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Some peculiarities of mechanical properties of amorphous metal alloys

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First experimental results are presented on amorphous $Fe_{80}B_{20}$ alloy strip spontaneous straining demonstrating itself as the strip twisting and simultaneous change in the sampl e length under linear heating. The coherent phenomena are simulated mathematically, the model applicability to description of relaxation processes in amorphous metal alloys has been checked.

Приводятся первые экспериментальные результаты для ленты аморфного сплава $Fe_{80}B_{20}$ по обнаружению спонтанной деформации, проявляющейся в виде кручения ленты и одновременного изменения длины образца в процессе линейного нагрева. Выполнено математическое моделирование когерентных явлений, опробована их применимость для описания релаксационных процессов в аморфных металлических сплавах.

Thermodynamically nonequilibrium states are known to be typical of freshly-prepared amorphous metal alloys. The subsequent heating of those alloys is accompanied by result in cause embrittlement, changes in density, hardness, and ductility while a high-temperature one, in crystallization. To explain those anomalies, the concepts of free volume and substantial contributions of relaxation processes (proceeding from nonequilibrium states) into the free volume change are often used [1]. Data on the free volume changes under isothermal annealing can be obtained, e.g., by studying time dependences of relative lengthening ($\Delta L/L$) of a sample shaped as a strip of initial length L. So, for $Fe_{40}Ni_{40}B_{20}$ glass under isothermal annealing in $T_g < T < T_m$ temperature range (where T_g and T_m are vitrifying and melting temperatures, respectively), a surprising result was obtained: on the background of usual logarithmic time dependence of relative lengthening (corresponding to compression process), a series of $\Delta L/L$ oscillations was observed (corresponding to short time intervals when the glass is in dilatation) [2]. The $\Delta L/L$ oscillation effect cannot be explained in the frame of simple model of the excess free volume relaxation according to logarithmic time dependence.

Experiments on thermal expansion of amorphous glasses revealed also the anomalous behavior of $\Delta L/L$ as a function of temperature. So, for binary SiO_2–TiO_2 glasses, the relative lengthening may change the sign as passing a certain critical temperature, the behavior being dependent on TiO_2 content and thermal pre-history [3]. Local torsion vibration modes are noticed to contribute to the negative thermal expansion (compression). This contribution, however, did not confirmed by experimental data described in other sources. In our opinion, evolution of amorphous alloy from the nonequilibrium state to another metastable one is accompanied by a substantial contribution of spontaneous relaxation mechanisms to the observed anomalous behavior of physical parameters, similar to the case of an ensemble of double-level particles with inverse occupancy of states. These concepts must follow obligatorily in existence of both longitudinal (responsible for lengthening) and transversal (responsible for twisting) components of spontaneous straining arising under linear heating.

To reveal simultaneously both components of spontaneous straining and temperature-dependent evolution thereof under linear heating, the experiment was carried out described in what follows. An equipment for simultaneous measurements of sample twist angle and length under thermal testing in vacuum was used. The equipment comprises a furnace and optical-mechanical sensors of twist angle and linear displacements and provides the data recording using a PC. In the furnace free of temperature gradients, an amorphous alloy strip of $8\times1.5\times0.031$ mm^3 was fixed between quartz holders. The upper holder was fixed and immobile during the whole experiment. To the free-hanging lower holder, a pointer was fixed as well as a light cylinder suspended on a thin thread. The pointer angular displacements provide data on the strip twisting about its long axis while the cylinder vertical displacements correspond to the strip length variations. The sample temperature was controlled by a thermocouple mounted at the strip near its upper holder.

Fig. 1 shows experimental temperature dependences of the twist angle φ (a) and relative lengthening $\Delta L/L$ (b) for a strip of initial length 8 mm obtained under continuous heating at the rate of 20 K/min. For convenience sake, the upper temperature axis and lower time one are used. The non-monotonous character of twist angle spontaneous variation with pronounced singularities in various temperature intervals evidences complex coherent processes in the sample during the annealing. A slight (almost linear) strip elongation at the initial annealing step is changed by its contraction near 600 K followed by the ΔL sign change near 650 K and appearance of singularities of step type up to temperatures answering to completion of crystallization.

In some works [4, 5] aimed at experimental studies of mechanical stress relaxation in amorphous metal alloys, signals were observed to arise spontaneously as response to pulse twisting under isothermal and linear anneals. The known theories do not explain such phenomena in inert materials as well as the amorphous state models do not take those into account. Before, when describing spontaneous relaxation of a double-level particle ensemble from non-equilibrium state [6], an expression $I(t) = AM(t)$ was obtained for emission intensity (where A is a certain constant; $M(t)$ is effective dipole moment for the ensemble). Within that

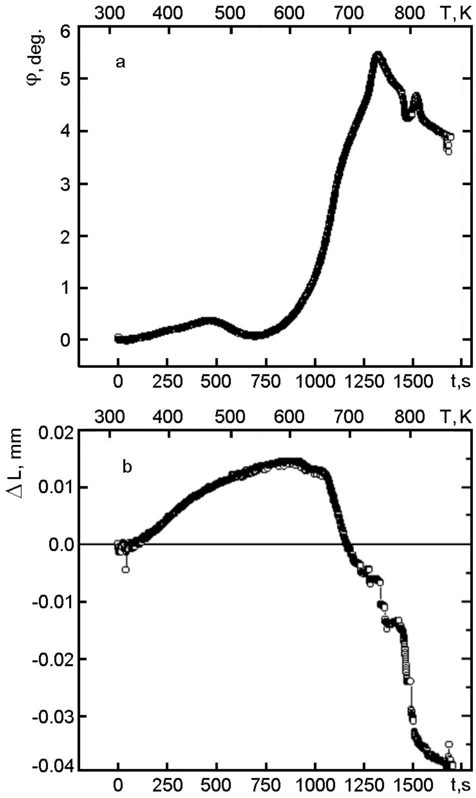

Fig. 1. Spontaneous variations of twist angle φ about the long axis under continuous heating at constant rate of 20 K/min (a); relative lengthening $\Delta L/L$ under continuous heating (b).

model, the particle interaction is taken into account through the emission field, thus resulting in a coherent contribution to the spontaneous relaxation process. We suppose that active structural centers in an amorphous alloy are also capable of interaction during the relaxation through the stress field; this may result in a coherent relaxation character, the main process regularities remaining conserved. To check this supposition, we have described analytically the signals observed.

By analogy with [6], let the time dependence of mechanical moment $M(t)$ be described explicitly as

$$M(t) = a_1 + a_2 \cdot \mathrm{th}[(t - t_0)/\tau] + a_3 \cdot \mathrm{sech}^2[(t - t_0)/\tau]. \quad (1)$$

Parameters a_1, a_2, a_3, t_0, τ depend heavily on the initial condition chosen. A maximum is observed in the experimental $M(t)$ curve at $t = k$. Taking this fact into account, let Eq.(1) be transformed into

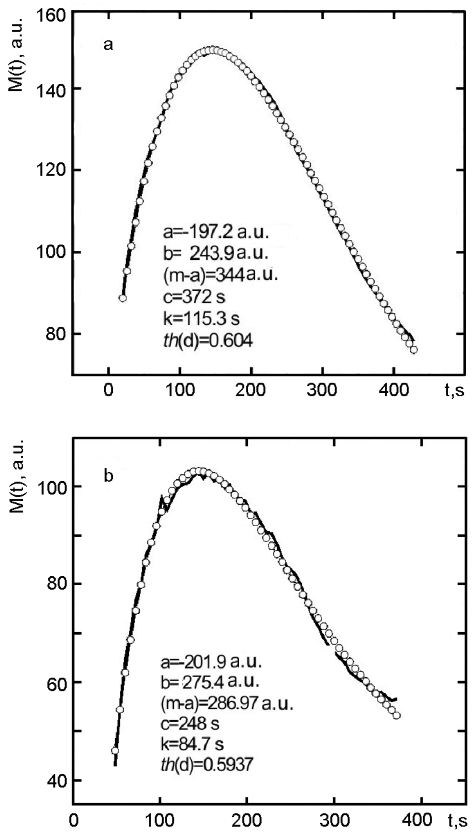

Fig. 2. Experimental (solid line) and calculated (circles) curves for linear heating of $Fe_{80}B_{20}$ (a) and $Fe_{40}Ni_{40}P_{14}B_6$ (b) samples. Inset: numerous values of parameters.

$$M(t) = \qquad (2)$$

$$= \frac{a + b \cdot \mathrm{th}\left(\frac{t-k}{c}\right) + (m-a) \cdot \mathrm{sec}h^2\left(\frac{t-k}{c}\right)}{\left(1 + \mathrm{th}(d) \cdot \mathrm{th}\left(\frac{t-k}{c}\right)\right)^2},$$

where a, b, $(m-a)$, c, k, d are new renormalized parameters.

To study in experiment the relaxation process dynamics in amorphous metal alloys, a sample placed in a vacuum chamber was either heated linearly at the constant rate of 20 K/min or annealed isothermally at a fixed temperature. In the course of anneal, the sample was strained in the pulse manner at a certain time moment. The straining consisted of twisting at the angle of 40°, exposure for a certain time and detwisting. After the straining pulse, the torque was measured continuously.

Fig. 2 presents experimental and calculated curves for $Fe_{80}B_{20}$ and $Fe_{40}Ni_{40}P_{14}B_6$ samples heated linearly. The parameters k

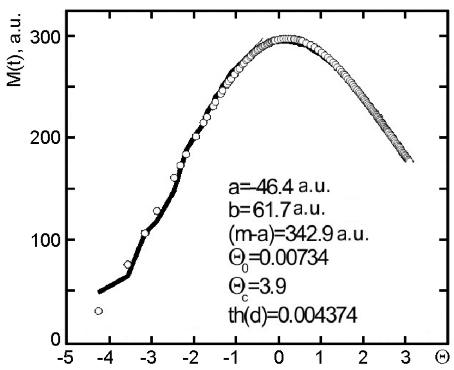

Fig. 3. Experimental (solid line) and calculated (circles) curves for isothermal anneal.

and c characterize the time of process delay and its development time (seconds), respectively; a, b, $(m-a)$ parameters are expressed in conventional $M(t)$ units. Experimental data and modeled response under isothermal annealing are shown in Fig. 3. When simulating, a transition to new logarithmic variable $\theta = \ln[(t-t_0)/\tau]$ is carried out. The parameters t, k, c in (2) are denoted as θ, θ_0, θ_c, respectively.

Thus, a spontaneous twist deformation has been revealed to accompany the length change of a $Fe_{80}B_{20}$ amorphous alloy strip under linear heating. The peculiarities of signals observed evidence qualitative changes in mechanisms of relaxation from non-equilibrium metastable states. The existence of the spontaneous signals forces to consider in a new fashion the nature of non-equilibrium metastable states in amorphous alloys. The satisfactory description of the experimental data evidences that it is possible in principle to draw quantitative data about physical parameters of the states mentioned.

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Деякі особливості механічних властивостей аморфних сплавів металів

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Подано перші експериментальні результати для стрічки аморфного сплаву $Fe_{80}B_{20}$ з виявлення спонтанної деформації, що виявляється як крутіння стрічки та одночасна зміна довжини зразка в процесі лінійного нагрівання. Виконано математичне моделювання когерентних явищ, випробувано їх придатність для опису релаксаційних процесів в аморфних металевих сплавах.