

THERMODYNAMICS OF PLASTIC DEFORMATION OF NANOCRYSTALLINE TITANIUM

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1. Introduction

Recent discoveries of unique properties of bulk nanostructural materials (BNM) (unusual mechanisms of deformation, anomalies of conductivity, magnetic and optical properties) have given an impact to new scientific direction related to nanotechnology. At present time, two general approaches to the development of BNM are considered. The first approach, the so-called «bottom-up approach», involves compaction of the nano-size powders (ultra disperse powders can be obtained by gas condensation in the inertial atmosphere or by plasma-chemical method, aerosol and chemical synthesis, and also by grinding of powders in a spherical mill, etc.). The second method is the intensive plastic deformation leading to the grain refining that provides a unique mechanical behavior of bulk nanostructural materials. Physical properties of BNM are defined by the length and intensity of the grain boundaries, which for the grain sizes of about 10-100 nm contain 10-50% of atoms of the material. Hence, the transition to bulk nanocrystalline state is characterized by pronounced scaling effects the increasingly growing role of grain boundary defects is the crucial for the explanation of unique properties of BNM.

An effective method for studying material properties under transition to nanocrystalline state is the analysis of energy absorption mechanisms, which by analogy with phase transitions can lead to qualitative changes in materials with fine-grain structure related to the specific interaction between the grain boundary defects. This work is concerned with investigation of the energy absorption process in coarse grain and fine grain titanium under plastic loading. It has been found that BNM exhibit energy dissipation anomaly, which can be treated as a result of specific structural evolution in this material.

2. Material and experimental conditions

The samples of titanium Grade 2 in submicrocrystalline state were manufactured by the method of intensive plastic deformation [1] and had the grain size of about 150 nanometers. The mechanical properties of titanium Grade 2 in polycrystalline and submicrocrystalline state are presented in Table 1. The quasistatic tension was carried out using Zwick 100 testing machine. The temperature field was recorded with the infra-red camera CEDIP Jade III. Sensitivity of the camera is higher than 25 mK at 300°K, a spectral range is 3-5 microns, and the maximal size of the frame is 320x240 points.

Type of treatment	tensile strength, σ_B , (MPa)	yield stress, $\sigma_{0.2}$, (MPa)	ultimate elongation, (δ ,%)
Initial coarse grain state (grain size 25 μm)	440	370	38
IPD + hot rolling (grain size 0.3 μm)	1090 \pm 20	980 \pm 20	13 \pm 1

3. Experimental results

Figure 2 presents the results of experiments. The nanotitanium shows high increasing of mechanical properties. The yield stress increases in 2.6 times. The deformation process of nanotitanium is characterized by long softening and long elastic part. The initial stage of nanotitanium deformation is accompanied by pronounced thermo-elastic effect. This fact proves that the deformation is “pure” elastic and material defects don’t initiate and move. The second part of temperature-time curve is more sharp. This fact allows us to conclude that defect evolution under plastic deformation of nanotitanium is more intensive than in coarse grain titanium. But, relative energy storage rate in nanotitanium is higher than in coarse grain specimen. The deformation localization in nanotitanium is more pronounced than in coarse grain one. A fracture of nanotitanium has brittle character and emergence at 15 percent of elongation. The final elongation of coarse grain titanium was 25 percent.

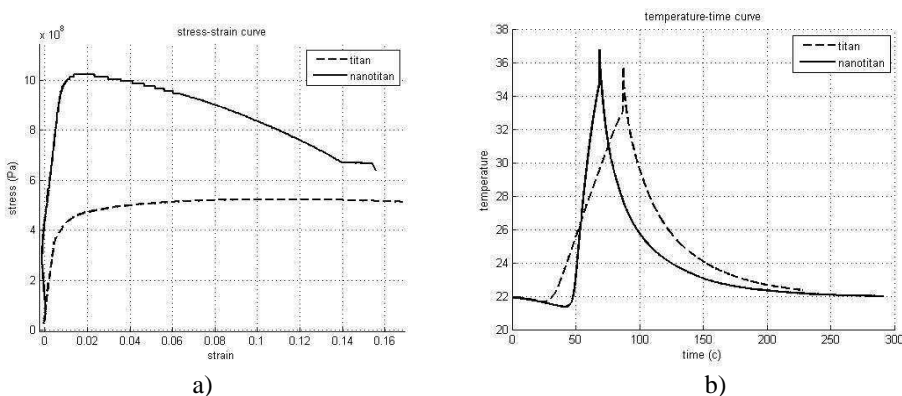


Fig. 1. The stress-strain curve (a) for coarse grain and nanotitanium. Temperature evolution (b) during the experiments for coarse grain and nanotitanium

The peculiarities of defect evolution can be investigated by calculation of energy balance in materials under deformation process. The procedure of energy balance estimation was presented in [2]. The specimen necking and strain rate fluctuation don’t allow us to exactly calculate the energy expended for specimen deformation. The curve can be analyzed on hardening part only. The conclusion can be formulated as follow. The nanotitanium stores more energy than coarse grain one. The evolutions of energy storage in both titanium are similar.

5. Acknowledgement

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6. References

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