CHAPTER 7. CONCLUSION

Machining performance of $Zr_{52.5}Ti_5Cu_{17.9}Ni_{14.6}Al_{10}$ metallic glass under different turning and drilling process parameters was evaluated in this study. Feasibility to use machining as a test method for investigating the behavior of BMG under extreme deformation conditions was studied. Both the machining mechanics and BMG chips characterization were conducted.

In the lathe turning of BMG, above a threshold cutting speed, the low thermal conductivity led to chip temperatures high enough to cause the oxidation of the Zr. The oxidation is associated with extensive light emission. Using a near-infrared spectrometer for radiation thermometry, chip flash temperatures in the 2400 to 2700 K range were estimated. The high temperature produced by this reaction causes crystallization within the chips. Optical microscopy of the polished and chemically etched chips showed a dendritic pattern due to crystallization. Four different regions were observed in the cross-section of the chips: oxide layer, amorphous region, fully crystalline regions, and crystalline-amorphous transition region.

The x-ray diffraction peaks match the pattern for monoclinic ZrO_2, confirming the earlier hypothesis that oxidation was associated with light emission and high flash temperature. Although optical microscopy and SEM showed crystallization inside the chips, no additional diffraction peaks could be detected by x-ray diffraction due to the thick oxide layer. The average oxide layer thickness was about 5 to 10 μm. The calculated average X-ray effective penetration depth value has about the same value. The oxide layer blocked the x-rays from penetrating into the chips to reveal other crystalline structures in the chips.

As the cutting speed increased, the morphology suggested that increasing amounts of viscous flow control the chip-removal process. It was noteworthy that viscous flow and crystallization could occur during the machining of the bulk metallic glass, even though the heating/cooling rates and strain rates was very high. For the BMG chip without light emission, the serrated chip with adiabatic shear band and void formation was observed. High cutting speed significantly reduced the forces for BMG machining due to thermal softening.

Roughness of machined BMG surfaces was generally better than Al6061-T6 and SS304. This indicated the potential to use BMG for single point diamond turning of very precise surface for optical and photonic applications. Tool wear, as in the machining of titanium and nickel-based alloys, was expected to be a problem for machining of BMG.

The study of the light emission, chip morphology and burr formation in drilling of BMG, concluded that holes with precision geometry and good surface roughness could be efficiently produced using WC-Co drills at spindle speeds that did not exceed the limit for chip light emission. The thermal conductivity of tool material and cutting speed were concluded as two critical factors that triggered the chip exothermic oxidation and light emission. Drilling at slow feed rate with BMG was not recommended since it promoted chip light emission.

Chip morphology studies revealed five traditional types of chip morphology, powder, fan shape, short ribbon, long ribbon and long spiral, as well as a new type of chip, long ribbon tangled, unique to BMG drilling. 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 surface under a quick stop condition.

Thrust force, torque, and tool wear study showed that, when feasible process parameters are selected, BMG could be efficiently drilled using either the HSS or WC-Co tools. The WC-Co tool with better mechanical and thermal properties is the best choice of tool for drilling BMG. The chip light emission, which associated with high chip and tool temperatures, showed the detrimental effect on the drill life. For the drilling process without light emission, both HSS and WC-Co tools performed well for drilling BMG.

The research on machining of BMG is continuing in several fronts. The next step is the micro-milling, grinding, polishing and electrical discharge machining processes which can further the understanding and capability of producing precision Zr-BMG components. In recent years, new Fe-, Al-, and Ti-based BMG materials have been developed. This has created the need and opportunities for research into machining processes for precision shaping of these new, advanced engineering materials.