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Light emission, chip morphology, and burr formation in drilling the bulk metallic glass

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Abstract

The chip light emission, chip morphology, burr formation and machined surface in drilling of Zr-based bulk metallic glass (BMG) material are investigated. This study demonstrates that the work- and tool-material as well as the feed rate and spindle speed, two drilling process parameters, all affect the onset of chip light emission. Slow feed rate and high spindle speed increase the specific cutting energy and promote the exothermic oxidation and light emission of the chip. Six types of chip morphology, powder, short ribbon, long ribbon, long spiral, long ribbon tangled, and fan, are observed in BMG drilling. The long ribbon tangled chip morphology is unique for BMG material. On the machined surface under quick stop condition, the fracture topography unique to metallic glass with tributary, void, and vein patterns is observed. Different burr formations are observed: the roll-over shape in the entry and the crown shape in the exit edge. The size of burr in the exit edge is typically larger than that in the entrance edge. High feed rate helps to reduce the size of burr in both entrance and exit edges. This study concludes that the WC–Co tool-material, due to its high thermal conductivity and hardness, performs better in drilling BMG than the high speed steel tool.

Keywords: Bulk metallic glass; Drilling; Light emission; Chip morphology; Burr formation

1. Introduction

Drilling is a widely used machining process for hole making. This study extends the research in machining of bulk metallic glass (BMG) from lathe turning to drilling [1–3]. Drilling is one of the important machining processes to produce BMG parts with complicated shape and high dimensional accuracy. The tool geometry and material deformation in drilling are more complicated than in the turning process. The cutting speed and rake angles change along the cutting edges of a twist drill during the chip formation in drilling. In the center web of the drill, the work-material is plowed under high negative rake angle. Effects of spindle speed, feed rate, and tool-material on the light emission, chip formation, and burr formation in drilling BMG are investigated.

BMG is a metal alloy with no long-range atomic order and no grain boundary. This new material offers unique mechanical, thermal, magnetic, tribological, and corrosion properties for various applications. In machining, the BMG work-material is under large deformation with high temperature and high strain-rate, which reveal the unique behavior of BMG under extreme deformation conditions. This research studies the drilling of $Zr_{52.5}Ti_5Cu_{17.9}Ni_{14.6}Al_{10}$ BMG, a commonly used Zr-based BMG [1,2]. A BMG rod of 6.35 mm diameter was prepared by arc melting and casting in a Cu-mold. The BMG rod was sliced into 2 mm thick disks for through-hole drilling tests.

To distinguish unique features in BMG drilling, a rod made of AISI 304 stainless steel, denoted as SS304, was machined to have the identical size as the BMG disk.

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Table 1
Mechanical and thermal properties of two work-materials

Material	Elastic modulus (GPa)	Hardness (Rockwell A)	Poisson ratio	Strain hardening exponent	Ultimate tensile stress (MPa)	Percent of elongation to fracture	Thermal conductivity (W/mK)	Fracture toughness (MPa $m^{1/2}$)
Zr-based BMG	96	77	0.36	∼0	1900	2 (All elastic)	4	40–55
AISI 304 stainless steel	193	60	0.29	0.60	515	40	16.2	75–100

Drilling tests under the same process parameters were conducted in BMG and SS304. These two work-materials have different mechanical and thermal properties, as summarized in Table 1. Previous BMG turning experiments reveal that, once the cutting speed exceeds a threshold value, spectacular light emissions due to oxidation of BMG material was observed [1–3]. Such unique characteristics as well as the feasible range of process parameters to enable the drilling of BMG are investigated.

In this paper, the experimental setup in a machining center and design of seven sets of drilling experiments are first introduced. The conditions that trigger the chip light emission are discussed. The chip morphology and crystallization are analyzed and the burr formation of drilled holes is examined.

2. Experimental setup and design

2.1. Drilling test setup and measurements

Drilling experiments were conducted in a Benchman VMC 4000 computer numerical controlled machining center, as shown in Fig. 1(a). The 6.35 mm diameter, 2 mm thick disk workpiece was clamped inside a support plate using a set screw (Fig. 1(b)). Seven 1 mm diameter or four 2 mm diameter holes can be drilled in a disk. Most of the drilling tests were conducted dry without using coolant.

The two tool-materials were M7 high speed steel and WC in cobalt matrix, denoted as HSS and WC–Co, respectively. The WC–Co tool-material has smaller than 1 μm grain size WC in 6% Co binder. For HSS, drills with 1 and 2 mm diameter were utilized. Only a 1 mm diameter WC–Co drill was used. The web-thickness of the 1 and 2 mm diameter drill was 0.35 and 0.5 mm, respectively. Table 2 summarizes the features and properties, including the grade, helix angle, hardness, and thermal conductivity, of the HSS and WC–Co drills. All drills had 118° point angle and two-flute geometry. Only the 2 mm HSS drill has the TiN coating. All other drills are uncoated.

As shown in Fig. 1(a), a piezoelectric force dynamometer (Kiestler 9272A) was used to measure the thrust force and torque during drilling tests. The chip was collected. Light emission during drilling was recorded. A Hitachi S-4700 scanning electron microscope (SEM) was

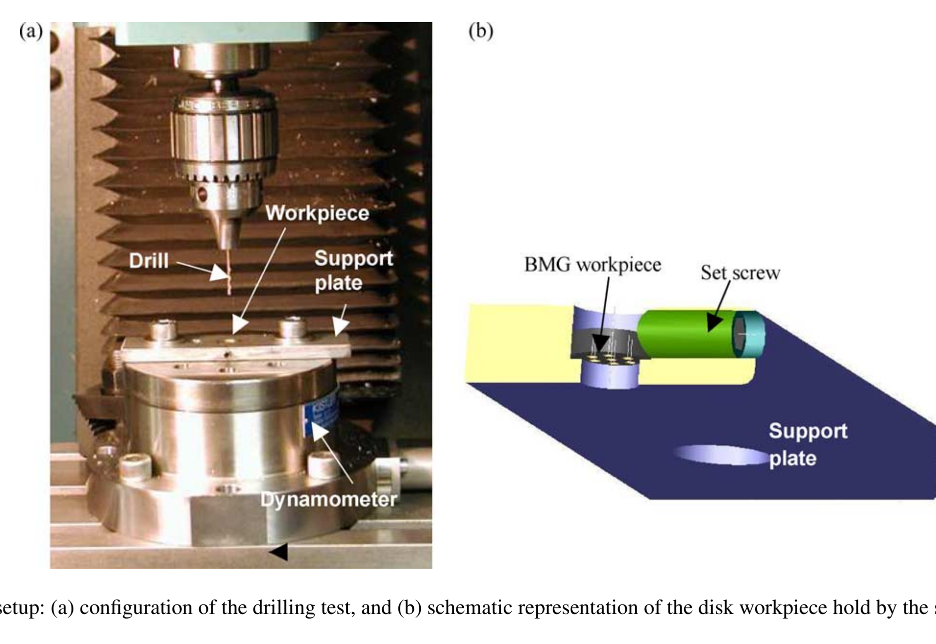

Fig. 1. Experimental setup: (a) configuration of the drilling test, and (b) schematic representation of the disk workpiece hold by the set screw inside a support plate.