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Anelasticity of B19′ martensitic phase in Ni–Ti and Ni–Ti–Cu alloys

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Abstract

Anelastic properties of the B19′ martensitic phase have been studied in two polycrystalline alloys: Ni–Ti with nearly equiatomic composition and Ni–Ti–Cu (about 49 at.% Ti, 46 at.% Ni, and 5 at.% Cu). Internal friction, dynamic shear modulus and torsional strain at zero applied stress were measured in a forced torsion pendulum for strain amplitudes of 2×10^{-5} to 2×10^{-4}, temperatures of 6–300 K, temperature change rates of 1–5 K/min and frequencies of 0.001–10 Hz. Several peculiarities have been found during thermal cycling: dependence of the internal friction on the temperature change rate and frequency of oscillation, which disappears with isothermal exposure, temperature hysteresis of the internal friction and dynamic shear modulus, and low-temperature anomalies in the temperature dependence of the dynamic shear modulus. The observed peculiarities result from reversible microplastic straining of the martensitic phase under the action of thermal stresses arising from anisotropy of thermal expansion of the B19′ phase. A relaxation peak in internal friction has been found in both alloys at temperatures of about 200 K. The temperature and the shape of the peak are influenced by the thermal stresses. The activation enthalpy of the relaxation has been evaluated both in isothermal and in nonisothermal conditions.

Keywords: Anelasticity; Intermetallics; Internal friction; Lattice defects

1. Introduction

Ni–Ti-based alloys represent the major family of shape memory alloys. Their high damping capacity both during the thermoelastic martensitic transformation and in martensitic phases is an important property for applications. There exists a considerable amount of research dealing with internal friction during phase transformations in Ni–Ti-based alloys, whereas investigations of anelastic properties of the martensitic phases in Ni–Ti-based alloys are rather scarce. Such investigations are necessary to clarify the mechanisms and structural levels responsible for the damping/anelastic properties of the martensitic phases, which are still under discussion. In the present work, we have studied low-frequency anelastic properties of the B19′ phase in two Ni–Ti-based alloys.

2. Experimental details

Polycrystalline Ni–Ti with nearly equiatomic composition and Ni–Ti–Cu (about 49 at.% Ti, 46 at.% Ni, and 5 at.% Cu) alloys were delivered by MTM-KULeuven in a cold-worked condition. Rod-shaped samples of circular section 1.3 mm in diameter and about 40 mm in length were machined, annealed at 973 K for 1800 s and water quenched to room temperature. The start and finish temperatures of the direct B2 → B19′ (M_s, M_f) and reverse B19′ → B2 (A_s, A_f) phase transformations were determined by differential scanning calorimetry: $M_s = 325$ K, $M_f = 302$ K, $A_s = 328$ K, $A_f = 354$ K for Ni–Ti and $M_s = 330$ K, $M_f = 305$ K, $A_s = 330$ K, $A_f = 358$ K for Ni–Ti–Cu. Samples of both alloys were studied just after quenching. The same sample of the Ni–Ti alloy was also studied after aging at room temperature for 2 years.

The mechanical loss angle tan ϕ, dynamic shear modulus (in arbitrary units) and torsional strain at zero applied stress (zero point drift) of the samples were measured in a forced torsion pendulum during controlled thermal cycling in the temperature range of 6–300 (or 100–300) K at strain amplitudes of 2×10^{-5}

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to 2×10^{-4}, temperature change rates of 1–5 K/min and frequencies of 0.01–10 Hz. Isothermal internal friction measurements were performed in a heating run from 180 to 300 K for obtaining frequency dependence of the internal friction in the range of 0.001–10 Hz at different temperatures. Temperature was stabilized for 600 s before each measurement of the frequency dependence.

3. Results

Fig. 1 shows the temperature dependence of the internal friction and normalized shear modulus of a Ni–Ti sample measured in a thermal cycle. The behavior of the zero point drift during the thermal cycle is represented by the inset in Fig. 1(a). A large internal friction peak appears at temperatures of about 200 K with a strong temperature hysteresis of about 45 K. The dynamic shear modulus and zero point drift exhibit similar temperature hysteresis. The zero point drift is reversible during thermal cycling. The internal friction peak on heating is slightly higher and considerably narrower than that on cooling. Details of low-temperature behavior of the dynamic shear modulus are depicted in the inset in Fig. 1(b). The negative temperature dependence of the dynamic modulus (modulus increase with temperature rise) is observed at low temperatures on heating: the modulus increases slightly between 6 and 30 K and much faster between 30 and 45 K.

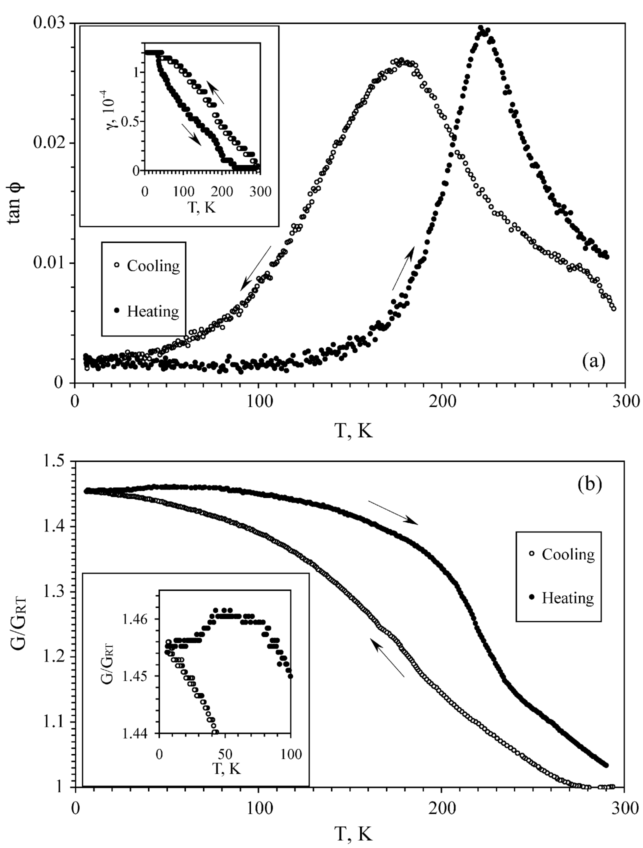

Fig. 1. Temperature dependence of the internal friction, $\tan\phi$ (a), and normalized shear modulus, G/G_{RT} (b), of an as-quenched Ni–Ti sample measured at frequency of 2 Hz, temperature change rate of 1 K/min and strain amplitude of about 8×10^{-5}. The zero point drift in the thermal cycle is shown in the inset in (a) in terms of the surface shear strain, γ. The inset in (b) depicts a low-temperature region of the modulus curve in extended scales.

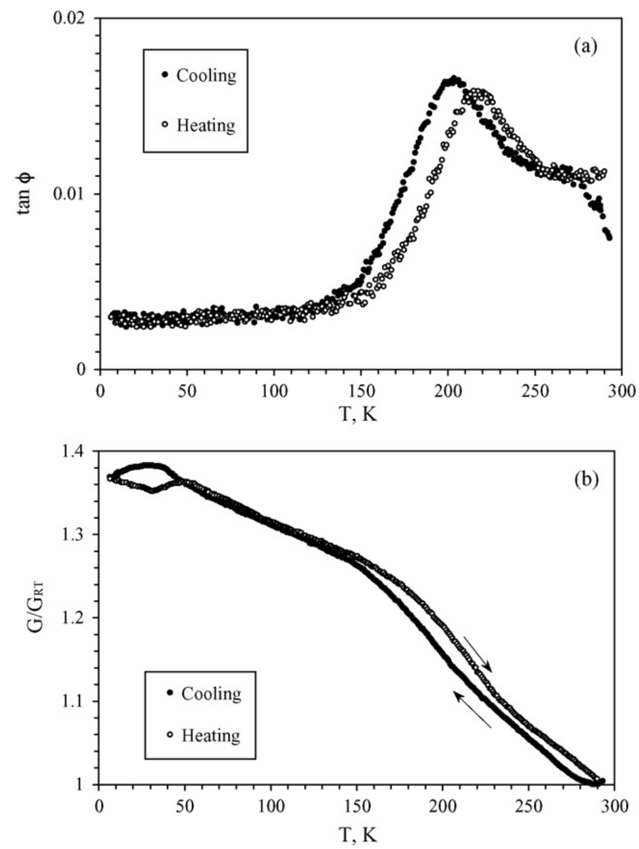

Fig. 2. Temperature dependence of the internal friction, $\tan\phi$ (a), and normalized shear modulus, G/G_{RT} (b), of a Ni–Ti–Cu sample measured at frequency of 2 Hz, temperature change rate of 1 K/min and strain amplitude of about 8×10^{-5}.

The temperature dependence of the internal friction and normalized shear modulus of a Ni–Ti–Cu sample, registered in a thermal cycle, is represented in Fig. 2. The internal friction peak appears also at about 200 K, but it is smaller than that for the Ni–Ti alloy. The shape of the peak is nearly the same for cooling and heating runs, in contrast to the data for Ni–Ti. The temperature hysteresis of the internal friction and dynamic shear modulus is much weaker in Ni–Ti–Cu (about 15 K for the internal friction peak). The temperature dependence of the dynamic shear modulus exhibits temperature hysteresis in two temperature ranges: in the vicinity of the internal friction peak (120–300 K) and at low temperatures (6–50 K). There are regions where the dynamic shear modulus exhibits negative temperature dependence both on cooling (35–6 K) and on heating (30–50 K).

Curves 1–3 in Fig. 3 show the internal friction spectra registered at different strain amplitudes on cooling from 300 to 100 K for the Ni–Ti sample aged for 2 years at room temperature. Curve 4 shows the temperature evolution of amplitude-dependent internal friction derived as the difference between curves registered at different strain amplitudes. One can see that the amplitude-dependent internal friction varies with temperature mainly in the temperature range of the internal friction peak, not evenly