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Aspects regarding the mechanical properties of amorphous metals - Part I

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Abstract. This paper analyzes the influence of different factors on hardness and fatigue strength in the case of certain amorphous metals.

Keywords: the hardness, the annealing temperature, the duration of the annealing treatment, the fatigue behavior

Introduction

Amorphous metals can be deposited, by special techniques, on the surface of some base metals or can be made in the form of strips, fibers and wires.

1. The way to determine the hardness

The small dimensions of the cross section of the last products mentioned above, lead to their incorporation in synthetic resins, following to be subjected to sanding operations, similar to the preparation of metallographic samples. The hardness is determined using the Vickers method, which allows the application of small loads on longitudinal or cross sections. In fig. 1 shows the scheme of determining the hardness in longitudinal section (a) and the variation of the hardness depending on the value of the maximum load, for different thicknesses of the specimen (b). In fig. 2 shows the principle scheme of determining the hardness in cross section (a) and the variation of the hardness depending on the value of the maximum load, for different thicknesses of the test piece (b). Similar variations have been registered for different types of amorphous metals ([4], [6]). It was observed that the microhardness varies throughout the test piece in the form of strips, fibers or threads and this is due to the inhomogeneities in the structure, resulting from the elaboration.

Other factors that influence the hardness values are the chemical composition of the amorphous metal and the type of heat treatment applied to it.

In the case of metal alloys (Ti, Cr, Mn, Fe, Co, Ni, Cu, Nb, Mo, Rh, Pd, Ag, W, Re, Ir, Pt, Au) - metalloid (B, Al, Si, P, S, Ga, Ge, As, Sn, Sb) [6], the duration of heating at a certain temperature, can increase or decrease the hardness (Fig. 3). In the case of Fe-based alloys, the increase in hardness is conferred by Ge, P, Si, C and B and is explained by the processes of separation of the intermetallic phases from the amorphous state. Thus, the increase in the number of metal-metalloid or metalloid-metalloid bonds is determined by the increase of the atomic content of metalloid [1]. There was also an increase in the hardness of various amorphous metals as the boron content increased (Fig. 4). In the case of Co-B alloys, the decrease in hardness (Fig. 3) is explained by the decrease of internal stresses, as well as of the network defects appeared during the application of the heat treatment [3]. The influence conferred by the increase of the weight of a metal on the value of the hardness of the different amorphous metals from this metal-metalloid category was followed. Three amorphous metals were considered (Fig. 5) and for the same participation of the bor metalloid, it was found that an increase in the Ni weight leads to a decrease in hardness.

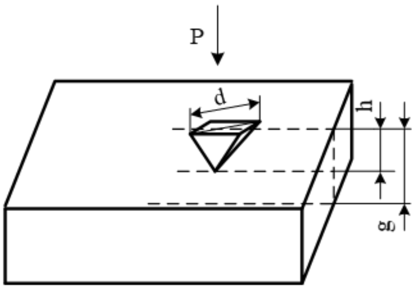

Fig.1a. Measurement of microhardness on the longitudinal section of the test piece

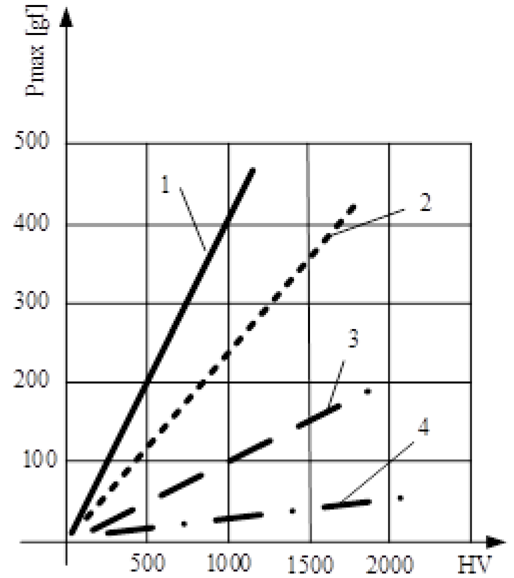

Fig.1b. Variation of microhardness depending on the maximum applied load, for different sample thicknesses: 1 – 40μm, 2 - 30μm, 3 - 20μm, 4 - 10μm

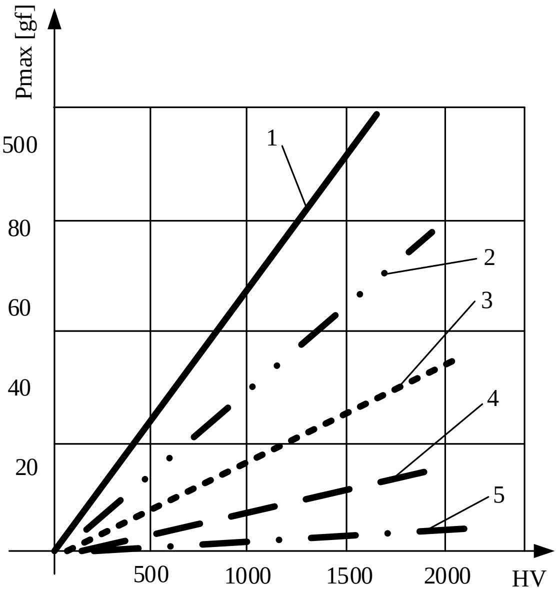

Fig.2b. Variation of microhardness depending on the maximum applied load, for different sample thicknesses: 1 – 50μm, 2 – 40μm, 3 - 30μm, 4 - 20μm, 5 - 10μm

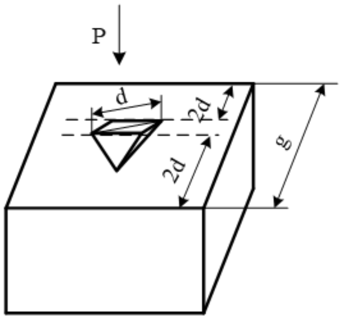

Fig.2a. Measurement of microhardness on the cross section of the test piece

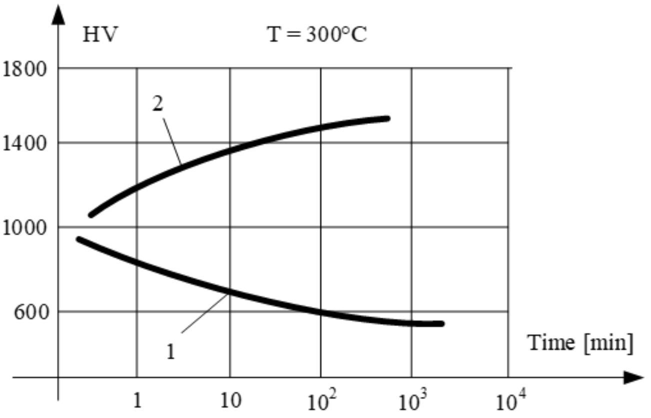

Fig.3. The influence of the heating time of the annealing treatment on the hardness of some amorphous metals: 1 - Co80B20, 2 - Feo80B20

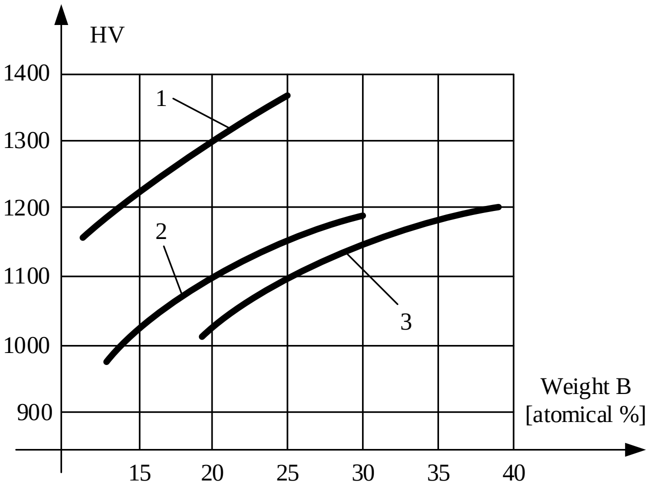

Fig.4. Influence of B content on the microhardness of certain amorphous metals: 1 - Mo-Rh-B, 2 - Fe-B, 3 - Co-B

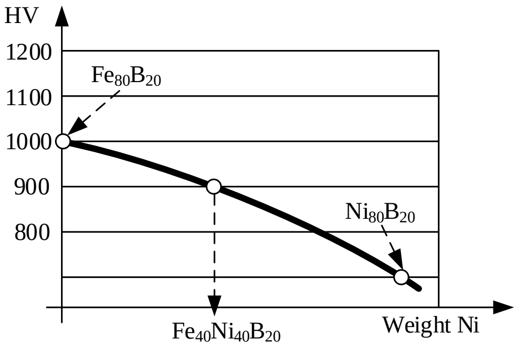

Fig. 5. The influence of Ni content on microhardness, when the weight of the metalloid remains constant

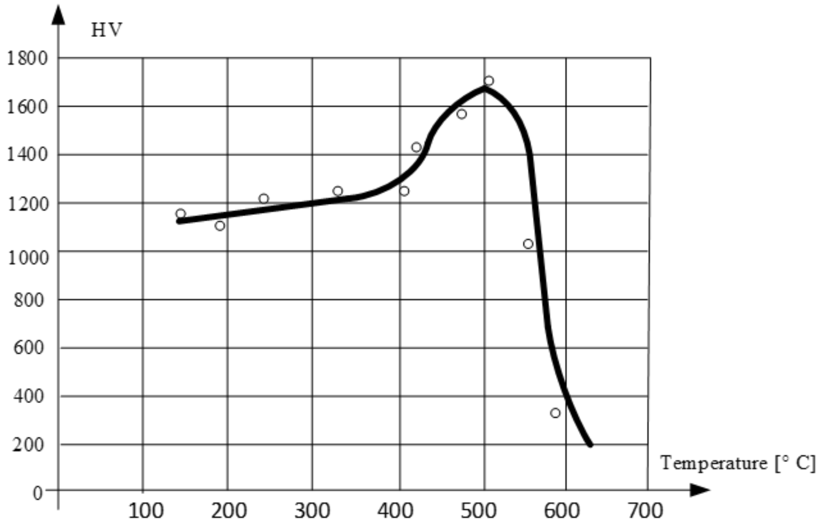

Fig. 6. Influence of annealing temperature on the hardness of the amorphous metal Fe-B-Si-C

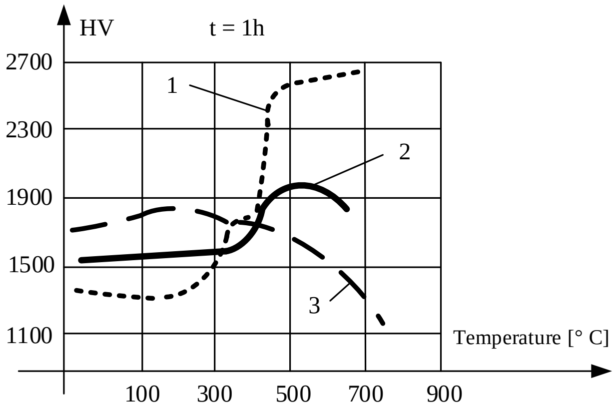

Fig.7. Influence of annealing temperature on the hardness of certain amorphous metals in the Co-B system: 1 – $Co_{62}B_{38}$, 2 - $Co_{74}B_{26}$, 3 - $Co_{80}B_{20}$

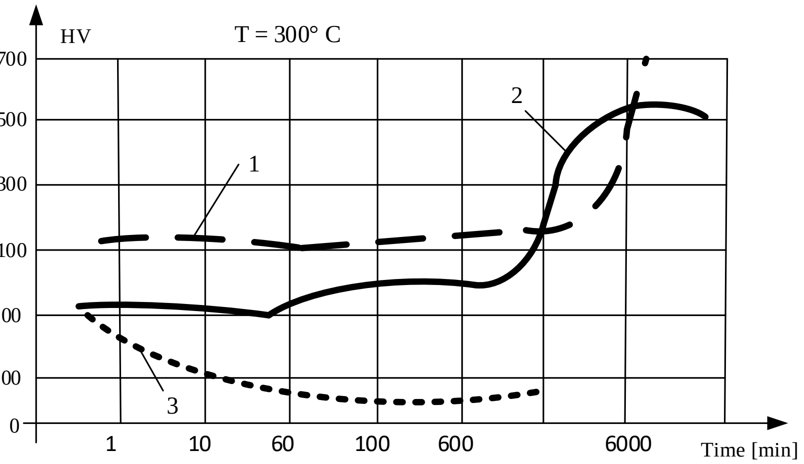

Fig.8. Influence of annealing time on the hardness of certain amorphous metals in the Co-B system: 1 – $Co_{70}B_{30}$, 2 - $Co_{81}B_{19}$, 3 - $Co_{79}B_{21}$

In the case of the amorphous metal having Fe-Si-B-C components, the influence of the annealing temperature on the microhardness was highlighted (Fig. 6). In this case there is a slow increase in hardness up to about 400°C, after which up to about 520°C there is a sharp increase and finally a sudden decrease in less than 100°C. Influences of the temperature increase or the duration of the heating phase corresponding to the annealing treatment, applied to the different types of amorphous metals from the Co-B system, were studied. Thus, it was found that when the temperature increases in a given time interval (Fig. 7), the increase of the hardness is favored by the increase of the boron weight, but up to a certain value of the temperature, so that then this hardness decreases. Regarding the influence of the heating time for a certain temperature (Fig. 8), there were decreases in hardness or its sudden increasing evolution, depending on the metal.

A conclusion regarding the reason for the increase of the hardness in the context of the increase of the temperature, respectively of the heating duration, is the separation of the intermetallic phases or even the germination of the crystals. Metals heated above the crystallization temperature or heated for a long time at constant annealing temperatures, show an increase in hardness [5]. The measurement of microhardness values thus allows the identification of the temperature of the beginning of crystallization.

The way in which hardness is influenced by another factor, such as elasto-plastic deformation [6], was studied. In the case of the metal-metalloid alloy $Pd_{80}Si_{20}$ there was a decrease in hardness, while for alloys in the Ni-Pd-P system there was a slight increase in hardness. In the case of amorphous metals formed by transition metal (Ti, Zr, Hf, Nb, Ta) - transition metal (Fe, Co, Ni, Cu, Rh, Pd) ([6], [10]) it was observed that the values hardness increases as the weight of the main metal increases. This conclusion was drawn by analyzing the amorphous metals based on Cu, $Cu_{46}Zr_{54}$ and $Cu_{56}Zr_{44}$, for which the microhardness increased from HV 495 to HV 600. Another study performed on the amorphous alloys Fe-Hf, Co-Hf, Ni-Hf shows that the weight of hafnium shows an increase in hardness values (Fig. 9).

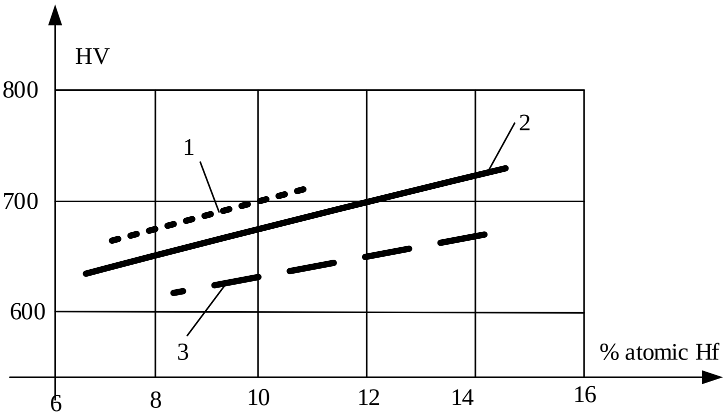

Fig.9. The influence of the weight of Hf on the hardness of certain amorphous metals in the systems: 1 - Fe-Hf, 2 - Co-Hf, 3 - Ni-Hf

2. Resistance to fatigue

This test is performed on wires, fibers or on strips provided either with a hole located on the axis of symmetry, or with a notch that favors the initiation of rupture. In the section of fatigue fracture of amorphous metals, a large number of sliding lines can be seen in the plastic area around the area specific to fatigue destruction. The fatigue behavior of amorphous metals is appreciated with the help of a function S = f (N) of the form:

$$S = A/(F_r - F_m), \tag{1}$$

in which were noted: A = amplitude of the force, Fr = breaking force, Fm = average value of the applied force, N = number of cycles to which the specimen yields.

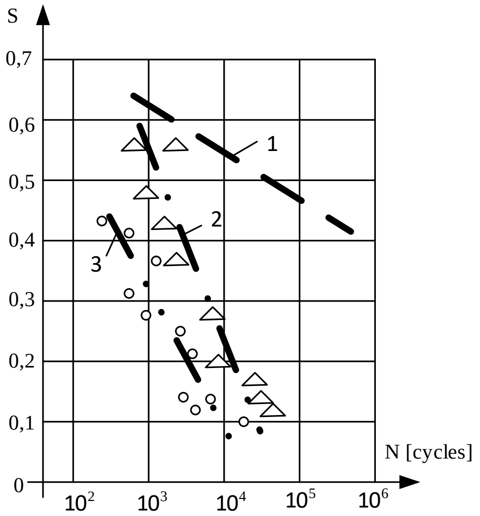

Fig. 10. Fatigue behavior of a crystalline metal versus an amorphous one

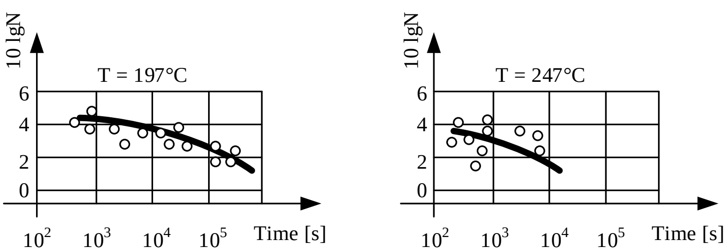

Fig. 11. Influence of annealing treatment temperature and temperature on fatigue resistance of amorphous metal $Ni_{36}Fe_{32}Cr_{14}P_{12}B_6$

High-strength steel and Ni-Fe-Cr-PB multicomponent metal-metalloid alloy specimens were tested, from which specimens were made that were not processed after elaboration and others that were polished. the edges (Fig. 10). It is observed that for the same level of stress, the highest fatigue resistance has the high strength steel (curve 1), followed by the amorphous metal strip with polished edges (curve 2) and finally the specimen (strip) unprocessed after processing (curve 3). The value of fatigue strength is influenced by the type of amorphous metal (transition metal - metalloid, transition metal - transition metal, simple metal (non-transitional) - simple metal (non-transitional) / rare earth metal) and by the treatment conditions. annealing (temperature, duration). For the same multicomponent alloy and the same stress level (S = 0.2) the following were highlighted (Fig. 11):

a) Resistance to fatigue decreases with increasing duration of annealing treatment, whatever the temperature of the treatment;
b) As the annealing temperature increases, the fatigue resistance decreases much faster, so that the same number of breaking cycles recorded at lower temperature values, are reached in a shorter interval when it comes to higher temperatures. It has been observed that for higher stress levels (high "S"), amorphous metal has a higher durability than high-strength steel, which can be explained by a higher value of the yield strength. For low stress levels (low "S"), the durability of amorphous metal is lower than that of high-strength steel, due to its lack of hardening.

3. Conclusions

Amorphous metals in the form of wires, fibers or strips (with a maximum size of 50 µm) are used in obtaining composite materials. They can also be applied in the form of film layers by laser melting, plasma jet spraying or by explosion welding, in order to increase the resistance to wear or corrosion.

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