The Production and Elevated Temperature Mechanical Behaviour of $Ca_{65}Mg_{15}Zn_{20}$ Bulk Metallic Glasses

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Overview

Calcium-based bulk metallic glasses (BMG's) are a new family of light-weight materials that exhibit high specific strength and hardness at room temperature, extraordinary ductility/superplasticity at slightly elevated temperatures and superior corrosion resistance in comparison to their crystalline counterparts.[1]

A repetitive inverted die casting technique was developed for optimising the processing parameters for casting amorphous $Ca_{65}Mg_{15}Zn_{20}$ samples of dimensions 3.15 × 7 × 125 mm. An investigation of the effect of various die casting control parameters, such as the charge temperature, injection velocity and casting pressure on the length and integrity of these samples was carried out. [2] In conjunction with this work, the deformation behaviour in the supercooled liquid (SCL) region of the $Ca_{65}Mg_{15}Zn_{20}$ BMG under constant load and constant strain rate conditions was investigated.[3]

Sample Production and Preparation

An inverted injection die casting technique [2] was used over a range of casting temperatures (400 - 600 ℃) and pressures (1.5 - 2.2 Bar) to generate a comprehensive processing map to determine the optimum casting conditions for the $Ca_{65}Mg_{15}Zn_{20}$ BMG in a copper mould (**Figure 1**). The amorphous structure of these samples was determined using XRD analysis.

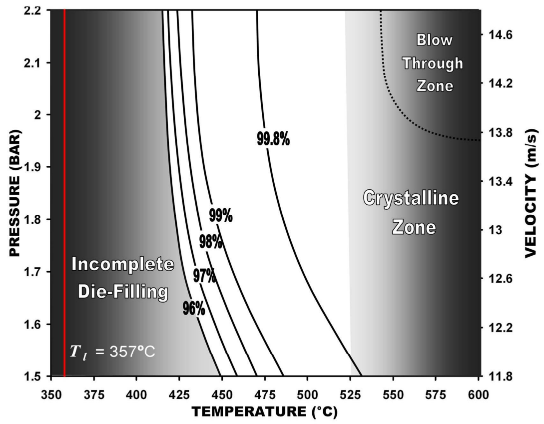

Figure 1: Comprehensive processing map, showing the effect of casting pressure/velocity and melt temperature on mould filling capacity and sample density (degree of porosity). It can be seen that for the $Ca_{65}Mg_{15}Zn_{25}$ BMG the optimal casting range is 480 - 525 ℃ and 2 - 2.2 Bar for the current laboratory set up.

It was found that the temperature and the pressure at which the samples were injected also effected the surface quality of the casting. This was found to be due to extended consolidation of the casting by the build up of pressure after the mould vent had been sealed. **Figure 2**(a) illustrates the consolidation time difference for a number of casting conditions (limited to 1 Bar). Once the optimal casting window had been determined, a number of high-quality samples were produced for further testing. (**Figure 2**(b)).

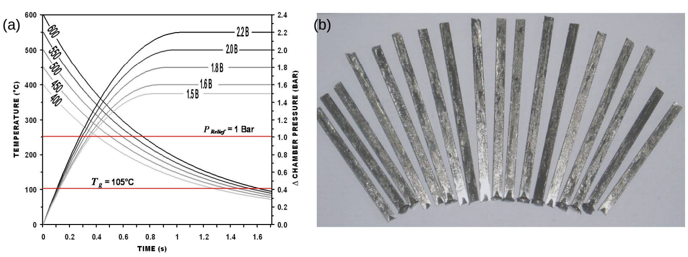

Figure 2: (a) The calculated cooling rate of castings for different injection temperatures and the rate at which pressure is applied to these castings in the mould (b) A number of $Ca_{65}Mg_{15}Zn_{25}$ BMG samples produced by inverted injection die-casting (T = 500 °C and P = 2 bar).

Elevated Temperature Mechanical Behaviour

$Ca_{65}Mg_{15}Zn_{20}$ BMG tensile samples were ground from the aforementioned injection-cast bars. These samples were deformed under constant load (heating rate of 5 ℃/min) and constant strain rate conditions over a range of temperatures within the SCL region (105 ° C to 120 ° C) and various strain rates (10^{-3} to 10^{-4} s^{-1}).

Samples tested under constant load conditions (20 - 50 N) displayed a near linear increase in strain rate in the SCL region as temperature was increased (**Figure 3** (c)). This corresponds to a steady decrease in viscosity in accordance with the VFT equation, yielding elongations in excess of 850%. Samples tested under constant strain conditions showed elongations generally limited by embrittlement caused by the onset of crystallisation. [3] An important finding of this work was that an increase in strain rate increased the delay in the stress increase due to crystallisation compared to static crystallisation (**Figure 3** (d)-(g)) i.e. dynamic stabilisation of the amorphous phase.

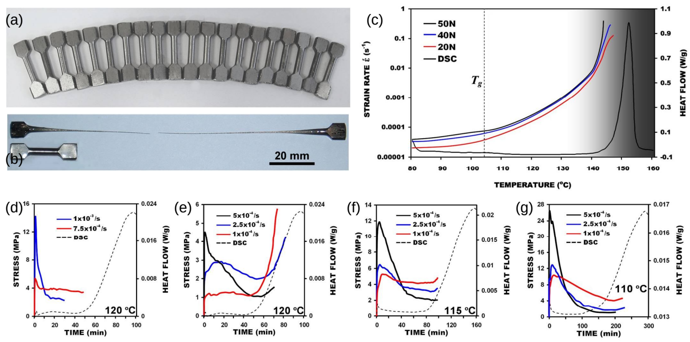

Figure 3: (a) ASTM E8-04 compliant tensile samples of gauge 3 mm and gauge length 12.3 mm. (b) Sample strained under a constant load of 50N and heating rate of 5°C/min to a strain of 855% (c) Instantaneous strain rate as a function of temperature (constant load testing) including the DSC curve for the same temperature interval and heating rate (5 °C/min). (d)-(g) Stress-Time plots for constant strain rate samples tested at 120 - 110 °C at indicated strain rates.

Deformation Mapping and Characterisation

Using tensile flow stress data gathered from $Ca_{65}Mg_{15}Zn_{20}$ BMG samples, [3] deformation maps showing the boundaries between Newtonian and non-Newtonian flow regimes and brittle fracture modes were developed (**Figure 4**).

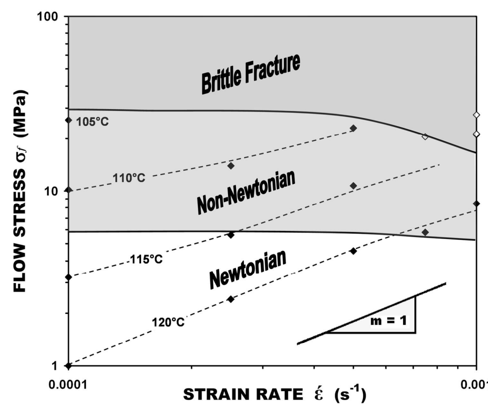

Figure 4: Deformation map showing the boundaries between Newtonian flow, Non-Newtonian flow and Brittle Fracture mode in the $Ca_{65}Mg_{15}Zn_{20}$ BMG for a given range of temperatures and strain rates. [3]

References

[1] **O.N. Senkov, J.M. Scott**; *J. Non-Cryst. Sols.* **351** (2005) 3087 - 3094
[2] **K.J. Laws, B. Gun and M. Ferry**; *Mater. Sci. and Eng. A*, (2007) *'Article in Press'*
[3] **K.J. Laws, B. Gun and M. Ferry; Mater**. *Sci. and Eng. A*, (2007) *'Article in Press'*

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