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# INFLUENCE OF STRUCTURE REFINEMENT ON ELECTROPLASTIC EFFECT IN SHAPE MEMORY TiNi ALLOYS

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**Abstract.** The influence of structure-phase features and electric current modes on the electroplastic effect (EPE) revealed at tension for coarse-grained, nanocrystalline and amorphous TiNi-based alloys is investigated. Grain-size refinement up to nanoscale and amorphization in alloys lead to decreases or even full disappearance of EPE. In nanocrystalline alloys with reverse thermoelastic martensite transformation, the introduction of current pulses suppresses downwards stress jumps induced by the EPE and causes active upwards stress jumps connected with the shape memory effect (SME).

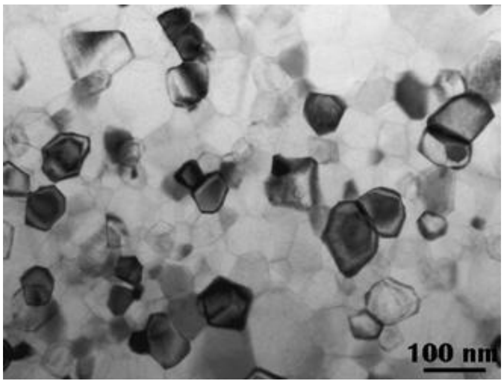
## 1. Introduction

It is well-known that the joint action of plastic deformation and an electric current of the large density ($10^3$A/мм$^2$) lead to a decrease in the applied stresses, named by electroplastic effect (EPE) [1]. It is displayed in stress jumping on a stress-strain tension curve when a single current pulse is introduced to a sample without an essential thermal effect and sample dilatation. It is supposed that the primary mechanism of EPE is electron-dislocation interaction resulting in stress relaxation in areas of dislocations pile-up in a crystal [2]. The phenomenology of EPE has been sufficiently fully investigated in monocrystals and coarse-grained (CG) single-phase metals [3]. It is shown that EPE exists only during plastic deformation of a material, and its value in relation to a flow stress varies from a few percent for polycrystals up to ten percent for monocrystals [1]. However EPE is poorly studied in modern materials, for example, multiphase materials, shape memory effect (SME) alloys, and nanocrystalline (NC) alloys [4], and for amorphous alloys these data are absent in general. Research on the influence on EPE on structural factors such as the grain size and phase state represents a special interest. In this work, an attempt is made to fill this gap. The experimental data received under tension in conditions of the introduction of a pulse current in shape memory alloys with CG, NC, and amorphous structures are demonstrated.

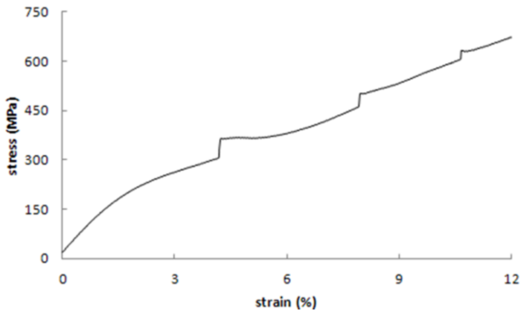
## 2. Materials and processing

The investigated materials were shape memory $Ti_{50}Ni_{50}$ and $Ti_{49.3}Ni_{50.7}$ alloys with CG (up to 50 µm), and NC (less than 100 nm) structures. The samples were in the strip form with section of 2x6 mm. CG states in alloys have been received by thermal treatment (annealing or quenching). NC states were processed by deformation method - a cold rolling with a current [5]. Besides, there were also investigated amorphous $Ti_{50}Ni_{25}Cu_{25}$ alloy in ribbon form with the section of 0.040 x 1.8 mm and length of 70 mm processed by the single-roller melt-spinning technique under argon atmosphere [6]. Afterwards, the ribbons were subjected to a heat treatment at 450 °C for 10 min to promote full crystallization and formation ultrafine-

Therefore, the amplitude of stress jumps upwards rises with increases in the current density but remains constant for stress jumps downwards. Another feature of this alloy is the presence of the area (designated in figures) on a tension curve in which neither kind of stress jump occurs, despite the introduction of the single pulse current in this place.



a

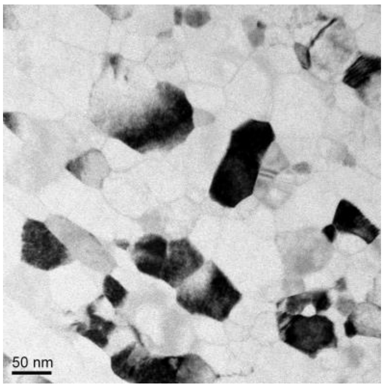



b

**Fig. 3.** Microstructure (a) and stress-strain curve with current density of 1500 A/mm$^2$, (b) in NC $Ti_{49.3}Ni_{50.7}$.

In the NC $Ti_{49.3}Ni_{50.7}$ alloy with grain size less than 100 nm (Fig. 3a), upwards stress jumps occur with decreasing amplitude with strain instead of stress jumps downward, which completely disappear (Fig. 3b).

Deformation behavior of the stoichiometric $Ti_{50}Ni_{50}$ alloy differs from the alloy mentioned above. Microstructure of $Ti_{50}Ni_{50}$ alloy in NC state with mean grain size of 50 nm processed by electroplastic rolling and the following annealing is presented in Fig. 4a. Stress-strain curves with current for the alloy in CG and NC states are shown in Figs. 4 b,c.

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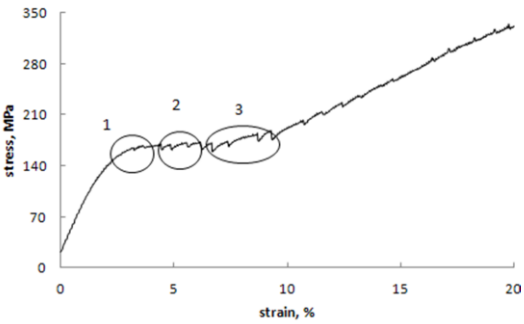


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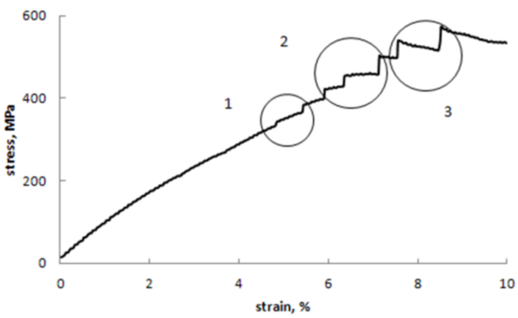


c

**Fig. 4.** Microstructure (a) and stress-strain curves with current (b, c) in $Ti_{50}Ni_{50}$:
b – CG state; c – NC state; 1- j = 500A/mm$^2$, 2 - j = 1000A/mm$^2$, 3 - j = 1500A/mm$^2$.

Change of chemical and, respectively, phase composition in CG TiNi alloys leads to change in sequence of stress jumps up and down. In the initially martensitic $Ti_{50}Ni_{50}$ alloy the appearing jumps down with deformation are transformed to jumps up (Fig. 4b), and in the initially austenitic alloy $Ti_{49.3}Ni_{50.7}$ this sequence changes on the contrary (Fig. 2a). Temperature dependence of flow stresses and a quantitative ratio of austenitic (A) and martensitic (M) phases in an initial alloy are the main reasons for such different deformation behavior under the influence of single impulses. In fact, a quantitative ratio is expressed as A>> M and M>> A in $Ti_{49.3}Ni_{50.7}$ and $Ti_{50}Ni_{50}$, respectively. Regarding flow stress it increases with temperature for M-phase and decreases for A-phase [10]. Nevertheless, this assumption needs additional structural research in future. It was shown above that EPE is suppressed in NC state, that is why the type of stress-strain curves and character of stress jumps for both alloys is identical (Fig. 3b and Fig. 4c).

In melt-spun amorphous $Ti_{50}Ni_{25}Cu_{25}$ alloy, EPE is absent (Fig. 5a), but it appears in the crystal state processed by annealing (Fig. 5b). This fact is in agreement with the reduction and disappearance of EPE in nanocrystalline structures. Really, it is not observed because of the absence of free dislocations in range-ordering areas in amorphous materials. On the contrary, crystallization of alloys promotes the occurrence of dislocations and the display of EPE.

The modes and kind of current also have an influence on the EPE. As the current density and pulse duration increase, the pulse energy of these parameters raises the amplitude of stress jumps. For the same reason, the change from single pulses to a multipulse current leads to the same effect.

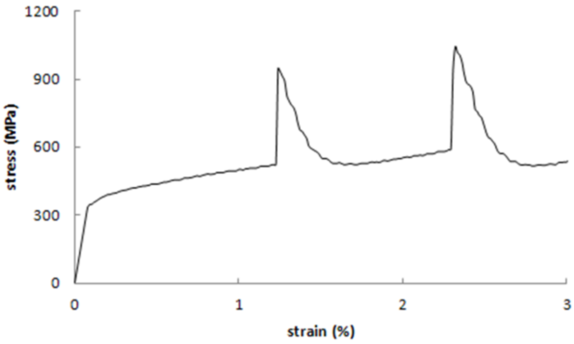


**Fig. 6.** Stress-strain curve with multipulse current in NC $Ti_{49.3}Ni_{50.7}$ alloy [11].

For example, earlier it was shown for $Ti_{49.3}Ni_{50.7}$ alloy that the Joule effect in the case of application of a multipulse current with duration up to 1 ms can lead to more significant stress jumps up to 500 MPa (Fig. 6) than in the case of the application of single pulses [11].

## 5. Conclusions

The influence of an initial structure-phase state and the current mode on deformation behavior under tension in shape memory TiNi alloys was investigated. The pulse current leads to the occurrence on the stress–strain curves of stress jumps conditioned by the electroplastic effect and the austenite-to-martensite transformation. It was shown that the amplitude and direction of stress jumps depend on structure refinement, ratio of austenite / martensite phases in the initial or deformed alloy, and modes of pulse current.

***Acknowledgements***

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## References

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