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Aspects regarding the mechanical properties of amorphous metals - Part II

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Abstract. This paper analyzes the influence of different factors on tensile strength and corrosion resistance, in the case of certain amorphous metals.

Keywords: brittleness, ductile-brittle transition, brittleness temperature, corrosion rate, annealing duration and temperature, cooling rate at processing

Introduction

Amorphous metals are obtained from a combination of transition metals and metalloids or from combinations of certain transition metals or from a combination of non-transitional metals with or without the participation of rare earth metals, which are subjected to ultrafast cooling when in the liquid state [8] . Amorphous metals can be obtained by electrolysis or vapor deposition on the surface of some base metals or can be obtained in the form of fibers, wires, strips.

1. Tensile strength

Because the dimensions of the specimens are very small, especially the thickness, the tensile test of the amorphous materials is quite difficult. In addition to this, the energy required for deformation and rupture being much lower than that which ensures the deformations in the elastic range of a soft steel, make unusable the classical technique after which this test is carried out. As a result, a special machine was designed for this [4] and which led to the obtaining of characteristic σ-ε curves, which were not continuous, but presented a slightly jagged appearance. This would have been caused by the slipping of the test piece in the clamping system or by the interactions between the predominantly plastic sliding systems.

Two factors influence the value of tensile strength: the nature of the amorphous material and the heat treatment to which it has been subjected. The same factors were highlighted in the case of the hardness study [4]. Both mechanical properties are influenced by the amount of metalloid in the amorphous metal content. Corresponding to the materials characterized by a ductile rupture, the relationship between these mechanical characteristics has been established:

$$R_m = 1/3{,}2 \cdot HV; \tag{1}$$

where they were noted: R_m - tensile strength, HV - Vickers hardness.

In the case of amorphous materials with brittle fracture, an increase in hardness has been observed, which leads to a decrease in tensile strength. In the case of Co-B alloy, it is observed that as the metalloid content increases, the amorphous metal becomes brittle (fig.1).

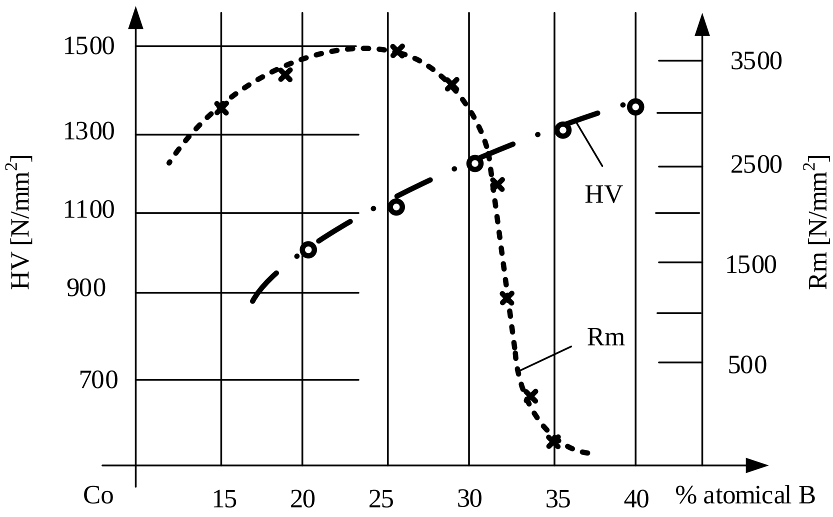

Fig. 1 Variation of mechanical strength and Vickers hardness of amorphous metal in the Co-B system depending on the B content

In the case of amorphous metals, the fragility is influenced by the method of elaboration, by the heat treatment applied and by the type of plastic deformations to which it was subjected. In the case of amorphous metals such as transition metal-metalloid, the fragility is due to the covalent metal-metalloid bonds. In the case of the other two groups of amorphous metals, of the metal-metal type, there is no significant fragility, but instead, the fragility can be induced by heat treatment. In the case of $Cu_{46}Zr_{54}$ alloy, embrittlement occurs with increasing duration of aging treatment (Fig. 2) [3]. In the use of amorphous material, it is important to know the tendency towards embrittlement.

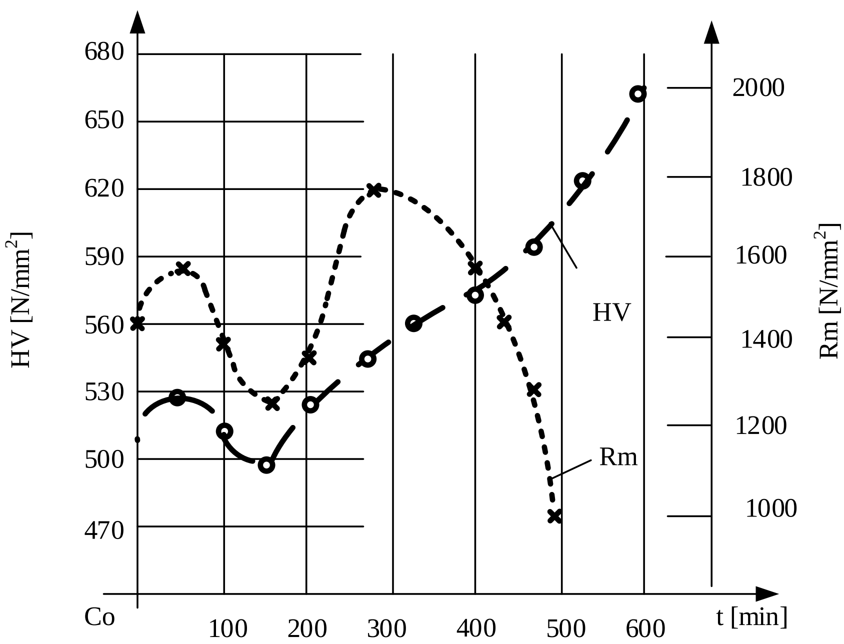

Fig. 2 Influence of aging treatment duration on mechanical strength and Vickers hardness in the case of amorphous metal Cu46Zr54

The ductile-brittle transition was studied by bending tests associated with the sclerometric ones on alloys from the Fe-Ni-B system [5]. Thus, the increase of the Vickers hardness at the increase of the temperature for any of the following alloys was highlighted (fig.3a): $Fe_{40}Ni_{40}B_{20}$ (curve 1), $Fe_{60}Ni_{20}B_{20}$ (curve 2), $Fe_{40}Ni_{40}B_{10}Si_{10}$ (curve 3). The annealing treatment lasted 2 hours.

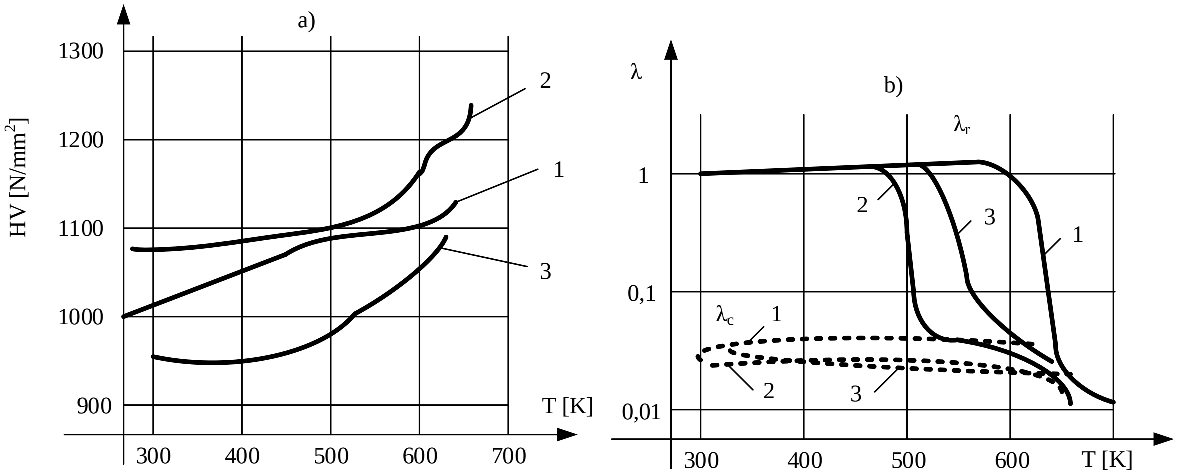

Fig.3 The ductile-brittle transition of amorphous metals from the Fe-Ni-B- (Si) group is highlighted: a) by the variation of hardness; b) by the variation of the deformation at flow and rupture

It was obtained for the same alloys the variation of the flow deformations λc and of the relative deformations at rupture λr (fig.3b) depending on the temperature. These relative deformations are determined by the relationship:

$$\lambda = g / (2r - g), \tag{2}$$

where: g - thickness of the strip; 2r - the distance between the gripping jaws of the specimen.
The embrittlement temperature corresponds to the inflection points of the hardness curves HV = f (Tinc), respectively to the curves λr = f (Tinc).

Increasing the metal (Fe) content increases the hardness and decreases the brittleness temperature. Decreasing the metalloid content (B) leads to a decrease in hardness and brittleness temperature.

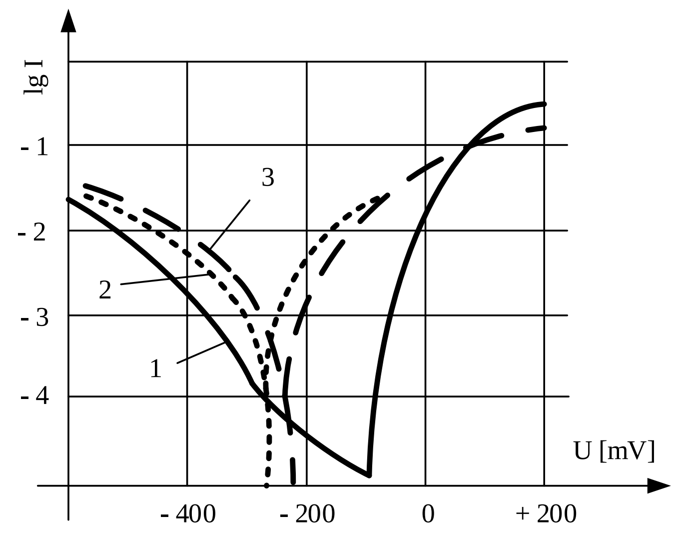

Fig.4 The shape of the polarization curves depends on the type of anions used

As a general aspect, the amorphous metals were observed to have a specifically small elongation of about 0.5%. Also, following the compression tests, it was highlighted that the material can suffer plastic deformations up to 40% without the appearance of hardening.

The conclusion of these experiments is that amorphous metals are characterized by high hardness and breaking strength.

2. Corrosion resistance

Amorphous metals have single-phase structures [1], which gives them a relative homogeneity from a chemical point of view. Their corrosion is studied [7] by the potentiometric method. Corrosion current is determined from the anodic and cathodic polarization curves. Electrolytes containing "active" anions (Cl^-) or "inactive" anions (ClO_4^{1-}, SO_4^{2-}) are used. The shape of the polarization curves depends on the type of anions used; for example polarization curve 1 (fig.4) is obtained in electrolytes with active ions, while curves 2 and 3 were obtained in electrolytes with inactive ions.

The corrosion resistance of two amorphous metal alloys $Fe_{70}Co_{10}P_{13}C_7$ (curve 1, fig. 5) and $Fe_{60}Cr_{10}Ni_{10}P_{13}C_7$ (curve 2, fig. 5) was studied, using sulfuric acid as the electrolyte at 30°C. In both cases, the passivation occurred very quickly, which demonstrates good corrosion resistance.

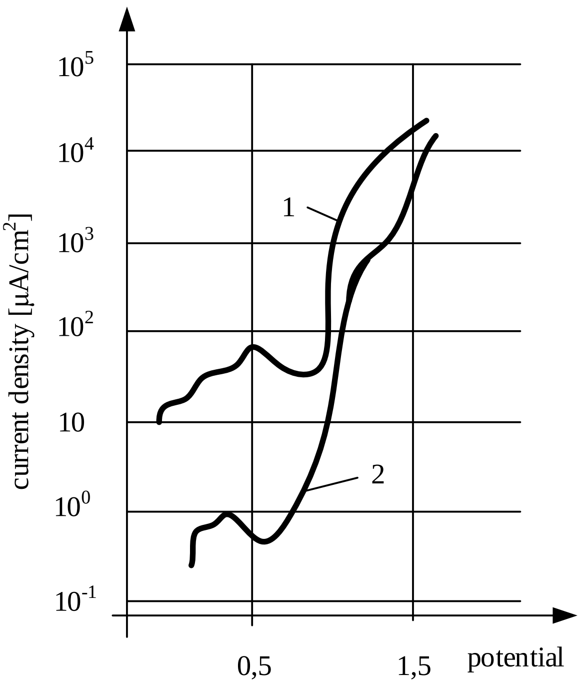

Fig.5 Polarization curves of amorphous metals in the system Fe-Cr-(Ni)-P-C

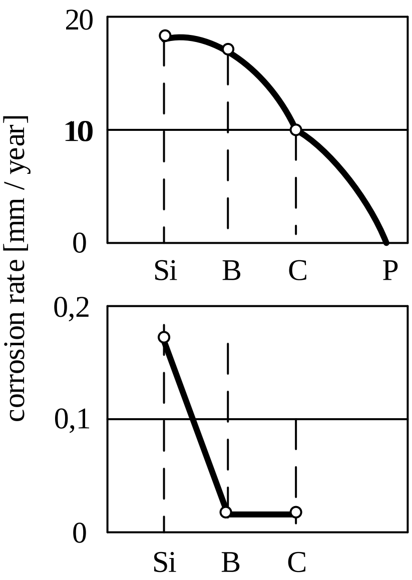

Fig.6 Influence of metalloid content on corrosion resistance of amorphous metal

In the case of Cr-containing binary amorphous metals, the formation of the passive layer of Cr oxides confers high resistance to corrosion, its value depending on the type of electrolyte used and the chromium content. In the case of amorphous metals that do not contain this chemical element, it has been observed that the corrosion resistance is influenced by the type and amount of metalloid in the composition. Experimentally it has been shown that in the case of amorphous metals in the Fe-Cr system, the content of the metalloids Si, B, C, P leads to a decrease in corrosion resistance (fig. 6). It is observed that phosphorus generates the lowest corrosion rate of amorphous metals in this system. It has also been shown that phosphorus positively influences the corrosion resistance of amorphous metals in the metal-metal system. Thus, from fig. 7 it is observed that experiments were performed on $Ti_{50}Cu_{50}$ alloys (continuous line curves), $Ti_{50}Cu_{44}P_6$ (dashed line curves), $Ti_{70}Cu_{25}P_5$ (dotted line curve), which reflect an increase in corrosion resistance when introducing phosphorus into the composition of metal alloys amorphous. Curves 1 were obtained for the amorphous state of the alloy structure mentioned above and curves 2 were obtained according to a crystalline structure. It is noted that the amorphous structure is preferred, according to the criterion of good corrosion resistance.

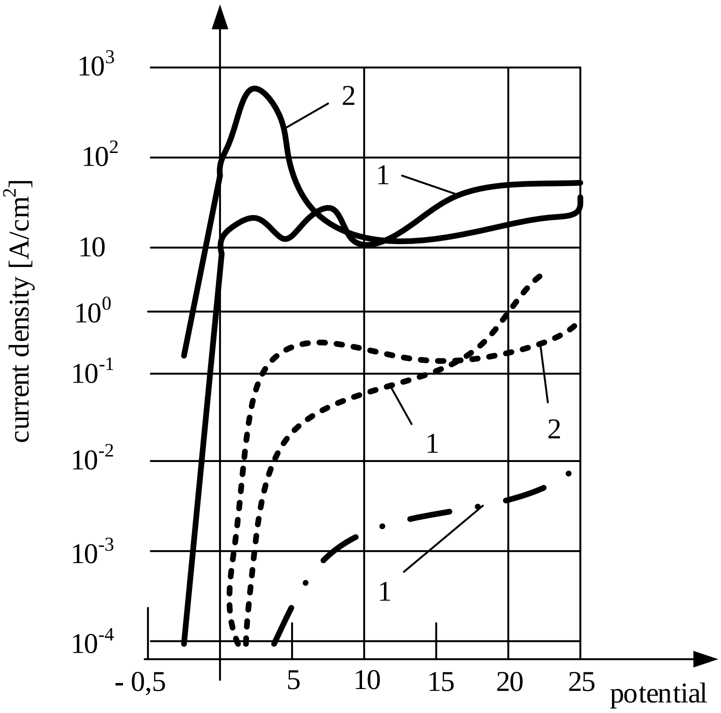

Fig.7 Influence of P on the corrosion resistance of some Ti-Cu alloys with amorphous and crystalline structure

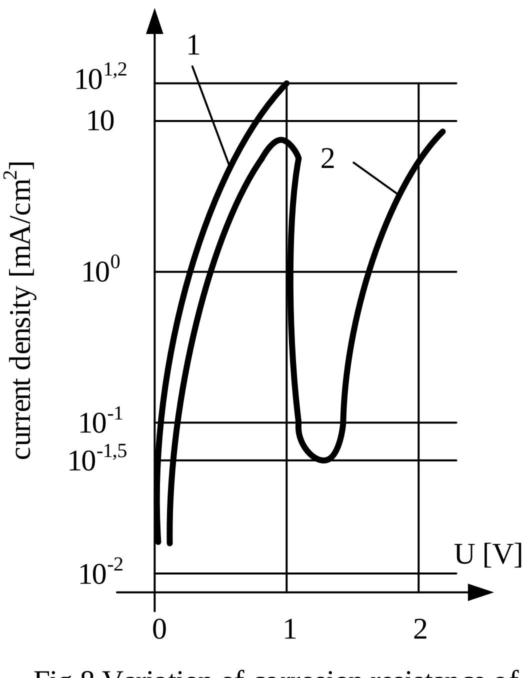

Fig.8 Variation of corrosion resistance of $Fe_{80}P_{14}B_6$ alloys depending on the metal structure

The influence of phosphorus on the corrosion resistance and for amorphous metals in the transition metal-metalloid system, which do not contain chromium, such as $Fe_{40}P_{14}B_6$ (Fig. 8), was studied. The conclusion is that an amorphous state of the structure confers a better resistance to corrosion. Another amorphous metal from the same system, in the form of $Fe_{100-a}B_a$ [2] was subjected to experiments and it was concluded that an increase in the amount of metalloid is registered a decrease in corrosion resistance. The results are presented in tab.1.

Tab.1 Influence of metalloid content on corrosion resistance

a [%]	R_{cor} x 10^5 [A/cm^2]
11,7	5,9
16,6	2,7
21,6	1,6

Another factor that influences the corrosion resistance is the way the amorphous metal is made. Thus, amorphous strips were elaborated by cooling on a disk with a diameter of 75 mm, which rotated at different speeds and it was observed that the best corrosion resistance was obtained for 6000rot / min (fig. 9). At the same time, the best values of this resistance are seen to be obtained in the elaboration with high cooling speeds.

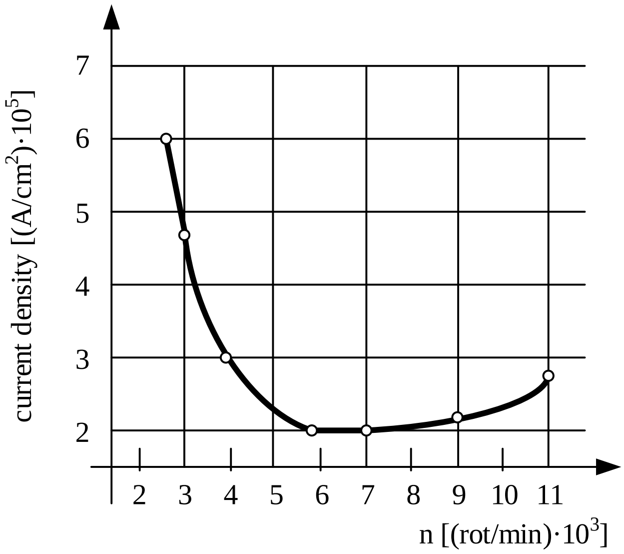

Fig.9 Variation of corrosion resistance depending on the cooling rate of the amorphous metal strip

It was also found that the corrosion resistance was higher on the face that came in contact with the disc than on the face opposite it. The explanation is that the cooling rate on the opposite side is slower, it would be time for crystallization centers to be born.

Other factors that influence the corrosion resistance are the duration and temperature of the heat treatments to which they are subjected [6]. Thus, amorphous metals of the form $Fe_{100-a}B_a$ were subjected to annealing heat treatments for a duration of 3h. It was found that for low temperatures of 200°C and 300°C the structure did not have internal stresses, while for high temperatures of 400°C and 800°C, two types of crystals were born in the structure. It has also been observed that the corrosion rate increases with increasing annealing temperature, especially with the appearance of the first type of crystals and after the structural balance that is formed with the second type of crystals, the corrosion rate begins to decrease.

3. Conclusions

Studying the different characteristics of amorphous metals, made in the form of wires, fibers or strips is important because they are used in the manufacture of composite materials. Studies show that they are characterized by high hardness and breaking strength. Also, these properties are conditioned by the way of applying the heat treatments, as well as by the way of exploitation, being important the knowledge of the embrittlement temperature.

Regarding of corrosion resistance, work was done on two types of amorphous metals, metal-metalloid (with or without chromium) and metal-metal. Chromium it turned out to grow this property, while in its absence it has been observed that corrosion resistance is influenced by the type and amount of metalloid in the composition. Thus, as the amount of metalloid (B) increases, a decrease in corrosion resistance is registered. Also, for better corrosion resistance, the existence of an amorphous structure is preferable. In the case of the metal-metal system, phosphorus favorably influences the analyzed property. The elaboration of amorphous strips with high cooling rates, as well as the application of annealing treatments at low temperatures, lead to an increase in corrosion resistance. The annealing carried out at high temperatures leads to an increase in the corrosion rate and to the transformation of the structure into a crystalline one.

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