DUAL AMORPHOUS PHASED BULK METALLIC GLASS WITH SOFT MAGNETIC PROPERTIES

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Abstract

In recent years, the dual amorphous phased bulk metallic glass (DAPBMGs) was studied with interest by researchers of materials science, which is a new class of bulk metallic glasses (BMGs). These materials consist of several amorphous phases and are expecting to bring together all the favorable properties for each phase.

The DAPBMGs with soft magnetic properties can be obtained by powder metallurgy process; the amorphous powders can be produced either by mechanical alloying (MA) or by high pressure Ar gas atomization. Compacting of the glassy alloy powder to obtain the dual amorphous phased bulk metallic glass can be achieved by using a hot-pressed technique (HP) or by spark plasma sintering (SPS) process, in the supercooled liquid region of the amorphous phases.

There are presented some families of dual amorphous phased bulk metallic glass (DAPBMGs) with soft magnetic properties.

This paper synthesizes the current work of the researchers that is the processing, characterization and understanding of these new classes of materials, the dual amorphous phased bulk metallic glass with soft magnetic properties.

Keywords: DAPBMGs, soft magnetic properties, methods of processing, spark plasma sintering, hot-pressed

1. INTRODUCTION

The amorphous alloys were first discovered by Duwez at Caltech, SUA, in 1960, in Au-Si system [1]. They have a scientific interest in material science field due to their unique mechanical, physical and chemical properties associated with the long-range disorder and short-range order atomic structure [2].

In last decades, many Fe -based BGAs have been found suitable for various applications [3]. The large industrial applicability of these materials is due their high strong and excellent magnetic properties, like high soft-magnetic properties including high saturation magnetization and permeability, low coercive force and core loss [4].

For all that, the applications of Fe -based BGAs with soft magnetic properties are limited because the glass forming ability (GFA) of these alloys are low and also they are brittle [5]. It is well recognized that the solving of these inconveniences will extend their potential applications [6].

In recent years, the dual amorphous phased bulk metallic glass (DAPBMGs), was studied with interest by researchers of materials science, which is a new class of bulk metallic glasses (BMGs). These materials consist of several amorphous phases and are expecting to bring together all the favorable properties for each phase. For example, the relatively brittle Fe -based BGAs can be improved by alloying it with high-toughness Zr-based BGAs [7].

The rules of glass-forming ability of this new class of advanced materials are different than the classics bulk metallic glasses (BMGs). The requirements for the formation of a two-phase metallic glass alloy are on one hand a high glass forming ability, on the other hand a strong de-mixing tendency of some components, which is in contradiction with the high glass forming ability [8].

An alternative technique to prepare dual-phase metallic glasses would be via powder metallurgical methods, where the amorphous phases can be prepared individually and then consolidated by hot pressing or other appropriate processes and it obtain a product with geometric shape like a disc [9].

2. METHODS OF PROCESSING

The DAPBMGs with soft magnetic properties can be obtained by powder metallurgy process, the amorphous powders can be produced either by mechanical alloying (MA) and mechanical milling (MM) or by high pressure Ar gas atomization [9 - 11].

Compacting of the glassy alloy powder to obtain the dual amorphous phased bulk metallic glass can be achieved by using a hot-pressed technique (HP) or by spark plasma sintering (SPS) process, in the supercooled liquid region of the amorphous phases. Thus it obtain this new advanced material called DAPBMGs [9, 12, 13].

2.1 Amorphous powders

2.1.1 Mechanical alloying and milling

The mechanical alloying (MA) and mechanical milling (MM) have been found in last the two decades as viable alternate routes for the obtaining of amorphous and nanocrystalline powders. Mechanical alloying (MA) is described as a solid-state powder processing technique involving repeated welding, fracturing, and rewelding of powder particles in a high-energy ball mill [14].

Those techniques use a planetary ball mill to grind and disintegrate powdered materials into smaller fractions by means of ball-milling and a milling bowl which rotates rapidly about its axis on a main supporting disc in the opposite direction. The resulting forces of friction and centrifugal motion lead to high energy collisions between the balls and the powder that occurs in equal and opposite directions on the inner walls of the milling bowl, thereby crushing the sample [15].

2.1.2 Gas atomization

For obtain the amorphous powders, is using a high-pressure gas atomization process (GA), the master alloy is remelted in a graphite crucible by induction heating via induction generator above the liquidus temperature in an inert gas atmosphere and then is applied a Ar gas pressure.

The melt is bottom casted through the atomization nozzle in a chamber and then is lead by the Ar Gas in a cyclone separator and is obtained the powder. The nozzle geometry and the Ar pressure influence the powders size [11, 17].

2.2 Powder consolidation

2.2.1 Hot pressing

The amorphous powders are introduced in a graphite die, then are heated by induction heating via induction generator in the supercooled liquid region of the amorphous phases, followed by applying of an axial pressure, in an inert gas atmosphere of a vacuum chamber. A schematic of hot pressing device is shown in **Fig. 1** [18, 19].

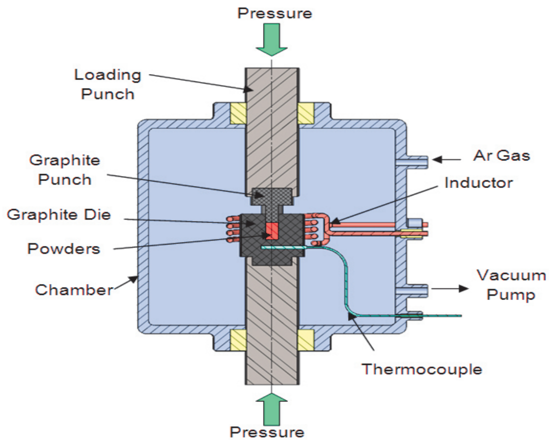

Fig. 1 Schematic drawing of a HP device [18, 19]

2.2.2 Spark plasma sintering

Spark plasma sintering (SPS) is a novel technique developed for rapid sintering of metals, ceramics and composite materials and has an excellent potential for obtain of BMGs. SPS involves: the powders are placed in a graphite die and then is applied a pulsed direct electrical current (DC) from the DC pulse generator, followed by the application of an uniaxial pressure by the punches to achieve the consolidation of the powders in a vacuum and cooling water chamber [20, 21].

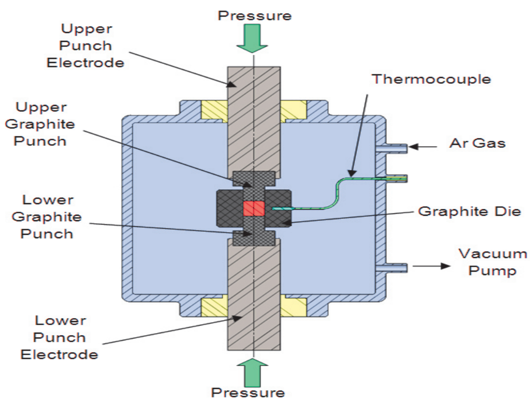

Fig. 2 Schematic drawing of a SPS device [20, 21, 22]

Pulsed direct electrical current (DC) passes through the punches (electrode and graphite), graphite die and through the amorphous powders. The consolidation, also is made in the supercooled liquid region of the amorphous phases, but at a relatively lower temperature and within relatively short time, compared to HP. A schematic of SPS device is shown in **Fig. 2** [20 - 22].

3. FAMILIES AND PROPERTIES OF DAPBMGs

In **Table1** there are presented some families of dual amorphous phased bulk metallic glass (DAPBMGs) with soft magnetic properties reported in the scientific literature in the last years.

Table 1 DAPBMGs with soft magnetic properties reported

Nr.	DAPBMGs with soft magnetic properties		Ref
	Phase 1	Phase 2	
1	Co-Fe-Zr-B	Fe-Cu-Nb-Mo-Si-B	[13]
2	Ni-Nb-Zr-Ti-Pt	Fe-Si-B-Nb	[20]
3	Fe-Co-Si-B- Nb	Pd-Ni-P-Cu	[19]
4	Fe-Ni-P-B-Ga	Zr-Cu-Ni-Al-Ti	[24]
5	Zr-Cu-Ni-Al-Ti	Fe-Ni-P-B	[23]

Both phases of DAPBMGs are mixed homogeneously with different mass %. For example DAPBMGs with soft magnetic properties with no. 4 and 5 of the **Table 1** have the ferromagnetic phases in different proportions. DAPBMGs 5 containing 40 % mass of Fe-Ni-P-B amorphous phase and DAPBMGs 4 containing 50% [24, 23]. As we can observe in **Table 2** and **Table 3**, recently there have been produced a DAPBMGs with soft magnetic properties, composed of two different glassy phases, Zr and a Fe-based. These materials have been found with an improvement of the glass forming ability as shown in **Fig 3. a)** and the tenacity due to the addition of Zr-based amorphous phases, while the soft magnetic properties are maintained due to Fe-based amorphous phases as high saturation magnetization (MS) and permeability, low coercive (HC) force [22, 4].

DAPBMGs was synthesized in shape of disc, and after consolidation they kept a considerable soft magnetic properties, similar to the classics BMGs Fe -based, as is shown in **Fig 3. b)**.

Table 2 Properties of some advanced materials

Advanced materials	Ms [T]	Hc [A/m]	Ref
DAPBMGs 5	0,59	27,60	[23]
DAPBMGs 4	0,59	28,91	[24]
Fe-Si-B-P	1,51	0,80	[25]
Fe-Si-B-P-C	1,44	1,20	[26]
Fe-B-Si-P-Nb	1,45	1,00	[27]

Table 3 Glass forming ability

Advanced materials	ΔTx [K]	Ref
DAPBMGs 5	47	[23]
Zr-Cu-Ni-Al-Ti	83	
Fe-Ni-P-B	40	

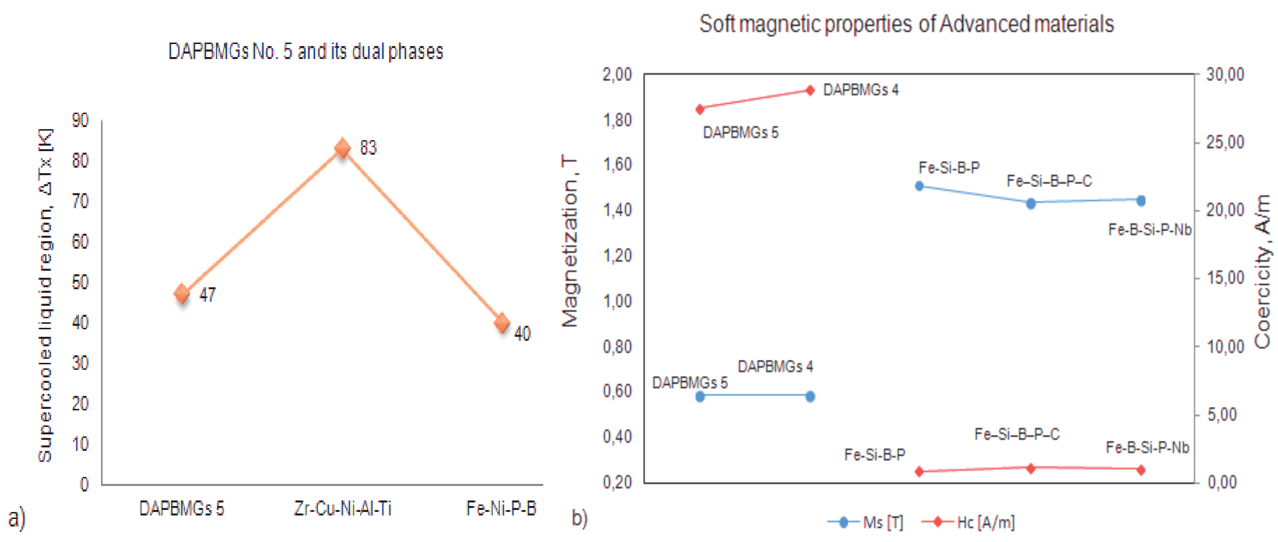

Fig 3 Glass forming ability a) and soft magnetic properties b) of recent advanced materials

4. OUTLOOKS

We propose to perform a DAPBMGs with soft magnetic properties, based Zr and Fe. We chose the following families of alloys: Zr-Cu-Al-Ni-Co-C and Fe-Co-P-B-Si-C. As methods, a route can be: obtaining of amorphous ribbons by melt spinning [16], obtaining of amorphous powders by mechanical milling (MM) of de amorphous ribbons and then consolidate by HP or SPS [13]. We will do more experiments, and we will choose the right dosage between this those two amorphous phases for obtaining the best soft magnetic properties as larger sizes and also we want to study the mechanical properties of this material.

CONCLUSIONS

A DAPBMGs with soft magnetic properties can be produced by different methods of powder metallurgy. Similarly to a composite material, DAPBMGs is expected to have the properties of the both amorphous metal alloys. Obtain of much larger sizes samples than the classic BMGs with soft magnetic properties will extend their further applications in industry.

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