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Internal Friction in Fe-Co-Ni-Ti Shape Memory Alloys

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Abstract: The anomalies of the temperature dependences of the logarithmic decrement and eigen frequency of the free damped vibrations for Fe-Co-Ni-Ti shape memory alloys were first found in the vicinity of the reverse α - γ martensitic transformation. It was shown the damping capacity in the alloys investigated is comparable with that for TiNi based alloys.

1. INTRODUCTION

Aging Fe-Co-Ni-Ti alloys are the new perspective shape memory materials (SMM) [1]. Irreversible martensitic γ - α transformation can be modified into thermoelastic one by a special thermomechanical treatment giving rise to the characteristics which are intrinsic to the martensitic transformations (MT's) in TiNi- and Cu- based alloys. In opposite to the traditional SMM usually Fe-Co-Ni-Ti alloys are ferromagnets with invar characteristics and provide higher level of the recovery stresses. Intense investigations of these alloys were performed last few years [2-4], but the attention to their damping behaviour was not paid.

In present study the internal friction (IF) in Fe-Co-Ni-Ti alloys was examined in order to have the initial information about their damping capability.

2. EXPERIMENTAL PROCEDURE

Three Fe-Co-Ni-Ti alloys with the chemical composition given in Table 1 were chosen in order to obtain SMM with the values of the characteristic temperatures of MT which can be compared with those for the binary nearly equiatomic TiNi alloys.

Table 1: Composition of the alloys investigated (wt.%), thermal treatment modes and characteristic temperatures of MT

Alloy	Co	Ni	Ti	Fe	Thermal treatment mode	Characteristic temperatures of MT, °C			
						M_s	M_f	A_s	A_f
1	34.3	19.0	8.5	Bal.	Quench. + 650 °C, 0.5h	23	-15	32	85
2	35.1	18.4	8.4	Bal.	Quench. +650 °C, 3 h	55	-2	70	140
3	27.1	23.4	5.8	Bal.	Quench + 650 °C, 0.5h	-10	-40	40	130

The alloys were melted by induction method , cast into copper mold and hot rolled into the bars. The bars were water quenched from 1100 °C and rolled at room temperature into the wire with 1 mm diameter. The wire was vacuum annealed at 1100 °C for 8h., subsequent water quenched from 1100 °C and aged at 650 °C in salt bath for time periods shown in Table 1. The internal friction measurements have been performed by the method of the free damped vibrations of the wire-like specimens with a length of 110 mm using inverted torsion pendulum machine. The temperature dependences of the logarithmic decrement (δ) were measured at heating-cooling rate of 2.5 °C/min in the temperature interval 20-450 °C in a vacuum of 10^{-3} Pa at a frequency about 2 Hz and oscillation amplitude about 10^{-6} . Simultaneously, the change the oscillation eigen frequency (f) was detected. Characteristic temperatures of MT were determined by the low field magnetic permeability (μ) vs. temperature plots. The microstructure of the specimens was observed in an optical microscope.

3. RESULTS AND DISCUSSION

The transformation behaviour of an alloy 2 is shown in Fig.1 as a typical example. Characteristic temperatures are taken as shown in Fig. 1 by arrows and listed in Table 1. From Fig. 1 it can be deduced

Figure 1. Magnetic permeability vs. temperature function of an alloy 2.

that austenite in the alloys studied is a ferromagnet and in case of an alloy 2 the Curie point is equal to about 150 °C. Optical micrographs confirmed the thin-plate morphology of the martensite in these alloys. The mobile interfaces can effectively dissipate the elastic vibrations. In other words one could expect the high level of IF in the transformation region and in martensite in these alloys.

The temperature spectrum of δ and f during the reverse α - γ transformation for the alloy 1 preliminarily cooled in liquid nitrogen is presented in Fig. 2. It is worth noting the IF results indicated the similar behaviour for all alloys studied here. So, experimental runs δ (T) and f (T) are displayed only for alloy 1. Inspection of Fig. 2 gives typical for SMM [5,6] internal friction and frequency behaviour during

Figure 2: (1) Logarithmic decrement , (2) Frequency of the free vibrations for the alloy 1.

MT, which means that a maximum of IF corresponding to a minimum of frequency is detected in α - γ transformation region. In accordance with the temperature hysteresis of γ - α transformation the upward curvature of $\delta(T)$ dependence near the start temperature of the forward MT is observed (Fig. 2). Increasing of δ at about 400 °C is likely due to the damping at the grain boundaries [7]. The peak value of IF at MT appeared to be comparable with that for the binary TiNi alloys [8,9] and can be attributed mainly to the mobility of the parent-martensite interfaces as well as to the transitory term proportional $\dot{T}/f$ [10]. Despite the measurements are not complete (because of the experimental limitations) according to the data of

Fig. 2 the intrinsic part of IF arising from the movement of twin boundaries in martensite seems to be low. Considering this contribution starts to increase at the amplitude value more than 5×10^{-5} [5] and due to the inherently high yielding stress of martensite in Fe-Ni-Co-Ti alloys [11] it can be indeed expected that the IF for account of stress-induced twin accommodation will be significant at much higher stress level.

Fig. 2 demonstrates the sharp increase of the shear modulus G while heating. The abrupt change values of G during MT are equal to 15, 24 and 34 % for alloys 1, 2 and 3, respectively. There is a positive slope on the cooling run of $G(T)$ near the forward MT which also was observed for the invar Fe-Co-Ni alloys near Curie point. The origin of such behaviour has to be a subject for the further investigations.

Conclusion

The IF measurements firstly performed with Fe-Co-Ni-Ti alloys are the initial step in understanding their damping capacity and elastic moduli behaviour in transformation region which extends in this case over 100 °C near room temperature. The enhanced level of damping at higher stress amplitudes can be anticipated. More systematic work is in progress to confirm such an idea and to propose modelling description of IF behaviour in Fe-Co-Ni-Ti alloys.

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