Mechanical Properties of Fe/Zr Dual Amorphous Phase Bulk Metallic Glasses

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Abstract. Dual amorphous phase bulk metallic glasses (DAPBMGs) are a new class of bulk metallic glasses (BMGs) containing several amorphous phases in order to bring together all the favorable properties of each phase. A Fe/Zr dual phase bulk metallic glasses of cylindrical form with the diameter of 10 mm and 5 mm in height, were successfully prepared by hot-pressing of Fe – based and Zr – based glassy alloy powder at different mixing times. The samples obtained were structural investigated by X-Ray diffraction and mechanically characterized by hardness and compression tests. It was found that increasing the mixing time of powders leads to a decrease in hardness and mechanical compressive strength.

1. Introduction

The bulk amorphous metallic materials with dual phases are characterized by the presence of two distinct metallic phases with amorphous structures, exhibiting a reunion of properties specific to each phase and thus attracting a great interest in the prospects of obtaining new materials [1]. The dual amorphous phase bulk metallic glasses (DAPBMGs), similar to a composite material, are expected to exhibit the properties of both amorphous alloys of which they are composed.

In the case of Fe / Zr dual phase bulk amorphous metallic materials, the Fe-based amorphous alloy has good magnetic properties, high hardness, and high compressive strength but has a low glass forming ability and high brittleness [2]. By introducing high-toughness Zr-based amorphous alloy, with excellent glass forming ability, it is desirable that this dual amorphous alloy retain its magnetic properties but also to improve toughness and ductility [3].

A viable method for obtaining dual bulk amorphous alloys is powder metallurgy [4]. It involves the following steps [3, 4]: (i) obtaining amorphous metal powders by atomization or milling; (ii) mixing of this two glassy alloy powders by mechanical milling for homogenization; (iii) compacting of the mixed glassy alloy powder in the supercooled liquid region using hot-pressing technique.

In this paper, has been studied the influence of mixing time, and thus the homogenization degree, on the mechanical properties of a Fe/Zr-based dual bulk amorphous alloy.

2. Experimental procedures

The glassy powders of the Fe₇₄Mo₄P₁₀C₇.₅B₂.₅Si₂ and Zr₅₂.₅Cu₁₇.₅Ni₁₄.₆Al₁₀Ti₅ were mixed in a volume ratio of 50%, using RETSCH PM400 planetary ball mill at 100 rpm for 1h, 10h, and 20h with a ball-to-powder mass ratio of 10:1. Subsequently, the powders were compacted by hot pressing in the
WEBER-PRESSEN pressing device. The hot pressing was performed in the supercooled liquid region, at 420˚C under an applied force of 60 kN, for 10 minutes.

The amorphous structure of the samples was identified by X-ray diffraction with an X'Pert³ Powder diffraction system, with the radiation of a Cu anode with a wavelength λ = 1.54 Å.

The mechanical properties were determined by Vickers method hardness test and compressive test. The hardness tests were performed using Volpert Micro - Vickers Hardness Tester with a 0.3 kgf load. The compressive tests were done at room temperature, at a loading speed of 1mm/min on a Zwick/Roell- machine.

3. Results and discussion
The hot pressed samples of 10 mm diameter and 5 mm in height are shown in Figure 1. The sample obtained after 1h mixing time was marked with S1, the sample obtained after 10h mixing time was marked with S2 and the sample obtained after 20h of mixing was marked with S3.

![Figure 1. The hot pressed samples mixed with different times.](image1)

![Figure 2. XRD patterns of the glassy powders and of the hot pressed samples.](image2)

The samples were subjected to structural analysis by X-ray diffraction both the Fe and Zr based glassy powders and the samples obtained by hot pressing.

The XRD patterns show that the amorphous structure is preserved also in compacted powders even after longer mixing times (Figure 2). It is also observed that in the case of hot pressed samples, the two amorphous phases are clearly distinguishable: one Fe-based amorphous phase and one Zr-based amorphous phase.

Therefore, X-ray diffraction analysis certifies the obtaining of a dual bulk amorphous alloy, which combines two distinct metallic amorphous phases, thus it can be considered a composite material.

The hardness tests were performed both on the Fe phase and on the Zr phase. The imprints left by the indenter on the surface of each examined sample are shown in Figure 3. Five tests were performed on each sample and the averages of the resulting values are listed in Table 1.

It can be seen that the Fe - phase has a higher hardness than the Zr - phase. It is also found that with increasing of powder mixing time, the hardness of the Fe - phase decreases and the hardness of the Zr - phase increases.

This can be explained by the fact that with increasing mixing time increase the homogeneity of the material and, after hot pressing of the mixed powder, diffusion processes occur that lead to the homogenization of the structure.
At the same time, the hardness of the material, calculated as the average hardness measured on the two phases, decreases with increasing mixing time as a result of the tendency to homogenize the structure.

Figure 3. The imprints left by the indenter on the dual bulk amorphous alloy.

Table 1. The hardness values obtained by the Vickers method.

| Sample | HV0.3 on Fe-phase | HV0.3 on Zr-phase | Average |
|--------|------------------|------------------|--------|
| S1     | 724.5            | 423.1            | 573.8  |
| S2     | 697.1            | 424.9            | 561    |
| S3     | 672.9            | 435.3            | 554.1  |

Figure 4 presents the compressive stress-strain curves of the hot pressed samples. The results of the compression tests are shown in Table 2.

Figure 4. The stress-strain curve of the hot pressed samples.
Table 2. Compressive strength of the hot pressed samples.

| Samples  | S1   | S2   | S3   |
|----------|------|------|------|
| Compressive strength, $\sigma_f$ [MPa] | 824  | 683  | 612  |

It can be observed that unlike Fe-based amorphous bulk alloys, which have a high compressive strength (over 2000…2500 MPa) and a reduced deformation (below 2…3%) [5, 6], the amorphous alloys have a lower compressive strength (under 1000 MPa), but a higher elasticity, the deformation exceeding 30%. The presence of the Zr–based amorphous phase led to a significant increase in material elasticity, but also to a decrease in compressive strength.

It can be seen that with increasing mixing time, the fracture strength decreases from 824 MPa, corresponding to the sample with a mixing time of 1h to 612 MPa, corresponding to the sample with a mixing time of 20h. Thus, by increasing the mixing time and implicitly the degree of homogenization of the structure, the influence of the Zr-based amorphous phase on the mechanical properties of the dual amorphous alloy is more pronounced.

4. Conclusions

Fe/Zr dual phase bulk metallic glasses of cylindrical form with the diameter of 10 mm and 5 mm in height have been successfully obtained by hot-pressing method.

With increasing the mixing time of Fe and Zr amorphous powders, decreases the hardness and compressive strength of the dual phase bulk amorphous alloy, but increases the elasticity. Consequently, augmentation the degree of homogenization by increasing the mixing time leads to a magnification of the Zr–amorphous phase influence on the mechanical properties of the dual phase bulk amorphous alloy.

Therefore, the mixing time of the amorphous powders in order to obtain the dual phase amorphous alloys can be optimized so that, on the one hand to preserve the amorphous structure and on the other hand to obtain the desired mechanical properties.

5. References

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