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INFLUENCE OF THERMAL TREATMENT ON INHOMOGENEOUS PLASTIC DEFORMATION OF ROLLED AMORPHOUS STRIPS OF IRON-BASED ALLOYS

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The effect of thermal treatment on the character of the development of shear bands near the concentrator of stresses in iron-based amorphous alloys has been studied. It was found that rolling facilitates a decrease of the temperature at which inhomogeneous plasticity of the condensed system that does not possess a long-range order disappears; as loading on the indentor increases, the number of semiring-type shear bands in the rolled specimens decreases, with the number and length of the beam-type shear bands being larger than in the original materials.

Introduction. At the present time, the problem of wide use of metallized glasses still remains to be solved [1]. Due to their unique magnetic properties, iron-based amorphous alloys are used in radioelectronics [2]. However, as was shown in [1, 3–7], condensed systems that do not possess a long-range order also manifest unique mechanical properties. These properties of thin (~80 μm) and very strong amorphous strips have not yet found wide application in technology. Here, a restrictive factor is the thermal instability of the properties of metastable materials, to which metallized glasses belong [1, 3]. Therefore, the search for ways of improving the exploitation properties is the main problem in investigating amorphous materials from the point of view of their practical application. One way of control over the characteristics of quickly hardened materials is the use of different means of their treatment. In our paper, we consider rolling as such a method of treatment.

The aim of the paper is to study the influence of rolling and subsequent thermal treatment on the character of the development of inhomogeneous plastic deformation of amorphous iron-based alloys of complex composition.

Experimental Technique. We studied amorphous alloys of the $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ and $Fe_{81.4}$–$Cr_{4.0}$–$Mo_{6.0}$–$Ni_{5.2}$–$C_{1.0}$–$Mn_{2.1}$–$Al_{0.3}$ (wt. %) systems, which were obtained by fast hardening of the melt onto the outer side of a copper hardening disk. The strip thickness was of about 70 μm. The rate of cooling was $8 \cdot 10^5$ $^{\circ}$C/sec. Rolling was performed on a special rolling mill at a constant rotational velocity of the rolls. The relative deformation of the strips was 10%.

Pressure-shaped specimens were annealed isochronically for 20 min at the given temperature. Then, after testing of the specimens, the temperature of annealing was step-by-step increased by 100°C. The maximum temperature of annealing was 720°C. For comparative analysis, original specimens were also subject to thermal treatment and subsequent tests.

Original, rolled and thermally treated, strips were tested on a PMT-3 device. We studied the evolution of the ensembles of shear bands arising at the indentation of the Vickers pyramid (Fig. 1). Both sides of the strips — one which was in contact with air (side 1) and the other which was in contact with the hardening disk (side 2) — were tested. The number of shear bands of the semiring type N_s and of the beam type N_b and the distance between semirings and the edge of the indentor L_s and the length of beams L_b were registered on the indentation. The load on the indentor P was varied from 0.25 to 0.50 N.

The deformation pattern arising at the indentation was observed by the optical microscope of the PMT-3 device and by a CamScan-4 scanning electron microscope. The structure of the original and annealed specimens was studied by a DRON-3 device in monochromatic CuK_{α} radiation.

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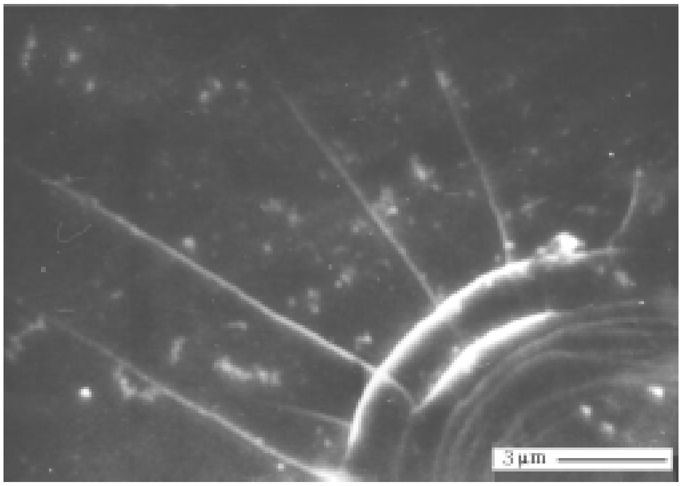

Fig. 1. Deformation at the indentation on the surface of the amorphous $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ alloy.

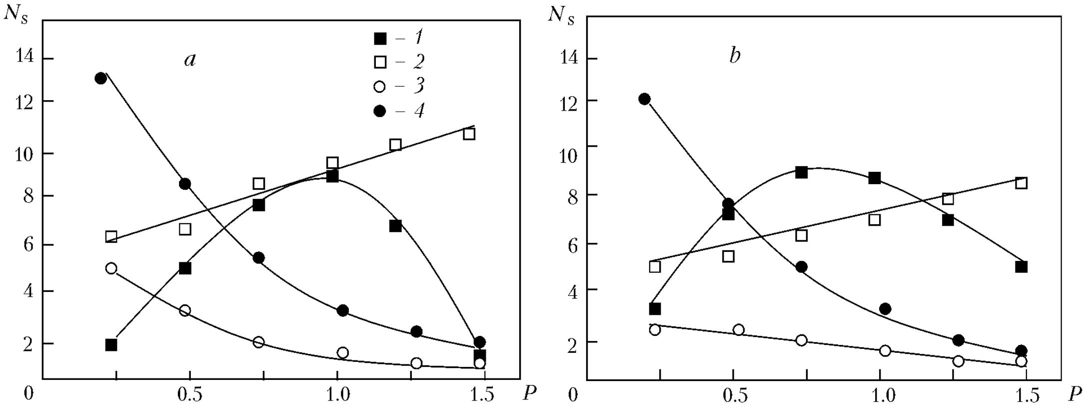

Fig. 2. Dependence of the number of semiring-type shear bands N_s on the loading on the indentor P: a) side 1; b) side 2 [1 and 2) original $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ and $Fe_{81.4}$–$Cr_{4.0}$–$Mo_{6.0}$–$Ni_{5.2}$–$C_{1.0}$–$Mn_{2.1}$–$Al_{0.3}$ alloys; 3 and 4) the same after rolling]. N_s, μm; P, N.

Experimental Results and Discussion. X-ray analysis showed that the original quickly annealed alloys are x-ray amorphous. This manifested itself in the presence of a typical strongly blurred peak, whose position corresponds to the position of diffraction reflection 011 α-Fe on the x-ray photographs [8]. Thermal treatment facilitated the origination of crystal inclusions in the amorphous matrix, thus decreasing blurring of the peak and promoting the appearance of new peaks. At the maximum temperature of annealing (in our experiments, $t = 720^{\circ}C$) the amorphous state did not disappear completely. This was indicated by blurring of the initial peak, which did not disappear completely.

Inhomogeneous plastic deformation [1], the main channel of which is manifested by narrow shear bands, manifests itself at a high level of external stresses of deformation of amorphous iron-based alloys. An ensemble of these shear bands at the indentation of the Vickers pyramid on the surface of metallized glass is shown in Fig. 1. Two types of shear bands are observed: in the form of beams from the indentation and in the form of semirings surrounding the indentation.

Figures 2–4 show the results of studies of special features of inhomogeneous plastic deformation of original and rolled $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ and $Fe_{81.4}$–$Cr_{4.0}$–$Mo_{6.0}$–$Ni_{5.2}$–$C_{1.0}$–$Mn_{2.1}$–$Al_{0.3}$ alloys. The dependences $N_s = f(P)$ and $L_s = f(P)$ of the original $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ alloy are extremal (see Figs. 2 and 3). The maximum is observed with a loading on the indentor close to 1.0 N. These dependences are linear for the $Fe_{81.4}$–$Cr_{4.0}$–$Mo_{6.0}$–$Ni_{5.2}$–$C_{1.0}$–$Mn_{2.1}$–$Al_{0.3}$ alloy (see Figs. 2 and 3). This situation is probably due to the fact that in the $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ alloy at loadings on the indentor higher than 1 N the beam-type shear bands are

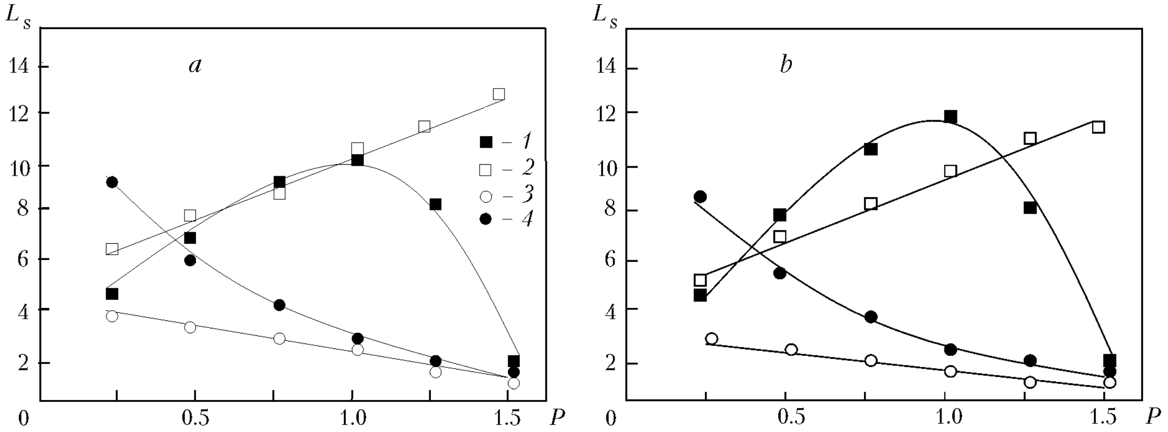

Fig. 3. Dependence of the distance between the indentor edge and the semiring-type shear bands L_s on loading P: 1) side 1; b) side 2. For the notation 1–4, see Fig. 2. L_s, μm; P, N.

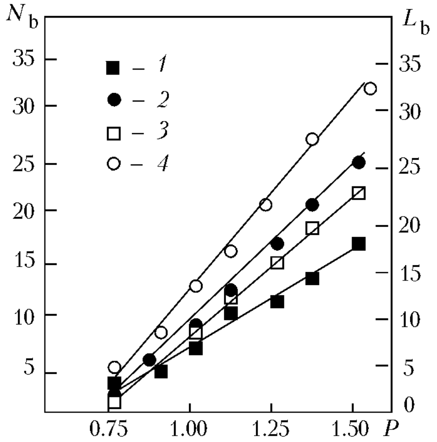

Fig. 4. Dependence of the number (1, 3) and length (2, 4) of the beam-type shear bands ($N_b = f(P)$ and $L_b = f(P)$) of the $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ alloy on the loading on the indentor: 1 and 2) sides 1 and 2 of the nontreated specimens; 3 and 4) sides 1 and 2 of the treated specimens. N_b and L_b, μm; P, N.

observed to form in the deformation region (see Fig. 4). In this case, the energy is redistributed among the considered channels of inhomogeneous plastic deformation toward decrease of its flow rate for development of the semiring-type shear bands. In the $Fe_{81.4}$–$Cr_{4.0}$–$Mo_{6.0}$–$Ni_{5.2}$–$C_{1.0}$–$Mn_{2.1}$–$Al_{0.3}$ alloy, the beam-type shear bands are observed at loadings on the indentor higher than 2 N, which is beyond the range of loadings considered in the present paper. Therefore, within the framework of the measurement error, the dependences $N_s = f(P)$ and $L_s = f(P)$ of the $Fe_{81.4}$–$Cr_{4.0}$–$Mo_{6.0}$–$Ni_{5.2}$–$C_{1.0}$–$Mn_{2.1}$–$Al_{0.3}$ alloy can be taken to be linear.

In the rolled specimens, the number of semiring-type shear bands and the distance between them and the indentor edge decrease as the loading on the indentor increases. This result can be explained proceeding from the fact that rolling facilitates the formation of microscopic shear bands and nanocrystal inclusions, which are formed due to the effect of plastic deformation, in the amorphous strip [9].

The mentioned structural changes impede the development of the semiring-type shear bands with an increase in the intensity of local deformation; this takes place against the background of activation of the processes of formation and development of the beam-type shear bands, whose number and length are, respectively, 2 and 1.5 times higher than in the original specimens. If we model the development of the semiring-type shear bands by motion of the groups of edge dislocations and that of the beam-type shear bands by motion of the groups of screw dislocations, then

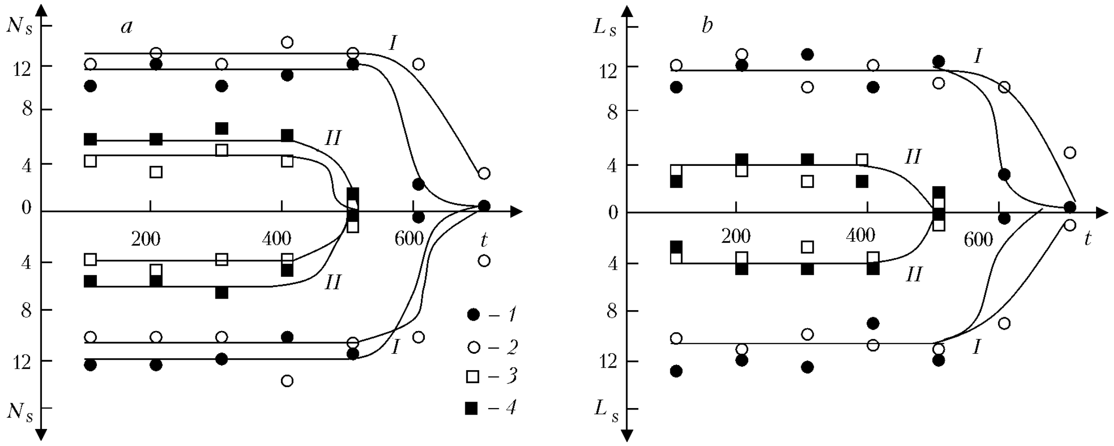

Fig. 5. Influence of isochronic annealing on the formation of semiring-type shear bands [a) N_s; b) L_b] in original (I) and rolled (II) specimens. In the positive region — side 1, in the negative region — side 2. For the notation, see Fig. 2. N_s and L_s, μm; *t*, ^{o}C.

it is clear that to overcome obstacles such as crystal inclusions, in the process of climbing the edge dislocations require more energy than the shear ones. However, as was shown in [5], the initiation of the formation of beam-type shear bands requires a higher level of external stresses than for the semiring-type shear bands. Therefore, as loading on the indentor increases, we observe a decrease in the activity of origination of semirings with considerable activation of the development of beams.

Results of the influence of isochronic annealing on inhomogeneous plastic deformation of original and rolled specimens are shown in Fig. 5. It is seen that an increase in temperature to 500–600^{o}C and 400^{o}C in the original and rolled specimens, respectively, slightly affects the increase of N_s and L_s. A further growth of temperature leads to a sharp decrease of N_s and L_s. This result can be due to the thermal instability of the amorphous alloys studied. At temperatures higher than 600^{o}C and 400^{o}C, in the original and rolled specimens, respectively, we observe a transition from the amorphous to the crystalline state; on the x-ray photographs this is manifested by a decrease in blurring of the peak corresponding to 011 α-Fe, an increase in its intensity, and the appearance of new peaks which belong to depositions of borides, carbides, and silicides. However, we did not observe complete disappearance of the amorphous component in the studied temperature range (the considerable general background that indicates the amorphous state did not completely disappear on the x-ray photographs). Therefore, we can draw the conclusion that decay of the process of formation and development of the shear bands formed in amorphous alloys at high temperatures is due to intense interaction between the shear bands and crystal inclusions. As a result of this interaction, crystallites block the operation of the sources forming the shear bands and pass the development of plastic deformation to the region of other mechanisms [9].

It follows from comparison of the dependences obtained for original and rolled specimens (see Fig. 5) that rolling not only damps the activity of formation of shear bands but also facilitates temperature decrease untill complete cessation of the process of inhomogeneous plastic deformation of deformed amorphous materials. The elastic energy, which is accumulated in the rolled amorphous material as the temperature increases, facilitates activation of diffusion processes, as a result of which small-radius atoms migrate in the compression region and large-radius atoms migrate in the extension region. This leads to the fact that in rolled specimens formation of the crystalline phase with an increase in temperature begins earlier than in the original specimens. Therefore, the effect of the loss of inhomogeneous plasticity in rolled strips is observed at lower temperatures than in the strips not worked mechanically.

CONCLUSIONS

As a result of studying the effect of thermal treatment on the character of development of inhomogeneous plastic deformation in local dosed deforming of the surface of amorphous $Fe_{46.3}$–Cr_{40}–$Mo_{7.2}$–$V_{0.5}$–$B_{4.0}$–$Si_{2.0}$ and $Fe_{81.4}$–$Cr_{4.0}$–$Mo_{6.0}$–$Ni_{5.2}$–$C_{1.0}$–$Mn_{2.1}$–$Al_{0.3}$ alloys, we found that:

1) as the loading on the indentor increases, the number of semiring-type shear bands in the rolled specimens decreases; however, in this case, the number and length of the beam-type shear bands are larger than in the original material;

2) rolling facilitates an almost 1.5-fold decrease in the temperature of blocking the development of shear bands.

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