CHAPTER 5. LIGHT EMISSION, CHIP MORPHOLOGY, AND BURR FORMATION IN DRILLING OF BULK METALLIC GLASS

5.1. 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 the 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. It reveals unique behaviors of BMG under extreme deformation conditions. This research studies the drilling of Zr52.5Ti5Cu17.9Ni14.6Al10 BMG, a commonly used Zr-based BMG [2,3]. A BMG rod of 6.35 mm diameter was prepared by the arc melting and casting in a Cu-mold. The BMG rod is sliced to 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. Drilling tests under the same process parameters are conducted in BMG and SS304. These two work-materials have different mechanical and thermal properties, as summarized in Table 4.1. Previous BMG turning experiments reveals 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 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.

5.2. Experimental Setup and Design

5.2.1. Drilling test setup and measurements

Drilling experiments were conducted in a Benchman VMC 4000 computer numerical controlled machining center, as shown in Fig. 5.1(a). The 6.35 mm diameter, 2 mm thick disk workpiece is clamped inside a support plate using a set screw (Fig. 5.1(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.
Two tool-materials are the 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 are used. Only 1 mm diameter WC-Co drill is used. The web-thickness of the 1 and 2 mm diameter drill is 0.35 and 0.5 mm, respectively. Table 5.1 summarizes the features and properties, including the grade, helix angle, hardness, and thermal conductivity, of the HSS and WC-Co drills. All drills have 118° point angle and two-flute geometry. Only the 2 mm HSS drill has the TiN coating. All other drills are uncoated.

**Table 5.1. Properties of two tool materials.**

<table>
<thead>
<tr>
<th>Tool designation</th>
<th>Material grade</th>
<th>Hardness (Rockwell-A)</th>
<th>Thermal conductivity (W/m-K)</th>
<th>Helix angle (°)</th>
<th>Manufacturer</th>
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<tbody>
<tr>
<td>HSS</td>
<td>M7</td>
<td>64</td>
<td>~20</td>
<td>28-32</td>
<td>Greenfield Industry</td>
</tr>
<tr>
<td>WC-Co</td>
<td>C3-C4</td>
<td>92</td>
<td>~80</td>
<td>25</td>
<td>Ultra Tool</td>
</tr>
</tbody>
</table>
As shown in Fig. 5.1(a), a piezoelectric force dynamometer (Kiestler 9272A) was used to measure the thrust force, \( F \), and torque, \( M \), during drilling tests. The chip is collected and light emission during drilling is recorded. A Hitachi S-4700 scanning electron microscope (SEM) was used to examine the chip morphology and burr formation. The cross-sectional surface of the polished and etched chip was studied using a Nikon Epiphot 300 optical microscope.

### 5.2.2. Experiment design

Seven sets of drilling experiment, marked as Exp. I to VII, were conducted. Effects of key process parameters, including the drill size, tool material, spindle speed, and feed rate, were studied in the first four sets of experiment (Exps. I to IV). Exps. V to VII investigates the effect of work-material, metalworking fluid, and surface under the quick stop or broken drill condition, respectively. Process parameters for Exps. I to VII are listed at Table 5.2 and summarized as follows:

Exp. I. Feed rate effect: 2.5, 5 and 10 mm/min feed rate for 1 mm diameter HSS drill at 10000 rpm spindle speed.

Exp. II. Spindle speed effect: 2500, 5000 and 10000 rpm spindle speed for 1 mm diameter HSS drill at 1.25 mm feed rate.

Exp. III. Drill size effect: 2 mm diameter HSS drill at 10000 rpm spindle speed and 2.5 and 10 mm/min feed rate.

Exp. IV. Tool-material effect: WC-Co drill with 1 mm diameter at 10000 rpm and 2.5, 5 and 10 mm/min feed rate.
Exp. V. Work-material effect: SS304 workpiece drilled using 1 mm diameter HSS and WC-Co drill at 10000 rpm and 2.5, 5 and 10 mm/min feed rate.

Exp. VI. Cutting fluid effect: The 3.5% water-based synthetic CIMTECH 500 metal working fluid was used for drilling the BMG with 1 mm diameter HSS drill at 10000 rpm and 2.5, 5 and 10 mm/min feed rate.

Exp. VII. Quick stop test: At slow feed rate (1.25 mm/min) and spindle speed (2000 rpm), the 1 mm diameter HSS drill broke during drilling. The bottom surface of the blind hole was examined to evaluate the machined and fractured surface of BMG.

Table 5.2. BMG drilling process parameters, light emission, chip formation, burr quality and length of heat affected zone in Exps. I to VII.

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Drill material</th>
<th>Drill diameter (mm)</th>
<th>Feed rate (mm/min)</th>
<th>Spindle speed (rpm)</th>
<th>Work-material</th>
<th>Cutting fluid</th>
<th>Light emission level</th>
<th>Chip morphology</th>
<th>Exit burr quality</th>
<th>Length of heat affect zone on drill [mm]</th>
<th>Number of finished holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>HSS</td>
<td>2.5</td>
<td>10000</td>
<td>BMG</td>
<td>No</td>
<td>1</td>
<td>SR</td>
<td>1</td>
<td>~4.5</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0</td>
<td>10000</td>
<td></td>
<td></td>
<td>1</td>
<td>LR</td>
<td>2</td>
<td>~2.5</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
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<td></td>
<td>10.0</td>
<td>10000</td>
<td></td>
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<td>0</td>
<td>LR</td>
<td>2</td>
<td>~0</td>
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<td>7</td>
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<tr>
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<td>BMG</td>
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<td>1</td>
<td>LR</td>
<td>2</td>
<td>~3.5</td>
<td>3</td>
<td>3</td>
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<tr>
<td></td>
<td></td>
<td>1.25</td>
<td>10000</td>
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<td></td>
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<td>LRT</td>
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<td>~8</td>
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<td>3</td>
</tr>
<tr>
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<td>10000</td>
<td>BMG</td>
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<td>P</td>
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<td>~12</td>
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<td>10000</td>
<td></td>
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<td>LS</td>
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<tr>
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<td>10000</td>
<td>BMG</td>
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<td>F</td>
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<td>0</td>
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<td>10000</td>
<td>SS304</td>
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<td>0</td>
<td>F</td>
<td>2</td>
<td>0</td>
<td>7</td>
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<tr>
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<td>F</td>
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<tr>
<td>VI</td>
<td>HSS</td>
<td>2.5</td>
<td>10000</td>
<td>BMG</td>
<td>Yes</td>
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<td>LR</td>
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<td>0</td>
<td>7</td>
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<tr>
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<td></td>
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<td>10000</td>
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<td>10.0</td>
<td>10000</td>
<td></td>
<td></td>
<td>0</td>
<td>LR</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>VII</td>
<td>HSS</td>
<td>1.25</td>
<td>2000</td>
<td>BMG</td>
<td>No</td>
<td>0</td>
<td>LS</td>
<td>0</td>
<td>~2.5</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

1. Sparking level -- 0: No spark, 1: sparsely sparking, 2: occasional continuous spark, 3: extensive sparking
3. Exit burr quality -- 0: No exit, 1: plastically deformed workpiece, 2: visible burr, 3: not visible burr
Seven through holes were drilled in each 1 mm diameter tool used test. Four through holes were drilled in 2 mm diameter tool used test. As recorded in Table 5.2, some drills were damaged during drilling.

5.3. Chip light emission

The light emission during drilling is the most unique feature in BMG machining. Not all BMG drilling processes trigger the light emission, which is caused by the exothermic oxidation of BMG during chip formation [1]. The work-material, tool-material, and drilling process parameters (feed rate and spindle speed) all influence the onset of chip light emission. For turning, the cutting speed was identified as a key process parameter to initiate the light emission [3]. Using the infrared spectrometer, the measured flash temperature of spark is high, in the 2400 to 2700 K range, and is independent of the cutting process parameters. Different levels of light emission occurred during the BMG drilling, marked from no spark (level 0) to significant, continuous spark (level 3). The light emission level for each drilling test is summarized in Table 5.2.

The highest level of light emission, as illustrated by the picture in Fig. 5.2, was observed in Exp. III using the 2 mm diameter HSS drill. The drill has high peripheral cutting speed, which triggers the exothermic oxidation of chip and the bright light emission. The oxidized BMG is brittle and the powder-like broken chip is always associated with significant light emission. This will be discussed in the chip morphology section.
No light emission (level 0) was observed in Exp. IV, drilling using the WC-Co tool which has over four times higher thermal conductivity than that of the HSS (80 vs. 20 W/m-K, as shown in Table 4.1). A higher percentage of heat generated at the tool-chip interface is conducted to the drill made of high thermal conductivity tool-material. This reduces the energy entering the chip and retards the light emission. For example, under the same drilling condition of 2.5 and 5.0 mm/min feed rate and 10000 rpm, the HSS drilling in Exp. I exhibited occasional chip light emission while the WC-Co drill in Exp. IV did not produce any light emission. No light emission was observed in drilling of SS304 (Exp. V) due to the lack of exothermic chemical reaction and in drilling with coolant (Exp. VI) due to the better cooling and lubrication.

In between two extreme levels 0 and 3, some drilling tests showed occasional but not continuous light emission in BMG drilling. Level 1 represents minor amounts of chip light emission, particularly at the start of the drilling when the drill first contacts the workpiece. More frequent light emission is denoted as level 2. The effect of feed rate on chip light-emission is demonstrated in Exp. I. Lower feed rate promotes more frequent light emission due to the rubbing of the tool and BMG work-material. Exp. II shows that higher spindle speed promotes the light emission. No light emission was seen at the very slow, 2500 rpm, spindle speed. The frequency of light emission gradually increases from 2500 to 10000 rpm. Both slow feed rate and high spindle speed increase the specific cutting energy and promote the exothermic oxidation and light emission of the chip.

Discoloring of the tool material due to high temperature can be observed at the tip of some HSS drills. The length of the heat affected zone is measured by visual
inspection. Results are summarized in Table 5.2. There is an obvious correlation between the light emission level, which results in high temperature, and the length of the heat affected zone.

5.4. Chip morphology

The drilling chip varies in size and shape due to the change in work- and tool-materials, process parameters, and drill geometry. In general, the chip morphology in drilling can be categorized as eight types: (1) needle, (2) powder, (3) fan, (4) short ribbon, (5) short spiral, (6) long ribbon, (7) long spiral, and (8) very long ribbon [4]. In this study, five of these eight types are observed in BMG chips. A new type of chip morphology, long ribbon tangled, was observed in BMG chips. The chip morphology for each test is summarized in Table 5.2. Each type of BMG chip morphology is summarized as follows:

1. Powder (P): The exothermic oxidation changes the BMG to brittle, easy-to-break ZrO$_2$ material and powder-like chips occurred in Exp. III at 10 mm/min feed rate. SEM micrographs of the powder chips are shown in Fig. 5.3.

![Fig. 5.2. The light emission in drilling of BMG (Exp. III).](image)
The rough, oxidized surface does not resemble the traditional machined chip surface. Brittle, fractured surfaces can be recognized in the close-up view in Fig. 5.3(b). The cavity seen on the fractured surface is likely due to melting and solidification of welded chips. Three optical micrographs of polished and etched cross-sections of the powder BMG chips are shown in Fig. 5.4. Different levels of crystallization inside the chip are recognized. Fig. 5.4(a) shows the BMG with the oxide surface layer and amorphous core. A BMG chip cross-section with fully crystallized core is illustrated in Fig. 5.4(b). Fig. 5.4(c) shows the partially crystallized core with the dendritic structure, which indicates the direction of maximum cooling rate. Similar microstructure has been observed in BMG chips after lathe turning [2].
Fig. 5.4. Optical micrographs of the polished and etched cross-section of BMG chips associated with light emission (Exp. III, 10 mm/min feed rate): (a) chip with oxide layer and amorphous core, (b) chip with oxide layer and fully crystalline core and (c) chip with oxide layer and mixture of amorphous and dendritic crystalline regions (arrows represent the direction of maximum cooling rate).

2. Short ribbon (SR): As shown in Fig. 5.5(a), the short ribbon shape BMG chip was generated in Exp. I with 2.5 mm/min feed rate. The chip hit the drill flute and broke into short ribbon segments. As shown in Fig. 5.5(b), edge splitting occurs during breaking. Chips in Fig. 5.5 exhibit neither light emission nor the oxidized surface seen in Fig. 5.3.
3. Long ribbon (LR): At the higher feed rate in Exp. I, the chip is thicker and does not break after hitting the flute. As shown in Figs. 5.5(c) and 5.5(d), a long ribbon chip is generated in Exp. I at 5 and 10 mm/min feed rate. Cracks on both sides of the ribbon chip due to extrusion in the drill center wedge and high cutting speed on the outside cutting edge can be seen. As shown in Table 5.2, LR chip morphology was also observed in Exps. II, IV and VI. The use of coolant in Exp. VI promotes the LR chip formation. Fig. 5.6(a) shows the LR chip in Exp. VI with 10 mm/min feed rate. In the close-up view in Fig. 5.6(b), serrated chip formation can be seen. A smooth
surface is observed on the other side of the serrated chip surface. This is the surface in contact with the tool during drilling. This chip morphology is similar to those observed in the machining of titanium and other low thermal conductivity work-materials [5].

![Fig. 5.6. Long ribbon (LR) BMG chip in Exp. VI (10 mm/min feed rate): (a) general view of chip and (b) close-up view of the box in (a).](image)

4. Long ribbon tangled (LRT): In Exp. II under the highest, spindle speed 10000 rpm, the long ribbon chip shown in Fig. 5.7(a), is tangled together into a ball shape that generates the unique LRT chip morphology. Light emission is associated with this type of chip formation and indicates some level of local chip oxidation. This can be further validated by examining the LRT chip closely, as shown in Fig. 5.7(b).
5. Long spiral (LS): Spiral shape chips are generated in Exp. IV, at slow feed rates 2.5 and 5 mm/min, and in Exp. VII using the WC-Co drill. The LS chip in Exp. VII is shown in Fig. 5.8. at four levels of magnification. Figs. 5.8(c) and 5.8(d) illustrate the serrated chip formation. The close-up view in Fig. 5.8(d) indicates that the spacing between adjacent shear bands is about 2 \( \mu \text{m} \). This chip morphology has been reported for lathe-turned BMG chips [3]. Fig. 5.9 shows chips from Exp. IV using the WC-Co drill. At the two slower feed rates (2.5 and 5 mm/min), LS chips are generated. At the high feed rate (10 mm/min), the chip morphology changes to LR. The effect of tool-material on chip morphology is revealed by comparing Figs. 5.5 (HSS, Exp. I) and 5.9 (WC-Co, Exp. VI). The drilling process parameters are the same in both experiments. The WC-Co tool-material produces more efficient material removal and promotes the LS chip formation.
Fig. 5.8. Long spiral (LS) BMG chip in Exp. VII: (a) general view of the long chip, (b) close-up view of the box in (a), (c) close-up view of the box in (b) with serrated chip surface and (d) spacing between shear band and the molten debris on the chip surface.
(a) (b) Close-up view of the box in (a)

(c) (d)

Fig. 5.9. BMG chips in Exp. IV: (a) and (b) 2.5 mm/min, (c) 5 mm/min and (d) 10 mm/min feed rate.

6. Fan (F): This chip begins with a spiral form but does not curl sufficiently to follow the flute and thus produces fracture prior to a complete revolution [6]. As shown in Fig. 5.10, the SS304 chip generated in Exp. V has this chip morphology.
Fig. 5.10. Fan shape (F) SS304 chip in Exp. V: (a) general view of chips and (b) close up view of the box in (a).

The short spiral shape is considered the ideal case for chip evacuation in drilling applications [6]. This chip morphology was not observed in BMG drilling. For chips produced without light emission, the optical micrographs of etched and polished cross-section show neither the oxide layer nor crystallization.

5.5. Fracture Surface For Quick Stop Conditions

In Exp. VII, the tool used for drilling BMG at the slowest feed rate (1.25 mm/min) and spindle speed (2000 rpm) broke during drilling in the second hole. During drilling, no chip light emission was observed. The drill breaking is likely due to clogging of the long spiral chip shown in Fig. 5.8. The broken drill promptly stops the drilling process and presents an opportunity to examine the fracture surface in the blind hole under a quick stop condition. Fig. 5.11 shows SEM micrographs of the surface in the blind hole.
Legend: C- center of the drill, T-tributaries, V-voids, TR-triple ridge point, W-well developed vein pattern, U-undeveloped vein pattern.

Fig. 5.11. SEM micrograph of the blind hole produced by broken drill or quick stop condition: (a) overall view of the blind hole, (b) close-up view of box in (a) near the center region, (c) close-up view of box in (b) below the center region and (d) close-up view of the box in (c).

Based on the location of burr on the edge of the entry hole, Fig. 5.11(a) indicates that, at the moment of drill breakage, the drill tilted to the right-side of the hole. The center of the hole is marked as C. From the close-up view of the center region in Fig. 5.11(b), two cutting edges were aligned above and below the center C at the moment of drill breakage. The fracture surface with more obvious features can be seen in a region below the center of the blind hole. A close-up view of this region below the center is
shown in Fig. 5.11(c). Since the web thickness of the drill is 0.35 mm, all the area in Fig. 5.11(c) is cut by the chisel edge in the drill center.

The fracture topography of metallic glass has been investigated by Pampillo and Reimschuessel [7] and classified by features that include tributaries (T), voids (V), well-developed vein patterns (W), undeveloped vein patterns (U), and triple ridge point (R). These unique topography features, as marked in Figs. 5.11(c) and 5.11(d), are results of the highly inhomogeneous shear deformation which occurs prior to fracture and defines a plane on which cracks nucleate and propagate. The vein patterns are produced by the collision of cracks. The V in Fig. 5.11(d) indicates the site of void nucleation. In the shear plane, voids nucleate and initiate the propagating cracks. Along the line where two cracks meet, due to the reduction in stress concentration and increase in temperature, a necked ridge is generated. These ridges form the tributaries and vein patterns on the shear fractured BMG surface.

Temperature at the crack intersection points is expected to be high due to the heat produced within the small plastic zone ahead of crack tip added in a narrow strip between two merging cracks. The temperature may rise to exceed the glass transition temperature and produce viscous flow. This is indicated by the elongated whisker at the triple ridge points, as reported by Leamy et al. [8] and marked by TR in Fig. 5.11(d).

For the river-like vein pattern, Spaepen [9] has developed a schematic representation of successive formation stages from the initial perturbation and difference in crack propagation speed. The vein pattern merged into “tributaries” (T), as indicated in Fig 5.11(c) [7].
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Figure 5.11(d) also shows vein regions at different development stages. According to Gilbert et al. [10], fracture surface roughness increases significantly with increasing crack (deformation) speed. In the well-developed vein patterns (W) in Fig. 5.11(d), the crack propagation speed is higher than that in the region with undeveloped vein patterns (U).

5.6. Burr formation

Burr formation is a commonly encountered phenomenon in drilling. Two distinctly different types of burr are identified in the entry and exit edges of drilled BMG holes.

SEM micrographs of the entry burr for BMG drilled by HSS and WC-Co drills in Exps. I and IV are show in Figs. 5.12 and 5.13, respectively. The HSS drill generates larger size entry burrs with an irregular roll-over shape [11], relative to those in WC-Co drilled holes. This is likely due to the rubbing and more severe margin wear of the HSS drill. The drill wear will be discussed in detail in a companion paper [12]. The tool wear, run-out of the drill and unique ductility of the BMG in machining all contribute to the shape of the entry burr. For an HSS drill, a higher feed rate does not produce a larger entry burr as shown in Fig. 5.12. For the sharp WC-Co drill, higher feed rates help to reduce the size of the entry burr as well as the exit burr.
Fig. 5.12. Entry burr of in BMG drilled by HSS in Exp. I: (a) 2.5 mm/min, (b) 5 mm/min and (c) 10 mm/min feed rate. (hole #1 in the drilling sequence)

Fig. 5.13. Entry burr in BMG drilled by WC-Co in Exp. IV: (a) 2.5 mm/min, (b) 5 mm/min, and (c) 10 mm/min feed rate. (hole #1 in the drilling sequence)

Novel shapes of entry burrs can be seen in holes drilled with chip light emission. Fig. 5.14 shows the three holes drilled in Exp. II at the high, 10000 rpm spindle speed. This drilling condition generates the LRT chip morphology (Fig. 5.7) and occasional continuous light emission (Table 5.2). On the hole entry edge of the first hole, the roll-over burr can be seen. The second hole has a less obvious burr extruding outside the entry edge. The third hole shows significant melting of the work-material surrounding the entry edge. This is likely due to the high temperature generated at high spindle speed and the accumulation of molten chip debris during the chip evacuation. The low thermal conductivity of BMG and high drill temperature in the third hole help to trigger the chip
melting and light emission and the extrusion of work-material in the entry edge. Fig. 5.14 also shows the gradual deterioration of roughness on machined surface inside the hole.

Fig. 5.14. Entry burr of the BMG sample in Exp. II at 10000 rpm spindle speed with constant light emission and LRT chip morphology (number indicated the sequence of three holes drilled): (a) overview of three holes and (b) close-up view of third hole.

For Exp. III with continuous light emission, the entry burrs on four holes drilled by a 2 mm diameter HSS drill are shown in Fig. 5.15. During drilling, there was continuous chip light emission. The high feed rate (10 mm/min) created plastically deformed and blue-color oxide covered burrs on both entry and exit sides. This burr formation is a unique feature in BMG drilling.
Fig. 5.15. Entry burr of 2 mm diameter holes drilled in Exp. III at 10 mm/min feed rate: (a) overview of the four holes (number indicated the sequence of drilling), (b) close-up view of hole #3 and (c) close-up view of hole #4.

The exit burrs for seven holes drilled for Exp. I at 10 mm/min feed rate are shown in Fig. 5.16(a). The unusually large crown shaped exit burrs, another unique feature in BMG drilling, can be identified. The drill sequence does not correlate to the size of exit burr. The exit burrs are larger than the entrance burrs. At high feed rate, the size of burr is generally reduced.

Fig. 5.16. Crown-shape exit burr formation in BMG drilled by HSS in Exp. I at 10 mm/min feed rate: (a) general view of exit burr forms (number indicated the sequence of seven holes drilled) and (b) close-up view of the crown shaped burr in hole #6.

All SS304 drilling tests produce high quality, clean entry and exit burrs.
5.7. Concluding Remarks

In this study, the light emission, chip morphology and burr formation in drilling of BMG was investigated. Effects of HSS and WC-Co tool materials for drilling BMG at various feed rates, spindle speeds and drill size were studied. The study concludes that holes with precision geometry and good surface roughness can be efficiently produced in BMG using the WC-Co drills at spindle speeds that do not exceed the limit for chip light emission. Large size burrs and several unique burr formations were identified. Minimizing the burr formation will be important for BMG drilling.

Tests of BMG drilling with cutting fluid SS304 tools were also conducted. The thermal conductivity of tool material and cutting speed are two critical factors that can trigger exothermic oxidation and light emission from chips. Drilling at slow feed rates for BMG is not recommended since it promotes light emission.

In this study, five traditional types of BMG chip morphology, powder, fan shape, short ribbon, long ribbon and long spiral, as well as a new type of chip, long ribbon tangled, were observed. Well-known topographical features, such as voids, vein patterns, triple ridge points and tributaries, on fractured metallic glass material were also observed on the machined surfaces under a quick stop condition.
References


