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Damping Behavior Of A Ti-richTi-Ni Binary Shape Memory Alloy

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ABSTRACT

Shape memory alloys attract increasing interest as materials that can be used for passive as well as active damping applications. The internal friction spectra of TiNi shape memory alloy (SMA), which involves thermoelastic martensitic transformation, can be divided into three different terms: intrinsic, transitory and phase transition. In this work, the damping behavior of $Ti_{50.5}Ni_{49.5}$ (at.%) SMA has been investigated using dynamic mechanical analyzer instrument. The internal friction spectra of a Ti-rich $Ti_{50.5}Ni_{49.5}$ SMA have been discussed quantitatively and divided into intrinsic and transitory contributions using an iterative method.

KEYWORDS

Internal friction;
Shape memory alloy;
Damping capacity;
Ti-Ni binary alloy.

INTRODUCTION

Ti-Ni alloys are known as the most important shape memory alloy (SMAs) because of their many applications based on the shape memory effect and pseudo-elasticity. This comes from the fact that Ti-Ni alloys have superior properties in ductility, fatigue, corrosion resistance, biocompatibility and recoverable strain, etc. it is also reported that Ti-Ni alloys can exhibit a high mechanical damping and are promising for the energy dissipation application[1-5]. Indeed, the motion of martensite interfaces can be a source of high damping, and several reviews have been devoted to this subject[6-8]. It's recognized that there are three different terms (i.e., intrinsic, transitory and phase transition) in the internal friction (IF) spec-

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trum during martensitic transformation[9-12].

In the past, there have been many applications to utilize the damping properties in civil constructions, especially in buildings and bridges against earthquake damage[13,14]. From the application point of view, the investigations about the influence factors on damping capacity are of importance. Nowadays, the effects of the temperature changing rate, the frequency and the strain amplitude on the damping capacity have been systematically investigated[15,16], and several researches have been conducted on TiNi-based alloys having different composition, processing histories, etc.[17,18]. Until recently, most of the internal friction related reports of Ti-Ni based SMAs focus on effects of composition, heat treatment condition, processing condition, etc. on internal friction spectra obtained by using experimental routes[19-22]. But the results of the quantitative analysis on internal friction for Ti-Ni SMAs involving thermoelastic martensitic transformation are very limited. The purpose of the present work is to get the systematic data of the internal friction spectra in a quantitative and precise way.

In this paper, the internal friction spectra of a Ti-rich $Ti_{50.5}Ni_{49.5}$ (at.%) SMA by dynamic mechanical analyzer (DMA) instrument and analyze quantitatively the internal friction by an iterative method.

EXPERIMENTAL

The Ti-rich Ti-Ni alloys were prepared from 99.7 mass% sponge Ti and 99.96 mass% electrolytic Ni by melting in a medium frequency vacuum induction using a lime crucible and homogenized at 860°C for 4h. The nominal chemical composition of the alloy prepared in the present experiment was $Ti_{50.5}Ni_{49.5}$ (at.%). The ingots with a weight of ten kilograms were hot-forged and then hot-rolled into plate with a thickness of about 3mm. The plate was solution treated at 860°C for 2.4ks followed by water quenching and then spark-cut into the internal friction specimen with dimensions of 50×10×3 mm.. The samples were mechanically polished and chemically etched in order to remove the affected surface layer. The etching agent consisted of hydrofluoric acid, nitric acid and water in the proportion of 10:40:50 in volume.

A dynamic mechanical analyzer (DMA) instrument of type TA Q800 conducted by the with the dual cantilever clamps and the multi-frequency module was used to measure the elastic energy dissipation coefficient of the $Ti_{50.5}Ni_{49.5}$ alloy as a function of temperature. The oscillation frequency was controlled at 1 Hz. In these measurements, the cooling/heating rate was taken at 0.17°C/s.

RESULTS AND DISCUSSION

The internal friction spectra during the forward martensitic transformation and the reverse martensitic transformation are shown in figure1. It can be seen clearly only one-stage phase transformation during cooling and heating processes corresponding to a transformation from austenite (B2) to mono-

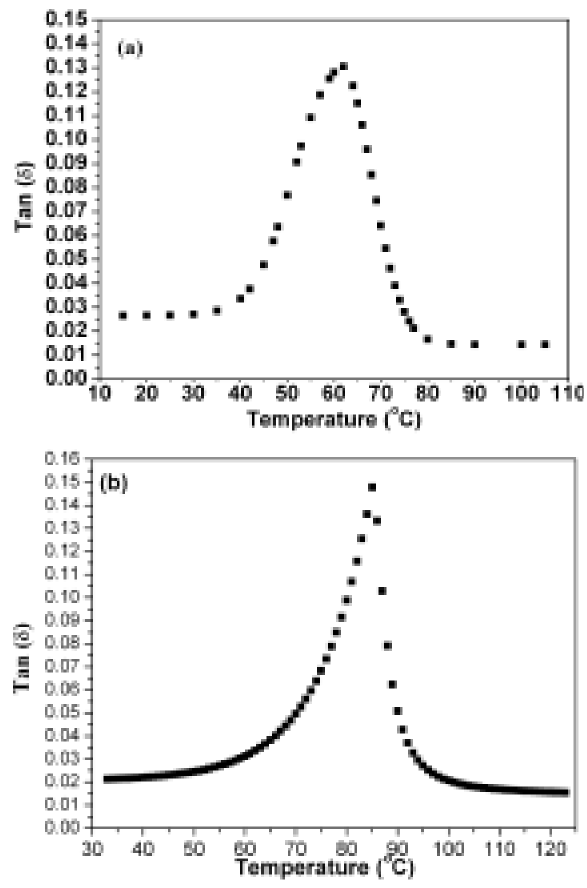

Figure 1: Experimental internal friction measurements during the forward (a) and reverse (b) martensitic transformation in the $Ti_{50.5}Ni_{49.5}$ SMA.

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clinic martensite (B19') and from B19' to B2, respectively, as shown in figure 1. The internal friction value of the martensite is bigger than that of the austenite during the forward and reverse martensitic transformation.

The iterative method can be utilized to analyze the normal internal friction spectra obtained at a constant temperature rate during martensitic transformation.

The volume fraction of the transformed martensite as a function of temperature can be expressed as[23]:

$$n(T) = \int_{T_s}^{T} IF_{TR}\omega\, dT \Big/ \int_{T_s}^{T_f} IF_{TR}\omega\, dT \quad (1)$$

Where T_s and T_f are two temperatures well above and below the martensitic start and finish temperature M_s and M_f, respectively, and ω is the oscillation frequency. J(T) and $J(T_f)$ can be expressed as[11,23]

$$J(T) = \int_{T_s}^{T} (IF - IF_{IN})\,\omega\, dT = \int_{T_s}^{T} IF_{TR}\,\omega\, dT + \int_{T_s}^{T} IF_{PT}\,\omega\, dT \quad (2)$$

$$J(T_f) = \int_{T_s}^{T_f} (IF - IF_{IN})\,\omega\, dT = \int_{T_s}^{T_f} IF_{TR}\,\omega\, dT + \int_{T_s}^{T_f} IF_{PT}\,\omega\, dT \quad (3)$$

Which using Eq. (1), it can also be expressed as

$$J(T) = n(T)\int_{T_s}^{T_f} IF_{TR}\,\omega\, dT + \int_{T_s}^{T} IF_{PT}\,\omega\, dT \quad (4)$$

It can then be shown that, when measured at low frequency and with an ordinary temperature change rate, there is a simple relationship between J(T) and n(T):

$$J(T)/J(T_f) = n(T) + \Delta n(T) \quad (5)$$

Here,

$$\Delta n(T) = \frac{\int_{T_s}^{T} IF_{PT}\omega\, dT - \frac{J(T)}{J(T_f)}\int_{T_s}^{T_f} IF_{PT}\omega\, dT}{\int_{T_s}^{T_f} IF_{TR}\omega\, dT}$$

$$IF_{IN}(T) = n(T)\, IF_m + [1 - n(T)]\, IF_a \quad (6)$$

Here $\Delta n(T)$can be neglected during low frequency measuring and high enough $\dot{T}$[11, 23], and in these cases, relationship between J(T) and n(T) will be:

$$J(T)/J(T_f) \approx n(T) \quad (7)$$

The intrinsic internal friction can be obtained by the following iterative process:

We can choose an arbitrary initial function of the intrinsic internal friction $(IF_{IN}(T))_{initial}$ on condition that it is in the range between IF_a and IF_m values. IF_a and IF_m are the internal friction values of austenite and martensite, respectively, and can be easily obtained from the normal internal friction spectra. $[IF(T)-(IF_{IN}(T))_{initial}]$ can be obtained by using the chosen $(IF_{IN}(T))_{initial}$ function. Calculating the integral J(T) and $J(T_f)$, volume fraction n(T) can be determined by applying Eq.(7).

By applying the following equation, a new expression $IF_{IN}(T)_1$ can be calculated:

$$IF_{IN}(T) = n(T) IF_m + [1 - n(T)] IF_a \quad (8)$$

By using $IF_{IN}(T)_1$, the iterative process is performed until the difference between the $(IF_{In}(T))_{i-1}$ and $(IF_{In}(T))_i$ in the iterative cycle becomes smaller than a prefixed value, e.g., 10^{-6}. Finally, the intrinsic internal friction term can be obtained easily and precisely. Subtracting the intrinsic internal friction term from the original internal friction spectra, the transitory plus phase transition terms can be easily calculated. Because the phase transition term is very small and can be neglected, a good approximate transitory internal friction term can be determined[11].

Applying the above iterative method, the intrinsic internal friction spectra during the forward and reverse martensitic transformation of $Ti_{50.5}Ni_{49.5}$ SMA are indicated in figure 2(a) and (b). It can be clearly seen that the intrinsic internal friction values increase slightly before and after the forward martensitic (or the reverse martensitic) transformation, increase sharply during the forward martensitic (or the reverse martensitic) transformation process with the decreasing of temperature.

Subtracting the intrinsic internal friction spectra from the corresponding internal friction spectra, the obtained transitory internal friction spectra are shown in figure 3. Figure 3(a) and (b) correspond to the approximate transitory internal friction terms during cooling and heating stages, respectively. The transitory internal friction term, which only appears during the temperature variation process, is greatly bigger than the intrinsic internal friction term. The result suggests that the potential damping application of Ti-Ni SMA should utilize these characteristics of internal friction although there are few examples.

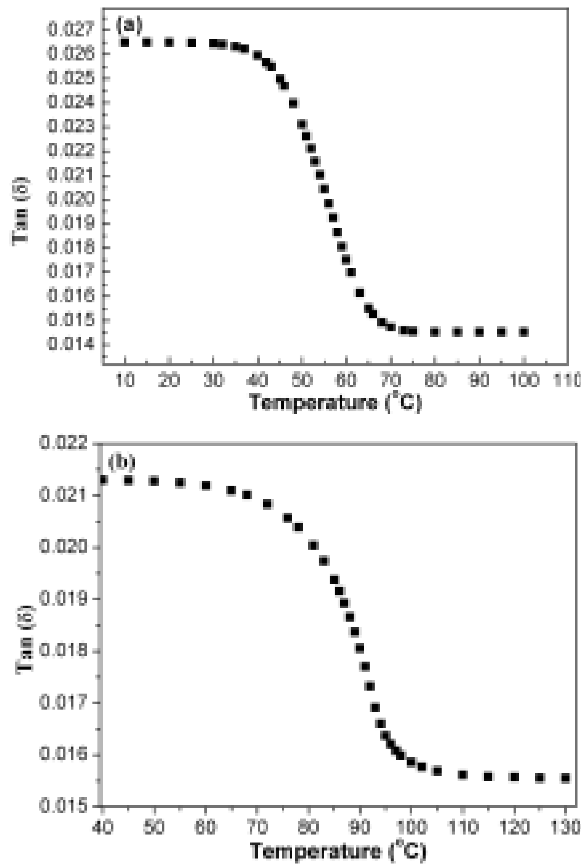

Figure 2: Intrinsic internal friction spectra during (a) the forward martensitic transformation and (b) the reverse martensitic transformation determined by an iterative method for the $Ti_{50.5}Ni_{49.5}$ SMA.

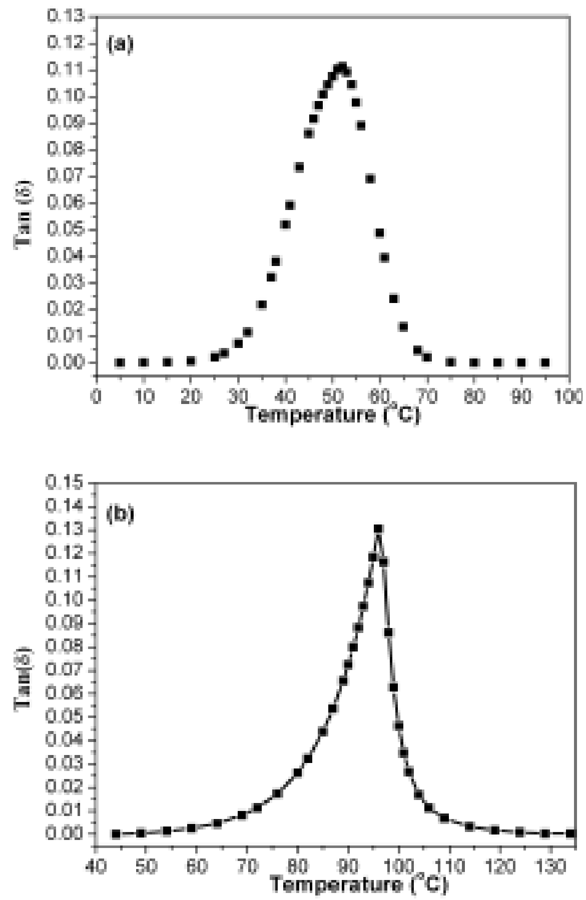

Figure 3: Experimental transitory internal friction measurements during the forward (a) and reverse (b) martensitic transformation in the $Ti_{50.5}Ni_{49.5}$ SMA.

CONCLUSIONS

There is only one peak during the forward and reverse martensitic transformation in internal friction spectra measured by DMA instrument. Using an iterative method, a quantitative analysis of normal internal friction spectra of Ti-Ni SMA can conveniently and easily carried out. A precise intrinsic and an approximate transitory internal friction contributions are obtained. The thermoelastic martensitic transformation in Ti-rich Ti-Ni shape memory alloy has a great potential for use in damping application in both the martensite phase and the austenite phase.

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