

FORMATION OF NON-EQUILIBRIUM STRUCTURES IN METALL ALLOYS UNDER HIGH INTENSITY ELECTRON BEAMS AND METROLOGY OF THESE BEAMS WITH A HELP OF MEMORY ALLOY TARGETS

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1. Introduction

The modern surface treatment technology of materials with a help of concentrated energy streams bases on the modification of surface properties by the structural state change under high intensity photon, ion or electron beams¹.

Perspectives of this technology are obviously connected with a formation of non-equilibrium structures in the surface sheet during the impulse treatment – the shorter impulse length, the more non-equilibrium states of a system and the brighter the property spectrum, correspondingly².

The nanosecond impulse interval is the boundary case because it is near the characteristic time for the reaching of the total electron-phonon equilibrium. In the non-equilibrium state the electron subsystem temperature is above the phonon subsystem one, and the temperature of the whole system as a thermodynamics parameter has no sense. The structural changes are possible due to non-equilibrium energy exchange between "hot" electrons and "cold" phonons without of considerable heating of the target material.

Experimental research of the super-short impulse action on the material surface is very difficult and it is impossible to observe the structural change in-situ during the radiation. It will be usually investigated the post-state of a target after the impulse switching out. Therefor, it is important that the target material be able to store the maximum of the information about processes during the radiation and to preserve (to memorize) this after the impulse switching off. Shape memory alloys are more perspective for this aim since they have a high structural sensitivity to different actions (temperature, stress, etc.) and short response time to them.

It was the aim of this paper to investigate the formation of non-equilibrium structures in different metal alloys and to propose on this base an measuring method that connects the measured structural change with the impulse beam parameters.

2. Experimental

As a target materials were taken the eutectic alloy $Ni_{60}Nb_{40}$, the one phase homogenous alloy $Fe-13wt\%Mn^3$ and inter-metallic equiatomic compound $NiTi$ after the standard heat treatment with memory properties⁴. The target shape is a disc with a diameter about 20 mm and the thickness $X=2$ mm.

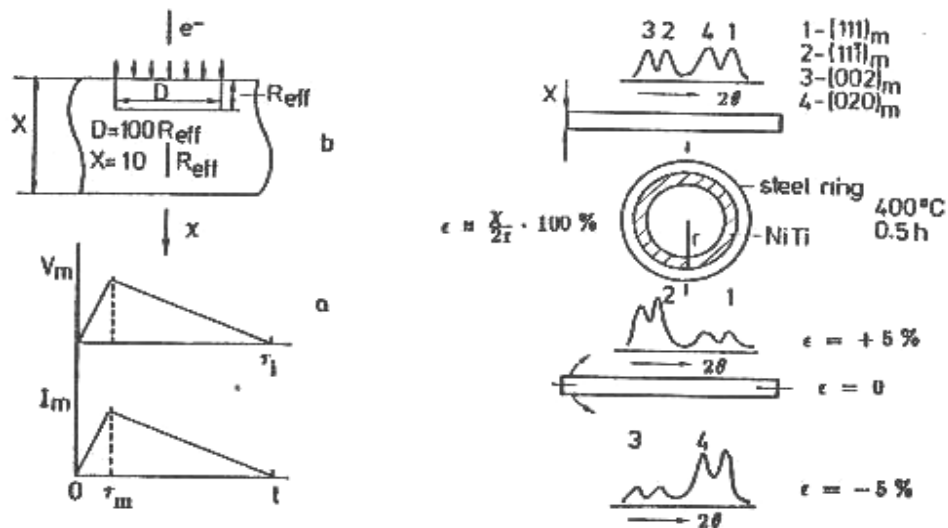


Fig 1. Left - irradiation scheme (a) and oscillograms of the electron beam (b); rights - deformation scheme (a) and diffractogram fragments for initial and deformed $NiTi$ - specimens

Electron mono-impulses with the length $\tau_i = 50 \cdot 10^{-9} s$, the maximum current density (Fig. 1a) $j_m = 10^3 A \cdot cm^2$ and the initial energy $E_0 = 250 keV$ have been used for the treatment of the target surface. The irradiation scheme is shown in Figure 1b, where D is the beam diameter. The boundary condition is reached for $D > X \gg R_{eff}$, where R_{eff} is the projection track of the beam electrons in the target. The structure of irradiated and deformed ($NiTi$ - Fig. 1, rights) is investigated with a help of a X-ray diffractometer.

3. Discussion

The initial equilibrium $Ni_{60}Nb_{40}$ -specimen consists in eutectic mix of two phase: rhombic one Ni_3Nb and hexagonal one $NiNb$ (Fig. 2a). After the electron irradiation with the energy 50 keV no visible structure change takes place. Irradiation with electron energy 70 keV lays to structural transformation. In the angle interval $35^\circ < 2\Theta < 53^\circ$ (Fig. 2b) is observed a bright diffuse maximum that is typical for an amorphous phase with a large concentration of structural defects.

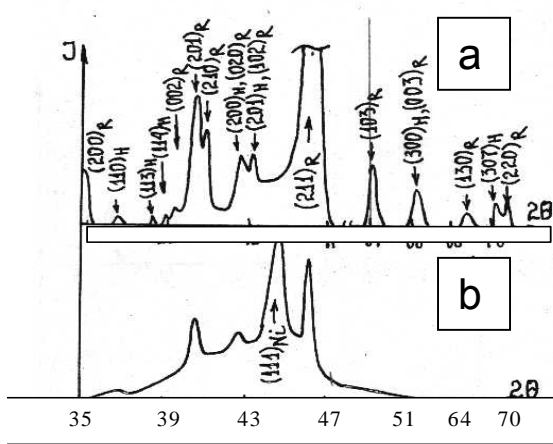


Fig. 2 Diffractogram fragments of the initial (a) and the irradiated (b) alloy $Ni_{60}Nb_{40}$

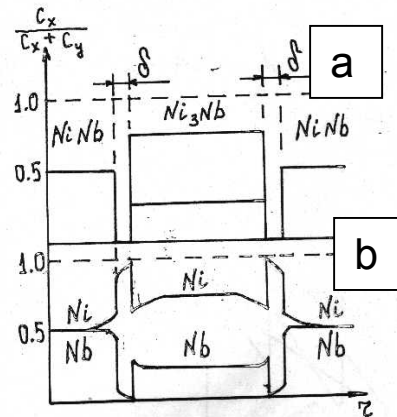


Fig. 3. Concentration profiles of Ni and Nb before (a) and after (b) the irradiation

But selective maximums of the initial crystalline phases remain too. The larger maximum corresponds to the reflex $d_{(111)} = 2.04 \overset{o}{\text{Å}}$ of the *fcc*-lattice of

pure Ni . Moreover there are new reflex in comparison with the initial state that correspond to unknown phases of $Ni - Nb$ -system.

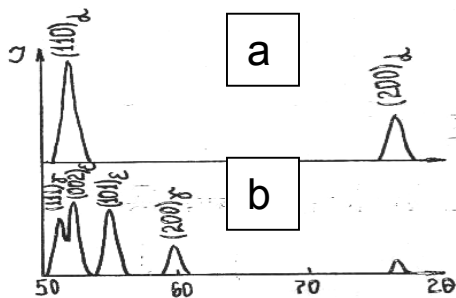


Fig. 4 Diffractogram fragments of the initial (a) and the irradiated (b) alloy $Fe - 13wt\% Mn$

Obviously, the formation of the pure Ni -phase is connected with the dynamic diffusion of Ni in the concentration gradient in non-equilibrium state under the radiation, as shown the

Fig. 3. The ordinate here is the relative component concentration and the abscise is the distance, δ is the thickness of grain boundary between eutectic phase. The Ni – component moves in the concentration gradient from Ni_3Nb to $NiNb$ through grain boundaries and locates in the boundaries areal.

Due to remaining vacancies on the Ni – and Nb – places of lattice become the ground phase amorphous. The electron irradiation of the alloy $Fe - 13wt\% Mn$ appears as quenching of the same alloy (Fig. 4). The initial specimen consist in the α -phase and the irradiated one in γ -austenite that forms from the α -phase at the thermal quenching and ε -martensite formed from γ -austenite.

The both examples show that during the irradiation can take place dynamic diffusion or a shear (martensitic type) transformation between phases in the non-equilibrium state or the formation of new non-equilibrium phase.

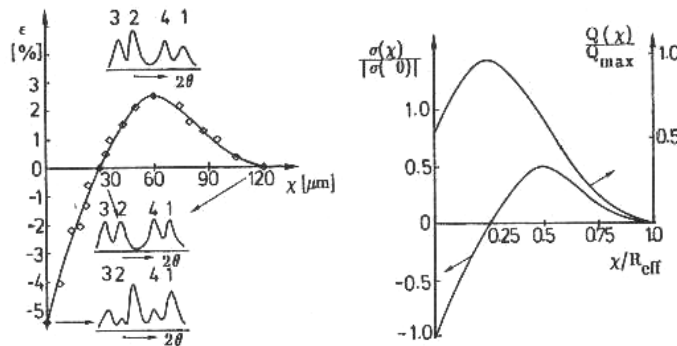


Fig. 5 Distributions of the martensitic strain with correspondingly X-ray diffractogram (lefts), the dynamic stresses and electron energy losses (rights) on the depth X in irradiated $NiTi$ – sample

Irradiated $NiTi$ -sample allows to measure the tensile-compression wave in the thin surface sheet with the length about $120 \mu m$ (Fig. 5). The measure method was developed as follows⁵.

The diffractogram of initial annealed sample in martensitic state shows reflexes with equal intensity (Fig. 1).

The ratio of the martensite reflex intensities $K_{12} = I_{111} / I_{11\bar{1}}$ deviates from 1 at the deformation, as shown the mechanical tests on the scheme in Fig. 1 rights. This ratio can be used for calculation of the martensitic deformation:

$$\varepsilon = \varepsilon_{\max} (1 - K_{12}) / (1 + K_{12}) \delta_{12} \quad (1)$$

where δ_{12} is a rearrangement symbol. With the help of eq. 1 was calculated the distribution of the martensitic deformation on the depth in the irradiated specimen by step-to-step etching (Fig. 5). It can be seen that in the depth from 0 to 30 μm acted at the irradiation tensile dynamical stress and from 30 up to 120 μm the compression one. The depth 120 μm corresponds to the projection track

$$R_{eff} \cong E_0^2 / \rho b, \quad (2)$$

where b is an empirical parameter connected with the atom number, ρ is density and E_0 is the initial electron energy.

It means that the structural change takes only place in the zone of immediate energy losses of the beam electrons, whose distribution Q_X is shown in Fig. 5 rights. It can be seen, too, that the stress distribution is the differential result of the energy losses distribution:

$$\sigma(X) = -grad_x [A \cdot Q(X)], \quad (3)$$

where A is a parameter whose determination allows the qualitatively correspondence between the stress distribution on the memory-target and energy losses as soon as electron beam parameters.

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