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ULTRASOUND INITIATION OF THERMOELASTIC PHASE TRANSFORMATIONS

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The effect of vibrations of ultrasonic frequency on SM materials causes considerable heating because of irreversible dispersal of sound energy. It is determined that the phase transformation in a material by the action of ultrasound starts and terminates at a lower temperature. The range of decrease of temperature of reverse phase transformation termination is up to 25 K. It is explained by the fact that signvariable mechanical stresses accelerate the movement of phase boundaries, responsible for realization of SME. Thermographic investigations on ultrasonic shape restoration show that ultrasonic heating leads to consecutive realization of SME on the sample length. Shape restoration does not occur simultaneously on the whole length of the sample, but consecutively from the wave guide of ultrasonic vibrations. It is caused by localization of mechanical stresses of ultrasonic vibrations, which conditions the division of the sample by phase transformation zone into two ranges: low- and high temperature one. This condition of development of deformation processes differs on principle from the character of SM realization at electric heating of a material or uniformly from the surface and extends the possibility to operate the constructions, opens the perspective to create new executive mechanisms.

Introduction

The display of SME is extremely related to the temperature factor. Heating can be done indirectly as well as directly, e.g. by conveying electrical current. Experimental papers [1] have recently been published which show that stress and temperature are equal stimuli for initiating martensite reactions, i.e. the same mechanical effects can be achieved by means of both stress and temperature.

The properties of TiNi after different thermal, mechanical and other special treatment have currently been examined. However the influence of ultrasonic vibrations (UVs) on this alloy has been studied only for the last decade. These researches concerning acoustic-plastic effect [2], and there is no direct conclusion on the possible initialization of SME only due to energy of ultrasonic vibrations. At the same time UVs may influence properties of the environment in which they are produced as well as kinetics of different processes. In the light of stated above the use of UV for the initiation of SME is of interest. UVs cause not only heating of the material but also occurrence of rather significant mechanical alternating-sign stresses in it.

Equipment and Research Methods

Specially designed experimental apparatus was used to examine the process of the restoration of the TiNi alloy shape in ultrasound field under settled static stress. This experimental apparatus allows to control the changes of the length and temperature of the sample and further to process the data on a computer considering time dependence.

The sample was fixed in the holders of apparatus, one served as waveguide the other conveyed static load to the sample. Heating was performed at speed 1°C/min within the temperature interval of reverse phase transformation from 15 to 150 °C. Extension was measured with induction sensor.

The procedure of tests is the following: a sample wire Ti-50,4at %Ni with characteristic temperatures $A_s = 50$, $A_f = 76$, $M_s = 30$, $M_f = 21$ °C and 120mm length and 0,39mm or 0,50mm in diameter is placed into high-temperature austenitic condition. The sample wire was subjected to settled load and cooled which initiated plasticity change effect (PCE). In the course of plasticity change mechanical ultrasound vibrations were impulsively produced in the samples. The system was sustained in resonance at frequency corresponding to the intrinsic frequency of magnetostrictive changer and waveguide (22,2 kHz). Vibrational amplitude of the waveguide end was equal to 5 μm. Having been cooled, the sample was unloaded and brought into austenitic condition by heating. During heating ultrasound vibrations were impulsively produced in the sample. Deformation, temperature and timing were measured during the ultrasound influence. It must be noted that increasing of UVs in 3mm samples helped to produce SME almost immediately. In case of sample rods with resonance length 8-10mm in diameter, i.e. waveguides with longitudinal vibrations, transformation of the sample into austenitic condition by ultrasound heating was accompanied with the reduction of inner friction. As

the result no further heating of the samples higher than A_f due to ultrasound vibrations occurred. The amplitude of mechanical shifts of UVs stabilized [3, 4].

Experimental Results and Discussion

Prior tests were held to confirm an opportunity for initiating of the shape restoration in alloys with the SME by means of ultrasound influence. A sample TiNi wire 1,2 mm in diameter was wound along the mandrel 20 mm in diameter at 3 mm coil pitch. The wire was rigidly fixed and annealed at 600°C for 30 minutes then it was cooled simultaneously with the furnace. Thus the sample was given an initial shape. Then the wire was drawn at indoor temperature (martensite condition) and subjected to UVs with amplitude of mechanical alternating-sign stresses 140 MPa and frequency 22 kHz. 6 seconds' influence of UVs resulted in the spiral shape of the sample. Thus the assumption was confirmed that UVs can really initiate the process of the shape restoration, i.e. the shape memory effect (SME) [5].

Phase transformations take place in TiNi during the ultrasound influence, therefore physical-mechanical properties (especially modulus of elasticity), which determine the speed of elastic waves expansion, change as well. Hence, the resonance frequency of vibration system must change in the process of thermoelastic martensite transformations, which was actually demonstrated by the experiment (Fig. 1).

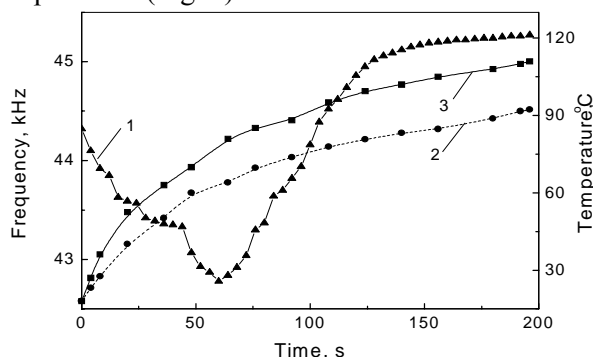


Figure 1. Alteration of UV resonance frequency (curve 1); maximal (curve 3), and average (curve 2) temperatures on the surface of TiNi sample with 80mm in length and 10mm in diameter in the process of ultrasound influence

The alteration of resonance frequency according to the time of UVs influence and the sample temperature demonstrates that the phase transformation in the material under the influence of ultrasound starts and finishes at lower temperature (Fig. 1). The interval of reducing the temperature of the reverse phase transformation according to the conditions of ultrasound initiation is equal to 0-25°C. It is explained by the fact that mechanical alternating-sign stresses speed up the movement of interphase limits, which are responsible for the SME realization.

Thermographic tests of ultrasound shape restoration after S-shape transformation of TiNi samples and Cu-Al-Ni monocrystals has shown that ultrasound heating leads to consequent

SME realization along the sample [6], i.e. shape restoration does not occur simultaneously along the sample but consequently from UV waveguide ("sliding" SME). It is caused by the localization of mechanical stresses of ultrasound vibrations which explains the division of the sample by zone of phase transformation into two segments: low and high temperature segments. These conditions of the development of deformation processes are fundamentally different from the realization of SME during the heating by electric current or simultaneously from the surface. The conditions also expand the opportunity for controlling the mechanisms which work under SME.

The experimental results of the initiation of SME in TiNi wire samples after bending strain have shown that the shape restoration is caused by producing UVs in the samples which experienced inelastic deformation in martensite condition [3]. Thus, the value of maximal fully reversible deformation for Ti-50,4at.%Ni sample wires with characteristic temperatures: $A_s = 48$, $A_f = 60$, $M_s = 30$, $M_f = 21$ °C and 0,61 mm in diameter in the process of ultrasound influence with amplitude 10 μ m and frequency 22 kHz is equal to 3%.

Researches of the kinetics plasticity change and shape memory effects (Fig. 2) have shown that during the stage of cooling UVs are impeding the realization of plasticity change in the alloy which brings back to the previously stored deformation. At the same time insignificant change of the sample temperature is observed which is related to its ultrasound initial heating. When ultrasound is switched off the temperature lowers and the realization of PCE resumes according to the kinetics of direct martensite transformation. The influence of UVs at the stage of heating (after unloading the sample in martensite condition) brings back the deformation of the sample at the insignificant temperature

increase. After ultrasound having been switched off further realization of SME is observed in keeping with temperature kinetics of reverse martensite transformation.

Thus, the UVs influence on TiNi at the stage of cooling at an interval of direct martensite transformation causes in the whole interval practically instantaneous reversion of the stored deformation which is followed by the temperature increase of the sample. The closer we are to M_f at the moment of ultrasound influence, the larger reversion we have, i.e. the more deformation is stored, the more its reversion under ultrasound influence is. Further cooling of the sample without ultrasound influence leads to the restoration of the deformation storing absolutely following the theory of the development of small thermal-mechanical hysteresis loops within the incomplete interval martensite transformation [7].

The restoration of deformation under ultrasound influence at the stage of heating of TiNi at the interval of reverse martensite transformation can also be explained by the ultrasound initial heating by means of UVs energy dissipation and subsequently by the formation of steady austenite. Small increase (0,3 %) of deformation at the moment after UV switching-off is probably determined by the formation of unsteady austenite under the influence of alternating ultrasound stresses (Fig. 3.).

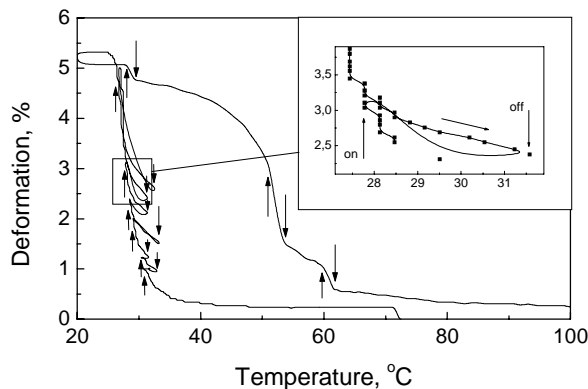


Figure 2. Temperature dependences of the deformation during realization of plasticity change in TiNi alloy at the load of 30 MPa and SME. The arrows show the moments of switching-on (\uparrow) and switching-off (\downarrow) of UVs

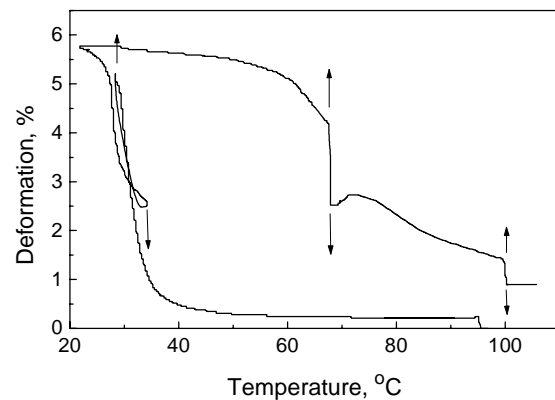


Figure 3. Temperature dependences of deformation during realization of plasticity change and SME in TiNi alloy at the load of 30 MPa; a time dependence of the deformation change of the sample as the result of ultrasound influence

Kinetics of the process of ultrasound initiation of the shape memory proves that the UVs influence at both direct and reverse martensite transformations causes reversion of the stored deformation. Since the process is accompanied with ultrasound initial heating, small thermal-mechanical hysteresis loops are observed at the stage of direct transformation which is especially valuable for actuating devices from shape memory alloys. The restoration of deformation at the stage of heating is related to ultrasound initial heating of the sample which is produced by means of dissipation of vibrations, and therefore to formation of steady austenite [8].

Ultrasound initiation of shape memory under natural conditions leads to the occurrence of reactive mechanical stresses in the material which relax after ultrasound influence stopped [9, 10]. Maximal value of developing stresses in samples has been equal to 100-150 MPa. The occurring reactive stresses do not practically depend on the means of initial loading. These data correlate with the suggested model of ultrasound influence on the SME materials and are related to the increase of the quantity of austenitic phase [8]. A new means of controlling of the power-driven actuator devices in isothermal conditions by means of UVs influence has been offered. The means is based on the discovered phenomenon of ultrasound generation of reactive mechanical stresses [8, 9].

Conclusion

The initiation of SME under the UVs influence in alloys with thermoelastic martensite transformations has been discovered. The stimulation of UVs produces restoration of the form in the samples which have been subjected to initial inelastic deformation. In particular, for the TiNi alloy with the

temperatures of the beginning and finishing of reverse transformation 48°C and 60°C correspondingly the value of maximal completely reversible deformation in the process of ultrasound influence with amplitude 10 μm and frequency 22 kHz at the temperature of 20°C has been equal to 3 %. Ultrasound vibrations give the opportunity for consecutive realization of SME along the sample (“sliding” SME). It has been discovered that manifestation of the ultrasound initiation of SME in constrained conditions produces reactive mechanical stresses within the material which relax only after UV influence stopped. The maximal value of developing stresses in TiNi samples is equal to 100-150 MPa. In the process of realization of both direct and reverse martensite transformations UV produce “discharge” of stored deformation and allow to form small thermal-mechanical hysteresis loops in within the incomplete interval of martensite transformations.

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