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Nanocrystal formation in Al- and Ti-based amorphous alloys at deformation

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ABSTRACT

The effect of deformation type on structural changes in Al- and Ti-based amorphous alloys has been studied using the methods of X-ray diffraction, scanning and transmission electron microscopy. The high pressure torsion and multiple rolling methods were chosen for the deformation. It is shown that under deformation by high pressure torsion and multiple rolling methods a large number of shear bands are formed on the sample surface. Although the bands density is roughly equal, the fraction of the nanocrystalline phase forming during deformation in the case of high pressure torsion is greater than that under multiple rolling deformation. The number of shear bands and the fraction of the nanocrystalline phase decrease as the distance from the sample surface increases.

1. Introduction

The development and production of the materials with a broad combination of physical and chemical properties are one of the most important tasks of modern science. In a number of alloys with a composite amorphous-nanocrystalline structure high strength at good plasticity was observed at early stages of investigations [1,2]. Partially crystalline alloys seem to be very promising to produce the materials with outstanding mechanical properties at room temperature [1–6]. Amorphous-nanocrystalline structures are usually obtained by the method of controlled crystallization of amorphous alloys under thermal treatment or deformation. There are a great number of studies devoted to the changes of an amorphous phase structure occurring under such exposures and the peculiarities of a structure forming under crystallization [7–11]. The parameters of the structure formed under thermal exposures are studied on the alloys of different chemical composition [10–14]; over the past years structural changes under deformation treatments have been investigated to a greater extent [15–17].

The formation of nanocrystals under severe plastic deformation (high pressure torsion or multiple rolling) is related to the formation of deformation bands (shear bands) which are the places of plastic deformation localization. The formation of nanocrystals occurs both in shear bands and their vicinities that is caused by an increased value of diffusion coefficient in these regions. It is believed that diffusion acceleration is related to a local significant rise of temperature in the region of deformation localization [18–22], and also to a decrease of material density (or an increase of free volume fracture) in the shear band [23–26]. It has been also determined that the change of an amorphous phase structure under deformation occurs not only in the shear band but also in a relatively wide region around it [27,28]. Thus, for example, microhardness of the deformed amorphous alloy changes at a noticeable distance from the deformation band, at that the deformation band is a certain central zone surrounded by a softer region of the material [29].

It is obvious that the deformation bands (or the shear bands) play an important role in the processes of nanocrystals formation. However, it should be noted that the formation of nanocrystals is not a compulsory consequence of the formation of shear bands. In a number of cases no nanocrystal is observed near the shear bands, at the same time the formation of pores in the shear bands occurs that is obviously caused by the coagulation of excessive free volume which appeared as a result of deformation. It is also obvious that deformation leads to a non-uniform change of the amorphous alloy structure. In the case of deformation by high pressure torsion the extent of deformation changes in radius of the deformed sample increasing from its centre to the periphery. At the usage of

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deformation by cold rolling near-surface regions are deformed more than those central in sample thickness. Both of these methods (high pressure torsion and multiply rolling) relate to severe plastic deformation and can lead to nanocrystallization [30]. Present work is devoted to the investigation of the structural change and nanocrystals formation in amorphous alloys under different methods of deformation and their change as the distance from the sample surface increases.

2. Experimental

Amorphous alloys of nominal composition $Al_{87}Ni_8La_5$, $Al_{87}Ni_8Gd_5$, $Al_{87}Ni_8Y_5$ and $Ti_{50}Ni_{25}Cu_{25}$ were obtained by rapid melt quenching as 50-80 μm-thick ribbons. The samples were subjected to isothermal annealing at different temperatures as well as to plastic deformation. Deformation was performed by high pressure torsion (HPT) and multiple rolling at room temperature (CR). Cold rolling of the samples was performed in a VEB Schwermaschinenbau four-roll mill by the multiple rolling technique; the run number being 50–150. The deformation value was calculated by the formula $\varepsilon = \Delta h/h_0$ where h_0 and Δh are the original thickness and its deformation-induced change, respectively. Deformation by HPT was performed by the standard methodology [30]. Pressure value was 5 GPa, the deformation was performed at 0.1–5 turns. The structure of the samples was controlled after each stage of the deformation.

The structure of the samples was studied by the methods of X-ray diffraction and by transmission and scanning electron microscopy. Co K_α radiation was used for X-ray diffraction experiments. At the early crystallization stages, the samples contained amorphous and nanocrystalline phases; therefore, separation of the overlapped peaks was made. The size of forming nanocrystals was determined both from dark-field electron microscope images and from the data of X-ray diffraction.

3. Results and discussion

On quenching all the prepared samples were amorphous. Deformation of the samples by both methods leads to the formation of numerous shear bands. Fig. 1 shows the surface of $Al_{87}Ni_8Y_5$ amorphous alloy deformed by high pressure torsion (Fig. 1a) and multiply cold rolling (Fig. 1b). The distance between the shear bands is some hundreds nanometers. It is seen that in the case of HTP the bands are bent that is related to the method of deformation. It is important that in both cases (under both high pressure torsion and multiply rolling) numerous shear bands are observed on the sample surface.

Figs. 2 and 3 demonstrate the X-ray diffraction pattern of $Al_{87}Ni_8Gd_5$ and $Al_{87}Ni_8La_5$ alloy sample after deformation by HTP. In addition to the diffuse halo from the amorphous phase there are diffraction reflections caused by the formation of aluminum nanocrystals. As the deformation extent increased, the fraction of a nanocrystalline phase increases in both alloys, and the average nanocrystal size does not change. In the process of deformation, new nanocrystals are forming and already formed nanocrystals do not grow. The fraction of nanocrystalline phase in $Al_{87}Ni_8La_5$ alloy is remarkable less than in $Al_{87}Ni_8Gd_5$ alloy. The average nanocrystal size 6 nm in of $Al_{87}Ni_8Gd_5$ alloy and 12 nm in $Al_{87}Ni_8La_5$ alloy. The formation of nanocrystals was observed mainly inside the shear bands. As mentioned earlier, the presence of shear bands in itself does not lead automatically to the formation of nanocrystals; apparently, repeated deformation leading to the intersection of shear bands and the formation of considerable regions with an amorphous structure of lower density is necessary for this.

Numerous shear bands which were observed on the surface of

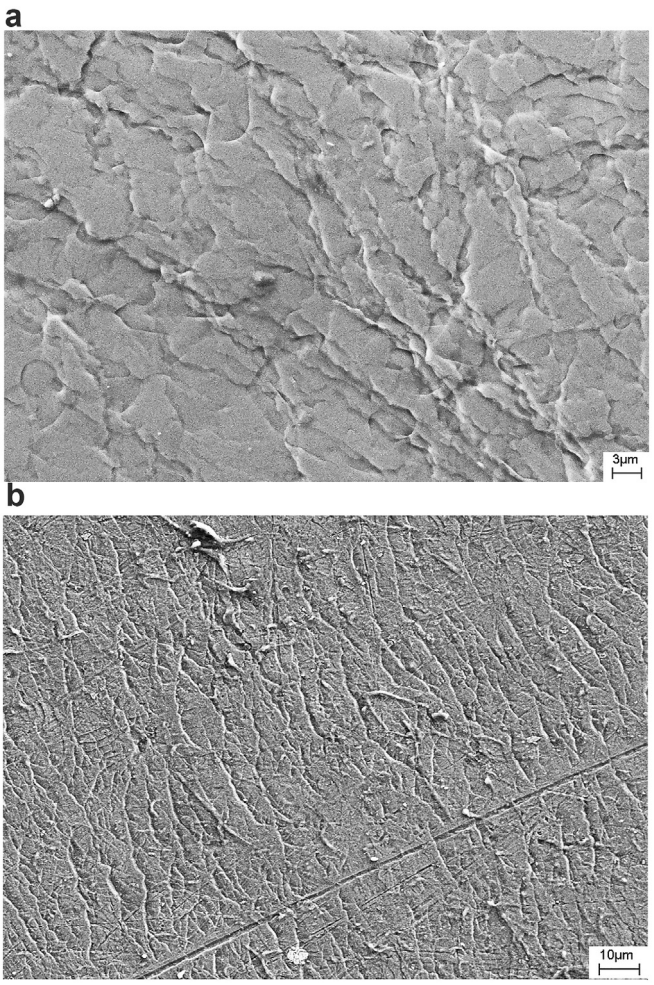

Fig. 1. The surface of $Al_{87}Ni_8Y_5$ amorphous alloy deformed by high pressure torsion (a) and cold rolling (b).

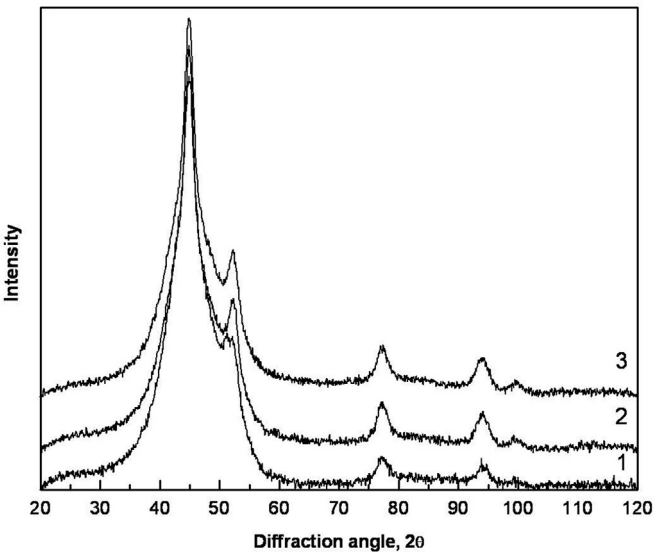

Fig. 2. The XRD pattern of $Al_{87}Ni_8Gd_5$ alloy after deformation by HTP for 1 (1), 3 (2) and 5 (3) turns.