Effects of the drill flute number on drilling of a casted AZ91 magnesium alloy

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Article Information

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Keywords
Number of flutes, casted AZ91 magnesium alloy, tool life, wear, force

This experimental study aims to reveal the effect of the drill flute number on the thrust force, tool wear, tool life, chip morphology, surface hardness and microstructure in the drilling of a cast AZ91 magnesium alloy. The results showed that the cutting flute number and cutting parameters have an important effect on thrust force, tool life, wear, chip morphology, microstructure, and drilled hole hardness. When the 2-flute drill was used, less thrust force was generated during the drilling. On the other hand, less tool wear occurred with the 3-flute drill. In scanning electron microscopy (SEM) microstructural analyses, grain refinement was observed in the microstructure of the borehole surface although grain growth was also observed due to a rise in temperature. In addition, the microhardness of the borehole surface decreased as the number of holes increased, and the 2-flute drill bit provided holes with higher stiffness than the 3-flute drill bit.

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As a result of carbon emission regulations and the reduction of fuel reservoirs, the interest in lightweight materials is gradually increasing, especially in the transportation industry. Magnesium alloys are some of the lightest materials that can be used for this purpose [1]. In addition, magnesium alloys have recently become candidate materials for the manufacturing of surgical implants due to their biodegradable structure [2]. Even though there is a variety of magnesium alloys, the AZ (aluminum zinc) series is the most commonly used in manufacturing [3].

Since AZ91 possesses high castability, mechanical strength, and ductility, it is one of the most preferred commercial magnesium alloys [1]. This alloy is used in the manufacturing of many automotive parts such as engine crankcases and power transmission elements. The drilling operation is widely used in the production process of these components [4]. However, the machining of Mg alloys is difficult due to their flammable nature at higher cutting speeds as compared with other alloys. Yet, by using proper cutting parameters, cutting tools, and coolants, the machinability of these alloys can be enhanced [3]. There have been many published studies investigating the machining performance of magnesium alloys. These studies have focused on the drilling performance of Mg alloys as affected by the aluminum content of magnesium alloy [3], the cutting tool coatings [4-6] and the cutting environment (coolants) [2,7-9].

Gariboldi [5] studied the drilling of a magnesium alloy using PVD-coated twist drills. Ratna Sunil et al. [3] investigated the influence of aluminum content on thrust force and chip formation during the drilling of AZ31 and AZ91 Mg alloys using different cutting parameters. They observed that an increase in the aluminum content of the Mg alloy led to an increase in thrust force and caused discontinuous chip formation. Karaca and Aksakal [6] researched the drilling performance of MA8M Mg alloy by using various cutting parameters and pointed out that higher spindle speeds and feed rates resulted in lower surface roughness. Bhowmick et al. [7] compared the drilling performance of AM60 magnesium alloy using no coolant (dry environment), mineral oil cutting fluid and minimum quantity lubrication (MQL). They reported that dry drilling showed unsatisfactory results while the performance of MQL and flooded drilling was almost equal in providing better results.

To date, there has been no study pertaining to the effects of cutting flute number on the drilling performance of Mg alloys although the effects on the drilling performance of aluminum alloys [10,11], steel [12], and composites [13-16] have been investigated previously. Ucun [11] researched the drilling performance of Al 7075-T6 aluminum alloy using twist and 3-flute drills both experimentally and numerically via the finite element method. He highlighted that the twist drill resulted in less thrust force, torque, and stress on the cutting tool as compared with the 3-flute drill. Moreover, he reported that there was a good agreement between the numerical and the experimental results. Faraz et al. [14] presented a new tool wear criterion in the evaluation of the tool wear of different drill types in the drilling of carbon fiber-reinforced plastics. Ekici et al. [13] examined the effects of drilling parameters and drill flute number in the drilling of glass fiber-reinforced plastics (GFRP). They reported that an increase in the flute number led to a decrease in the damage factor. Ramkumar et al. [16] analyzed the effects of workpiece vibration on thrust force, temperature, power consumption, and tool wear during the drilling of GFRP. They used tipped WC, 2-flute solid carbide and 3-flute solid carbide drills. The vibration generated during drilling reduced the thrust force, temperature, power consumption, and tool wear. In addition, the 3-flute solid carbide drill presented the best performance among the three different drill types used in this study. Kim and Lee [12] investigated the influence of the cutting flute number on the machining characteristics of plastic mold steel. Better surface roughness and bore roundness were obtained using a 4-flute drill as compared with a 2-flute drill.

In the experimental work reported here, the effect of the cutting flute number on the drilling performance in AZ91 Mg alloy was experimentally investigated. Thrust force, tool wear, chip morphology, and surface integrity were evaluated. This paper studied the role of the drill flute number on machinability when drilling cast AZ91 magnesium alloy.

Materials and experimental procedures

The samples used in this work were prepared from cast AZ91 magnesium alloy blocks. All drilling tests were carried out on a Quaser MV 154C CNC vertical machining center. Thrust force was recorded by means of a Kistler 9257B type dynamometer. Specimens of 170 × 100 × 15 mm were clamped on the force dynamometer with back-up. Tool wear and chips were measured via a Keyence VHX-900F digital microscope. The experimental setup and measurement instruments are shown in Figure 1.

Cast AZ91 magnesium alloy was drilled using 2- and 3-flute drills, five different cutting speeds and five different feed rates as a preliminary test. As a result of these experiments, the optimal cutting and feed parameters were determined. No cutting fluid was used. Aqua-coated solid carbide drills with 2- and 3-flute bits were used to create holes. The geometric characteristics and related information on the drills used are given in Table 1.

Results and discussion

Thrust force comparison. The thrust force data measured using the Kistler 9257B dynamometer was transformed into a graph via Dynoware software. Thrust force evaluation was carried out according to the maximum thrust force value measured during the hole drilling.

There are many publications showing how cutting parameters affect thrust force, temperature, chip morphology, tool wear, and surface integrity. However, not enough studies have been conducted on the effects of the cutting flute number on the drilling process. Therefore, the influence of drill flute number and cutting parameter combinations have been presented in this study.

	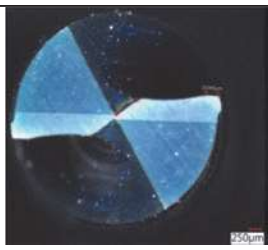	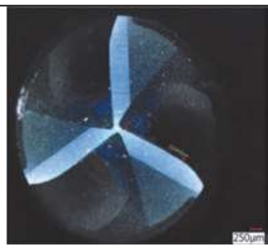
Specification	AQDEXS	AQD3F
Number of flutes	2-flute	3-flute
Point angle (°)	135	150
Flute length (mm)	25	26
Overall length (mm)	61	70
Diameter (mm)	5	
Shank type	Cylindrical	
Shank tolerance	h6	
Helix angle (°)	30	
Helix	Normal helix flutes	
Coating	Aqua	

Table 1: Specification of the drills

Figure 1: Experimental setup and tool wear measurement

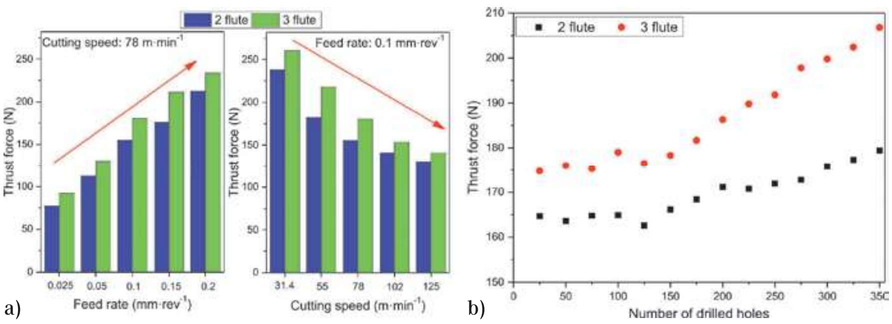

Figure 2: Thrust force, a) recorded during experiments, b) variation depending on number of drilled holes

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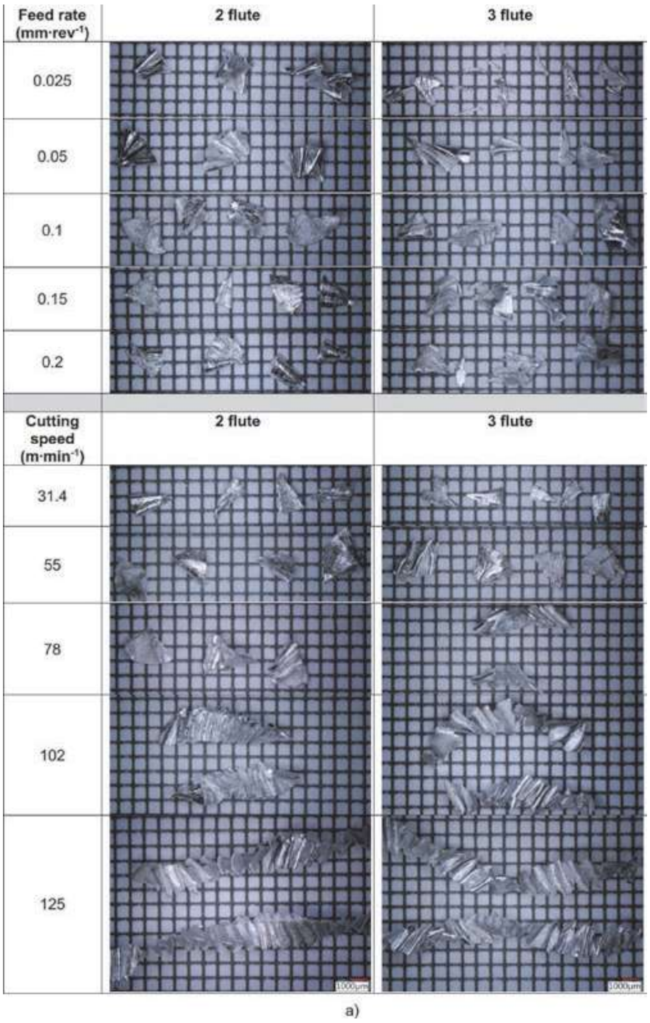
Firstly, the magnesium plate was drilled at a constant 78 m × min^{-1} cutting speed and varied feed rates (0.025, 0.05, 0.1, 0.15 and 0.2 mm × rev^{-1}) using 2- and 3-flute drills. The feed rate was then kept constant at 0.1 mm × rev^{-1}, and the drilling was carried out at varied cutting speeds (31.4, 55, 78, 102 and 125 m × min^{-1}). Thrust forces generated during the drilling experiments are given in Figure 2a. As can be clearly seen, the thrust forces increased as the feed rate increased for both drills. This phenomenon stemmed from the higher feed rates, which caused an increase in the amount of uncut chip and the energy required for cutting. As a result, the drill removed more material per revolution and higher cutting forces were measured [17]. In addition, approximately 20 % more force was generated by the 3-flute drill than by the 2-flute drill. The reason for the larger forces generated in drilling with the 3-flute drill was that the 3-flute point angle, being greater than that of the 2-flute drill, increased the contact area with the specimen during drilling, which stimulated greater cutting force [18].

When the cutting speed was increased, the thrust force decreased for both drills in this study, and this finding was consistent with results in the literature. This behavior was ascribed to the reduction of the contact area at the cutting tool-workpiece interface and the reduction of the specific cutting energy. Furthermore, with the increase in cutting speed, the cutting temperature increased and subsequently reduced the material hardness. As a result, the thrust forces were reduced [19].

After the determination of the influence



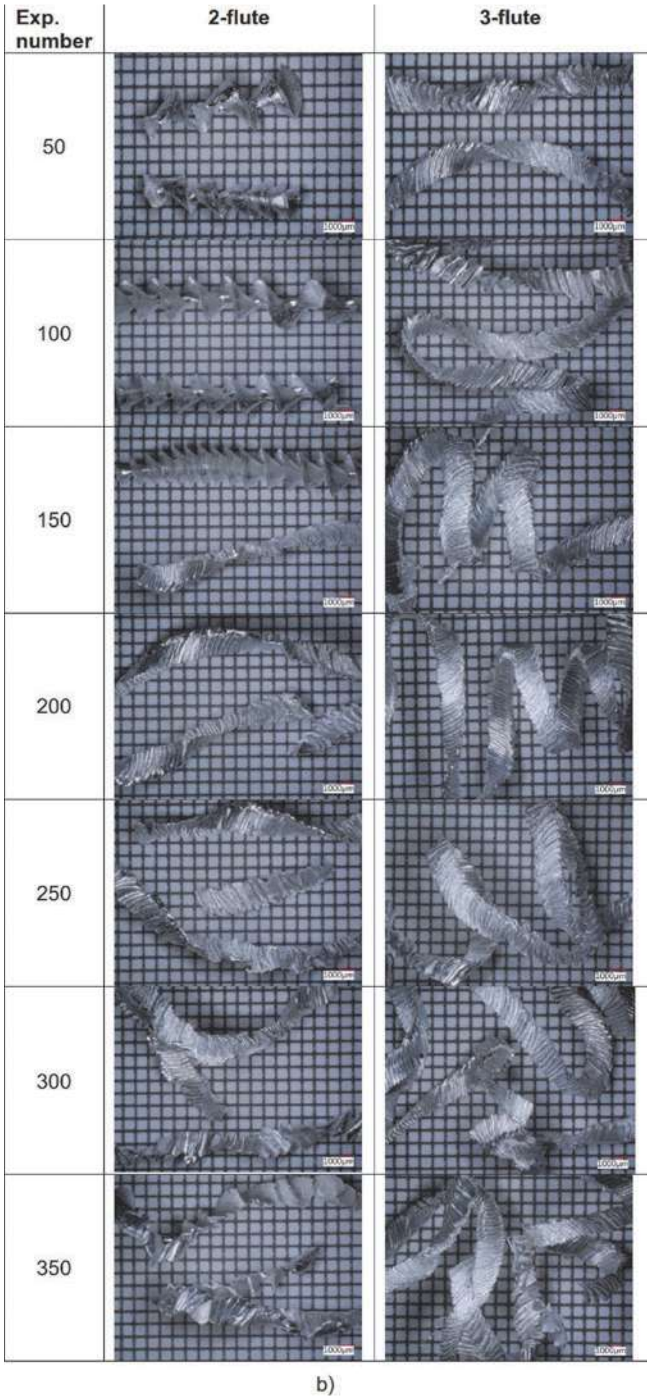


Figure 3: Chip images, a) at varying feed rates and cutting speeds, b) depending on varying hole numbers at constant feed rate and cutting speed

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of the cutting parameters and drill flute number on thrust force, 350 holes were drilled at a constant 0.1 mm × rev^{-1} feed rate and 78 m × min^{-1} cutting speed in order to specify thrust force formation depending on the increase in the number of holes (see Figure 2b). Thrust forces were measured after every 25 holes. As can be seen, the thrust forces increased as the number of holes increased. The fundamental reason for this situation was simply tool wear. In addition, greater thrust forces occurred when using the 3-flute drill than when using the 2-flute drill during the tool life test. At the onset of the tool life test, the tool had maximum sharpness and lower forces occurred. However, as the number of holes drilled by the tool increased (machining time), the tool began to wear, resulting in a larger contact area at the tool-chip and tool-workpiece interfaces, and higher friction was generated. Consequently, high forces were generated at the end of the tool life test. In the tool life test using the 2-flute drill, the thrust force varied between 162 and 180 N while in the tool life test using the 3-flute drill, it varied between 174 and 206 N, thus demonstrating that the thrust force was about 12–26 N greater with the 3-flute drill than with the 2-flute drill.

Chip morphology. Chip shape is the most significant factor affecting the smoothness of a machining process. The process will be smooth as long as chips are broken well and easily [20]. However, as the chips get larger, they cannot move well via the flutes, and this increases torque requirements. Moreover, it may cause the drill bit to break [21]. Yet, many ductile materials do not break but form continuous chips during drilling [20]. In order to show the chip shape depending on cutting parameters and an increase in the number of holes, the selected chips from the experiment are presented in Figure 3a and b.

Figure 3a shows photographs of the chips formed with 2-flute and 3-flute drills. The most frequently observed chip type was determined for each test, and these chips were investigated in detail. In most cases, short, fan-shaped chips, zigzag chips and short, needle-like chips were generated at variable feed rates. There were no significant differences between chips from holes drilled at different feed rates using the 2-flute drill. The chip shapes were similar to each other, as was the case in a previous study [6]. When chips formed by the 3-flute drill were examined, needle-type chips occurred at lower feed rates, while longer chips were obtained at higher feed rates. This was due to increased cutting edge engagement leading to a greater undeformed chip thickness and also possibly due to the increased strength of the resulting chip in relation to bending, and thus delaying fracture [21]. During the drilling of the AZ91 magnesium alloy, because of its ductile characteristic, chips were broken into smaller, short chips. In addition, a uniform variation of the chemical composi-

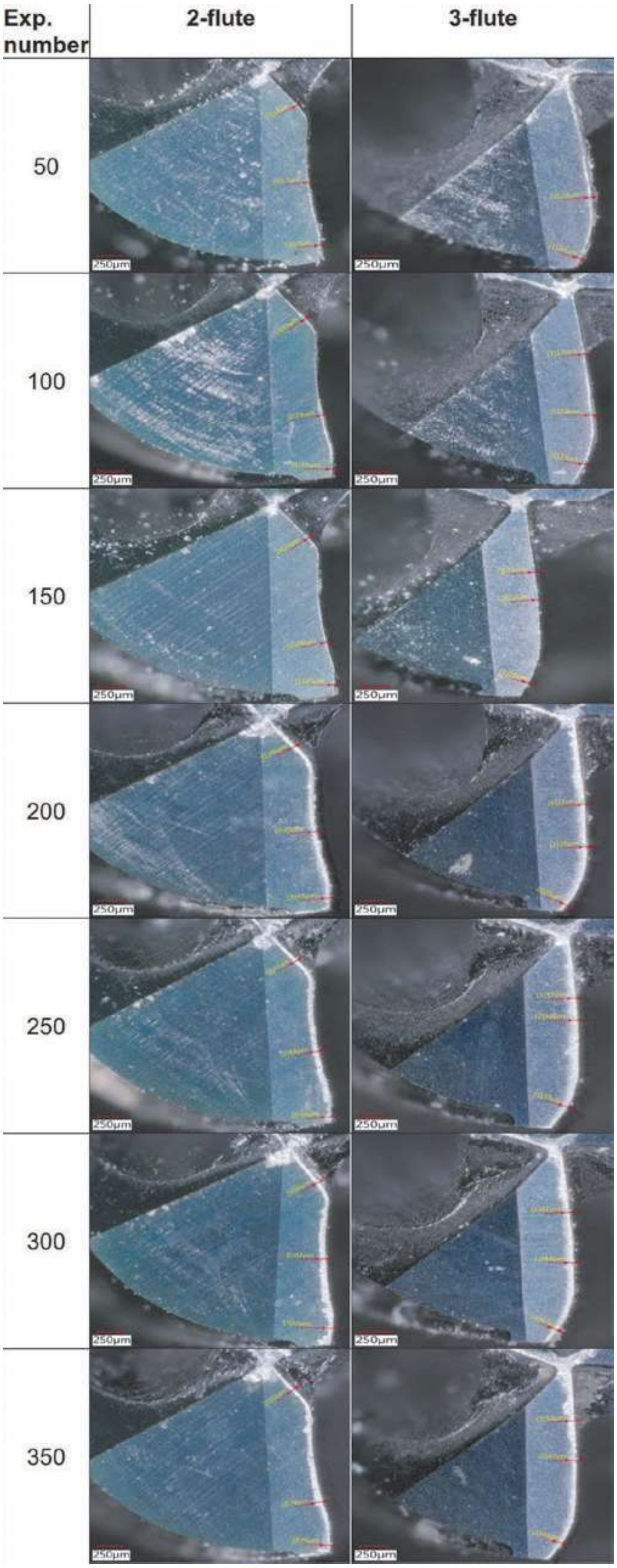

Figure 4: Comparison of the tool wear obtained at different fluted drills

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tion within the material affected chip continuity. The AZ91 involves different phases, including α, β, and α + β phases and due to its microstructure, discontinuous chips were formed [3]. According to the chips obtained, the cutting speed seemed to be a more effective parameter than the feed rate. Fan-type and zigzag-type chips were formed at lower cutting speeds, whereas long, zigzag-type chips were formed at higher cutting speeds. Since more heat was generated at higher cutting speeds, continuous chips were formed during the machining. In addition, with the increase in cutting speed, less force was needed to plastically deform the material [3]. When compared, longer chips were formed by the 3-flute drill than the 2-flute drill. The reason for this was that the same amount of uncut chips were removed by the 3-flute instead of the 2-flute drill.

During the tool life test, for every 50 holes, chips were collected (see Figure 3b). Chip-type changes based on the number of holes could be clearly seen. As the number of holes increased, longer chips were formed and the 3-flute drill generated longer chips than the 2-flute drill. The chip shape for the first 100 holes using the 2-flute drill was in the form of a spiral cone which was more easily ejected. Chips formed during the drilling of holes between 1 and 100 were in the desired short and spiral shape; however, they were transformed into long, folded wavy-type chips at 150–250 holes. After the 250th hole, depending on the increase in the thrust force and wear, the chip thickness decreased as the chip pitch increased, thus forming ribbon chips. During the drilling of the material in this study, the material volume subtracted (294.5 mm^3) was removed in three nearly equal parts (98.16 mm^3) by the 3-flute drill, while with the 2-flute drill, the same volume was subtracted in two nearly equal parts (147.25 mm^3). For this reason, the chips formed by the 3-flute drill were longer and narrower than those of the 2-flute drill. For the 3-flute drill, there was not so much alteration in chip formation depending on the number of holes as there was for the 2-flute drill. Generally, long, folded wavy-type chips and thick, long ribbon and string-shaped chips were formed. Tool wear was the fundamental reason for the variation of chip shape based on an increase in the number of holes.

Tool wear. A study of the wear of the 2-and 3-flute drills was made using a Keyence digital microscope. Figure 4 shows the drill wear at a constant cutting speed (78 m × min^{-1}) and feed rate (0.1 mm × rev^{-1}) after drilling 50, 100, 150, 200, 250, 300, and 350 holes in the Mg alloy under dry conditions. Flank and chisel edge wear were observed in the tool life experiments. Figure 4 also shows that the dominant wear during the dry drilling tool life tests was flank wear. Wearing of the chisel edge was mainly seen in the tests using the 3-flute drills. This can also be an indication of the high cutting forces induced during the drilling process. More wear occurred in the 2-flute drill, while less tool wear occurred in the 3-flute drill. The main reason for the formation of more tool wear in the 2-flute drill was believed to be the cutting temperature and friction. The deterioration in the cutting edges and loss of sharpness were less than under the 3-flute drill conditions. Flank wear of 78 µm was observed in the 2-flute drill, while 67 µm of flank wear was observed in the 3-flute drill as a result of the tool life tests. After drilling 350 holes, the flank wear for the 2-flute drill rose by approximately 333 % from the 50-hole value, while this difference was about 235 % for the 3-flute drill.

SEM observations and surface hardness. Holes drilled at 78 m × min^{-1} cut-

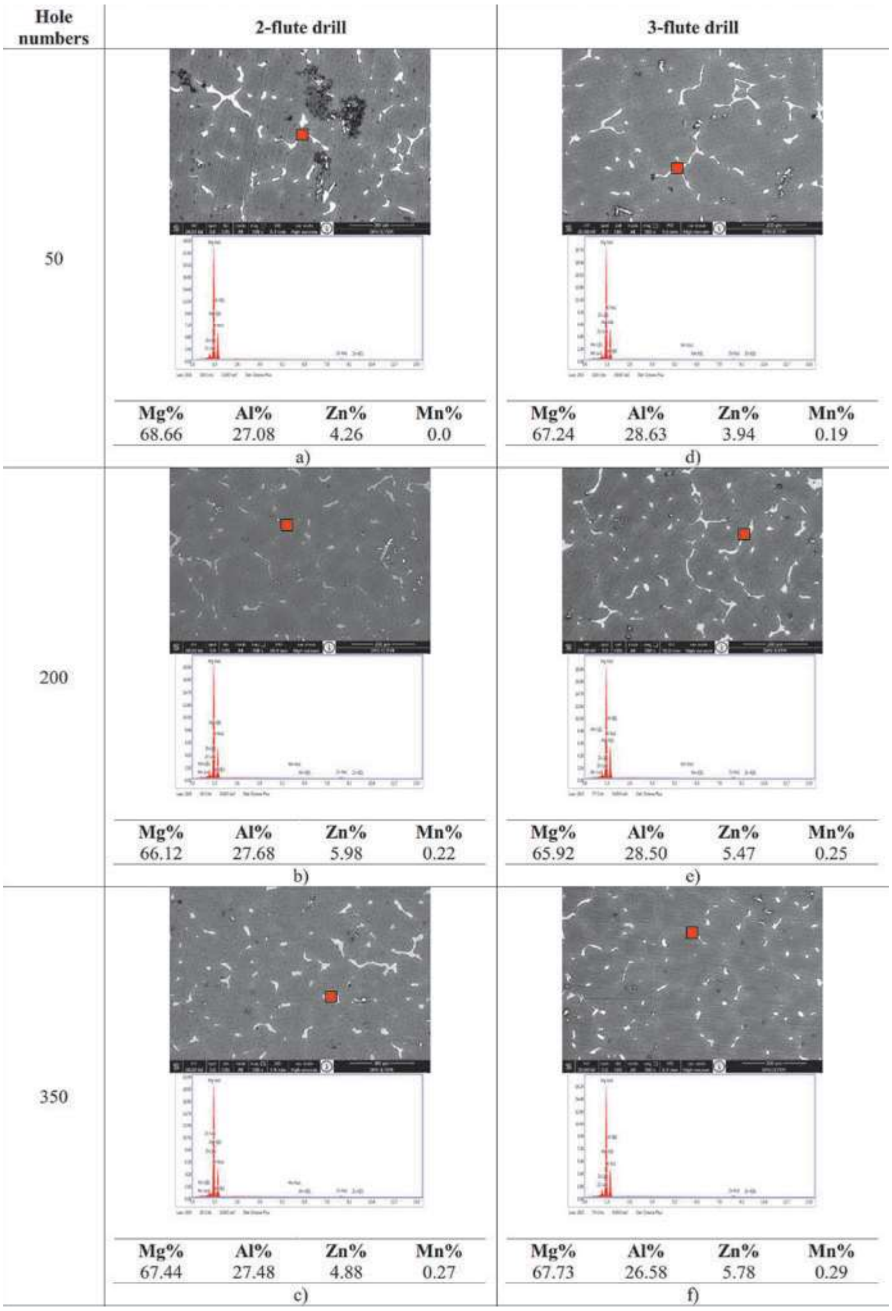

Figure 5: SEM images and β-phase EDS analysis of holes drilled under dry conditions, a) 2-flute 50th, b) 2-flute 200th, c) 2-flute 350th, d) 3-flute 50th, e) 3-flute 200th, f) 3-flute 350th

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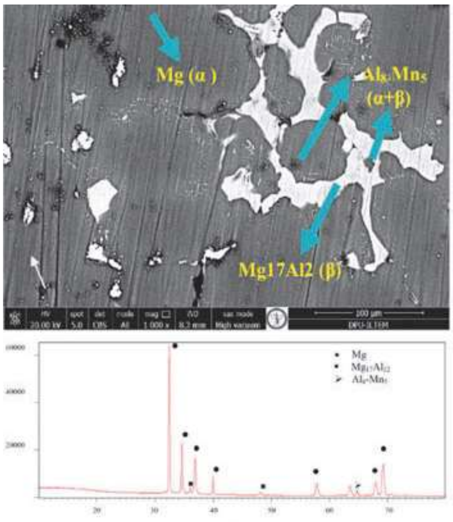
ting speed and 0.1 mm × rev^{-1} feed rate using 2- and 3-flute drills under dry conditions were divided in half using a hand saw, and the boreholes were examined in detail with a scanning electron microscope (SEM). The microstructure changes and surface morphology of the drilled holes were studied using SEM imaging to identify the influence of the flute number of the drill. A total of 350 holes were drilled on the magnesium alloy workpiece. The SEM images and EDS analysis of the 50th, 200th, and 350th boreholes are presented in Figure 5. Energy-dispersive X-ray spectroscopy (EDS) analysis was implemented using a JEOL JSM-6360 LV electron microscope.

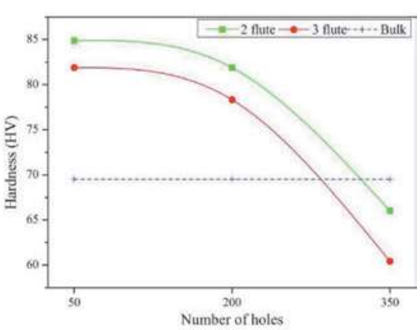
As the number of holes increased, mechanical deformation and recrystallization occurred due to a rise in temperature; therefore, the grain size of the material became smaller to some extent. In addition, the AZ91 alloy contains an α-Mg as well as a β (Mg17Al12) intermetallic and α+β eutectic matrix. The Mg does not affect tensile strength but increases corrosion strength when used in the structure alone. However, Mn and Al used together comprise intermetallic phases which enhance the strength of the material. The SEM analysis and the X-ray diffraction (XRD) depending on it are shown in Figure 6a. It can be seen from the XRD analysis that the Mg17Al12 and Al8Mn5 intermetallic phases were formed in the grain and grain boundaries, which prevented dislocation.

As a consequence of the greater thrust forces occurring during drilling, these phases made plastic deformation difficult and complicated the chip removal process by increasing the strength of the material. Variations in the phases and tool wear gave rise to greater forces as the hole numbers increased (see Figures 2b, 4, and 5).

After the SEM analysis, the microhardness (HV) of the 50th, 200th, and 350th holes was measured at different locations on the drilled bore surface. In addition, the bulk (initial) hardness of the Mg alloy was determined as about 69 HV. The measurement results are shown in Figure 6b, where it can be clearly seen that the microhardness values of the 50th and 200th holes were higher, whereas those of the 350th holes were lower than the bulk hardness for holes drilled by both the 2- and 3-flute drills. This finding is supported by the SEM images in Figure 5. Moreover, the holes drilled with the 2-flute drill had higher hardness values as compared with those drilled with the 3-flute drill. It is shown in Figure 5 that as the number of holes increased, temperature and deformation at the cutting zone increased and recrystallization took place as a result. Depending on the increase in the number of holes, the cutting force, cutting temperature, plastic deformation and also workpiece hardening increased. Smaller grain size led to higher hardness values according to the Hall-Petch relationship [22]. After the 200th hole, very high-temperature resulted, thrust force increased, and tool wear increased as well, giving rise to thermal softening of the material and a decrease in hardness. It was observed that the hardness of the material increased until the cutting temperature reached the recrystallization temperature, but decreased during recrystallization.



a)



b)

Figure 6: a) SEM and XRD analyses for AZ91 after machining, b) microhardness of the borehole surface

Conclusions

An experimental study was carried out on the drilling of cast AZ91 Mg alloy using 2-flute and 3-flute drills. The drilled holes were examined in terms of thrust force generation, wear formation, tool life and chip morphology using SEM, EDS and micro hardness analyses during the drilling and the following conclusions have been drawn:

1. During drilling using the 3-flute drill bit, greater thrust forces were generated due to the larger contact area at the cutting tool-workpiece interface.
2. Cutting speed parameter was more effective on chip shape than feed rate. At lower cutting speeds, fan-type and zigzag-type chips were formed, while long, zigzag-type chips were formed at higher cutting speeds owing to greater heat generation.
3. In general, the 3-flute drill formed longer and narrower chips as compared with the 2-flute drill. Long, folded wavy-type chips and thick, long ribbon and string-shaped chips were observed in the drilling of AZ91.
4. More tool wear was observed in the 2-flute drill. After the 350th hole, 78 μm flank wear occurred in the 2-flute drill, while 67 μm was measured in the 3-flute drill.
5. The SEM observations showed that borehole surface grain size became smaller during drilling; however, grain growth also occurred due to high temperatures.
6. Intermetallic phases varied as the number of holes increased; therefore, the chip removal process became more complicated depending on the intermetallic phases.
7. The microhardness of the borehole surface was greater than the bulk hardness but decreased because of thermal softening as well as grain growth. Furthermore, the microhardness of the holes drilled by the 2-flute drill bit was higher than that of those drilled by the 3-flute drill bit.

Acknowledgement

The authors would like to thank the NACHI Company, Istanbul, Turkey, for providing the cutting tools.

References

1 P. Mónica, P. M. Bravo, D. Cárdenas: Deep cryogenic treatment of HPDC AZ91 magnesium

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For personal use only.

Materials Testing downloaded from www.hanser-elibrary.com by Hanser - Library on March 4, 2019
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alloys prior to aging and its influence on alloy microstructure and mechanical properties, Journal of Materials Processing Technology 239 (2017), pp. 297-302
DOI:10.1016/j.jmatprotec.2016.08.029

2 Z. Pu, J. C. Outeiro, A. C. Batista, O. W. Dillon, D. A. Puleo, I. S. Jawahir: Enhanced surface integrity of AZ31B Mg alloy by cryogenic machining towards improved functional performance of machined components, International Journal of Machine Tools and Manufacture 56 (2012), pp. 17-27
DOI:10.1016/j.ijmachtools.2011.12.006

3 B. R. Sunil, K. V. Ganesh, P. Pavan, G. Vadapalli, C. Swarnalatha, P. Swapna, P. Bindukumar, G. Pradeep Kumar Reddy: Effect of aluminum content on machining characteristics of AZ31 and AZ91 magnesium alloys during drilling, Journal of Magnesium and Alloys 4 (2016), No. 1, pp. 15-21
DOI:10.1016/j.jma.2015.10.003

4 S. Bhowmick, A. T. Alpas: The role of diamond-like carbon coated drills on minimum quantity lubrication drilling of magnesium alloys, Surface and Coatings Technology 205 (2011), No. 23-24, pp. 5302-5311
DOI:10.1016/j.surfcoat.2011.05.037

5 E. Gariboldi: Drilling a magnesium alloy using PVD coated twist drills, Journal of Materials Processing Technology 134 (2003), No. 3, pp. 287-295
DOI:10.1016/S0924-0136(02)01111-1

6 F. Karaca, B. Aksakal: Effect of the TIBN coating on a HSS drill when drilling the MA8M Mg alloy, Materiali in Tehnologije 50 (2016), No. 1, pp. 75-79
DOI:10.17222/mit.2014.290

7 S. Bhowmick, M. J. Lukitsch, A. T. Alpas: Dry and minimum quantity lubrication drilling of cast magnesium alloy (AM60), International Journal of Machine Tools and Manufacture 50 (2010), No. 5, pp. 444-457
DOI:10.1016/j.ijmachtools.2010.02.001

8 S. Dinesh, V. Senthilkumar, P. Asokan, D. Arulkirubakaran: Effect of cryogenic cooling on machinability and surface quality of bio-degradable ZK60 Mg alloy, Materials & Design 87 (2015), pp. 1030-1036
DOI:10.1016/j.matdes.2015.08.099

9 Z. Pu, D. Umbrello, O. W. Dillon, T. Lu, D. A. Puleo, I. S. Jawahir: Finite element modeling of microstructural changes in dry and cryogenic machining of AZ31B magnesium alloy, Journal of Manufacturing Processes 16 (2014), No. 2, pp. 335-343
DOI:10.1016/j.jmapro.2014.02.002

10 E. Bahce, C. Ozel: Influence of a stepped feed rate on burr formation when drilling Al-5005, Materials Testing 60 (2018), No. 3, pp. 316-324
DOI:10.3139/120.111154

11 İ. Ucun: 3D finite element modelling of drilling process of Al7075-T6 alloy and experimental validation, Journal of Mechanical Science and Technology 30 (2016), No. 4, pp. 1843-1850
DOI:10.1007/s12206-016-0341-0

12 J. W. Kim, S. C. Lee: A study about microhole machining characteristics of plastic mould steel, Materials Research Innovations 18 (2014), No. sup2, pp. S2-661-S2-665
DOI:10.1179/1432891714Z.000000000550

13 E. Ekici, B. Işık: Experimental investigation of surface damage occurred on the sides of hole entrance in drilling of glass-fiber reinforced polymer composite materials, Technology 13 (2010), No. 1, pp. 31-40

14 A. Faraz, D. Biermann, K. Weinert: Cutting edge rounding: An innovative tool wear criterion in drilling CFRP composite laminates, International Journal of Machine Tools and Manufacture 49 (2009), No. 15,pp. 1185-1196
DOI:10.1016/j.ijmachtools.2009.08.002

15 A. Yardimeden, E. Kilickap, Y. H. Celik: Effects of cutting parameters and point angle on thrust force and delamination in drilling of CFRP, Materials Testing 56 (2014), No. 11-12, pp. 1042-1048
DOI:10.3139/120.110666

16 J. Ramkumar, S. K. Malhotra, R. Krishnamurthy: Effect of workpiece vibration on drilling of GFRP laminates, Journal of Materials Processing Technology 152 (2004), No. 3, pp. 329-332
DOI:10.1016/S0924-0136(03)00622-8

17 J. Xu, Q. An, M. Chen: A comparative evaluation of polycrystalline diamond drills in drilling high-strength T800S/250F CFRP, Composite Structures 117 (2014),pp. 71-82
DOI:10.1016/j.compstruct.2014.06.034

18 T. N. Valarmathi, K. Palanikumar, B. Latha: Measurement and analysis of thrust force in drilling of particle board (PB) composite panels, Measurement 46 (2013), No. 3, pp. 1220-1230
DOI:10.1016/j.measurement.2012.11.024

19 E. A. Rahim, H. Sasahara: A study of the effect of palm oil as MQL lubricant on high speed drilling of titanium alloys, Tribology International 44 (2011), No. 3, pp. 309-317
DOI:10.1016/j.triboint.2010.10.032

20 F. Ke, J. Ni, D. A. Stephenson: Continuous chip formation in drilling, International Journal of Machine Tools and Manufacture 45 (2005), No. 15, pp. 1652-1658
DOI:10.1016/j.ijmachtools.2005.03.011

21 S. A. Batzer, D. M. Haan, P. D. Rao, W. W. Olson, J. W. Sutherland: Chip morphology and hole surface texture in the drilling of cast aluminum alloys, Journal of Materials Processing Technology 79 (1998), No. 1-3, pp. 72-78
DOI:10.1016/S0924-0136(97)00324-5

22 Z. Pu, O. W. Dillon, I. S. Jawahir, D. A. Puleo, Microstructural changes of AZ31 magnesium alloys induced by cryogenic machining and its influence on corrosion resistance in simulated body fluid for biomedical applications, Proceedings of the International Manufacturing Science and Engineering Conference, ASME, Pennsylvania, USA(2010), pp. 271-277
DOI:10.1115/MSEC2010-34234

Bibliography

DOI 10.3139/120.111315
Materials Testing
61 (2019) 3, pages 260-266
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ISSN 0025-5300

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