Conference paper

The Features of Martensite Transformation in the (TiNiMo)Nb Alloys Under Loading

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Abstract

Researches of multiplecomponent (TiNiMo)Nb alloys with 0.5, 1 and 1.5 at.% Nb. Experimental dependences of strain accumulation and recovery at multiple SME have showed a hysteresis behavior in all the studying alloys at temperature changing. A growth of hysteresis characteristics with an increase in Nb content was established. The quantities microanalysis let to identify the following structure of (TiNiMo)Nb: matrix on the base of intermetallic compound B2 – TiNi; eutectic, NiTiNb and Ti2Ni phases. In the study of structure revealed that NiTiNb particles are local obstacles that cause the increase of hysteresis width.

1 Introduction

All biological system exhibits hysteresis response on any deformation influence. The hysteresis behavior is appeared both in metallic materials and alloys with phase transitions of the martensite type, for example, in TiNi-based alloys (TN-10 alloy) [1]. Different biological tissues have an individual value of hysteresis width ΔH therefore it is necessary to choose an alloy with certain parameters of hysteresis ΔH and a value of reversible strain for them.

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Doping with Nb can change directionally value ΔH in TiNi-based alloys. The wide hysteresis of thermoelasticmartensite transformation (MT) is a distinguishing feature of binary TiNi alloys with Nb (up to 1 at. %) due to crystallization of refractory precipitates with Nb at the grain boundaries [2, 3]. Therefore, in order to obtain a material with a wide region development of hysteresis properties the TN-10 alloy was doped with Nb up to 1.5 at.%.

2 Experimental

The studied alloys were produced in the vacuum induction furnace by remelting the Ti sponge and electrolytic Ni plates with the addition of Mo, Fe and Ag alloying elements.

Table 1 shows the composition of (TiNiMo)Nb alloys determined by the charge. The weight losses during melting did not exceed 0.01 %.

Table 1. Composition of (TiNiMo)Nb alloys

No of alloy	Concentration of elements [at. %]			
	Ti	*Ni*	*Mo*	*Nb*
1	50	49,2	0,3	0,5
2	50	48,7	0,3	1
3	50	48,2	0,3	1,5

Produced ingots with a weight of ≈ 650 g, length of 150 mm and a diameter of 20 mm were spark cut by the electric-discharge wire to make (50×1×1) mm samples. Samples for microstructure analysis have plate shapes with dimensions of (1×1.5×1.5) mm.

The microstructure of the alloys is investigated with the metallographic microscope CarlzeissAxiovert 40 mat. The elemental microanalysis was carried out by the method of scanning electron microscopy PHILIPS SEM 515 on the microprobe EDAX ECON IV. Samples for microstructure investigations were prepared by the standard way and we have used the solution of the following composition (3 ml HF, 2 ml HNO_3, 95ml H_2O) to reveal the polished sample microstructure.

Testing of temperature dependence of strain change at multiple shape memory effect (SME) and temperature region of shape memory effect were conducted in condition of tension at constant load. The heating-cooling cycle in the MT temperature region was carried out under external load = 2 kg using samples with dimensions of (50×1×1) mm.

3 Results and discussion

In case of a practical application of TiNi-based implants the SME implementation often occurs under constant stress. At the same time a transition from one structural state to another is performed by means of interphase bounder movement and it is followed by energy dissipation [1]. In TiNi-based alloys showing phase transitions under loading a loss of energy in the form of hidden warmth and phase friction in case of temperature decreasing and an absorption of energy upon heating cause the MT hysteresis.

Fig. 1 shows temperature dependences of strain accumulation and recovery at multiple SME ε(T) under the constant stress in the MT temperature region for TiNiMoNb alloy.

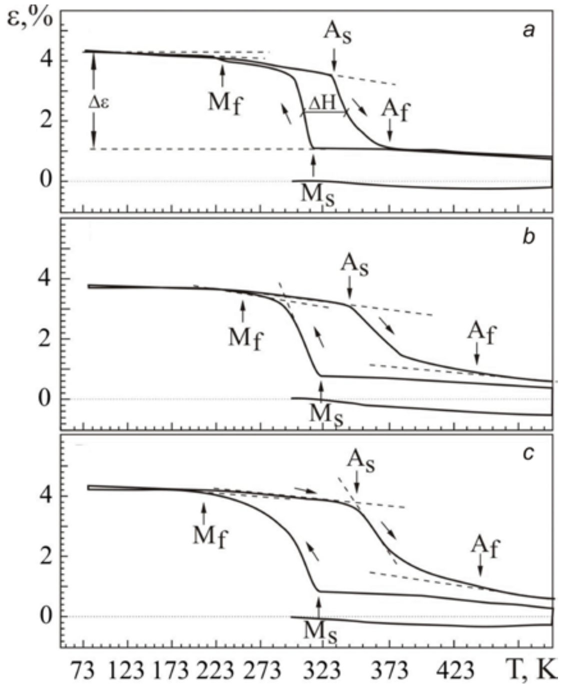

Fig. 1. Multiple shape memory effect in (TiNiMo)Nb with C_{Nb}: *a*) 0.5 at.%; *b*) 1 at.%; *c*) 1.5 at.%

The hysteresis behavior was found in all the studying alloys at temperature changing. From analysis of **ε**(T) dependences the MT characteristic temperatures (M_s, M_f, A_s, A_f), a value of temperature hysteresis width (*ΔH*), reversible strain ($\varepsilon_{reversible}$), residual strain ($\varepsilon_{residual}$) were determined. All the basic hysteresis characteristics of (TiNiMo)Nb alloys is given in Table 2.

Table 2.Shape memory parameters of (TiNiMo)Nb alloys

Shape memory parameters	Concentration of Nb (at. %)		
	0.5	1.0	1.5
M_S [K]	315	324	325
M_f [K]	231	253	208
A_S [K]	331	343	348
A_f [K]	373	443	448
$\varepsilon_{revers}^{heating}$(%)	3.2	3.4	4
$\varepsilon_{revers}^{cooling}$ (%)	3.2	3.2	3.6
$\varepsilon_{residual}$ (%)	-	0.2	0.4
ΔH [K]	31	61	70

Width of the temperature intervals of direct and reverse MT (Fig. 2) and reversible strain value (Fig. 3) are increased with Nb concentration rise. Microstructure investigations explain these results.

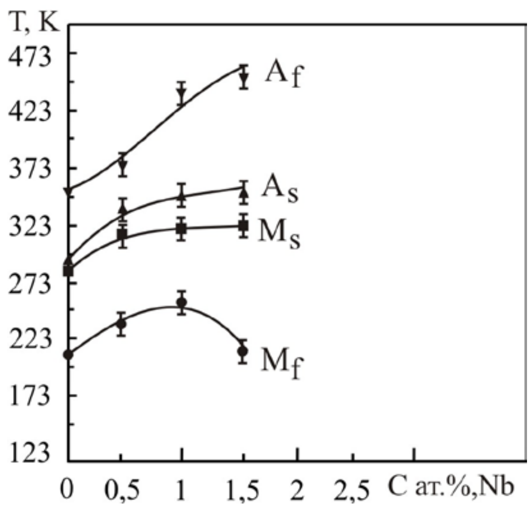

Fig. 2. Concentration dependence of the MT characteristic temperatures in (TiNiMo)Nb alloys

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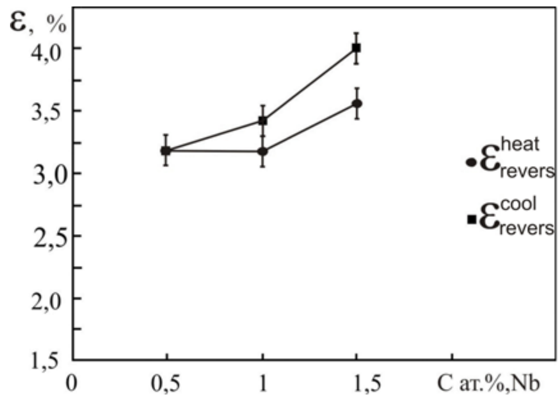

Fig. 3. Concentration dependence of reversible strain value(●-heating, ■-cooling) in (TiNiMo)Nb alloy

The quantities microanalysis was carried out by means of SEM method and it let to identify the following structure of (TiNiMo)Nb (Fig. 4): matrix on the base of intermetallic compound*B2* – TiNi; eutectic, NiTiNb precipitates crystallized mainly as light particles at the TiNi grain boundaries and Ti_2Ni phase. The Nb content rise lead to increasing of volume fraction of NiTiNb and Ti_2Ni particles.

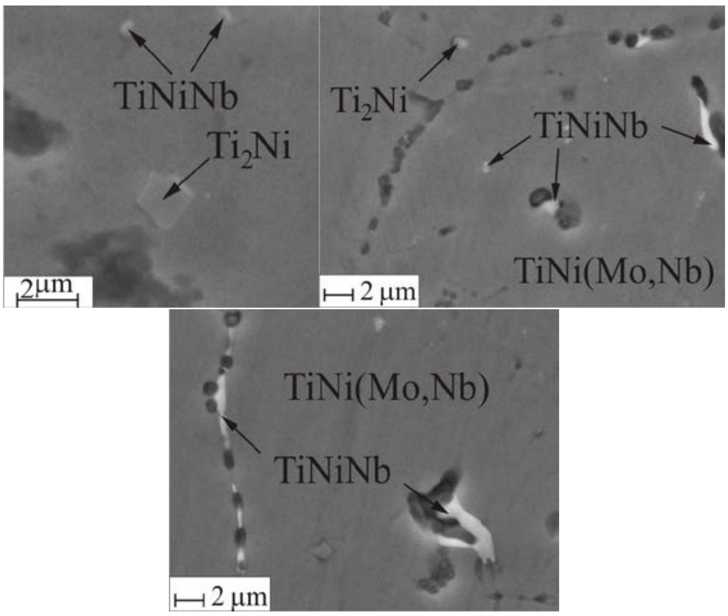

Fig. 4. SEM microsrtucture of (TiNiMo)Nb alloy with: 0.5 at. % Nb(*a*), 1 at.% Nb(*b*) and 1.5 at. % Nb(*c*)

The NiTiNb particles in the initial phase are local obstacles during the interphase boundary movement; it is followed by energy dissipation as a result of friction. These great dissipative losses in the alloys with 1-1.5 at. % Nb causes the increase of hysteresis widthΔH twice. In addition, the high volume fraction of NiTiNb particles induces the accumulation of plastic deformation, which is shown by residual deformation on the **ε**(T) dependences (Fig. 3). The plastic deformation in these alloys is also the reason of temperature intervals shift of shape recovery to the high-temperature region (Fig. 2). As for the growth of start temperature of direct MT M_S with Nb concentration increasing, that it is connected with NiTiNb particle presence at grain boundaries. These particles promote to the transition under the load, facilitating the formation of martensite crystals. The MS characteristic temperature increasing can be described by the Clausius–Clapeyron relation (Eq. 1) [1]:

$$\Delta\sigma = k\Delta T \quad (1)$$

where $k = \frac{\Delta H}{T_0 \varepsilon_i}$. The increase of stress by value $\Delta\sigma$ leads to a proportional increase of M_S temperature. The intensity of this process is connected with the k coefficient and it is determined by enthalpy of transition ΔH, the equilibrium temperature T_0 and value of martensite shear ε_i.

4 Summary

Thus the received experimental results in this research confirm the published dates about Nb enrichment of grain boundaries in TiNi solid solution. The NiTiNb particles increase the value of hysteresis width**Δ**H twice and it is the cause of residual deformation emergence on **ε**(T).

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