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Mechanical strain and temperature annealing effect on structural relaxation kinetics of the $Fe_{89.8}Ni_{1.5}Si_{5.2}B_3C_{0.5}$ amorphous alloy

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Structural changes of amorphous ribbon $Fe_{89.8}Ni_{1.5}Si_{5.2}B_3C_{0.5}$, causing its isothermal expansion, were investigated by sensitive dilatation method and X-ray analysis. The measurements were carried out concerning ribbon samples thermal expansion, having been exposed to constant strain degrees of σ_1 = 130 MPa, σ_2 = 300 MPa and σ_3 = 475 MPa at temperatures T_1 = 653 K, T_2 = 673 K and T_3 = 693 K. It has been determined that isothermal ribbon expansion is caused by the structural relaxation process. It has been shown that structural relaxation process occurs in two stages. In initial time interval linear logarithmic dependence of isothermal ribbon expansion upon time exists. This leads to a conclusion that activationally-controlled process is carried out in this time interval. The process time decreases with the increase in annealing temperature. The second time interval of structural relaxation process is characterized by linear dependence of isothermal expansion upon the square root of process time. Such time dependence of isothermal expansion shows that this time interval of structural relaxation process is a slow diffuse process. For both stages of structural relaxation process, for the ribbon sample exposed to strain degree of 475 MPa, rate constants were determined $k_1^{'}=6.25\times10^{-3}\,s^{-1}$, $k_1^{''}=9.56\times10^{-3}\,s^{-1}$, $k_1^{'''}=14.59\times10^{-3}\,s^{-1}$, $k_2^{'}=2.82\times10^{-4}\,s^{-1}$, $k_2^{''}=6.11\times10^{-4}\,s^{-1}$, $k_2^{'''}=16.48\times10^{-4}\,s^{-1}$ as well as activation energies E_1 = 79.72 kJ/mol, E_2 = 165.80 kJ/mol. The results of X-ray analysis show that during these processes the ribbon preserves its amorphous structure with reduced defects density and reduced internal strain. The paper shows that dilatation method may be successfully used in analysis of structural relaxation process kinetics, which, on the other hand, is not possible by means of DSC and X-ray analyses.

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1. Introduction

Annealed glassy alloy is far from the equilibrium state. By heating, glassy alloys crystallize upon a certain period. Structural relaxation occurs before the onset of crystallization. It is only then that slight changes in the atomic structure occur, which provides metastable state [1]. These changes are mainly related either to the disappearance (for $T < T_g$) or occurrence (for $T > T_g$) of free volume (T – annealing temperature, T_g – glass transition temperature) [2, 3, 4]. Thermal expansion and viscosity of the glassy alloys are structural relaxation-sensitive [5]. When annealed isothermally, the entire glassy alloy shows practically a linear increase in viscosity with the rise of annealing temperature [6, 7]. Viscosity is expected to attain the constant value when the metal glass reaches the metastable state at determined temperature. Measuring of isothermal thermal expansion is suitable for the obtainment of quantitative data related to the key major parameters of the glassy state: activation energy of relaxation, diffusion activation energy, frequency factor, and the initial defect concentration.

2. Experimental

The amorphous ribbons of $Fe_{89.8}Ni_{1.5}Si_{5.2}B_3C_{0.5}$ alloy have been investigated. The ribbon samples were 20 cm long, 2 mm wide and 3 μm thick. Both nonisothermal and isothermal expansion of the ribbons was measured at the following strain degrees and temperatures respectively: σ_1 = 130 MPa, σ_2 = 300 MPa and σ_3 = 475 MPa, and T_1 = 653 K, T_2 = 673 K and T_3 = 693 K. These parameters were measured by a 10^{-5} m sensibility dilatometer. X-ray diffraction analysis of the as-cast and relaxed samples was performed by the Cu-K_α radiation lines on a Phillips PW1710 device.

3. Results and discussion

In our previous papers [8, 9] we showed that the amorphous alloy $Fe_{89.8}Ni_{1.5}Si_{5.2}B_3C_{0.5}$ crystallize within the temperature range from 799 K to 890 K. Therefore, the process of the structural relaxation was studied at temperatures for 100 – 150 K lower than initial crystallization temperature. XRD patterns of samples of the investigated alloy exposed to the strain degrees σ_1 = 130 MPa and isothermally annealed for 30 minutes at