



Short communication

Transformation hysteresis and shape memory effect of an ultrafine-grained TiNiNb shape memory alloy



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ABSTRACT

In present work, transformation hysteresis and shape memory effect of an ultrafine-grained Ti₄₄Ni₄₇Nb₉ alloy processed by ECAP were studied. After deformation, the ECAPed sample showed a much wider transformation hysteresis than the initial sample due to the enlarged strength mismatch between matrix and β -Nb phase. The shape memory effect and its cycling stability of the ECAPed sample were obviously improved.

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1. Introduction

In past years, TiNiNb shape memory alloys have received considerable attention because of their wide hysteresis which benefits the storage and transportation of coupling component [1–5]. In order to realize a reliable fastening, it is important to lower the martensitic transformation start temperature (M_s). In this aspect, addition of quaternary element [6,7] and refinement of microstructure are effective. Very recently, our group employed equal channel angular pressing (ECAP) to achieve a grain refinement from 3 μm to 0.3–0.6 μm for the matrix of Ti₄₄Ni₄₇Nb₉ alloy [8]. After this processing, M_s temperature was remarkably reduced and the yield strength was improved to some extent. However, our question on how the ECAP affects the transformation hysteresis and shape memory effect is open. This present investigation was conducted to answer the above question, and is a sequel to a previous work [8].

2. Experimental

A commercial Ti₄₄Ni₄₇Nb₉ (at%) alloy was studied. Please read our previous work [8] for the detailed ECAP processing. Martensitic

transformation behavior was studied by using a Perkin–Elmer Diamond differential scanning calorimeter (DSC). Deformation was carried out by a WDW tensile machine equipped with a thermal chamber. Shape recovery property was determined by a bending method [9]. The bending deformation strain was determined to be $\varepsilon_d = t/d + t$, where t is the thickness of the sample, and d is the diameter of the cylinder. The shape recovery ratio was measured by the value of $\eta = (180 - \theta_h)/180 \times 100\%$, where θ_h is the angle after heating the sample above the reverse transformation finish temperature.

3. Results and discussion

In order to investigate the transformation hysteresis, the samples were deformed to a critical strain range of 14%–18% at $M_s + 30^\circ\text{C}$, which is the optimum condition to obtain an increased transformation hysteresis and a high shape recovery ratio [1]. After being deformed to 18%, the reverse transformation proceeded into a multiple-stage manner upon the first heating (Fig. 1(a)). The reverse transformation start temperature (A_s) and M_s of the undeformed sample were also given. The A_s' increased obviously as compared to that of the undeformed samples. The ECAPed sample shows a wider hysteresis ($A_s' - M_s$) than the initial sample

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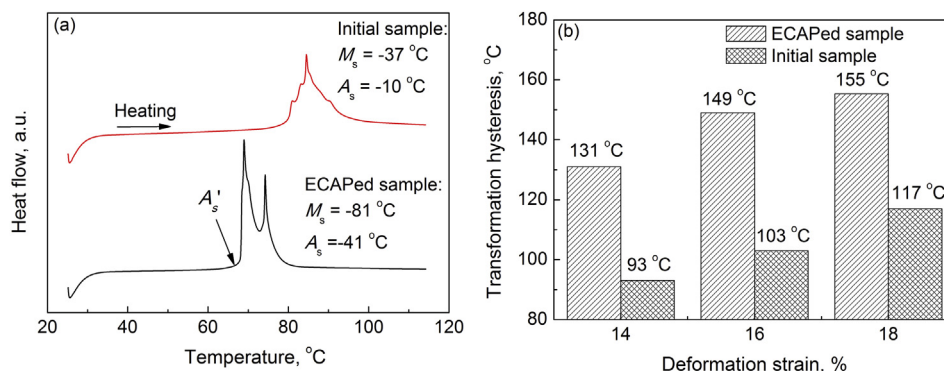


Fig. 1. DSC curves of the deformed samples upon the first heating (a) and effect of deformation strain on transformation hysteresis (b). The transformation temperatures of the undeformed samples are given in (a).

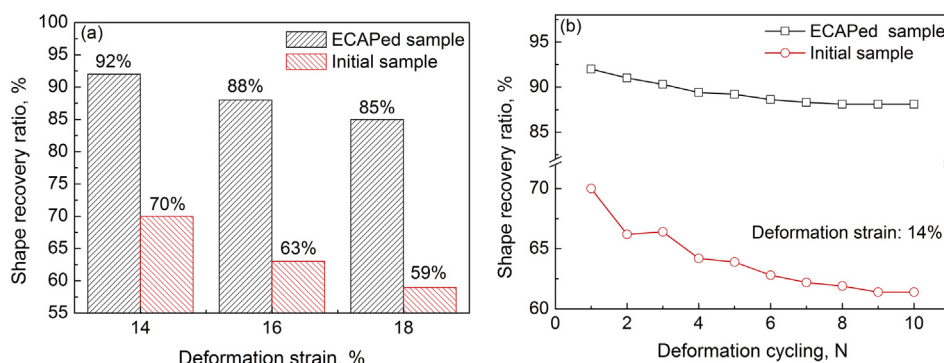


Fig. 2. Shape recovery ratio as a function of deformation strain (a) and cycling number (b).

(Fig. 1(b)). The maximum transformation hysteresis obtained in the ECAPed sample is about 155°C , which is larger than the values previously reported [1,10]. It is accepted that the plastic deformation of β -Nb particles can relax the stored elastic strain energy of martensitic transformation, which acts as the driving force for the reverse transformation [2]. Accordingly, a wide $A'_s - M_s$ is obtained. After ECAP, the change of microstructure can be divided into two aspects. The first one is related to the distribution of β -Nb particles, which changes from network structure to elongated chain-like one [8]. This change may not significantly influence the transformation hysteresis according to the previous results [11–13]. The second aspect is related to the grain refinement by ECAP. The grain size of matrix was greatly refined. However, ECAP is less effective in reducing the grain size of β -Nb phase [8]. This enlarges the strength mismatch between matrix and β -Nb phase. During deformation, the β -Nb phase in the ECAPed sample may be subjected to a larger plastic deformation than that in the initial sample. This is supported by the fact that the ECAPed sample requires much larger tensile stress than the initial sample when deformed to a strain larger than 10% [8]. This implies that the plastic deformation of β -Nb particles of ECAPed sample can relax more elastic strain energy than that of the initial sample. Thus, the ECAPed sample shows a wider $A'_s - M_s$ than the initial sample.

The ECAPed sample showed a higher shape recovery ratio than the initial alloy, irrespective of deformation strain (Fig. 2(a)). This is ascribed to the refined grain size and the dislocations introduced during ECAP [8]. When the deformation strain was fixed at 14%, with increasing cycling number, the shape recovery ratio first decreased and then reached a stable value (Fig. 2(b)). After ten cycles, the ECAPed sample showed a smaller reduction of shape recovery ratio than the initial sample.

Combining previous [8] with current results, it is summarized that the ECAPed $\text{Ti}_{44}\text{Ni}_{47}\text{Nb}_9$ alloy has the following advantages

over the initially coarse-grained alloy: (1) lower transformation temperatures; (2) further enlarged transformation hysteresis; (3) improved yield strength and shape recovery properties; (4) better cycling stability. This implies that ECAP is effective in enhancing the reliability of pipe coupling made of TiNiNb alloy.

4. Conclusions

The ECAPed $\text{Ti}_{44}\text{Ni}_{47}\text{Nb}_9$ sample shows a much wider transformation hysteresis than the initial alloy due to the enlarged strength mismatch between matrix and β -Nb phase. The shape recovery ratio and its cycling stability of ECAPed sample are remarkably improved as compared to the initial alloy.

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