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Multicycle electric pulse loading of amorphous cobalt- and iron-based alloys

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The effect of electric current pulses on the mechanical characteristics of Co and Fe-based ribbon amorphous alloys is investigated. It is shown that the alloy tensile strength and the maximal pulse amount for destruction decrease linearly growth current density. The dependences between the σ tensile strength of current-induced parallel magnetized materials and ε relative sample deformation is noticed, and micro-bursts of mechanical stress appear at mentioned conditions. The manifestation of microbursts may be associated with a magnetocaloric effect.

Keywords: magnetic field, pulse current, strength.

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1. Introduction

Ribbon and bulk amorphous metal alloys are widely used for various industrial applications (from aircraft engineering to next generation medical implants). Alloys are exposed to various environmental impacts, in particular, electromagnetic fields — both stationary and variable [1,2]. There is little information about the variation of alloy properties under electromagnetic exposure and stress-strain behavior. Therefore, the effect of pulse current on the stress-strain behavior of Co- and Fe-based ribbon amorphous alloys and on variation of their strain-stress properties is studied herein.

2. Experiment

Ribbon samples of cobalt-based (AMAG-170, AMAG-180) and iron-based (AMAG-221, AMAG-225) amorphous soft magnetic alloys were studied herein [3]. Dimensions of the samples are $40 \times 3.5 \times 0.02$ mm. Alloy amorphism was controlled by the X-ray method. The samples were subjected to uniaxial tension using Instron-5565 electromechanical machine with a constant crosshead speed of 0.1 mm/min at room temperature. At the same time, sawtooth current pulses wit current density from 10^8 to $6 \cdot 10^8$ A/m^2 were applied to the sample. Pulse width was $\tau \approx 250$ ms. Pulse repetition rate was 0.5 Hz. Temperature of the strain test sample was measured using Testo-845 pyrometer.

The first part of the experiments included simultaneous exposure of the sample to electric current (heating due to Joule heat) and mechanical load in self-magnetic field (pinch effect). Mechanical strain relieve was observed on the dependence of the ultimate tensile strength σ vs. relative strain ε [3]. Variation of strain-stress properties of amorphous metal alloys depending on the number of applied current pulses and on the increase in pulse current density. For all alloys, linear reduction of the tensile strength (Figure 1, *a*) was observed with an increase in the current density. The number of current pulses passed through the sample to failure with an increase in current density also decreases linearly (Figure 1, *b*). Young's modulus in all specified conditions varies within the measurement accuracy which is supported by the curve $\sigma(\varepsilon)$.

Electron microscopy has shown that a developed system of branched cracks forming a stepped system is observed in the alloys at failure (Figure 2, *a*). When the current density increases up to $5 \cdot 10^8$ A/m^2, local melting regions were observed near the fracture path on the sample surface (Figure 2, *b*), that were probably associated with additional heating of failure-induced structure defects [4]. Microhardness measured on the contact surfaces of the samples in the specified current exposure conditions was almost unchanged.

In the second part of the study included the experiments where the sample was strained without passage of pulse current through it. Current pulse were passed through the other, though unloaded, similar sample located parallel to and in close vicinity to the strain test sample. A ~ 1 mm dielectric heat insulating gasket was placed between the samples to prevent pulse heating of the strain test sample. Thus the test sample was in the magnetic field generated by the current flowing through the same, but unloaded, sample.

The experimental results are shown in Figure 3. When current is flowing, the strain test sample is gradually heated through the heat insulating gasket. Temperature rise results in gradual decrease in strain stress. When the temperature rises by $\Delta T = 7$°C (Figure 3, *b*), stress reduction is about

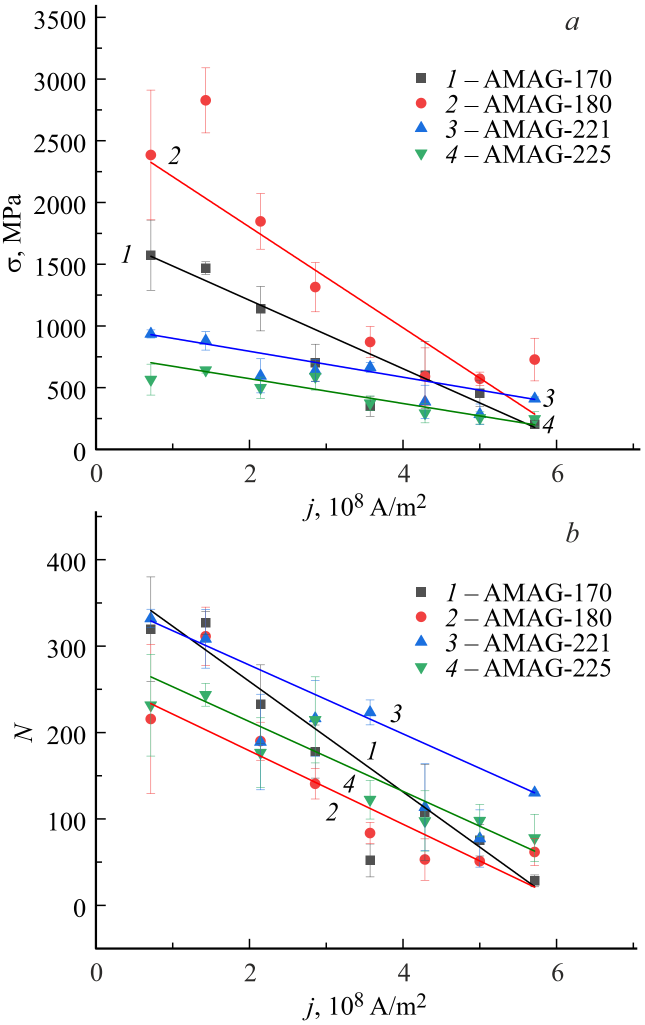

Figure 1. Dependences on pulse current density j: a — of the ultimate tensile strength of a material σ and b — of the number of current pulses N to failure for cobalt-based (AMAG-170, AMAG-180) and iron-based (AMAG-221, AMAG-225) alloys.

100 MPa while a dramatic stress relieve (Figure 3, a, detail) achieving $\sim$ 200 MPa with an appropriate temperature rise by $\sim 20^\circ$C is observed during pulse heating of the strain test sample. After termination of current pulsing, dependence $\sigma(\varepsilon)$ returns to the initial slope. The same deviation of $\sigma(\varepsilon)$ was observed during furnace heating of the samples. At the same time, with decreasing strain stresses, micro-relieves of mechanical stress equal to about 7–8 MPa were observed on $\sigma(\varepsilon)$ corresponding to the time of test sample temperature jumps 0.7–0.8°C (Figure 3, b). The dependence on Figure 3, b shows the general temperature rise of the test sample due to the heat released in the sample through which current pulses were flowing. Heating and cooling after termination of pulsing take place gradually. The observed micro-relieves of mechanical stress throughout the curve are constant in magnitude, which might be due to some factor that is also constant in magnitude. A magnetic field generated by the sample through which the current pulse is flowing may be such factor. In this case, magnetocaloric effect may occur [5]. Additional pulse heating results in additional micro-relieves of mechanical stresses. The X-ray images show that the amorphous state of the alloys remain unchanged after current pulse flow.

3. Conclusions

1. Current pulse flow through Co- and Fe-based ribbon amorphous alloys leads to linear reduction of the tensile strength and the number of pulses to failure depending on the current density. This is attributed to the Joule heat release that reduced hardening stresses.

2. Heating of samples exposed to the pulsed magnetic field results in the occurrence of micro-relieves of mechanical stresses on $\sigma(\varepsilon)$ that might be caused by additional heating due to magnetocaloric effect.

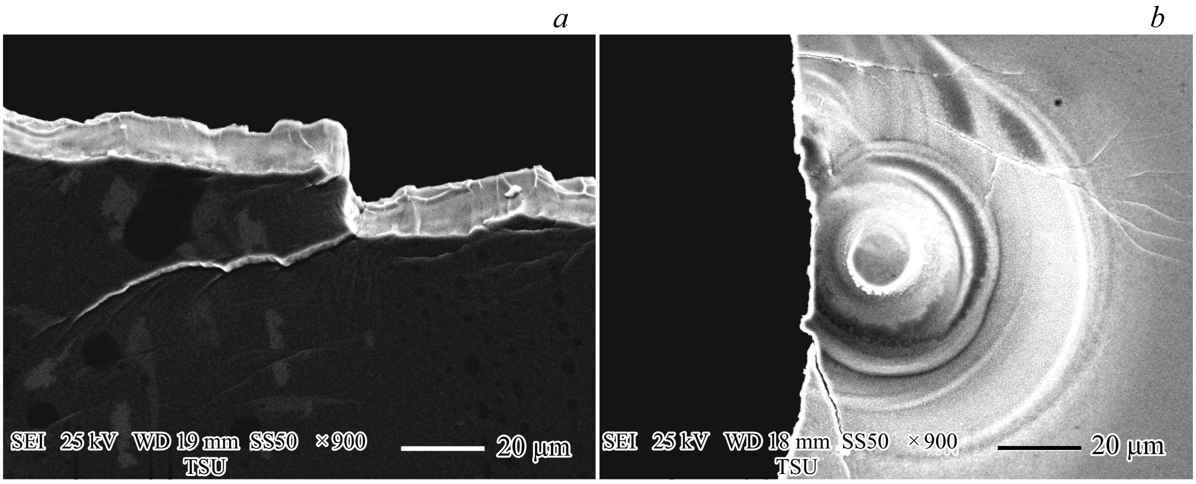

Figure 2. a — fragment of step formation and crack branching at failure of AMAG-225 alloy; b — local melting region near the fracture surface of AMAG-186 alloy. Current density $5.7 \cdot 10^8$ A/m^2.

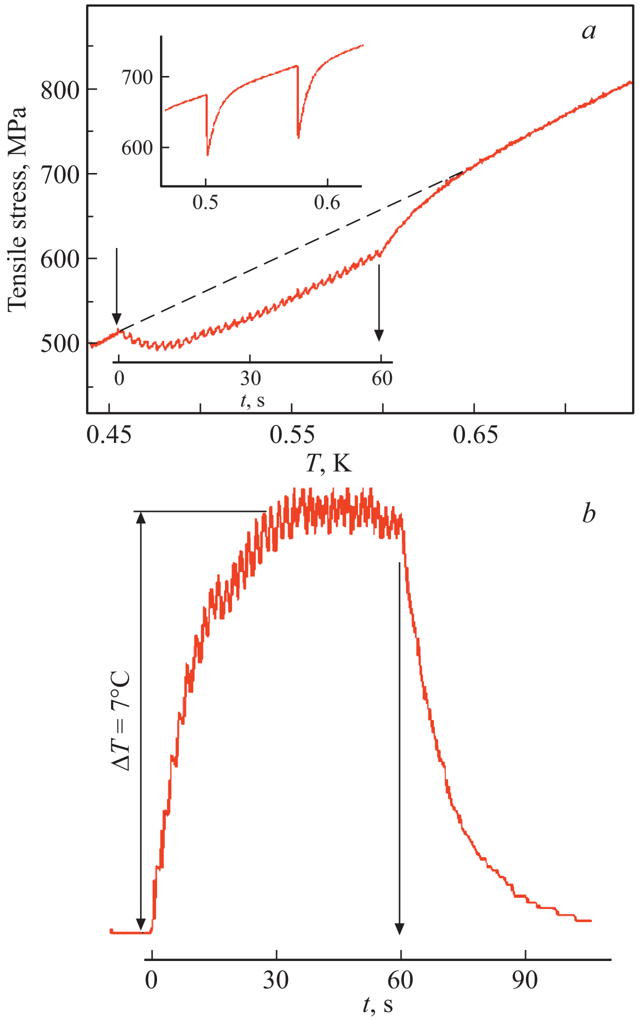

Figure 3. AMAG-186, pulse frequency 0.5 Hz, current density $5 \cdot 10^8$ A/m^2: *a* — loading diagram, detail — loading diagram for the sample subjected to current pulsing; *b* — temperature variation of the strain test sample. The arrows show the beginning and termination of current pulses.

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Conflict of interest

The authors declare that they have no conflict of interest.

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