The obtaining and characterization of amorphous alloys in ribbons form used for brazing of advanced materials

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1. Introduction

Compared to crystalline alloys, which have an orderly space arrangement of atoms, the amorphous alloys have a nearly random space arrangement of atoms.

Amorphous alloys are structurally homogeneous, both macroscopic and microscopic scale, the order of atoms is missing, although it is a short distance arrangement of topological and chemical nature. [1], [3].

Most of the amorphous alloys are obtained by continuous solidification methods, with a cooling rate of 105 K/s [1], [3], [5]. The thickness of these alloys does not exceed 60µm. Theoretical, any molten metal can be transformed into an amorphous alloy if the cooling rate is high enough.

The melted alloy must have high viscosity and low diffusion speed, in order to avoid the formation of crystalline phases.

The chemical composition of the alloy must be favourable to obtain metastable structures, due to the limitation of the cooling rates.

The solidification of metallic alloys by rapid cooling leads to the formation of amorphous structures with improved physical, mechanical and chemical properties. [1], [3].

The ribbons (filler material) are obtained by direct casting of the melt, so it is not necessary any further processing operations.

The method used to obtain amorphous alloys is planar flow casting, because this method allows obtaining ribbons with higher dimensions, which allows processing the specimens for the tensile tests.

The specimens are used strictly for this type of alloy [7]. The shape and size of these alloys are perfect for the brazing process. The filler material presents good mechanical characteristics and the thickness of the addition layer is uniform in the bonded area.

2. Experimental procedure

2.1. The obtaining of amorphous metallic alloys

The obtaining of amorphous alloys on an industrial scale can only be realized by continuous processes, using rapid quenching (Figure 1).

These techniques have the advantage that the materials are obtained by direct casting, and not by processing of preforms. The process has been extensively studied, especially the kinetics of the processing conditions.

The process implies the presence of a free jet of the melt, a metal bath from which the material is extracted and quenched in ribbon form.

The metal bath form determines and limits the size of the ribbons. In this method, the nozzle is positioned at a small distance (less than one millimetre) from the cooling surface, this way the cooling surface ensures a mechanical constraint and minimizing the perturbations.

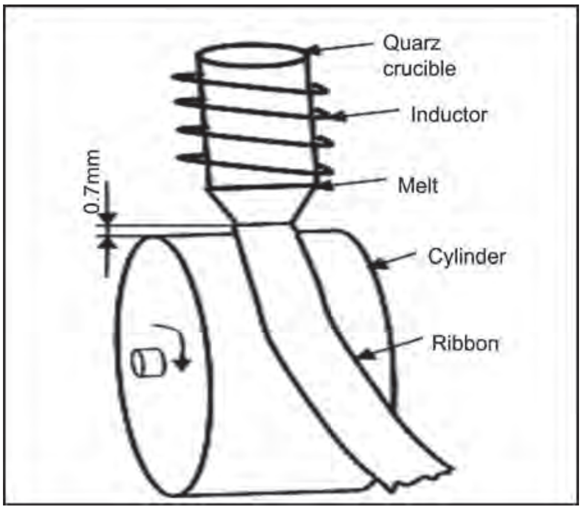

Figure 1. Schematic representation of planar flow casting process

The method of utrahigh cooling of the melt on a cylinder in rotation can achieve excellent performance, being able to develop products with a wide range of sizes and high efficiency.

The master alloy, with a crystalline structure and chemical composition favorable for amorphization is melted by induction in a quartz crucible and forced to pass through the nozzle ejection, falling on the surface of a cylinder in rotation [3].

If the casting is not realized in a vacuum chamber, perturbations may occur during the process, because of the weak links between the air and the cooling support being in rotation.

Thus, between the cylinder and the ejected material is very thin air layer that reduces the cooling rate.

The flow of molten metal through the nozzle slot influences decisively the development of the ribbons.

It is necessary to ensure a constant speed of flow of molten metal on the crucible and the nozzle length.

The amorphous metallic alloy obtained during the solidification process has the chemical composition Ni68 Fe3Cr7 Si8 B14 and the dimensions are presented in Figure 2.

Following the solidification process, the ribbons obtained presents small notches on the edge caused by the flow of the melt on the cooling cylinder.

The width of the sample presented in figure 2 is obtained after a cutting machining. The final dimensions are: length 300mm, width 100mm, 50µm thickness.

2.2. Tensile test

The tensile tests were realized using an universal testing machine, with class 1 of precision for strength and deformation.

The conditions of precision and rigidity imposed to the system machine-specimen, and also regarding the application of load refer to the reliability of the machine.

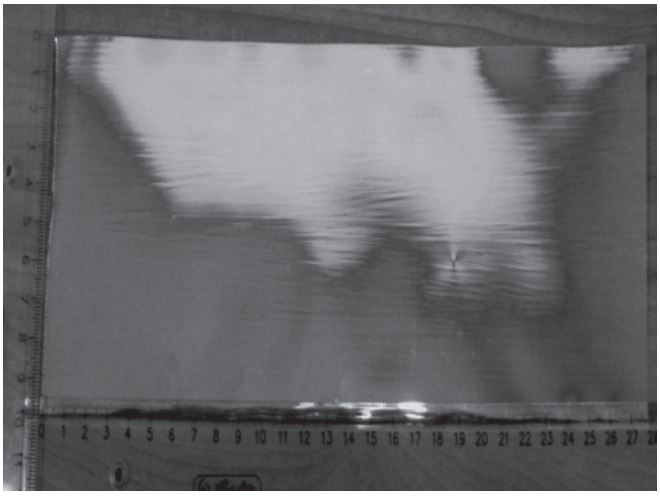

Figure 2. The ribbon obtained during the solidification process

The machine used is Zwick/Roell- with a maximum force that can be applied of 5 [kN]. The tests were realized at room temperature, at a loading speed of 1mm/min.

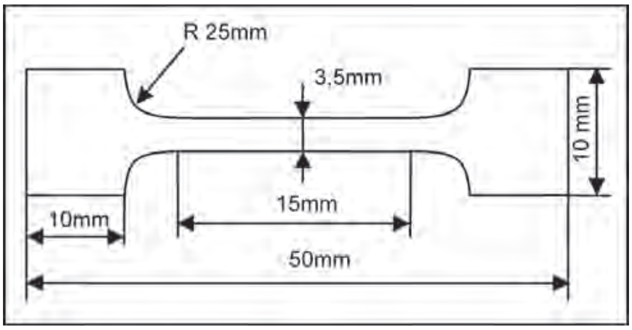

Figure 3. Form and dimensions of the specimen used for tensile test

The specimens used for the tensile tests were obtained by electroerosion wire cutting according to the scheme represented in Figure 3.

The specimens were accurately processed at the final dimension, the surface is not heat affected (an X-ray diffraction was realized to certify if the material was heat-affected or not) and presents a good quality.

Figure 4. The specimen with calibrated portion used for tensile test

For this test were used specimens with calibrated portion (Figure 4).

The fixing of these specimens in the machine's jaws was done using a clamping device (Figure 5).

Figure 5. Fixing system of specimen

It was used this clamping device because the surface of the machine's fixing system is provided with striations which causes shear in the specimen in the clamping area [6].

3. Rezults

3.1. Structural analysis

The amorphous alloys obtained were subjected to X-ray diffraction analysis in order to certify the amorphous state. In Figure 6 it is presented the X-ray diffraction pattern which certifies the amorphous structure.

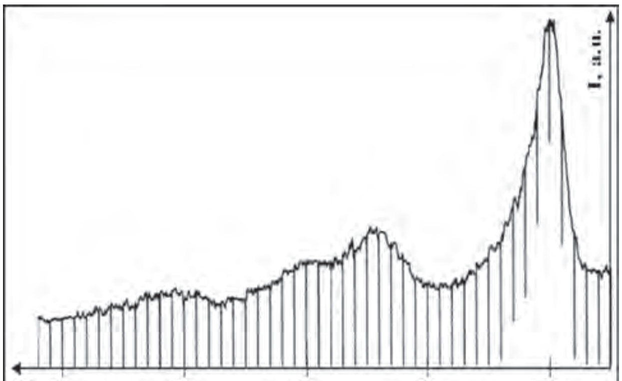

Figure 6. X-ray diffraction pattern

The roughness of the surface (Ra) that is in contact with the cooling cylinder is in the range of 0.23 ÷ 0.33 μm, in longitudinal direction, 0.30 ÷ 0.48 μm transverse and on the free surface the roughness is 0.21 ÷ 0.46 μm longitudinal and 0,32 ÷ 0.68 μm transverse.

The roughness measurements were made in order to prevent the material's failure due to the surface quality. Figure 7 highlights the area processed by of electroerosion wire cutting, images obtained by scanning electron microscopy.

The quality of the surface obtained after the cutting process is good and presents circular microcavities. If these cavities are sharp can behave as stress concentrators and may cause the material breaking.

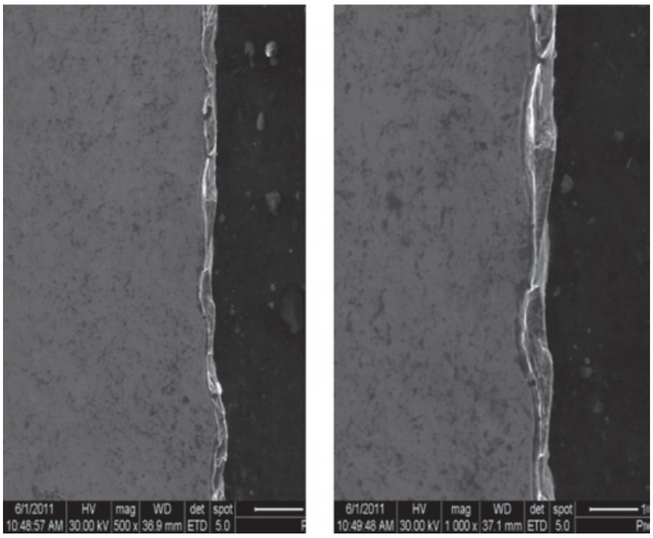

Figure 7. The aspect of the surface after the electroerosion wire cutting process

The shape and size of these cavities varies depending on the nature of the material, cutting parameters and wire diameter. By this method all the specimens are obtained after a single processing and the dimensional accuracy is good.

3.2. Tensile test

In order to determine the mechanical characteristics, for tensile test were used 3 specimens.

After the static tensile test of short duration, were obtained the traction characteristic curves (Figure 8), which allows the determination of the mechanical strength and yield resistance.

Themechanical strength at break represents the ratio of the maximum force Fmax recorded on the characteristic curve, and the initial sectional area of the specimen S0, according to equation 1.

$$R_m = \frac{F_{\max}}{S_0} \qquad (1)$$

Because on the characteristic curve appears a plateau flow, it can be determined the apparent yield flow using relation 2.

$$R_e = \frac{F_e}{S_0} \qquad (2)$$

The mechanical properties (mechanical strength, yield strength) of the alloy are obtained based on the traction characteristic curves presented in Table 1.

The form of the curves and the maximum values of forces resulted from tensile test, shows that the method used for processing specimens with calibrated portion is adequate for this type of alloys.

The amorphous alloy presents a behavior similar to ductile fracture of steels, fact confirmed in the literature indicating that amorphous metal alloys don't have brittle behavior, being tenacious materials.

The values of the mechanical properties obtained are much higher than the alloys in equilibrium state.

Table 1. The values of the mechanical properties obtained

Specimen Mark	Mechanical strength Rm [N/mm^2]	Yield strength Re [N/mm^2]
T1	1825	1764
T2	2186	2084
T3	1940	1922
Average value	1984	1923

Figure 9 shows the aspect of the breaking surface of the amorphous metallic alloy during the tensile test.

Analyzing the aspect of the breaking surface in figure 9, it can be observed that the material presents small plastic deformation, by vein appearance.

These protrusions are found on both breaking surfaces and about the same size. Because the material is plastic deformed in these vein areas, small bumps are appearing in the material and then the material breaks, forming protrusions on both surfaces in the same areas. Smooth surface is characteristic of glass breakings, where the cracks branch off and spreads quickly. In this case, the breaking occurs suddenly, similar to brittle materials. The material behaves more ductile as there are more vein areas, because the crack propagation is slower.

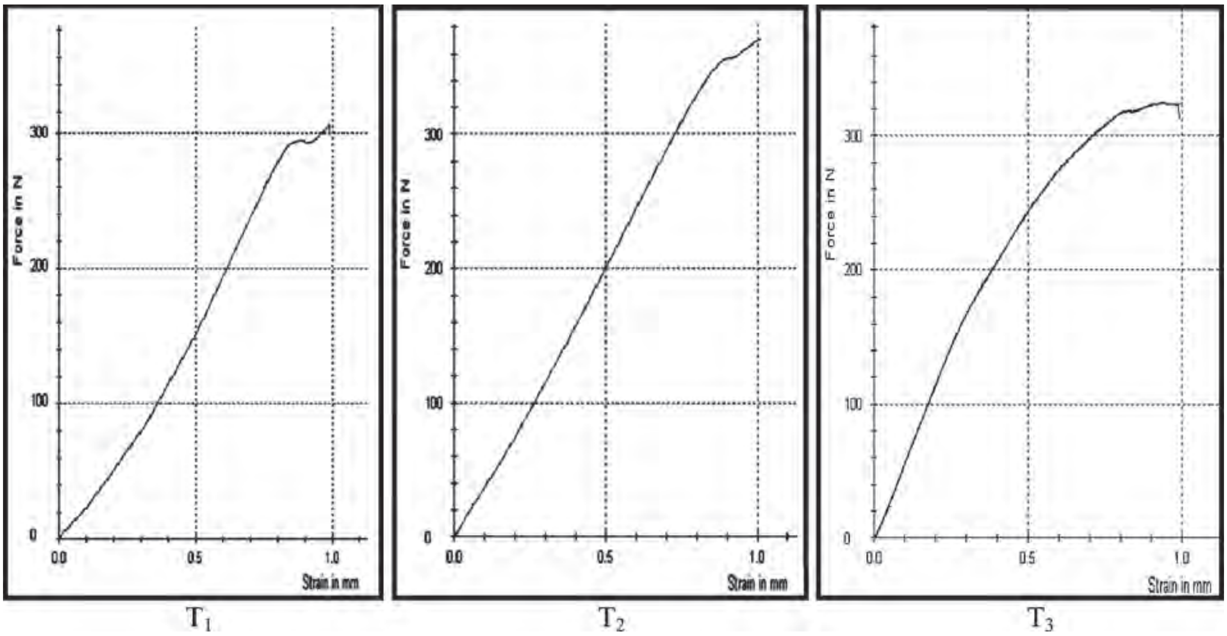

Figure 8. The characteristic traction curves obtained during the tensile test

Thus, on the characteristic curve appears a plateau flow, the material deforms plastic and then suddenly breaks. In Figure 10 we can see how the material breaks and the cracks propagation due to the stress produced by tensile test [2]. First, in the material are produced cracks, they branch off and spreads in different directions causing the specimen breaking.

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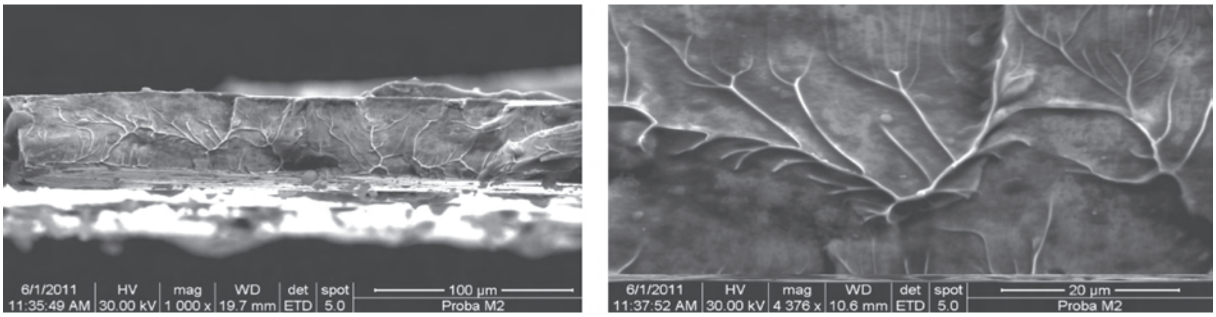

Figure 9. The aspect of breaking surface obtained by scanning electron microscopy

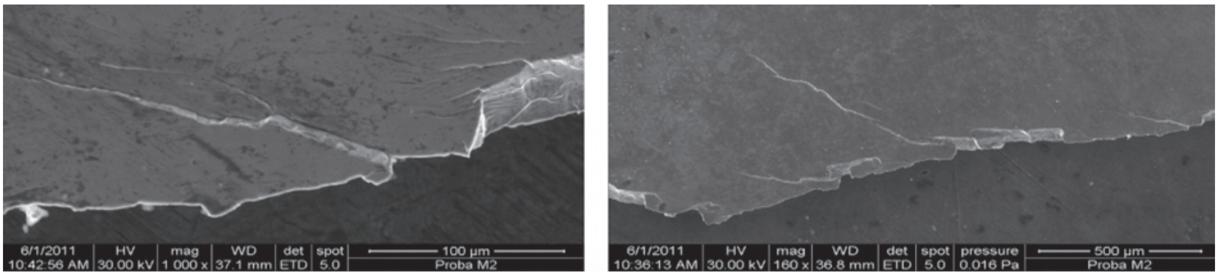

Figure 10. The aspect of crack propagation in the breaking surface obtained by scanning electron microscopy

4. Conclusions

This paper aimed to obtain amorphous metallic alloys that can be successfully used for brazing of advanced materials. Due to their size and extremely high mechanical properties, it is quite difficult to achieve samples with calibrated portion by conventional processing methods. So, after a detailed study, the electroerosion wire cutting method was chosen for processing specimens. The material was not heat affected and the surface quality and dimensional accuracy were good.

The mechanical properties of the alloy present quite high values (mechanical strength 1984 N/mm^2, respectively yield strength 1923 N/mm^2). The material breaking observed in SEM images can be explained by local destruction of short order arrangement in the amorphous alloy.

From the tensile curves is can be clearly observed that the material deforms plastic a little until local destruction of the short distance links, then suddenly breaks. The cracks propagate in different directions favouring the breaking.

The amorphous metallic alloy can be successfully used for brazing of advanced materials working in special conditions, if used in solicitations under yield strength.

If the heating of the amorphous metallic alloy is well controlled, it can be obtained highly homogeneous crystalline alloys and ultra-fine grains. It also can be obtained by crystallization metastable phases impossible to obtain by solidification and heat treatment classic technologies. The ribbons uniformity and the lack of organic binder lead to a narrower joint, stronger and more ductile.

The product form obtained, the high mechanical properties and fracture behaviour of the amorphous metallic alloy is perfectly adapted to the purpose.

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