1-1-2012

Bonding of Mg-base metallic glass through rapid resistive welding

Karl F. Shamlaye
University Of New South Wales

Kevin J. Laws
University of New South Wales

Bob De Jong
University Of Wollongong, rdejong@uow.edu.au

Michael Ferry
University Of New South Wales

Bonding of Mg-base metallic glass through rapid resistive welding

Abstract

Efficient joining of Magnesium-base bulk metallic glass can be achieved via bonding through resistance welding using rapid heating rates. Bonding of Mg-base metallic glasses (as well as regular magnesium alloys) is a process hindered by the ease of oxide formation in these materials. In this work, resistance welding of Mg65Cu25Y10 metallic glass sheets was investigated up to 627 K , below the liquidus temperature; and also within the supercooled liquid region (443-483 K) of the metallic glass; during processing times of a few seconds, creating strong joins -even when processed in air. It is seen that a fluxing pre-treatment of the material surface aids in achieving effective bonding. Our work has also shown that Mg-base metallic glasses can be effectively and easily joined to other types of materials.

Keywords

metallic, base, welding, mg, resistive, bonding, rapid, glass

Disciplines

Engineering | Science and Technology Studies

Publication Details

Shamlaye, K. F., Laws, K. J., De Jong, B. & Ferry, M. (2012). Bonding of Mg-base metallic glass through rapid resistive welding. Materials Science & Technology 2012 (pp. 1-8).

BONDING OF Mg-BASE METALLIC GLASS THROUGH RAPID RESISTIVE WELDING

Karl F. Shamlaye*, [1,2] Kevin J. Laws,[1,2] Bob de Jong,[3]Michael Ferry[1,2]

[1] Australian Research Council Centre of Excellence for Design in Light Metals, UNSW, Sydney, NSW 2052, Australia
[2]School of Materials Science and Engineering, University of New South Wales, Sydney, NSW 2052, Australia
[3]University of Wollongong, Wollongong, NSW 2522, Australia

*corresponding author: k.shamlaye@unsw.edu.au

Keywords: Resistance welding, Magnesium-base metallic glass, rapid heating

Abstract

Efficient joining of Magnesium-base bulk metallic glass can be achieved via bonding through resistance welding using rapid heating rates. Bonding of Mg-base metallic glasses (as well as regular magnesium alloys) is a process hindered by the ease of oxide formation in these materials. In this work, resistance welding of $Mg_{65}Cu_{25}Y_{10}$ metallic glass sheets was investigated up to 627 K , below the liquidus temperature; and also within the supercooled liquid region (443-483 K) of the metallic glass; during processing times of a few seconds, creating strong joins –even when processed in air. It is seen that a fluxing pre-treatment of the material surface aids in achieving effective bonding. Our work has also shown that Mg-base metallic glasses can be effectively and easily joined to other types of materials.

1. Introduction

Metallic glasses have useful properties due to their amorphous structure, such as high strength and nearly 100% elastic energy transfer [1]. In particular, industry is gearing towards strong, lightweight materials and Mg-base metallic glasses may provide a useful candidate. In addition joining of metallic glasses may become essential for assembling components for industrial applications [2]. Various attempts at joining metallic glasses have been trialled, such as various forms of welding, e.g. friction [3], laser [4] and electron [5]. But these methods usually left a partially or fully crystallized interface of often weak brittle products [6] creating possibility of subsequent failure at the joins. The challenge is that the join should be fully amorphous, without formation of brittle compounds due to full or partial recrystallization at interfacial zones of joins.

With this consideration, Wang *et al* [7] and Maeda *et al* [8] have had some success in joining similar metallic glasses without producing any crystalline interface however at long processing times (the former mentioned work involved joining two metallic glass surfaces for over 60 minutes) or insufficient bonding strengths.

Efficiency in joining of metallic glasses can be attempted by reducing the time required for joining. All the aforementioned processes for joining metallic glasses involve heating the

samples. Heating through the sample boundary does not allow uniform heating in short times (even between 1 to 10 seconds). Rapid heating requires that power is dissipated homogeneously and volumetrically to avoid temperature variations in the sample [9].

A current pulse can be used to achieve rapid and uniform heating through metallic glasses can be done [9] by taking advantage of their typically large and nearly temperature-independent electrical resistivity [10, 11].

A suitable Mg-base metallic glass to consider for rapid heating experiments is the $Mg_{65}Cu_{25}Y_{10}$ alloy as it has a large processing window of approximately 60 K [12]. This processing window is called the supercooled liquid region (SCLR) and defined as $\Delta T = T_x - T_g$, where T_g is the onset of glass transition and T_x the onset of crystallization (all of which are heating-rate dependent). In this temperature region, metallic glasses can undergo significant plastic deformation as the viscosity drops significantly, whereby viscosities of 10^6 Pa.s and lower can be achieved. The larger the value of ΔT the higher the metastability of the supercooled liquid with respect to crystallization [13]. As seen in **Figure 1.** above a heating rate regime, crystallization can be avoided during heating.

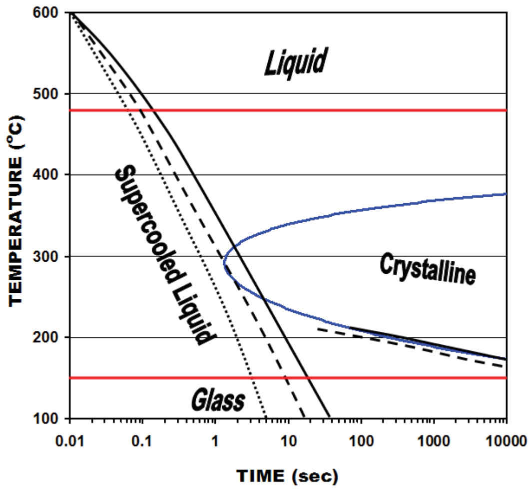

Figure 1: Time-temperature-transformation diagram including cooling curves from wedge casting of $Mg_{65}Cu_{25}Y_{10}$, isothermal annealing data showing the onset and completion of crystallisation at given temperatures [14] and the C-curve predicted by the Takeuchi model [15]

In a similar vein to work done by Kuroda *et al* [16], we aim to attempt joining of metallic glass plates using resistive welding, however to note, their experiments were on Zr-base glasses and conducted over a 20 s forming period. Additionally, if this method is successful this may generate further interest for combining conventional alloys to metallic glasses [17].

For our work a Gleeble 3500 system was considered for thermomechanical processing, given its capability for rapid heating (up to 10,000 °C /s), in addition to its usage of low voltage AC (at 50 Hz) which allows for excellent control for rapid heating; along with the capability for precise force application.

2. Experimental

Suction cast 70mm × 10 mm × 1 mm bars of $Mg_{65}Cu_{25}Y_{10}$ bulk metallic glass were cut to 10 mm × 10 mm × 1 mm plates using a slow speed diamond saw and the surfaces polished using 1200 grit paper and further surface cleaned using acetone.

In the first part of the experiment, four plates were stacked together (**Figure 2**) to be joined via resistive heating between two copper platens in a Gleeble 3500 Thermomechanical simulator. To monitor the temperature of the arrangement, a type-K thermocouple was attached to the centre plate. In the second part, a copper sheet (having similar dimensions to the metallic glass plates) was put in between two metallic glass plates to be joined. The samples were heated from a low set temperature to a processing temperature between T_g and T_M (the melting temperature) in less than 1 second.

A thermomechanical program (as summarised in **Table 1**) was imputed for rapid heating in the Gleeble 3500, which involved five stages: (i) Heating the sample to a 'stabilising temperature' of 125 °C; (ii) holding at for 5 seconds in order to remove possibility of heating localisation during (iii) rapid heating. A heating rate of 320 °C per second was applied, with heating to a processing temperature of 400 °C with subsequent (iv) holding at for 5 s followed by (v) quenching.

In order to minimise possible arcing between the plates, a compressive holding force of 245 N was applied during period (i) to minimise any gaps caused by misalignment of the plate surfaces. To accommodate the drop in viscosity at the processing temperature (during period (iii), the compressive force was lowered to 177 N.

Table 1. Thermal cycle input

Stage	Temperature	Comments
(i) Heat stabilization	Heat to 125 °C	To avoid heat localization
(ii) Holding period	Hold at 125 °C	5 s holding time
(iii) Rapid heating	Heat to 400 °C	Heating rate at 320 °C/s
(iv) Hold at process temp	Hold at 400 °C	5 s holding time
(v) Quench	To ambient temperature	Water quenching

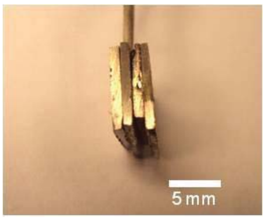

Figure 2: Stack of four metallic glass plates with a type-k thermocouple attached

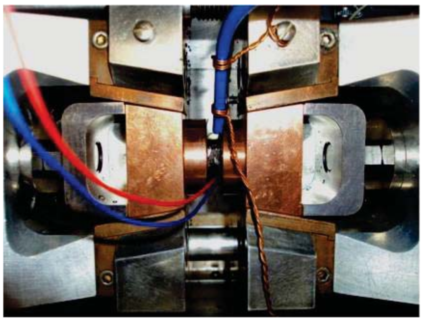

Figure 3: Set up of stacked material to be welded between copper platens in the chamber of a Gleeble 3500. A blue pipe from overhead releases a water jet at 40 ksi to quench the samples. A type-k thermocouple is attached to the centre of the arrangement to monitor sample temperature throughout the process.

3. Results and Discussion

3.1 Formed specimens

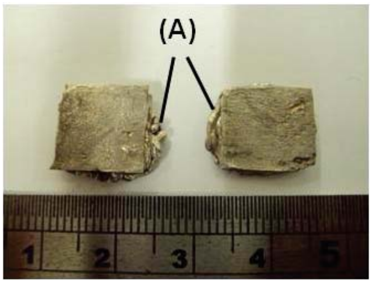

Figure 4: Two specimens of joined metallic glass made up of four plates each. Region (A) shows parts which have bulged out during processing as the viscosity of the glass drops during heating through ΔT under compressive force (The original width was 10 mm, and the average final width was 12.58 mm).

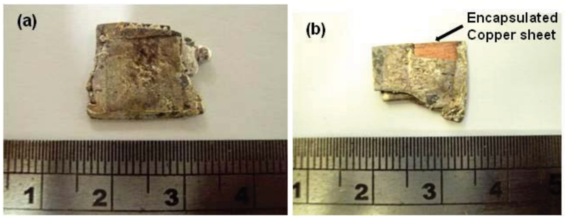

Figure 5: Cu sheet encapuslated between two metallic glass plates: (a) A square outline of the Cu sheet can be seen through the covering plate, as the metallic glass has flowed through processing and 'bulged out'. (b) A part of the Cu sheet is revealed after removal of part of the formed sample.

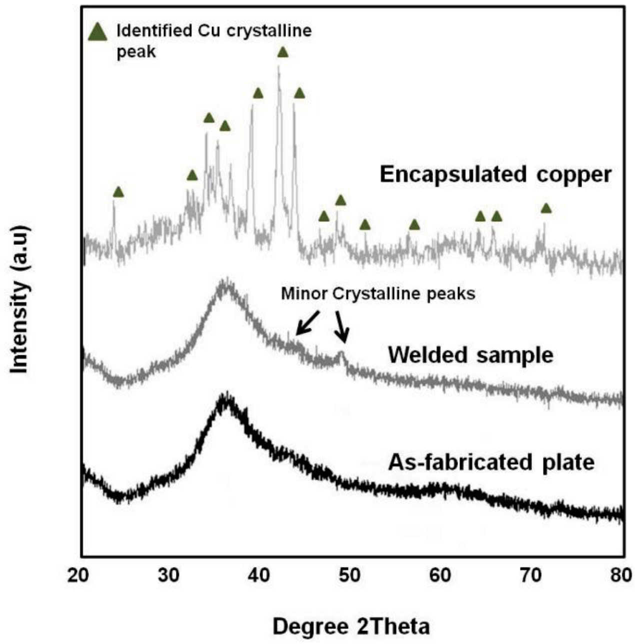

Figure 6: X-ray diffraction patterns of the as-fabricated $Mg_{65}Cu_{25}Y_{10}$ metallic glass plate, the welded sample showing possible presence of some crystalline phases and the encapsulated copper sheet.

3.2. Thermomechanical processing

The results of the thermal profile of welding 4 metallic glass plates are shown in **Figure 7**.

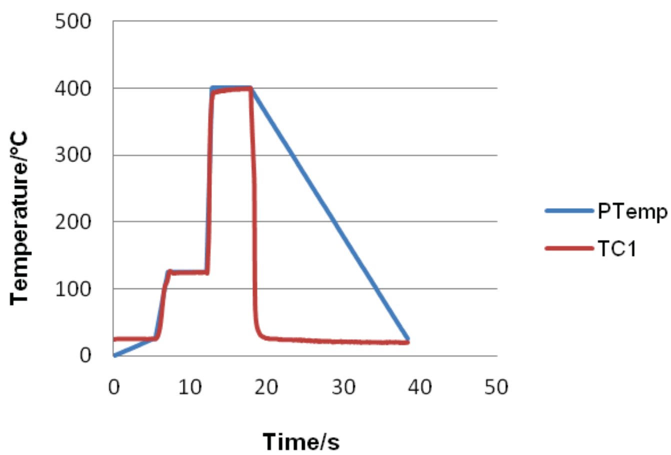

Figure 7: Thermal cycle profile (TC1) of a stack containing 4 metallic glass plates, achieving rapid heating as directed by the set program (PTemp).

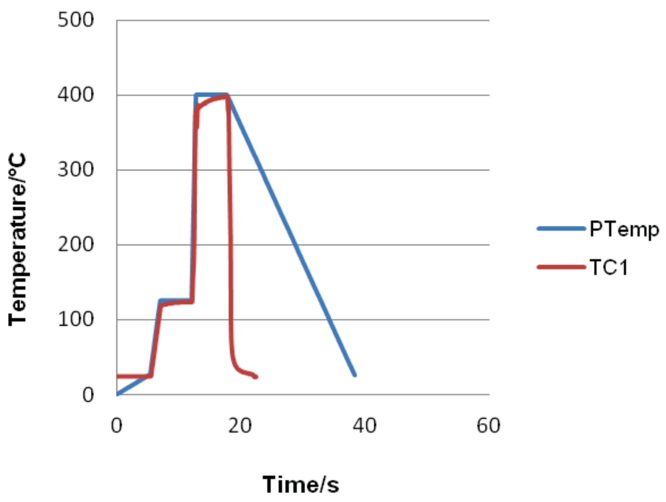

Figure 8: Thermal cycle profile (TC1) of a copper sheet inserted between two metallic glass plates. The sample temperature builds up from 380 C to the set processing temperature, indicating some power loss to the sample.

3.3. Microstructure

3.3.1 Joined metallic glass plates

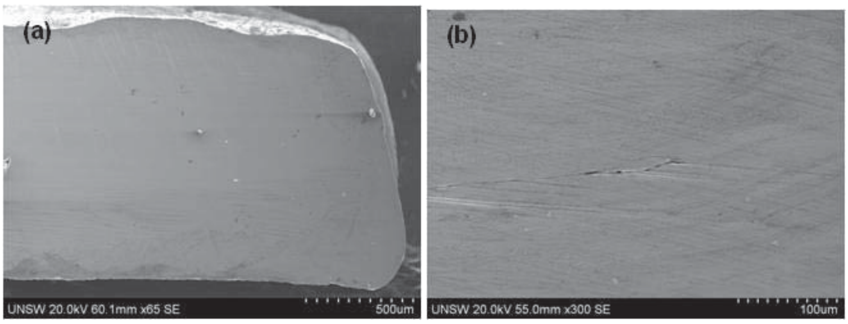

Figure 9: (a) Polished cross section of 4 plate welded Mg-base metallic glass. (b) SEM image showing the disappearance of an interface region (between two plates) going towards the centre of the welded metallic glass.

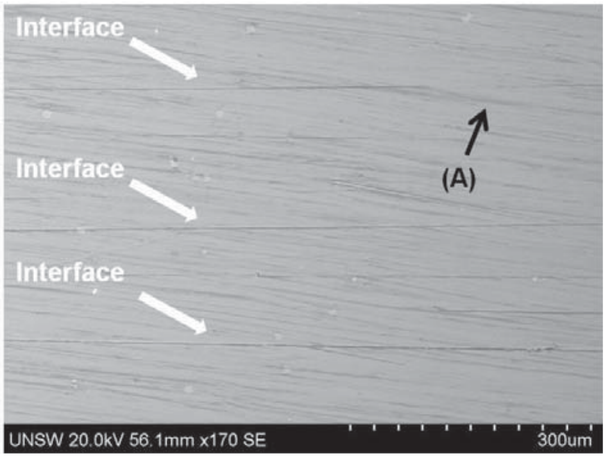

Figure 100: Surface cleaning and immersion in acetone for several minutes enable the interface regions between the four plates to be seen. To note, no defects are present at the interfaces and region (A) even shows disappearance of part of the interface.

3.3.2. Copper sheet sandwiched between metallic glass plates

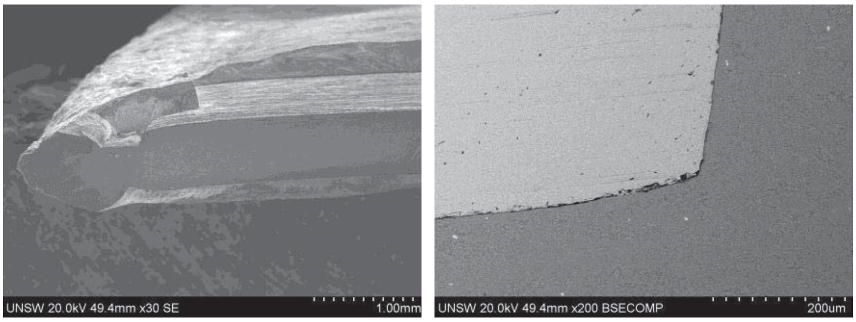

Figure 11: (a) Sectioned tip of encapsulated copper sheet, with good contact between metallic glass and copper; (b) backscattered electron micrograph showing a close-up of an edge of the copper sheet (light coloured region) in contact with the metallic glass (dark coloured region).

4. Conclusion

A method of rapidly heating metallic glasses through and above the SCLR to cause joining was investigated. The time for rapid heating was calculated to be close to 0.87 s.

Efficient joining of Mg-base metallic glass plates was achieved, with up to four plates joined together. Additionally, joining of conventional crystalline copper to Mg-base metallic glass was possible.

The process ensued that the occurrence of oxidation was minimised with X-ray diffraction showing amorphous halo traces similar to the as-cast metallic glass. The encapsulated copper specimen did show crystalline peaks associated with Cu-crystalline peaks.

The interface between metallic glass plates showed no defects and revealed a successful welding between plates.

In conclusion, it is seen how the Gleeble 3500 Thermomechanical simulator makes the possibility of rapid resistive welding of metallic glasses possible, even through processing in air.

References

[1] W.H. Wang, C. Dong, C.H. Shek "Bulk metallic glasses",*Materials Science Engineering R* 44, (2004), 45-89.

[2] N. Nishiyama, K. Amiya, A. Inoue, "Bulk metallic glasses for industrial products" *Materials Transactions* 45 (4) (2004), 1245-1250.

[3] Y. Kawamura and Y. Ohno, *Scripta Materialia* 45 (2001), 279–285.

[4] J. H. Kim, C. Lee, D. M. Lee, J. H. Sun, S. Y. Shin and J. C. Bae: *Materials Science Engineering A* 449–481 (2007), 872–875.

[5] S. Kagao, Y. Kawamura and Y. Ohno, "Superplastic bonding of bulk metallic glasses using friction",*Materials Science Engineering A* 375–377

(2004), 312–316.

[6] Y. Kawamura, A. Inoue, "**Friction joining of $Ti_{40}Zr_{25}Ni_3Cu_{12}Be_{20}$ bulk metallic glass** " *Applied Physics Letters* 77 (2000), 1114–1116.

[7] P-H. Kuo, S-H. Wang, P.K. Liaw, G-J. Fan, H-T. Tsang, D. Qiao, F. Jiang "Bulk-metallic glasses joining in a supercooled liquid region, *Materials Chemistry and Physics* 120 (2010), 532-536.

[8] M. Maeda, Y. Takahashi, M. Fukuhara, X. Wang and A. Inoue "Ultrasonic bonding of Zr55Cu30Ni5Al10 metallic glass" *Materials Science Engineering B* 148 (2008), 141–144.

[9] W.L. Johnson, G. Kaltenboek, M.D. Demetriou, J. P. Schramm, X. Liu, K. Samwer, P. Kim, D.C. Hofmann, "Beating crystallization in glass-forming metals by millisecond heating and processing, *Science* 323 (2011), 828-833.

[10] H. J. Güntherodt, *Advanced Solid State Physics* 17 (1977), 25.

[11] S. R. Nagel, *Physics Review* B 16 (1977), 1694.

[12] A. Inoue, A. Kato, T. Zhang, S.G. Kim and T. Masumoto, *Materials Transactions Japan Institute of Metals* 32 (1991), 609.

[13] J. Schroers , "Processing of bulk metallic glass", *Advanced Materials* **22** (14) (2009), 1566-97.

[14] K.J. Laws, "The production and properties of lightweight bulk metallic glasses, (PhD Thesis, UNSW, 2007), 111.

[15] A. Takeuchi and A.Inoue, *Materials Science and Engineering A* 375-377 (2004), 449

[16] T. Kuroda, K. Ikeuchi, M. Shimada, A. Kobayashi, H. Kimura and A. Inoue, "Microstructure of bonding interface for resistance welding of Zr-based metallic glass sheets" *Materials Transactions* 50 (6) (2009), 1259-1262.

[17] J-J. Blandin, S. Gravier, S. Puech, M. Suéry, " New metallic glass/alloy (MeGA) rods produced by co-extrusion, *Advanced Engineering Materials* 10 (2006) 948-953.

[18] H. Somekawa, A. Inoue, K. Higashi, "Superplastic and diffusion bonding behaviour of Zr-Al-Ni-Cu metallic glass in supercooled liquid region, *Scripta Materialia* 50 (2004), 1395-1399.