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Shape memory behavior of a Ni_3Ta alloy pre-deformed in compression

A. Rudajevová*, J. Pospíšil

Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 5, 121 16 Praha 2, Czech Republic

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ABSTRACT

Shape memory behavior of a Ni_3Ta shape memory alloy pre-deformed in compression up to 1% was studied by dilatometry. Dilatation characteristics were measured for non-deformed as well as pre-deformed polycrystalline and single crystal alloys from the room temperature to 950 °C. Shape recovery processes in the polycrystalline sample occur at room temperature where the martensite exists and then continue during the phase transformation from M → A. However, the major part of the compression pre-deformation is relaxed at high temperatures in the austenite region. This shape recovery process is associated with the elongation of the sample. Only small changes in length were found for the single crystal sample after pre-deformation and a single thermal cycle. Compression deformation increases the TWSME in the polycrystalline alloy and decreases the TWSME in the single crystal alloy.

1. Introduction

The shape memory effect takes place in many metal alloys; however, their practical applications depends on the suitability of their physical properties and, not insignificantly, reasonable costs. The most known and commonly used shape memory alloy, NiTi, undergoes martensitic transformation just above room temperature. There are many applications where high temperature shape memory alloys (HTSMA) are in demand. However, using shape memory alloys with high temperatures of martensitic transformation is complicated by the physical processes occurring at high temperatures, such as recrystallization, recovery, precipitation, etc. Therefore, knowledge of the HTSMA behavior at high temperatures is a necessary condition of its practical use.

A review on HTSMAs can be found in the work of Firstov et al. [1]. The relatively low price of the raw materials is the main reason for studying the ternary Ni–Ti–Zr and Ti–Ni–Hf alloys [2,3]. In a recent study of Ti–Ni–Hf, Meng et al. show that one-way shape memory effects (OWSME) and two-way shape memory effects (TWSME) are improved by aging processes [4]. This is a consequence of precipitation of $(TiHf)_3Ni_4$ particles and strengthening of the alloy [5]. The simply homogenized TiNiHf shape memory alloy exhibits an inferior shape memory effect compared to the TiNi binary alloy because the Ti–Ni–Hf austenite strength is low, thereby allowing the dislocation slip and martensite variant reorientation to occur simultaneously, while the material is deformed in the martensite state [6].

The Ni–Mn–Ga alloy is a promising HTSMA. The martensitic transformation temperatures are sensitive to composition, and Ni excess stabilizes the martensitic structure [7]. Ma et al. [8] have shown that in $Ni_{50+x}Mn_{25}Ga_{25-x}$ (x = 2–11), the transformation temperature A_s increases from 44.6 °C for x = 2 to 520 °C for x = 11. In our previous works [9,10], small compression deformations (up to 3%) were applied to samples of polycrystalline $Ni_{53.6}Mn_{27.1}Ga_{19.3}$ alloy. This alloy exhibits TWSME before deformation, due to the existence of structures within the columnar grains in the sample. After compression and a single thermal cycle, a pre-deformation of OWSME and an increase of TWSME were found.

A new candidate among HTSMAs is Ni_3Ta, which has been studied by Firstov et al. [11]. The binary phase diagram of Ni–Ta is similar to the binary phase diagram of Ni–Ti. The tetragonal-monoklinic phase transformation in Ni_3Ta was found to be of martensitic origin [12]. The thermally induced martensitic phase transformation took place with 50 °C hysteresis. The alloy was also studied after 10% prestraining in compression at room temperature. This deformation was completely recovered during heating over a wide temperature range. The authors have studied the Ni_3Ta alloy by DSC, X-ray diffraction and dilatometry. Their conclusion was that this alloy may be a superior HTSMA.

The aim of the present work was to study the Ni_3Ta shape memory alloy as a new candidate HTSMA. This alloy was examined in both non-deformed and pre-deformed states. Dilatation characteristics were measured and analyzed over the temperature range from room temperature to 950 °C to determine the influence of high temperature processes on the shape memory effect in this alloy.

* Corresponding author. Tel.: +420 22191 1654; fax: +420 224 911 061.
E-mail address: rud@mag.mff.cuni.cz (A. Rudajevová).

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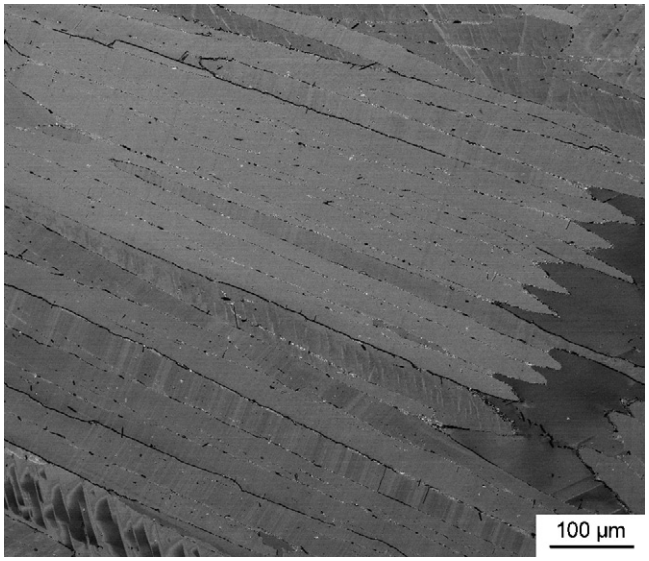

Fig. 1. Microstructure of the polycrystalline Ni_3Ta alloy.

2. Experimental details

The polycrystalline samples of Ni_3Ta were prepared by arc melting stoichiometric amounts of components in a water-cooled copper crucible under an Ar (6N) protective atmosphere. Samples were re-melted three times to ensure good homogeneity. The microstructure of the polycrystalline sample is shown in Fig. 1. Columnar grains are perceptible in the plane perpendicular to the longitudinal sample axes. A single crystal of Ni_3Ta was prepared in a four mirror optical furnace using a polycrystalline rod obtained by arc-melting. The rod was melted under the Ar protective atmosphere and slowly moved at a speed of 8–10 mm/h through the hot zone of focused light. The orientation of the single crystal was studied with the MEREDIT powder diffractometer. It was found that the crystal has a monoclinic structure at room temperature. A (2 0 1) plane was observed parallel to the growth direction and a (0 4 0) plane was observed perpendicular to the growth plane [13].

The linear thermal expansion of the samples was measured in a helium atmosphere using the Netzsch 402E dilatometer over the range from room temperature to 950 °C. The heating and cooling rates were 2 K/min. The samples were 6 mm in diameter and about 22 mm in length. The accuracy of the measuring apparatus was checked by determining the coefficient of thermal expansion (CTE) of pure Mg and comparing it with the data available in the literature. The agreement between the measured values and the values in the literature is in the range of ±1%. The thermal expansion curves were studied during a minimum of three thermal cycles (runs). The material was pre-deformed by compression up to 1% using an Instron-type deformation machine. The samples were deformed in the direction parallel to the longitudinal sample axes.

3. Experimental results

Fig. 2 shows the temperature dependences of the relative elongation and the CTE before pre-deformation. The initial transformation temperatures were $A_s = 325$ °C and $M_s = 250$ °C. The final transformation temperatures were $A_f = 400$ °C and $M_f = 140$ °C. The dilatation characteristics obtained in the first thermal cycle (up to 450 °C) after compression deformation are shown in Fig. 3. It can be seen that the CTE of the pre-deformed martensite is higher than the CTE of the non-deformed martensite. After the first thermal cycle (after pre-deformation), a high value was found for the elongation sample. Fig. 3b demonstrates incomplete shape recovery in this thermal cycle (since the value of the CTE after the phase transformation M → A is far above the CTE value without deformation). Even further thermal cycling (2 run) up to 470 °C did not result in complete shape recovery. Therefore, an additional thermal cycle

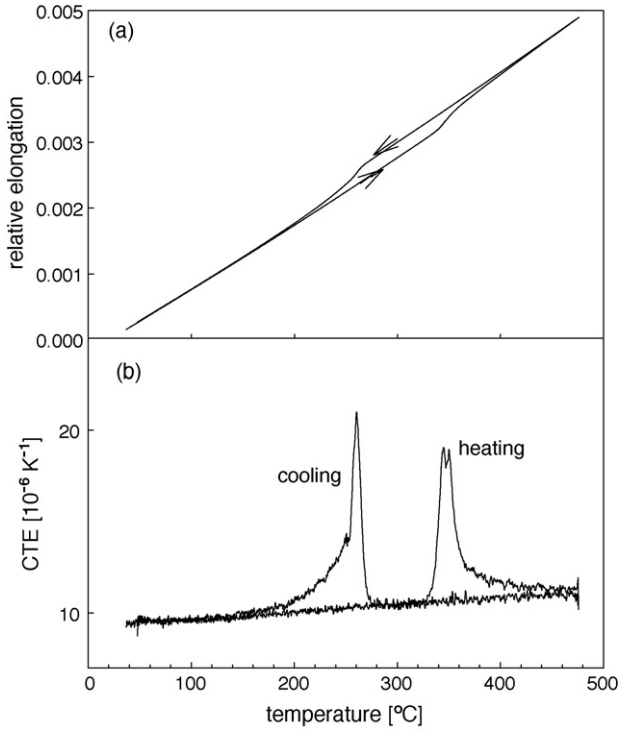

Fig. 2. Dilatation characteristics of polycrystalline Ni_3Ta sample.

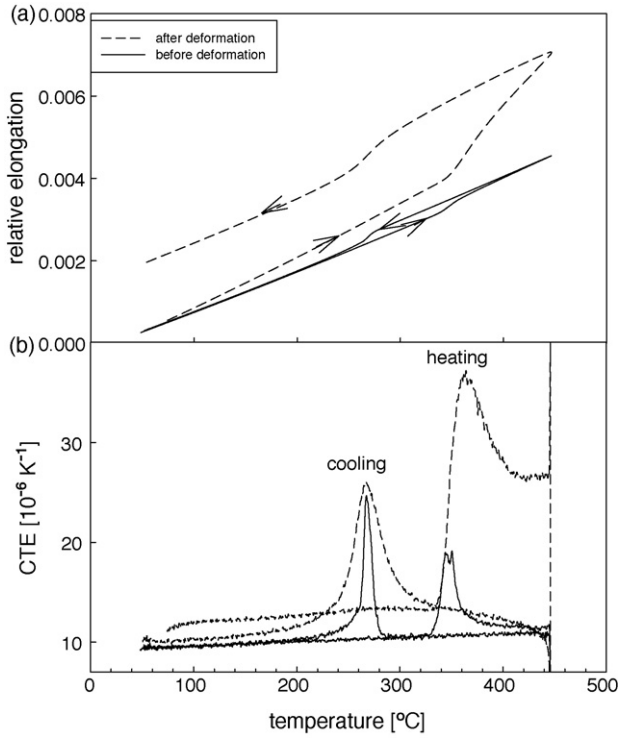

Fig. 3. Dilatation characteristics of the Ni_3Ta alloy obtained in the first thermal cycle after compression pre-deformation with a maximum thermal cycle temperature of 450 °C.