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doi:10.4028/www.scientific.net/AMR.1085.299

Revised: 21.08.2014
Accepted: 17.10.2014

Features of Stress Changes in the Alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ under Loading in a Wide Temperature Range

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Keywords: shape memory effect alloys, titanium nickelide, martensitic transformations, mechanical properties.

Annotation. The results of the study on properties of shape memory effect alloys, obtained on the basis of the experimentally determined temperature dependency of the shear martensitic stress in the alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$, are described. It has been established that the total strain of the sample and the yield point reach a maximum value (ε = 25.5 %, σ_B = 1280 MPa) at a test temperature of 300 K. It has been methodically shown how using this experiment in NiTi-based alloys it is possible to estimate temperature ranges of shape memory effect occurrence and to determine parameters of mechanical properties.

Introduction

Manufacture of new materials and development of technologies for their production has always been one of the most essential and important scientific and applied problems of physical materials science. In medicine, an important role is played by alloys based on titanium nickelide with a shape memory effect (SME) [1]. Structural-and-phase states of titanium nickelide based alloys are very dependent on the chemical composition, thermal and thermomechanical treatment. Doping of titanium nickelide and its alloys with vanadium is perspective for regulation of physical-and-mechanical properties [1,2]. It is known that doping with vanadium leads to grain refinement, appropriation of viscosity, reduction in brittleness, and increase in the alloy strength [3].

There are virtually no papers dedicated to the study of the influence of vanadium doping on physical-and-mechanical properties of multicomponent TiNi-based alloys [2]. The aim of the paper is to study mechanical properties of an industrial alloy TH-10 based on titanium nickelide doped with vanadium.

Materials and research methods

An alloy of the composition $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ was melted for the research in the Scientific Research Institute of Medical materials and shape memory implants. Samples were subjected to isothermal annealing in an electric-vacuum furnace with a vacuum of 10^{-4} mm of mercury under temperatures of 720, 920 and 1120 K during 1 hour with a subsequent slow cooling in the furnace up to a room temperature.

Temperature dependencies of the electrical resistance were measured on an original installation on wire samples by the four-point method [1].

Temperature dependencies of critical martensitic shear stresses $\sigma = f(T)$ were obtained using the technique developed in [1]. The studies on the inelastic behavior and the plasticity were carried out using the mechanical testing technique by the method of uniaxial tension on an original installation of the “Instron” type.

At the first stage of the experiment the tested sample was fixed at one end in a non-movable clamp of the testing machine. The second end of the sample was fixed in a movable clamp, which was joined to a measuring system and a loading device. The second stage included cooling of the sample up to a temperature lower than the temperature of the onset of the thermoelastic martensitic transformation (MT). The third stage included tensile strain of the sample up to the value of 6% with a subsequent fixation of the movable clamp. The fourth stage included an increase in the sample temperature within the investigated temperature range in a “predeformed” state. At the same time, the temperature and the developed stresses of the alloy had to be measured. The obtained values determine the value of the martensitic shear stress.

An error in the measurement of stresses and the temperature under the dependency of critical stresses of the martensitic shear is nearly 5%. As a result of the carried out tensile tests under a constant loading, strain dependencies in coordinates σ from ε were obtained.

Features of changes in the stress of TiNi-based alloys under loading in a wide temperature range

The obtained dependencies σ(T) provide important information on thermomechanical properties of shape memory alloys. One of the main mechanical characteristics is a yield point of the material at which elastic stresses, arising during strain or in thermal-cycling conditions, relax by means of plastic shear. At temperatures below the onset of martensitic transformation (MT) the yield point of alloys with a shape memory effect, in its physical meaning, is the martensitic shear stress, i.e. the stress required for formation and reorientation of plates of the martensitic phase B19'. The actual resistance to plastic shear is determined by an extrapolation curve from high temperatures to low temperatures (Fig. 1). The minimum on the curve σ (T) corresponds to the existence domain of the temperature M_S. Here, the M_S is the temperature of the onset of the MT without loading. The maximum of this curve corresponds to the temperature M_d, at which the curve that characterizes the actual resistance to plastic deformation and the curve of the temperature dependency of the martensitic shear stress coincide, and above which formation of martensitic strain is no longer possible. Here, M_d is the maximum temperature at which martensitic transformation is still possible under external loading, and only plastic shear is higher. The maximum and the minimum stresses σ_{max} and σ_{min} are determined by stresses in corresponding points and M_d and M_S. The difference between the values of the yield point and critical stresses of martensitic shear $\sigma_{max} - \sigma_{min}$ characterize the susceptibility of the material to plastic strain and, as a consequence, features of the shape return at memory effects. The higher the yield point and the lower the martensitic shear stress, the lower the probability of relaxation of elastic stresses accumulated during martensitic transformation by means of plastic shear [1].

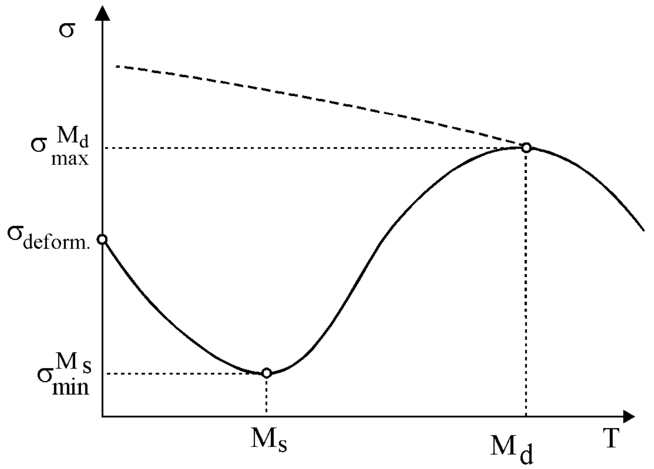

Fig. 1. Schematic representation of developing forces at heating of alloys with a thermomechanical memory. The dashed line shows the extrapolated yield point in the austenite phase B2 in the MT field [1]

Results of the experiment

For determination of the intervals of martensitic transformations in the alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ the temperature curves of electrical resistance were obtained. These curves reflect changes in the structural-and-phase state of the alloy (Fig. 2).

Features of changes in electrical resistance curves at cooling and heating have a characteristic appearance for TiNi alloys with a two-stage character of the MT *B2↔R↔B19'* [1]. It appears that isothermal annealing at different temperatures (720, 920 and 1120 K) of the alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ lead to a noticeable change in the shape of temperature dependencies of the electrical resistance ρ(T) and to an insignificant change in characteristic temperatures of the MT (Fig. 2). The analysis of temperature dependencies of electrical resistance curves ρ(T) indicates that the area of the direct MT *B2→R→B19'* falls into a range from 330 up to 290 K. The findings allowed selecting the temperature range to obtain the dependency $\sigma = f(T)$ in the alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ and the temperature to obtain strain diagrams $\sigma = f(\varepsilon)$ (Fig. 3, *insert a - j*).

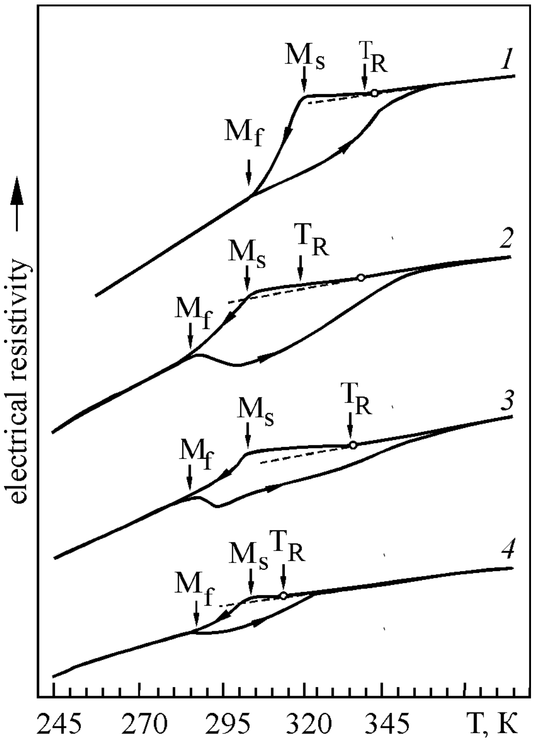

Fig. 2. The temperature dependency of the electrical-resistivity of the alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ without annealing and after isothermal annealing during 1 hour at different temperatures: 1 – without thermal treatment; 2 – annealing 720 K; 3 – annealing 920 K; 4 – annealing 1120 K

The analysis of the diagrams $\sigma=f(\varepsilon)$ revealed that they have typical dependencies for alloys with a MT under the influence of the applied loading. In the investigated alloys the austenitic *B2*-phase under external tensile stresses experiences thermoelastic MTs *B2→R→B19'*, which occur differently depending on the location of the temperature with respect to the MT without the applied loading.

The diagrams "σ–ε", obtained in the range of temperatures of the onset of the MT M_S (260 – 350 K) (Fig. 3, inserts *a – d*), clearly reveal a feature that has an appearance of a "plateau" on strain curves. The section AB (Fig. 3) of the strain curve characterizes the strain MT. At higher test temperatures, a disappearance of the flat segment AB takes place, which is caused by plastic strain processes of martensitic phase domains.

When the test temperature approaches the temperature range of the temperature M_d (Fig. 3, *k*) the arising stresses are close to the value of the yield point. At these temperatures (≈ 600 K) during the strain process under loading, a stress relaxation takes place, not due to occurrence of the martensitic phase, but, mainly, due to plastic strain. Moreover, with an increase in the external loading, plastic strain processes become predominant and in a greater degree influence the origination and the growth of the martensitic phase [1]. The total strain of the sample and the yield point reach a maximum value (ε = 25.5 %, σ_B = 1280 MPa) at a test temperature of 300 K (Fig. 3, insert *b*). It is important that the shape of strain curves depends on test temperatures.

Conclusion

In the paper it has been shown that the experiment on determination of the dependency $\sigma = f(T)$ based on the proposed technique allows to determine temperature ranges of the occurrence of the SME and temperatures M_S and M_d in alloys with thermoelastic MTs. On the tested alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ it has been found that the temperature M_S of the thermoelastic MT under loading is 380 K, the temperature M_d=600 K. On the basis of the analysis of the dependency $\sigma = f(T)$, the following has been determined: $\sigma_{\min}^{Ms}$=330 MPa, $\sigma_{\max}^{Md}$=660 MPa. The temperature of SME has been obtained: 350-420 K. The calculation gave the value of 300 MPa. These data suggests that the alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ has high plastic properties and possesses a well-defined SME.

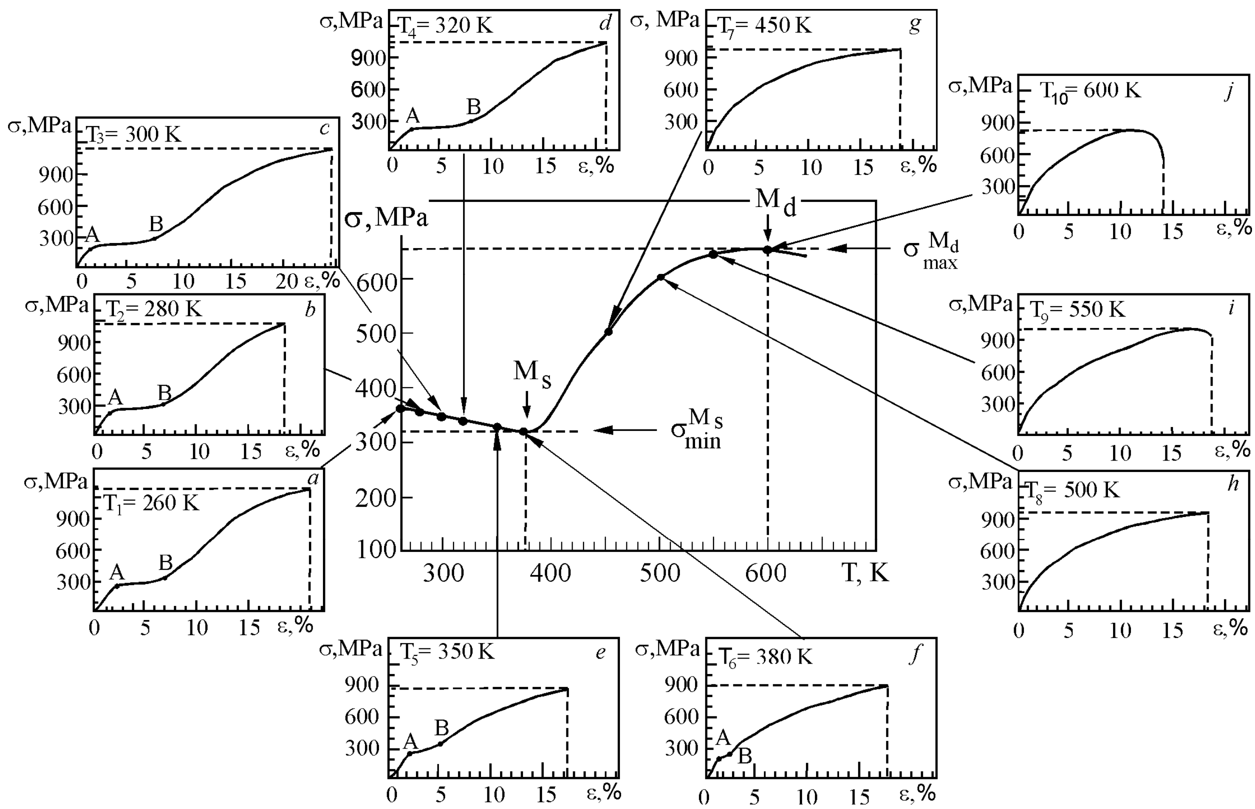

Fig. 3. The dependency of critical stresses of the martensitic shear on the temperature in the alloy $Ti_{50}Ni_{48.7}Mo_{0.3}V_1$ at different temperatures. Inserts (*a*–*j*) correspond to the dependencies $\sigma = f(\varepsilon)$ until failure at test temperatures: *a* – T_1= 260 K; *b* – T_2= 280 K; *c* – T_3= 300 K; *d* – T_4= 320 K; *e* – T_5= 350 K; *f* – T_6= 380 K; *g* – T_7= 450 K; *h* – T_8= 500 K; *i* – T_9= 550 K; *j* – T_{10}= 600 K, respectively

Acknowledgement

The authors acknowledge the financial supports from Tomsk State University Competitiveness Improvement Program.

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