Design of In-Situ Mg-Based Amorphous Alloy Matrix Composites

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Abstract： The Mg-based amorphous alloys possess low density, high specific strength, and high anti-corrosion property, which makes them have great application potentials in the 3C industry, biomaterials, etc. However, the room-temperature brittleness of Mg-based amorphous alloys, which results from the localized shear flow, limits their applications. The approaches to improve the ductility of these materials limit in ex-situ direct adding method. The present study designed a novel fabrication process based on the dealloying in metallic melt reaction and has successfully induced a variety of in-situ reinforcing phases. We further optimized the composite structure and mechanical property via process parameter. The present study provides a theoretical basis and practical experiences in the following research related with the composite fabrication via dealloying reaction.

Keywords: Mg-based metallic glass; composites; dealloying reaction; mechanical property

1 Introduction

Due to the high strength and good corrosion resistance compared with the corresponding crystalline counterparts, bulk metallic glasses (BMGs) have attracted great attention in the last decades. Mg-based BMGs exhibit considerable application prospects in lightweight structural components. However, Mg-based BMGs tend to break into small pieces under uniaxial compression before their elastic limit at ambient temperature, which greatly limits their further application. Introducing crystalline particles as secondary phases into the BMG matrix has been proven to be an effective method to improve the plasticity of the amorphous alloys. Considering the introducing approaches of the secondary phase, the preparation process of the Mg-based BMG matrix composites (BMGCs) can be classified as the ex-situ method and the in-situ method. In fact, most Mg-based BMGCs are synthesized by ex-situ method with adding the fibers or crystalline particles. However, the poor interfacial bonding between the added phase and the matrix in the ex-situ BMGCs degrades the reinforcing effects in mechanical properties. In contrast, the in-situ BMGCs, fabricated by precipitation during solidification or partial nanocrystallization in BMGs via thermal treatment, always exhibit better mechanical property than the ex-situ ones as a result of the lack of interfacial oxidation layer or other crystalline layers. Recently, a novel dealloying reaction in metallic melt has been proposed by Wada et al. in fabrication porous alloys. The reaction is based on the differences in the enthalpy of mixing between pre-alloy element and the metallic melt, i.e., negative value in the enthalpy of mixing indicates miscibility or reactivity and visa versa. In the present study, we have applied the above dealloying reaction in metallic melt to synthesis several kinds of Mg-based BMGCs with various reinforcing phases. Furthermore, the composite structure has been optimized to improve the mechanical properties of such composites.

2 Experimental procedure

The fabrication process has been firstly designed based on dealloying reaction in the metallic melt. With different composition of the materials, the experimental procedure is similar. Firstly, the precursors were fabricated by arc-melting, then the precursors were immersed in Mg-based melt to induce dealloying reaction. The melt temperature and time were set in different values. After the dealloying reaction finished, the melt were poured into mould to prepare master alloys. Finally, the BMGCs were fabricated by injection copper mould casting. The phase constitutions of the specimen were characterized by X-ray diffraction (XRD, Shimadzu XRD-6100) with monochromatic Cu Kα radiation. Thermal properties of the glassy transition temperature, the onset first crystallization temperature and the endothermic enthalpy of crystallization were measured by differential scanning calorimeter (DSC, NETZSCH STA 449C DSC) under ultra-high Ar gas atmosphere with a constant heating rate of 20K/min. Microstructures of the specimen were examined by scanning electron microscope (SEM, Carl Zeiss GeminiSEM300) equipped with energy-dispersive x-ray spectroscopy (EDS, AZtec X-Max 50). The chemical composition of the submicron crystalline phases was analyzed by electron probe micro analysis (EPMA). The specimens were tested by uniaxial compression at ambient temperature at a strain rate of 1×10^{-4} s^{-1} with a ZwickRoell Z020 machine. Five samples were tested for each specimen to ensure the reproducibility.

3 Result and discussion

All BMGCs showed the diffraction hump from the amorphous matrix and the sharp crystalline peaks from the reinforcing phases, which indicates that the dealloying reaction has been successfully induced. The DSC curves of all specimens show an obvious glassy transition, supercooled liquid region, and exothermic peak related with the crystallization process. The SEM images of the composites show the homogenously distributed porous Ti /Fe particles in the glassy matrix. According to the image analysis, the average size and volume fraction of such phases are given. The pores in the bicontinuous porous Ti particles are fully filled with the amorphous matrix, agreeing well with our design. To further analyze the pore structure, we used nitric acid solution to separate the particles from the composites, the surface morphology of the porous particle and the detailed pore characteristics, including porosity and the distribution of pore size, is measured by a mercury porosimeter. As the processing zone size of Mg-based BMGs is about 0.1–1μm, thus the present pore size or the filled matrix size in the pores is very close to such value and optimum reinforcing effects should be realized in the local area inside porous particles.

The uniaxial compression tests are performed for all samples. A sudden fracture with almost no plastic strain can be found for the monolithic amorphous sample. With the introduction of porous Ti/Fe particles, the BMGCs exhibit the obvious yield phenomenon due to the avoidance of premature fracture, and the fracture strength is improved when compared with Base alloy. In addition, the plastic strain of the composites is also increased. The porous Ti/Fe particle provides effective obstacle for the rapid propagation of main shear bands, prohibiting the propagation of shear bands and promoting the multiplication of shear bands, therefore improving the mechanical properties of BMGCs. The size of glassy matrix inside one porous particles should lead to a more homogeneous deformation instead of localized shear flowing in shear bands, thus avoiding the temperature rise and softening in shear bands as well as transformation from shear bands to cracks, which should further contribute to the improved mechanical properties of the present porous particle reinforced BMGCs. The obtained composite structure can be further optimized by adjusting the composite composition and the process parameters. The present results have shown the feasibility of applying the dealloying reaction in fabricating metal matrix composites.

4 Conclusion

A novel fabrication process of in-situ porous Ti/Fe particle reinforced Mg-based BMGCs have been proposed based on the dealloying reaction in metallic melt, and the composites have been successfully synthesized. The introduction of porous Ti/Fe particle into the glassy matrix improves the fracture strength and the plasticity. The pores are fulfilled with the glassy matrix, and the ligament of porous particle has a good bonding with the matrix. The average pore size diameter is close to the processing zone size of the present glassy matrix. The high interface area is in favor of arresting the propagation of main shear bands, and also facilitating the multiplication of shear bands. The present study offers a feasible way to synthesis the bicontinuous porous particle reinforced BMGCs, which should contribute to the breakthrough in designing novel metal matrix composites.