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Full Length Article

High speed cutting of AZ31 magnesium alloy

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Abstract

Using LBR-370 numerical control lathe, high speed cutting was applied to AZ31 magnesium alloy. The influence of cutting parameters on microstructure, surface roughness and machining hardening were investigated by using the methods of single factor and orthogonal experiment. The results show that the cutting parameters have an important effect on microstructure, surface roughness and machine hardening. The depth of stress layer, roughness and hardening present a declining tendency with the increase of the cutting speed and also increase with the augment of the cutting depth and feed rate. Moreover, we established a prediction model of the roughness, which has an important guidance on actual machining process of magnesium alloy.

Keywords: AZ31 magnesium alloy; High speed cutting; Cutting parameters; Hardening; Roughness; Stress layer

1. Introduction

Magnesium alloy has many advantages, such as high strength-to-weight, high stiffness-to-weight ratios, and no pollution, etc., so it has a very broad application prospect, and thus it was called green metal material in 21st century [1–3]. As for today's energy crisis, it is urgent to accelerate the development of magnesium materials. Nowadays, the current research of magnesium alloy mostly focus on plastic processing technology (e.g. forging, extrusion, rolling, drawing, stamping) and heat treatment (e.g. annealing, solid solution and aging) [4–7]. Machining (e.g. cutting, turning, milling) is one of the basic manufacturing processes usually found in fabrication of components and structures [8]. However, the research about high speed cutting of magnesium alloy is very few. The tools about cutting steels and other alloys have been commonly reported in previous reports [9,10], the temperature variation during the cutting process was referred [11], the optimization of surface roughness and cutting force were also studied [12,13], and how the cutting parameters affect cutting chip, roughness and residual stress were further studied [14,15]. However, the high speed cutting of Mg alloys still lacks systematic study and deepen analysis.

In this work, we carried out a series of experiment to systematically reveal the effect of cutting parameters on the microstructure, residual stress, hardening behavior, and roughness of AZ31B Mg alloys. Combing the analysis of microstructure and vickers hardness, the residual stress distribution after high speed cutting was discussed. Meanwhile, the roughness was measured to reflect the surface quality of workpiece, and the new predicted model of roughness was established.

2. Materials and experimental procedures

The materials used in this study were commercial AZ31 magnesium alloy; the main ingredients was shown in Table 1.

The size of cutting billets was Φ23 mm × 200 mm, which were machined from the extruded AZ31 Mg alloys with a diameter of Φ23 mm and a length of 1000 mm. High speed cutting was conducted on LBR-370 numerical control lathe, and the material of cutting tool with 15 mm in length and 15 mm in width and 5 mm in thickness used was YT15, and the cutting edge angle was 6°, the cutting edge radius r was 0.2 mm, and

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Table 1
Chemical composition of the AZ31 magnesium alloy.

Element		Al	Zn	Mn	Si	Cu	Ni	Fe
Wt%	min	2.5	0.6	0.2				
	max	3.5	1.4	1.0	0.1	0.05	0.005	0.005

Table 2
Cutting parameters of the AZ31 magnesium alloy.

Order number	Speed (r/min)	Ap (mm)	F (mm/r)
1	1000	1	0.05
2	1400	1	0.05
3	1800	1	0.05
4	2200	1	0.05
5	1400	0.5	0.05
6	1400	1	0.05
7	1400	1.5	0.05
8	1400	2	0.05
9	1400	1	0.02
10	1400	1	0.05
11	1400	1	0.08
12	1400	1	0.11

the rear angle was 9°. The cutting parameters were listed in Table 2. It should be noted that all the cutting length was 20 mm.

Surface roughness was measured by a portable surface roughness equipment (LINKS-HOMMLET1000). Five points were selected from each cutting surface, and their average value was calculated to be roughness value. After that, the optical microscopy (OM) observations of cross section were carried out, and the observation samples were machined from the plane of cross section, which can be seen from Fig. 1. The OM samples were prepared by polishing surface mechanically and etching in a solution of 10 ml acetic acid, 4.2 g picric acid, 10 ml water, and 70 ml ethanol. Finally, the hardness of cross section was measured from edge to internal, and the distance between two adjacent points was 5 µm. The Hv was measured over ten successful readings for each sample using a digital tester DMH-1 (Matsuzawa Seiki Co., Ltd.), the indenter load and holding time at test pressure were 100 g and 8 s, respectively.

3. Results and discussion

3.1. Microstructure

The original microstructure of the work piece is shown in Fig. 2. Many coarse and tiny grains are observed. The size of some coarse grains reaches up to 150 µm, and the tiny grain size is about 6 µm. It is statistically found that a large amount of grain size is measured to be between 50 µm and 100 µm.

From the Fig. 3, there is an obvious stress layer at the edge of the cross section of cutting product, and the stress layer depth decreases from 40 µm to 25 µm with the increase of cutting speed from 1000 r/min to 2200 r/min. Careful observation reveals that the number of crystal twins also presents a decreasing tendency with the increase of the cutting speed, which can be attributed to the contacted time between the tool and the work piece reduces with the increase of the cutting speed, and the stress layer gets small, imposing an important effect on the time of interaction force between the tool and the work piece, thus preventing the formation of the residual stress in the surface of the work piece. There are some reasons for this special residual stress: (1) as for the high speed cutting process, the density of the work piece is mainly affected by the surface variation, and the high speed cutting can easily increase the surface temperature, which decreases the tendency of residual stress on the surface of work piece. From Fig. 3a, one can see that many slim twins come out. However, the number of them is gradually reduced for the effect of increasing temperature with the increase of cutting speed (Fig. 3b–d). (2) The cutting surface is subjected to severe plastic deformation under the action of cutting force, after the cutting completion, a large amount of work hardening remains, resulting in serious residual stress in the work piece surface [16].

From the Fig. 4, as the cutting depth increases from 0.5 mm to 2 mm, there are no great changes for the stress layer depth of the work piece. As for the work piece with 0.5 mm and 1 mm cutting depth, the stress layer depth are measured to be about 20 µm and 25 µm, respectively (Fig. 4a and b). It is interesting to find that the same stress layer depth comes out for the work piece with 1.5 mm and 2 mm cutting depth, indicating that the influence of cutting depth on the stress layer depth is not

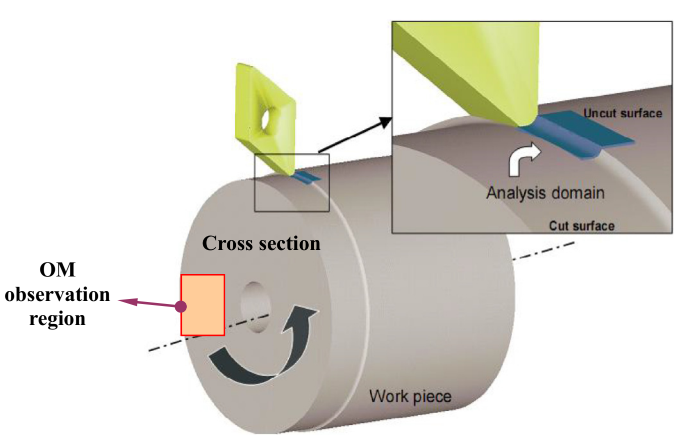

Fig. 1. Schematic of the cutting method and OM observation region.

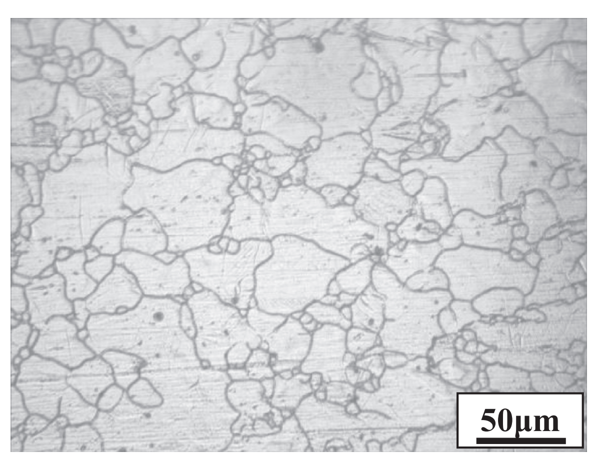

Fig. 2. Microstructure of AZ31 Mg alloys before cutting process.