Journal of Materials and Manufacturing (2022) 1: 7-13

Journal of Materials and Manufacturing

Drilling of AZ31 magnesium alloy under dry and cryogenic conditions

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Abstract

It is extremely important to machining the materials without harming the environment and with high efficiency. In this study, the machinability of AZ31 magnesium alloy in dry and cryogenic conditions was investigated experimentally. Experimental variables; cooling conditions, cutting speed, feed rate, and cutting length were selected. In the drilling tests conducted at in dipped cryogenic approach, no burrs were formed at the hole exit and a clean surface was obtained. On the bore-hole surface roughness evaluation, smoother surfaces were obtained in the drilling tests performed under the cryogenic approach. In the bore-hole surface hardness comparison, lower hardness values were measured with the use of cryogenic bath conditions.

Keywords: Drilling, AZ31, Magnesium, cryogenic.

1. Introduction

The drilling process is one of the most widely used traditional machining methods among metal cutting processes. Mechanical engineering, automobile manufacturing, aerospace-aircraft industries, medical engineering are widely applied in many industrial sectors. One of the main quality parameters in traditional machining methods is surface roughness [1]. Some problems are encountered in the dry machining of magnesium alloys. These problems are; the tendency of the alloy to chip ignite, stick to the cutting tool and tool wear at high cutting speeds [2-4]. The use of coolant in the metal cutting process has many negative environmental consequences. Therefore, there is increasing interest in the machining of metallic materials, either without the use of coolant or in the use of environmentally friendly coolants. Bertolini et al. [5] investigated the effect of drill bit and cryogenic cooling on hole quality when drilling magnesium-based fiber metal laminates. In their studies, three different drills were selected and their machinability under dry and cryogenic conditions was investigated. It has been stated that the application of spur drill bit and cryogenic cooling significantly improves the hole quality. Kheireddine et al. [6] experimental and numerical studied the effect of cryogenic coolant on hole surface integrity in the drilling of magnesium alloy. It was emphasized that the surface hardness of the bore holes obtained by cryogenic cooling improved. In another study [7] of the authors, tests executed under dry and cryogenic were compared and it was stated that the holes obtained in the tests achieved under cryogenic approach had higher hardness values. The drilling performance of AZ31 magnesium syntactic foams with cryogenic, dry and wet cooling application was investigated [8]. Cryogenic machining improved surface roughness by 75% and produced minimal subsurface machining-induced defects. Koklu and Coban [9]

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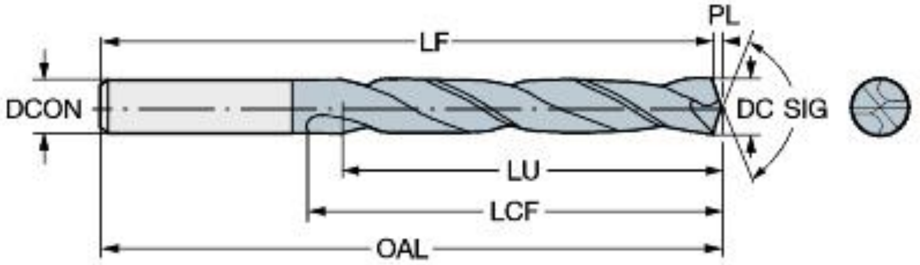
DOI: 10.5281/zenodo.7107296
Received: 15 June 2022, Revised: 09 August 2022 and Accepted: 01 September 2022
ISSN XXX-XXXX.

extensively investigated cutting force, temperature, drill wear and chip formation in AZ31 magnesium alloy drilling under dry and cryogenic conditions.

In this study, the environmentally friendly and highly efficient machining process of AZ31 alloy was investigated. In this context, the drillability of the Mg alloy was tested under dry and cryogenic cutting conditions. Since there are limited studies on the machinability of this alloy under cryogenic bath conditions, it will fill both an industrial and academic gap.

2. Experimental Procedure

In this study, the drilling of AZ31 magnesium alloy under dry and dipped cryogenic machining conditions was investigated. In the first part [9] of the experimental study, thrust force, temperature, tool wear were investigated, and in this part, the hardness of the drilled surface, surface roughness and hole exit were focused. In the experiments, PVD (TiAlN) coated carbide drills with two helical flutes with a diameter of 4 mm were used. Geometric information of the drill is given in Figure 1 [10]. For other details about the experiment, mechanical properties and chemical composition of the AZ31 magnesium alloy, the reference [11] can be reviewed.



DC: 4 mm, DCON: 6 mm, LU: 12.6 mm, SIG: 140°, LCF: 24 mm, OAL: 66 mm

Fig. 1. Geometric information of the drill

Two different experimental design were used in the experimental study. In the first experimental design, the effect of cutting parameters on the results was investigated. These experimental design parameters and levels are given in Table 1. In the second experimental design, the effect of cutting length variation on the results was investigated. The cutting parameters used here are a constant cutting speed of 80 m/min and feed rate of 1000 mm/min.

Table 1. Input parameters and their levels

Parameters	Level 1	Level 2	Level 3	Level 4
Cooling	Dry	Cryogenic	-	-
Cutting speed (m/min)	40	120	-	-
Feed rate (mm/rev)	0.1	0.15	0.2	0.25

Experiments were made in CNC vertical machining center. An insulating fixture was used to carry out the experiments in the cryogenic environment. Liquid nitrogen was used as cryogenic environment. Experiments were carried out while the material was in a liquid nitrogen bath. The drilled holes were cut in two and the in-hole surface topography was performed by optical profilometer (Zygo ZeGAGE). Hardness measurements of the samples were made with Digirock hardness measuring device using Rockwell F scale (HRF) method. Hardness and roughness measurements were made from 3 different points inside the bore holes. The hole exit was visualized with a digital microscope in both dry and cryogenic tests (Figure 2).

Burr measurement | Surface topography measurement | Hardness measurement

Fig. 2. Measurement equipment

3. Results and Discussion

3.1. Inspecting the hole exit

Burrs formed at the hole exits are one of the most negative factors encountered in the drilling process. It creates extra time and cost for the 2nd operation to clean the burrs as it occurs in mass production. The hole exits obtained from the experiments carried out under dry and cryogenic conditions are given in Figure 3. As it can be seen from the Figure, since the material exhibits a ductile behavior under dry cutting conditions, the burrs did not break off at the hole exits and remained suspended on the workpiece. In the mechanical drilling experiments carried out under cryogenic environment, almost no burrs were formed at the hole exits. The reason why burrs do not form at the hole exit in the experiments carried out in the cryogenic condition is that the liquid nitrogen makes the material embrittle by lowering its temperature. Accordingly, brittle rupture occurs at the hole exit.

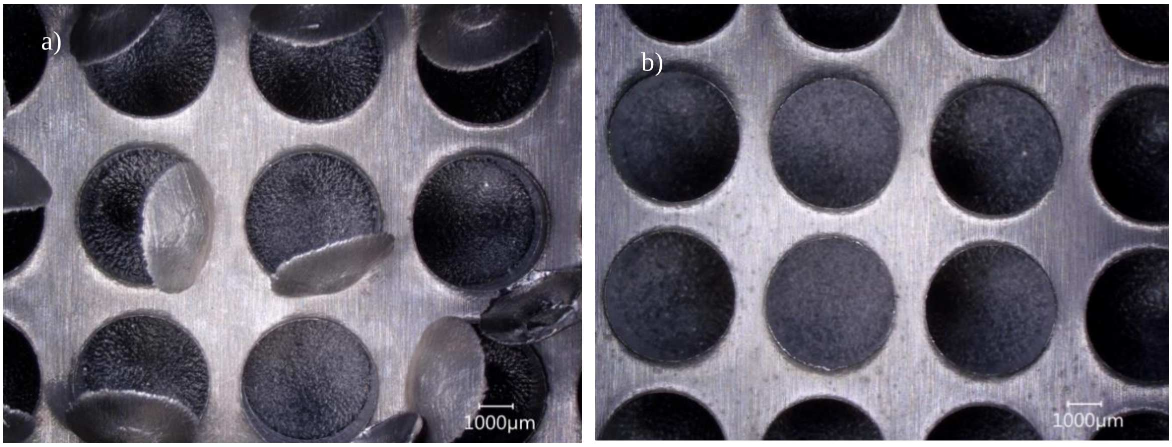


Fig. 3. Burrs formed at the hole exits (a) dry drilling and (b) cryogenic drilling

The hole exit images formed in the tool life experiments at constant cutting speed of 80 m/min and feed rate of 1000 mm/min are given in Figure 4. As can be seen in the Figure, no serious burr formation was observed at the hole exit. However, in tests performed under dry conditions, more plastic deformation was observed compared to cryogenic conditions.

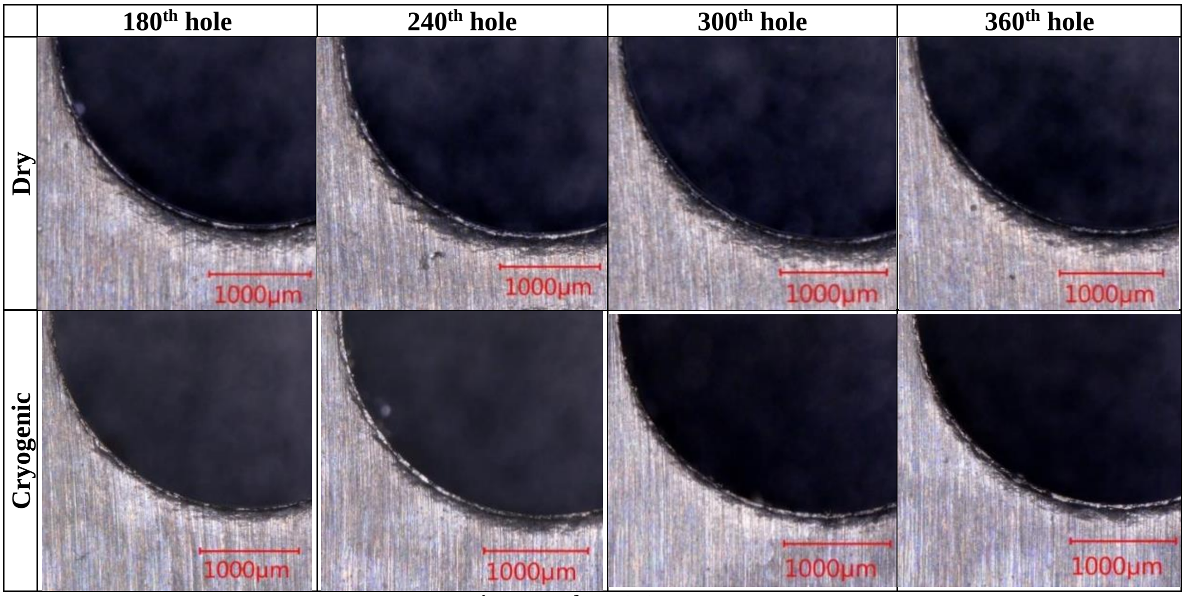


Fig. 4. Hole exit images

3.2. Evaluation of surface roughness results

After the drilling tests, the surface roughness of the drilled holes was measured by cutting the holes in half from their axes. In Figure 5 and 6, the surface topographies and roughness (R_a and R_z) formed on the hole surfaces are given. When the Figure is examined, while the surface quality of the holes improves with the increase in cutting speed, the surface quality of the holes deteriorates with the increase in feed rate. When the cryogenic and dry cutting and drilling conditions were compared, smoother surfaces were obtained with cryogenic drilling.

In Figure 6, the graph of the variation of surface roughness values (R_a) with cutting speed and feed rate is given. The highest surface roughness value (0.352 µm) occurred in dry cutting conditions, 40 m/min cutting speed and 0.25 mm/rev feed parameters. The lowest surface roughness value (0.055 µm) occurred in cryogenic cutting conditions, cutting speed of 40 m/min and feed rate of 0.10 mm/rev. When the cutting speed is 120 m/min, the highest surface roughness value is 0.284 µm in dry condition and 0.25 mm/rev feed rate, while the lowest 0.052 µm feed rate is 0.10 mm/rev in cryogenic condition. When the surface roughness values formed in dry and cryogenic machining conditions are compared, it is seen that the surface roughness values formed in dry cutting conditions are higher. The reason for this situation is that because the material is cut as ductile in dry cutting conditions, plastering on the material surface is more. In the tests caried out under cryogenic environment, a better surface was formed compared to the dry cutting tests. The high temperature formed in the cutting zone is removed from the cutting zone by means of liquid nitrogen and better-quality surfaces can be obtained.

3.3. Bore hole hardness analysis

After the AZ31B magnesium alloy was drilled, its hardness was measured by cutting it in half from the hole centers. In bore-hole hardness measurement results are given in Table 2. In both dry and cryogenic conditions, the surface hardness values increase with increasing cutting speed. Increasing the cutting speed causes more heat generation in the cutting zone. In this case, it increases the surface hardness. A general trend regarding the effect of feed change on hardness was not observed. When drilling operations are evaluated in dry and cryogenic conditions, it is seen that the hardness value in cryogenic conditions is lower than that in dry conditions.

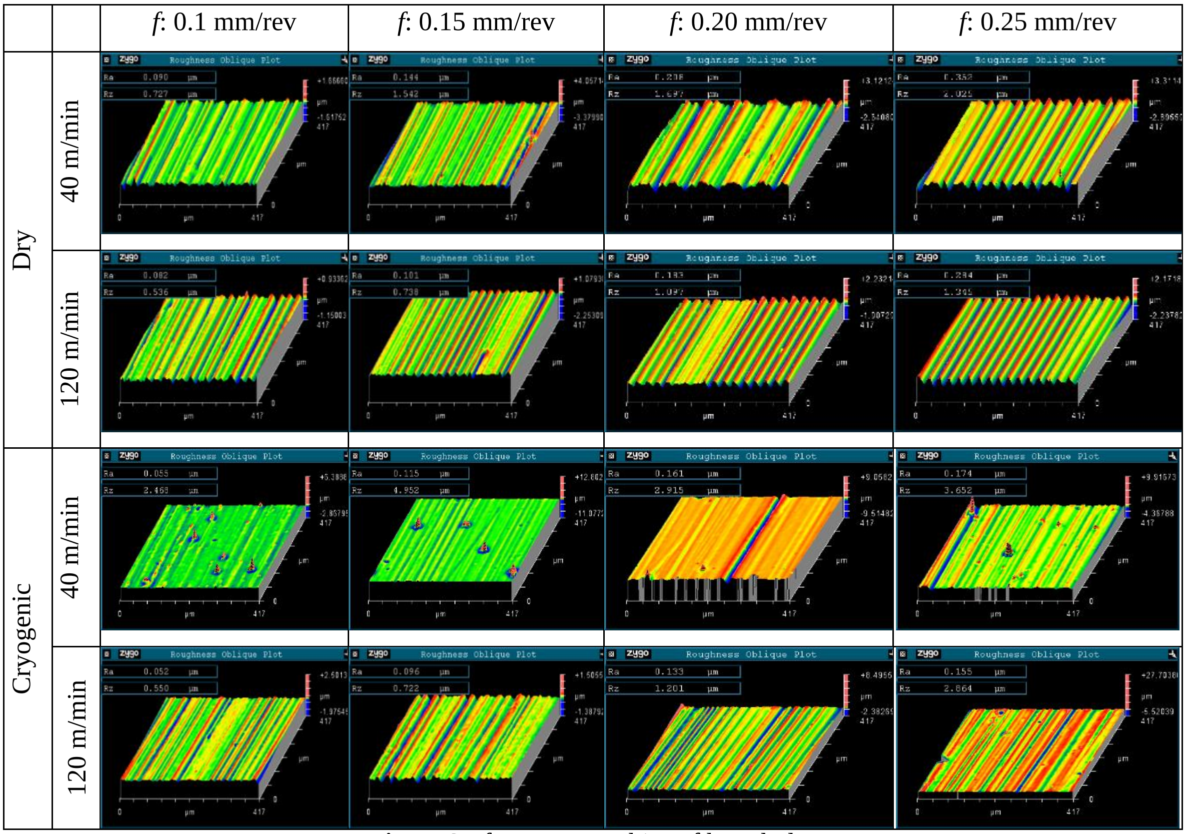


Fig. 5. Surface topographies of bore holes

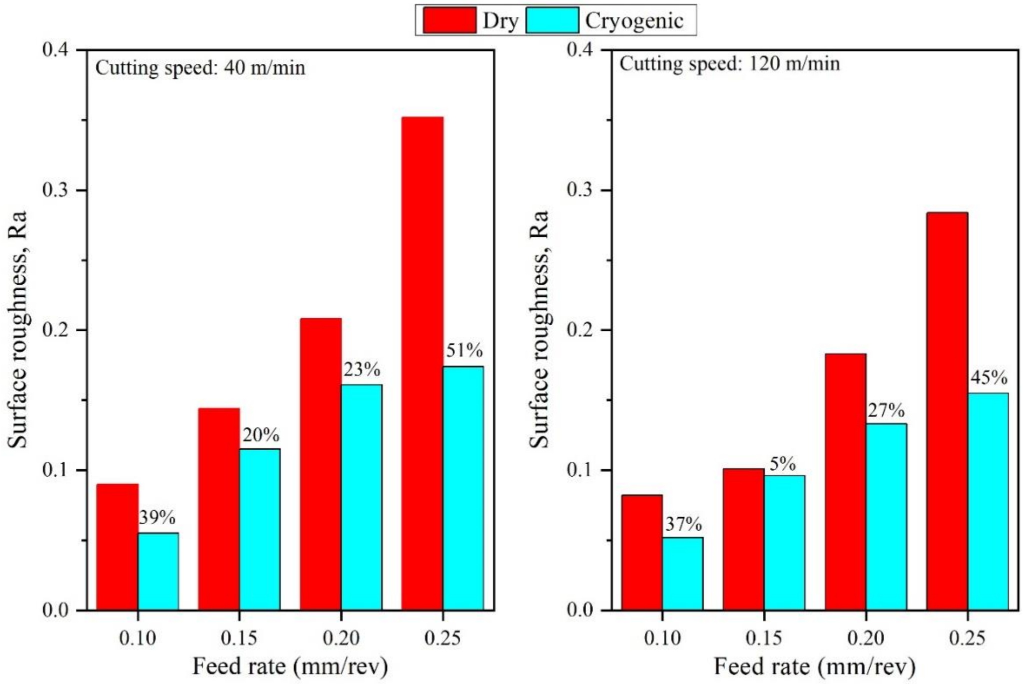


Fig. 6. Effect of cutting speed and feed variation on surface roughness

Table 2. Bore-hole hardness results

	Dry drilling					Cryogenic drilling			
	Vc: 40 m/min		Vc: 120 m/min			Vc: 40 m/min		Vc: 120 m/min	
f: (mm/rev)	Avg	SD	Avg	SD		Avg	SD	Avg	SD
0.1	57.00	6.95	65.37	4.10		56.17	8.52	64.43	5.56
0.15	54.00	10.06	64.90	3.06		41.13	7.61	63.63	1.03
0.2	56.67	6.30	59.50	2.69		60.13	4.00	63.30	0.80
0.25	55.87	11.38	56.60	9.71		55.93	4.37	62.33	2.13

f: feed rate, Vc: Cutting speed, Avg: average, SD: standard deviation

4. Conclusion

In this study, drilling of AZ31B magnesium alloy using four different feeds (0.1, 0.15, 0.20, 0.25 mm/rev), two diverse cutting speeds (40 and 120 m/min) and two different machining conditions (dry and cryogenic) was investigated experimentally. Obtained results and findings are given below.

- While it was observed that the burrs did not break due to the ductile behavior of the material in the drilling operations performed in dry drilling conditions, it was found that the burrs were broken off in the drilling test performed in cryogenic environment because the material had a brittle structure.
- In tests performed under dry and cryogenic conditions, the surface quality of the holes improves with the increase in cutting speed, while the surface quality of the holes deteriorates with the increase in feed rate. When cryogenic and dry cutting conditions were compared, smoother surfaces were obtained with cryogenic conditions.
- The surface hardness values increased with the increase in cutting speed in the drilling tests carried out under dry and dipped cryogenic conditions. The surface hardness value formed in the tests performed under dipped cryogenic conditions is less than in dry cutting conditions.
- In addition, with the use of liquid LN_2, the negative effects such as ignition and chip formation during the machining of magnesium alloys are minimized.

Acknowledgements

This work was supported by Commission of Scientific Research Projects of Karamanoglu Mehmetbey University (Project No. 04-YL-17).

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