Microstructuring of Bulk Metallic Glass

P. Niedermann, M. Dadras, A. Pezous, J. Kettkaew •, W. Chen •, J. Schroers •, M. Despont

Results of molding of a Pd-based bulk metallic glass are presented, using microfabricated silicon as a mold. This molding technique, which is reminiscent of polymer injection molding, is expected to allow the fabrication of components such as elastic elements with outstanding mechanical properties.

Bulk metallic glasses (BMGs) are a novel class of material that holds high promise for applications as microparts such as springs. They are characterized by slow crystallization kinetics, which make it possible to produce them from the melt in thicknesses of several mm. Alternatively and uniquely amongst metals, they can be molded in a so-called supercooled liquid state, where they exist in viscous form analogous to injection molding of thermoplastics [1]. Their material properties in the amorphous state are outstanding. In particular, they have a high elastic limit and excellent resistance against corrosion [2].

This makes micro-molding an interesting possibility for fabricating microparts with superior mechanical properties. Here, an injection type molding in silicon was explored and the molded parts characterized by TEM and X-ray diffraction.

A variety of BMG materials are known, with different degrees of processability, mechanical properties, and characteristic temperatures. Figure 1 shows the main classes of the materials with their elastic limit and Young's modulus values. Remarkably, the material classes lie on a line corresponding to a deformation of 2%, which is much higher than for steel.

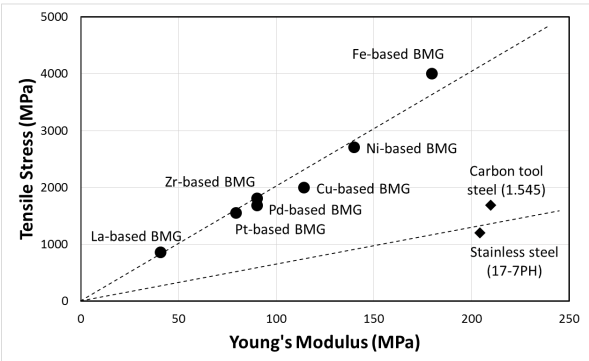

Figure 1: Tensile stress and Young's modulus of the main BMG material classes.

The Pd-based and Zr-based BMGs are the most readily available BMGs and have a high glass-forming ability. Their mechanical properties make them good spring materials, whereas Fe-based BMGs are known to be brittle. The Pd-based material of atomic composition $Pd_{40}Cu_{30}Ni_{10}P_{20}$ with its record high glass forming ability was used for this work.

A first class of molds was made by bonding two silicon wafers, with the first wafer containing injection holes and the second one, the mold of the parts to be formed. As Figure 1 shows, the molds could be successfully filled by pressing the raw BMG material (PdCuNiP alloy) into the injection holes under vacuum. The silicon was removed by wet chemical means. It can be seen that very fine details were reproduced, namely, vertical ripples that are characteristic of the dry etching of the walls of the silicon mold.

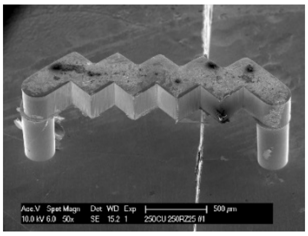

Figure 2: Molded PdCuNiP structure of zigzag shape, showing the injection structures.

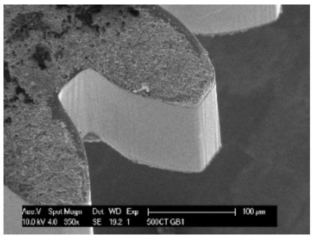

Figure 3: Detail of a molded gear, with vertical ripples characteristic of the (non-optimized) dry etching that was used for the fabrication of the mold.

The resulting finely replicated shape indicates that the material remained amorphous for a long enough time to completely fill the mold. The resulting parts were also investigated by TEM, EDX and XRD. TEM images showed them to be primarily amorphous, whereas XRD showed both fully amorphous state as well as residual crystallinity, indicating that the crystallization limit was reached in some cases (Figure 4).

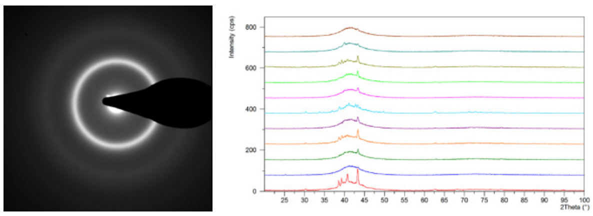

Figure 4: TEM image and XRD theta-2theta curves, indicating mainly amorphous state with residual crystallinity in some samples.

EDX analysis confirmed the composition of the material, and was able to detect defects such as occasional Si residues from the mold as well as gold residues on the top of the parts that are also visible in the SEM image of Figure 1. These defects can be eliminated by improved processing and using direct wafer bonding for the molds.

• School of Engineering & Applied Science, Yale University, USA

[1] J. Schroers, Adv. Mater. 22 1566 (2010)

[2] A. Inoue, A. Takeuchi, Acta Mat. 59 2243 (2011)