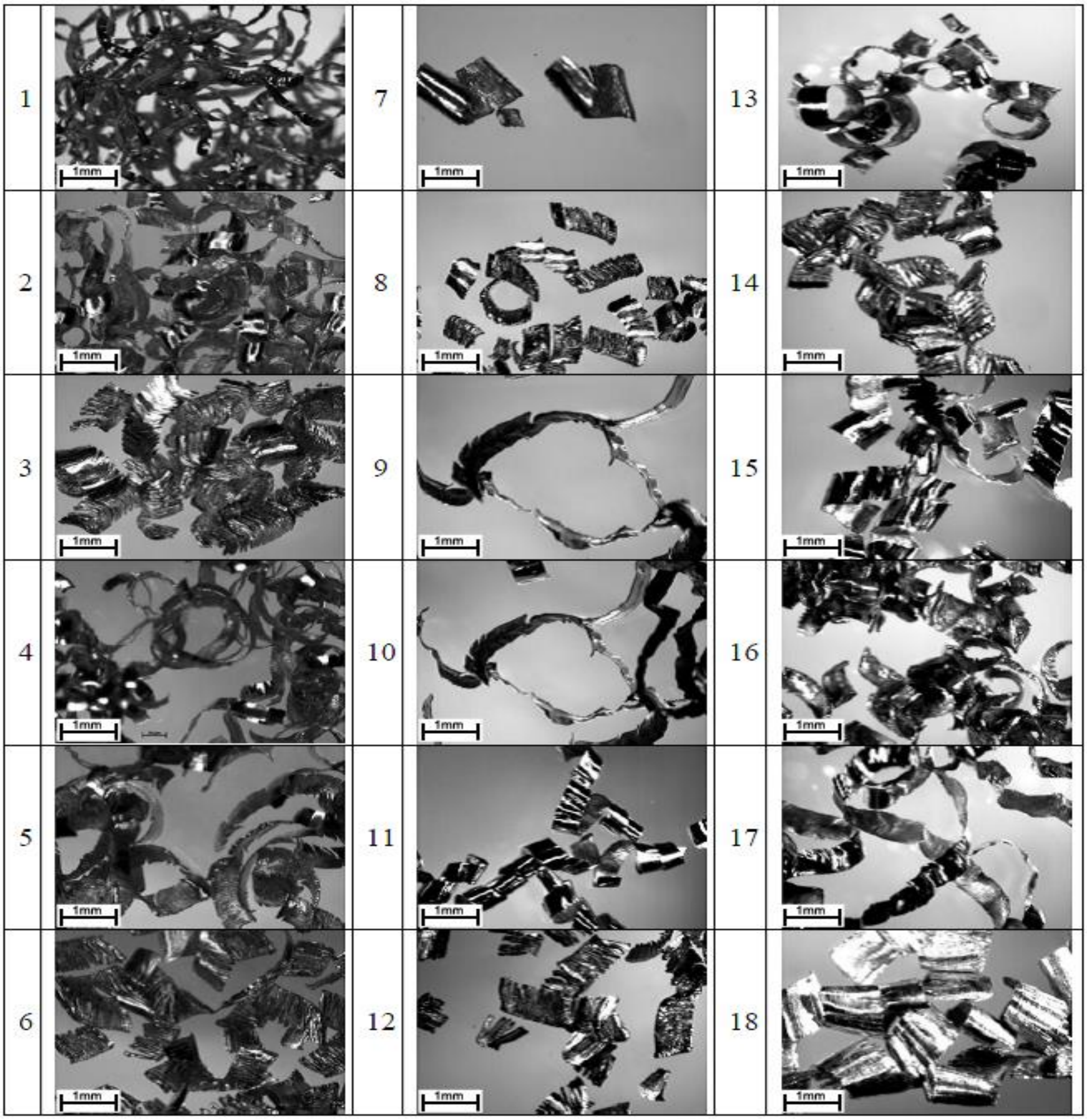


Figure 3. Optical microscopy chip morphology image comparison at different

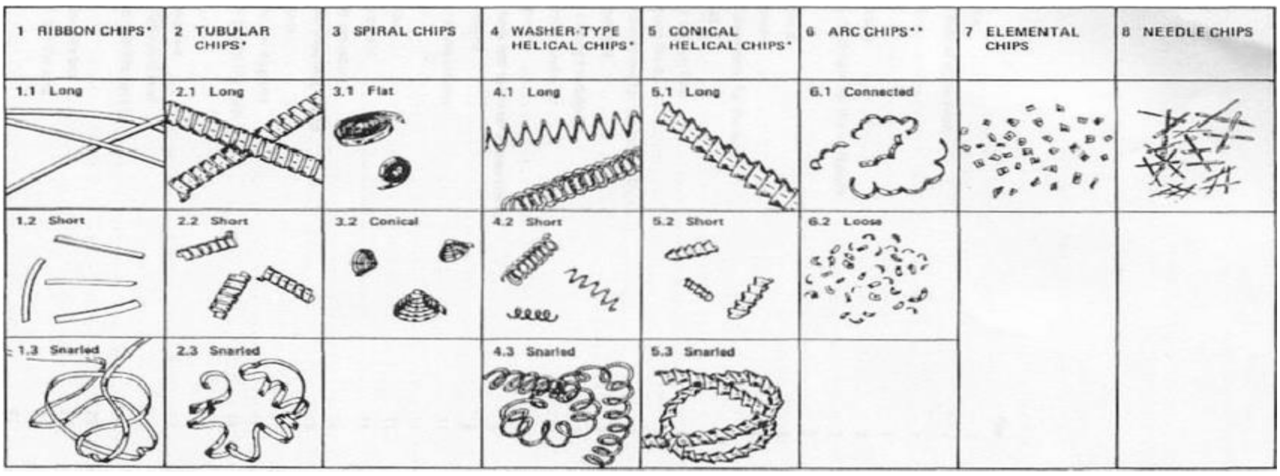
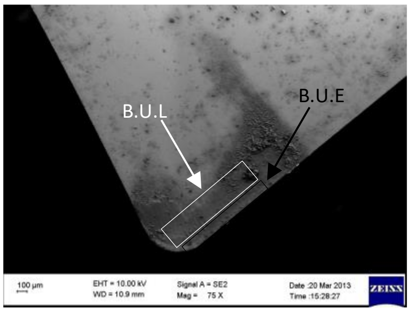


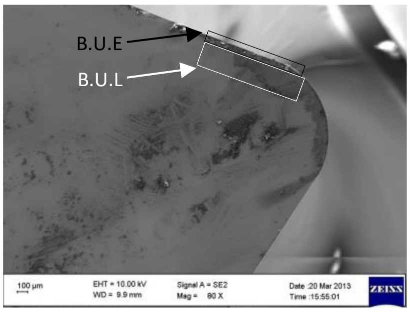
Figure 4. Chip form classification [23]

3.4. Cutting tool wear

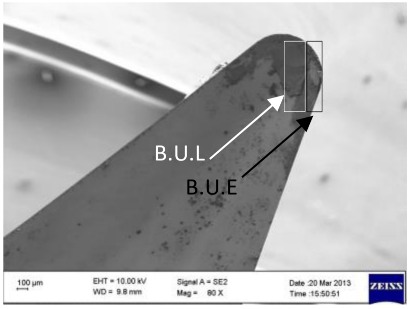
The machining of aluminum alloys is relatively easy as the cutting forces involved are low. Therefore, there is no significant force on the cutting tool during cutting process. Also, the wear on cutting tools is negligible at low cutting forces. Beginning of the built up layer (B.U.L) and built up edge (B.U.E) types of wear were observed and they were marked with white and black arrows on the Figure 5. images. B.U.E complete formation can be related to the short cutting process. The SEM image of the cutting area is shown in the Figure 5. after experiments with DCGT, VCGT and CCGT series cutting tools. AZ91D alloy adheres to the tool at cutting time along the chip depth. In these figures, it can be seen that the alloy material is present in different parts of the tools. In fact, the accumulation of materials on the edge of the tool means that BUE is formed. On the other hand, the formation of the alloy layer on the chip surface shows the presence of BUL.



(a)



(**b**)



(**c**)

Figure 5. a) SEM image of DCGT cutting tool after experiments b) SEM image of CCGT cutting tool after experiments c) SEM image of VCGT cutting tool after experiments

4. Conclusion

In our study, chip formations were investigated for magnesium alloy machining. The experiments were conducted at CNC lathe with turning process. The different machining parameters were applied and different chip formations were obtained. Generally, the chips formation was occurred as connected formation. However, no.7 experiment and no.18 experiment has can be accepted as natural broken chips. The experimental material alloy has hexagonal close-packed structure and that not allow the chips continuous formation. That's the major reason of the chip formation type for magnesium alloy. It is expected that the medium condition has the biggest effect on the chip formation, which has not been observed. Furthermore, It seems that the cutting force, feed rate, depth of cut and tool type is not a significant influence. Nevertheless, it was seen that the cutting speed was an important influence on the chip formation.

Conflict of interest:
There is no conflict of interest with the concerned persons.

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