

EFFECT OF PULSED ELECTRIC CURRENT ON DEFORMATION OF AMORPHOUS AND NANOCRYSTALLINE METALLIC ALLOYS AGED IN ACIDIC ENVIRONMENTS

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Abstract. Specific features of deformation of amorphous and nanocrystalline metallic alloys influenced by pulsed electric current were studied. It has been discovered that passing pulse electrical current causes a momentary relief of mechanical stresses in loaded samples with its subsequent reduction. The effect of aggressive media (20 % solutions of H_2SO_4 and HNO_3) on the value of mechanical stress drop in samples of amorphous cobalt-based alloys and nanocrystalline iron-based alloy was also investigated. It depends on the tensile stress – tensile strain and occurs when electric current pulses are passing. The paper determines dependence of the mechanical stress value in tested materials on the density of pulsed electric current. It also investigates the structural and morphological state of the alloy surface after its exposure to aggressive media of different concentration.

1. Introduction

It is known [1] that amorphous metal alloys have structural relaxation that leads to a change in physical properties of materials and their products. Structural relaxation apparently also occurs when amorphous alloys are heated by pulsed electric current. Expanding the range of application of amorphous and nanocrystalline alloys sets targets for study structure and properties of these materials after exposing them to various influences. These may be both stationary and non-stationary thermal fields, pulse and static electric and magnetic fields, and different media leading to oxidation and corrosion. Metallic glasses that have a high level of corrosion resistance show a significant sensitivity to the effects of hydrogen and corrosive environments, resulting in embrittlement of these materials [1]. Consequently, the study of the effect of pulsed currents and exposure to corrosive environments on the deformation and structural state of amorphous and nanocrystalline alloys is an urgent task.

2. Results and discussion

The following alloys were chosen for testing: amorphous cobalt-based metal alloys (AMAG-172–186) and nanocrystalline Fe-based alloy (AMAG-200) obtained by melt spinning. Sample dimensions: $\sim 3.5 \times 0.02 \times 40$ mm. The uniaxial stretching experiments were performed on the electromechanical machine for static testing Instron-5565. The current density (j), passing through the samples ranged from $1 \cdot 10^8$ to $5 \cdot 10^9$ A/m². Pulses of duration $\tau_1 \sim 2.5$ ms and $\tau_2 \sim 5$ ms were used. Heating the samples during the whole process of deformation was controlled by the laser thermometer Testo-845 at the rate of 10 sec^{-1} . The phase composition of the samples was determined by X-ray methods using the X-ray

effect, the deformation of the samples was carried out as follows. Initially, the sample was subjected to tension at a constant rate of a grip (0.1 mm / min) at room temperature. Upon reaching the mechanical load corresponding to the time of mechanical stress relief, on diagrams $\sigma - \varepsilon$, after transmitting pulse current, the deformation stopped, but the load was not removed. Then, heating was performed using the thermal machine console Instron-5565. The sample loading was continued at the same strain rate as in the first step, but at an elevated temperature of the sample equal to the heating temperature arising from the pulse current. Experiments on all of the studied alloys have shown that the dependence of mechanical stress $\Delta\sigma$ on the value ΔT is linear. Similar curves were obtained experimentally for the transmission of electrical current pulses. The experimental dependences were approximated by the linear function $\Delta\sigma = k \Delta T$, where k is a coefficient showing the amount of stress drop when heated by $\Delta T = 1$ °C.

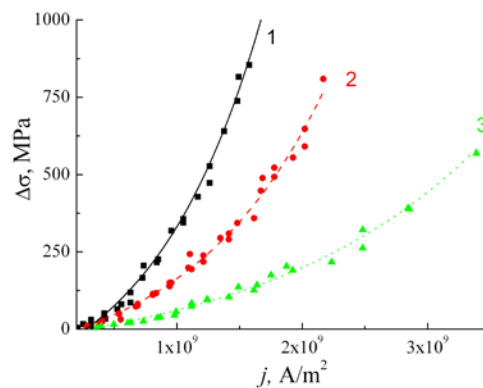


Fig. 2. Dependence of stress relief values on current density at pulse duration $\tau = 5$ ms for alloys: (1) AMAG-180, (2) AMAG-172, (3) AMAG-200

The results of experiments have shown that the mechanical stress drop induced by passing an electric current pulse in the amorphous cobalt-based alloys is ~ 1.5 times larger than the stress relief caused by heating in a furnace (Fig. 3a). It is obvious that the stress relief in the sample is not only due to thermal expansion, but also because of different mechanisms, triggered by the passage of an electric current pulse (Fig. 3, above the dotted line, shows mechanical stress relief caused by heating, below – stress relief resulting from incipient processes of irreversible structural relaxation). Furthermore, magnetostrictive phenomena caused by passing electric current are also excluded, as in amorphous alloys with a high content of Co magnitude of the magneto is practically zero [4].

For alloy AMAG-200 the values of mechanical stress reliefs caused by pulse current and heating in a furnace are the same (Fig. 3b) at the same temperature. It may be due to structural features of the material which is more stable than amorphous metal alloys, at least when heated to temperatures of ≈ 100 °C. Consequently, stress reliefs in this alloy can be explained only by thermal expansion caused by passing pulse current.

A comparative analysis of radiographs of unaffected alloys, alloys exposed to current pulses, and alloys annealed at different temperatures was done. It was discovered that: a) amorphous alloys based on Co (AMAG-170–186), after a series of electrical current pulses at density of $10^8 - 10^9$ A/m², remain X-ray amorphous. It may be associated with initial stages of reversible atomic rearrangements, which are not sensitive to X-ray methods; b) nanocrystalline alloys based on Fe (AMAG-200), after a series of current pulses and heating not exceeding 100 °C, have shown minor changes on the diffractograms which may be caused by partial drop of quenching stresses. This reduces ultimate stress values, but the values of the coefficient of thermal expansion do not change.

reduces the stress relief value by 30 % as compared with the effects of sulfuric acid and by 50 % as compared with the stress relief value at the initial state. Effects of an acidic medium on nanocrystalline Fe-based alloy do not affect the value of mechanical stress drops.

Decrease in the value of stress relief may result from surface phenomena. Figure 6 presents a surface of samples after their aging in an acidic medium. It is seen that the exposure of amorphous materials to an acid medium leads to oxide formations on the surface, which is confirmed by the study of elemental composition. It was found that almost the entire area of the specimen surface was covered with sulfate formations about 3 microns thick.

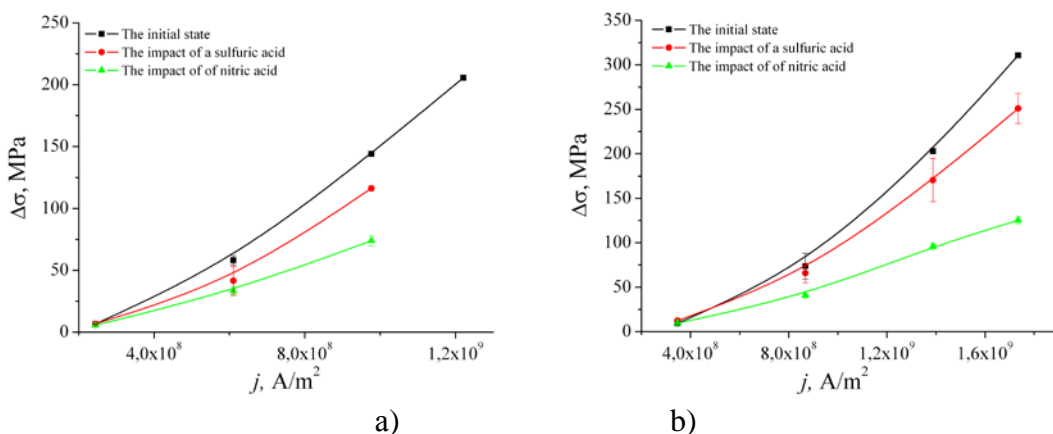


Fig. 5. Dependence of the mechanical stress drop value on current density in an alloy: after exposure to a 20 % solution of sulfuric and nitric acids: a) AMAG-172; b) AMAG-180).

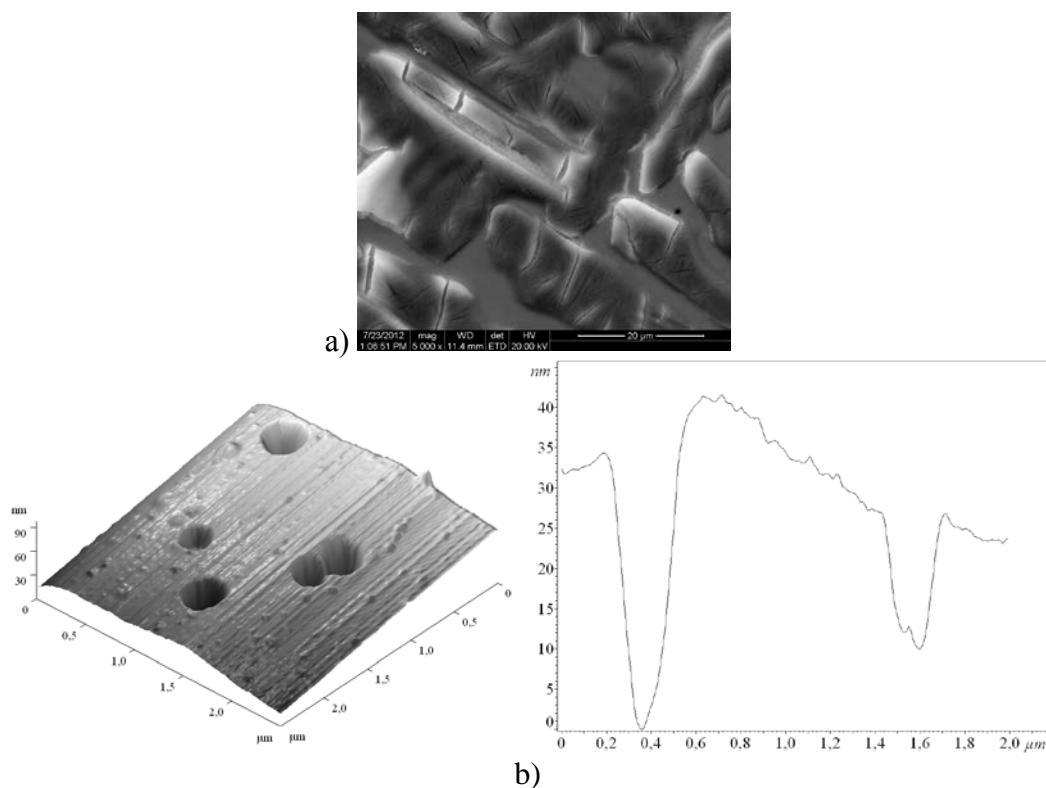


Fig. 6. Sulfate formations on the surface of AMAG-180 after its exposure to a 20 % sulfuric acid solution (a); pitting corrosion on the surface of the nanocrystalline alloy AMAG-200 (b).

The oxide film, formed on the surface, reduces the metal section of a sample which

leads to the increase in resistance and decrease in current strength acting on the sample. This, accordingly, causes less heating of the sample, which results in decreasing the value of mechanical stress relief caused by passing pulse current [6, 7].

Cobalt is capable of absorbing large amounts of hydrogen [8] without forming compounds of constant composition. Therefore, hydrogen, apparently, does not evaporate but remains in the surface layer of the material, causing its embrittlement, which is observed experimentally.

Keeping a nanocrystalline iron-based alloy in solutions of sulfuric acid leads to the formation of pitting corrosion (Fig. 6 b). A typical size of pitting holes is 300 - 350 nm, ≈ 40 nm deep. In this case, there is a decrease in the values of the ultimate strength of the alloy. Thus, after exposure to sulfuric acid and 4 pulses of current with density of $2 \cdot 10^8 - 2 \cdot 10^9$ A/m² the ultimate strength decreases by 20 %.

3. Conclusions

Passing an electric current pulse of density $j \leq 4 \cdot 10^9$ A/m² causes a reversible mechanical stress relief on the loading charts of amorphous alloys. The value of mechanical stress relief in amorphous alloys is determined not only by thermal expansion, but also by incipient structural relaxation.

In a nanocrystalline alloy, the value of critical density of pulse electric current, which does not cause unrecoverable reset, is $j = 8 \cdot 10^8$ A/m². The mechanical stress relief is caused by thermal expansion alone.

Exposure to acid forms sulfate compounds on the surface of amorphous alloys, resulting in a marked reduction of the metal section of a sample, which leads to increasing resistance of the material, reducing current strength and consequently, to less heating of the sample, thus decreasing the value of the mechanical load drop.

Nanocrystalline alloys, in spite of pitting corrosion, keep the value of the mechanical stress relief when pulse electric current is passed.

The change in the value of the mechanical load relief caused by pulse current in these alloys after their exposure to aggressive media occurs only due to the change of heating value of the alloys.

Acknowledgements

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