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NEW TECHNOLOGIES FOR THE PROCESSING OF TENSILE TEST SPECIMENS MADE OF RIBBON SHAPED AMORPHOUS ALLOYS

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ABSTRACT:. Amorphous alloys, especially the ones based on Fe, Ni, Co, Cr are characterized by exceptional resistance properties. At industrial scale, these amorphous alloys are obtained in the shape of ribbons with thicknesses that do not exceed 60 µm and widths ranging from a few millimeters up to 300 mm. The geometry of these products makes it difficult to obtain specimens for mechanical testing. This paper presents the research conducted in order to process these specimens using non-conventional technologies (water jet cutting, electrical erosion wire cutting) as well as the way in which the specimen processing technology influence the results of mechanical tests.

KEY WORDS: tensile test, amorphous alloys, water jet cutting, electrical errosion wire cutting

1. INTRODUCTION

Amorphous metallic alloys show properties that are often outstanding, which are not associated in such way in no other category of known materials. The absence of crystallinity, structural homogeneity and a specific composition lead to high values of tensile strength and a ductility which provides the possibility to be processed by plastic deformation and a non brittle behavior at tensile testing [1].

On industrial scale, amorphous alloys with high mechanical strength (Fe, Co, Ni, Cr based) are obtained by melt-spinning in the shape of ribbons with widths that do not exceed 60 µm and widths ranging from a few millimeters to 300 mm [2]. Testing of the mechanical properties of these alloys require the processing of specific specimens, adapted and designed strictly for this type of alloys. Obtaining these specimens for mechanical testing by conventional mechanic processing is difficult, as the quality of the processed surface is affected. For example, processing by punching of specimens made from ribbon shaped amorphous alloys for their mechanical testing, lead to the formation of microcracks in the marginal area of the specimen (figure 1). These microcracks constitute stress concentrators during mechanical testing and initiate the breaking process. Mechanical properties will be significantly diminished by the presence of these defects produced by the processing process of the specimens.

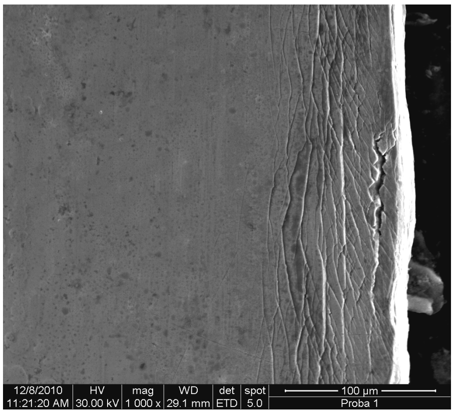


Figure 1. Aspect of the specimens surface processed by cold plastic deformation (punching) [3]

Following a detailed study on alternative processing methods, two non-conventional processes were chosen: electrical errosion wire cutting and water jet cutting.

2. PROCESSING OF SPECIMENS BY NON-CONVENTIONAL TECHNOLOGIES

In order to perform tensile tests of ribbon shaped amorphous alloys it is necessary to obtain samples with a calibrated portion (figure 2) [4]. For such specimens, rupture occurs in the central area and a correct value for the mechanical strength is obtained. An amorphous alloy with the chemical composition $Ni_{68}Fe_3Cr_7Si_8B_{14}$ was used during testing; this alloy is used for brazing stainless and refractory steels.

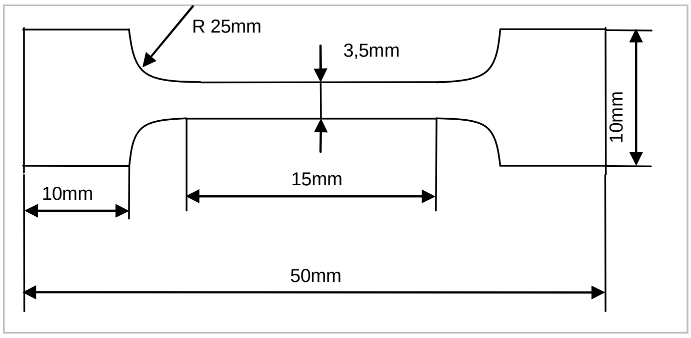


Figure 2. Schematics of the specimen for tensile testing

2.1. Cutting by electrical erosion with wire

Cutting by electrical erosion with wire is based on the erosion of the material by the electrical discharges produced between the workpiece and the wire. This technological operation is made using a cutting machine for electrical erosion with wire (figure 3), which can perform complex geometric shapes, high dimensional accuracy and low roughness [5]. The machine is capable to cut various thicknesses by adjusting the intensity of the current in the wire. Having a CNC equipment provides high machining precision in terms of material economy. The continuous dielectric environment supports the cutting process.

Figure 3 Equipment for cutting with electrical errosion with wire

The processing technology using electrical erosion for the obtaining of specimens with a calibrated portion implies the following steps:

- cutting of the material in the form of strips using a plate shears,
- packaging of the strips (8 pieces),
- writing a program that defines: shape, size, cutting direction, taking into account the gap between the piece and the scrap,
- applying the program,
- fixing of the package in the clamping device,
- starting the actual cutting.

2.2. Watter jet cutting

For this cutting process, water is forced through a nozzle of the special cutting head at a pressure of 1500÷4200 bar. During the process, water pressure is transformed into speed when exiting the nozzle. Water leaves the cutting head at a speed approximately three times higher than the speed of sound. Impact of the water jet on the material determines its cutting [6]. For soft materials cutting, pure water can be used. For hard materials, as in the presented case, higher cutting energy is required; water is mixed with an abrasive powder. The equipment is equipped with numerical control (CNC) and it allows efficient cutting/operating programs.

Usually, cutting equipment (figure 4) contains: running path, guidance path, left and right stroller, beam, sled, cutting head, grill pan with positioning and water jet dumping, CNC, facility for storage and delivery of abrasive material, water softener, high pressure pump group.

The technology for cutting specimens with calibrated portion implies the following steps:

- cutting of the material in the form of strips using a plate shears,
- packaging of the strips (8 pieces),
- fixing the package on a sheet,
- power supply of the pump group, water softener, CNC Burny, abrasive tank,
- compressed air supply,
- starting of the abrasive,
- start up of the recirculation system of the hydraulic system to achieve optimum operating temperature of the system,
- start up of the pump group,
- positioning of the part to be cut,
- positioning of the cutting head,
- choosing the form of the cut,
- adjustment of the cutting parameters: cutting water pressure 2000 bar, cutting speed 100 mm/min, abrasive flow: 30 g/min,
- start up of the cutting process.

Figure 4 Water jet cutting equipment

3. TENSILE TESTING

Tensile tests were conducted on a Zwick/Roell machine, with a maximum applicable force of 5 kN.

The tensile tests were conducted at room temperature with a load speed of 1 mm/min [4, 7]. Specimens with a calibrated portion processed by the technologies described above were used for this test; a clamping device with plane and flat fixing surface is used for their griping (figure 5). Such a device is necessary because the existing clamping device has stripes that shear the specimens during testing.

Following the static tensile testing, mechanical strength was calculated for the two types of nickel based amorphous alloys. Mechanical resistance is the ratio of the maximum force recorded on the characteristic curve, F_{max} and initial sectional area of the specimen, S_0, according to equation 1:

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

Figure 5 Fastening of the specimens into the test machine jaws

Specimens cut with wire by electrical erosion were marked T1, and the ones cut by water jet were marked T2. Three tests were conducted for each specimen type.

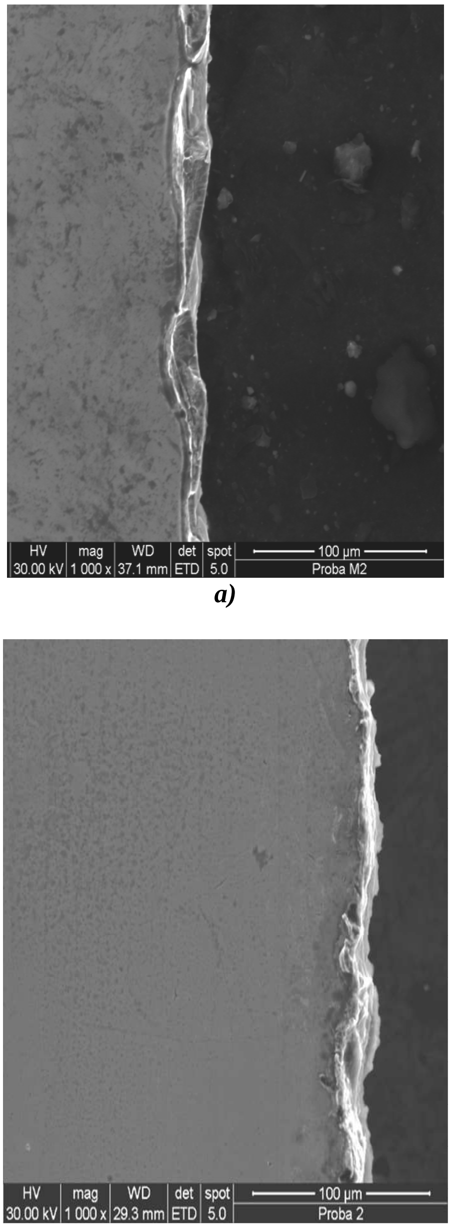
The results obtained following the tensile tests are presented in table 1.

***Table 1** Results obtained after tensile testing*

Specimen type	Test number	Thickness g [mm]	Width of the calibrated part [mm]	Length of the calibrated part [mm]	Maximum force F_{max}[N]	Mechanical strength R_m[N/mm^2]	Average R_m[N/mm^2]
1	**2**	**3**	**4**	**5**	**5**	**7**	**8**
T1	1	0,05	3,33	25	323	1940	1984
	2	0,05	3,31	25	302	1825	
	3	0,05	3,34	25	365	2186	
T2	1	0,05	3,54	25	322	1819	1719
	2	0,05	3,50	25	266	1520	
	3	0,05	3,51	25	319	1817	

4. SPECIMENS ANALYSIS

The samples were analyzed by scanning electron microscopy before and after breaking, in order to examine the surfaces resulting after the cutting process, and after tearing, in order to examine the rupture surface. Microscopic analysis was conducted on a FEI Quanta Inspect FP 2017/11 scanning microscope.



a)

b)

Figure 6 Aspect of the surface as the result of the cutting process

Electrical erosion with wire produces surfaces that show no micro cracks (figure 6a). Also, cavities that might be generated by the cutting process are not present in the examined surfaces. One can conclude thus that the surface quality and dimensional precision are good in this case.

In the case of water jet cut (figure 6 b), small sharpened cavities are present on certain areas of the investigated samples. Presence of these cavities may be due to the fact that in addition to water, an abrasive powder was used to cut the samples. Impact between the abrasive particles and the materials to be cut facilitate the formation of such cavities, which can be considered as stress concentrators when applying the force for the tensile test. The presence of the cavities might also explain why the samples cut by water jet show lower mechanical strength than the ones cut by electrical erosion. It is worth mentioning that no micro cracks are present also for these samples, and they show good dimensional precision.

In the case of electrical erosion cutting, due to the electric discharges between the wire and the work piece, there is the risk of heating the material to a temperature higher than the crystallization temperature, compromising thus the initial amorphous structure of the specimen. In order to study this aspect, after cutting, the specimens were analyzed by X-Ray diffraction, using a DRON 3 diffractometer.

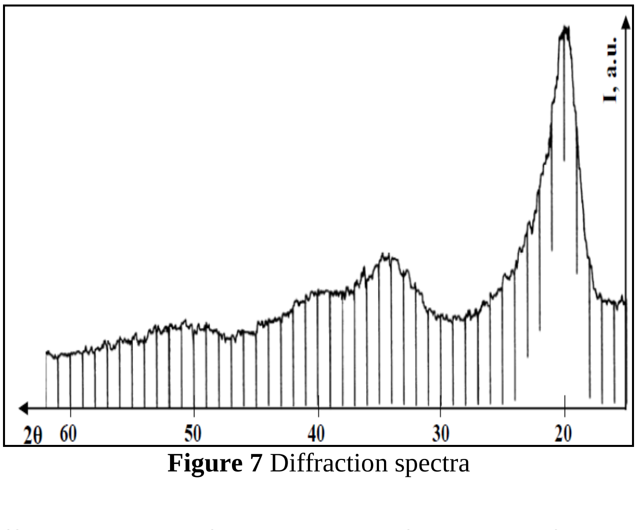
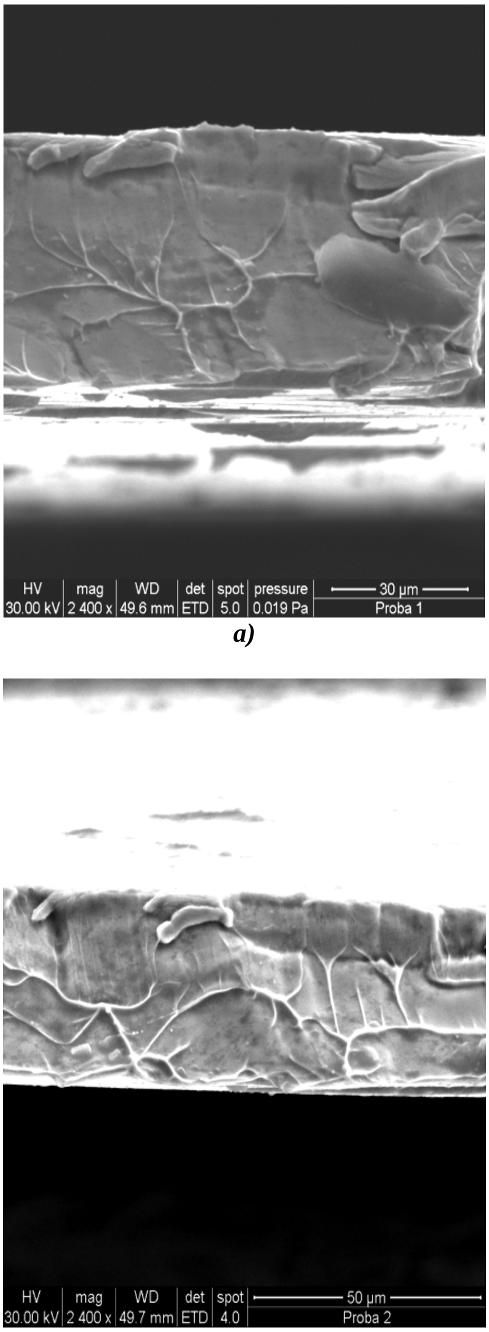


Figure 7 Diffraction spectra

Diffraction spectra of the specimens (figure 7) confirm their amorphous structure, so one can conclude that the electrical erosion cutting process did not affect the structure of the specimen.

Microscopic analysis of the break surfaces of the samples that were submitted to tensile testing highlight specific features of these amorphous alloys [8, 9]. As can be seen in figure 8, both types of specimens have a breaking surface with areas that have small protrusions. These protrusions are due to plastic deformations that appear during tensile testing. Also, the fracture surface is characterized by the presence of smooth surfaces that mark areas of occurrence and propagation of microcracks, leading to tearing.



a)

b)

Figure 8 Aspect of the breaking surfaces of the tensile test specimens

In the case of samples prepared by electrical erosion, the protrusions that are formed are finer (figure 8 a), and the tearing occurred slower, marking a ductile behaviour. Specimens processed by water jet cutting (figure 8 b) show a sudden shear breaking, preceded by the formation of pronounced protrusions. This is due to the presence of stress concentrators on the cut surface, in the form of small cavities resulting from the processing.

6. CONCLUSIONS

Obtaining the tensile test specimens with a calibrated portion from amorphous metallic materials is difficult due to their size and high mechanical properties. Conventional processes based on mechanical methods lead to the formation of microcracks and stress in the surfaces resulting from processing, which has a negative influence on the results of mechanical tests.

Usage of non conventional processes such as electrical erosion with wire and water jet cutting does not produce any microcracking on the surfaces and has no thermal influence on the structure.

Microscopic analysis of the specimens obtained by the mentioned non conventional processes show that in the case on electrical erosion with wire the quality of the cut surface is higher than in the case of water jet cutting. The latter showed on the processed surface stress concentrators in the shape of microcavities.

The result of the tensile tests conducted on the specimens prepared by the proposed non conventional methods show that these technologies can be successfully applied for the processing of the ribbon shaped amorphous alloys.

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