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**INTERNAL FRICTION AND ULTRASONIC ATTENUATION ASSOCIATED WITH THE
NORMAL TO INCOMMENSURATE TRANSITION IN NiTi(Fe) ALLOY**

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Abstract - Two ultrasonic attenuation maxima with two corresponding minima of longitudinal sound velocity and two internal friction peaks have been measured in NiTi(Fe) alloy on cooling at about -26°C and -90°C respectively. EM observation shows the maximum at -26°C is associated with the normal-incommensurate transition whereas that at -90°C is due to lock-in transition. The mechanism of the internal friction associated with N/I transition is centered on.

I - INTRODUCTION

A number of anomalies have been observed in NiTi alloys above the martensitic transition temperature, which was considered to be the pre-martensitic effect. Electron microscopic investigation made by Wayman /1/ on NiTi(Fe) alloys shows that these anomalies are induced by the normal-incommensurate(N/I) transition and the subsequent incommensurate-commensurate(I/C) or named lock-in transition which has no direct relationship with martensitic transition. Discommensurations have been found in NiTi by Michal /2/ through lattice images. The incommensurate phase transition has been observed in many crystals in recent years. However, ultrasonic attenuation and sound velocity studies related to the N/I and I/C transition were made in only a few crystals such as Rb_2ZnCl_4 , K_2ZnCl_4 /3/ and K_2SeO_4 /4/ and internal friction measurements were made in NiTi (Fe) /5/, TaSe_2 /6/ at KHz range. Analysis was made on the variation of C_{55} in the vicinity of I/C transition in K_2SeO_4 , considering the influence of discommensurations, but no satisfactory theoretical explanation has been made for internal friction and attenuation coefficient associated with N/I transition yet. In this paper, NiTi(Fe) is used because in this alloy, the C/I transition temperature (T_c) is widely separated from the N/I transition temperature (T_i) that enables one to concentrate on the ultrasonic attenuation and internal friction investigations of N/I transition. Some electron microscopic observations have been made and the mechanism of internal friction are discussed.

II - EXPERIMENTAL TECHNIQUE

The samples with concentration 52.12 at% Ti, 46.06 at% Ni and 1.82 at% Fe, were treated with standard method /1/. Internal friction (Q^{-1}) was measured by an inverted torsion pendulum and ultrasonic attenuation by Matec Model 6600 and sound velocity measurement was carried out using pulse echo overlap method on the same apparatus.

III - EXPERIMENTAL RESULTS AND DISCUSSION

(1) ultrasonic attenuation and sound velocity

ultrasonic attenuation measured on cooling shows that there are two attenuation maxima at -26°C and -90°C respectively with two corresponding minima of longitudinal sound velocity (Fig. 1). Electron microscopic observation shows that weak superlattice diffraction spots near $1/3$ (110) and $1/3$ (111) position of B_2 structure appear at

Fig. 1 - Attenuation and longitudinal sound velocity as function of temperature at 4.6MHz

Fig. 2 - $[111]_{B_2}$ zone diffraction patterns showing $1/3$ (110) superlattice reflections at -40°C

about -26°C and intensify with decreasing temperature (Fig. 2) until forming needle-like domains of R phase about -90°C (Fig. 3), which is in accordance with Wayman's EM observation on the analogous alloy /1/. It is convincing that -26°C attenuation maximum is related to the N/I transition whereas the maximum at -90°C is due to I/C transition. Since the phase formed in the I/C transition bears the characteristics of martensite, it is reasonable to consider the mechanism of attenuation to be similar to that of MT /7/8/. Fig. 4 shows the attenuation measured at 4.6-12.1 MHz in the process of N/I transition, it is clearly seen that the attenuation is proportional to the square of measuring frequency (Fig. 4(b))

Fig. 3 - Electron micrograph showing a typical example of needle domains at -95°C

in which the background attenuation in higher temperature side has been deducted. However, the variation of sound velocity shows no dispersion in the frequency range. Though the square relation is obeyed both in fluctuation dissipation mechanism and phonon relaxation, we consider, in view of the linkage between N/I transition and the softening of acoustic phonon, that bilinear interaction of ultrasonic wave with soft

Fig. 4 - (a) Attenuation as function of temperature at 4.6 MHz, 9.7 MHz, 12.1 MHz (b) Attenuation vs square of measuring frequency at different temperature.

Fig. 5 - Internal friction as function of temperature at $f = 1.7$ Hz and $T = 1^\circ\text{C/min}$.

phonon to be the principal cause of the attenuation.

(2) Internal Friction

The Q^{-1} , measured in an inverted torsion pendulum on cooling (fig. 5), shows a small peak about -26°C and a larger one about -90°C with a high plateau between two peaks. EM analysis manifests that peak at -26°C is associated with N/I transition while the one at -90°C with I/C transition. Thinking on the presence of needle type domains in the lock-in transition similar to the situation in martensitic transition, it is reasonable to attribute internal friction to stress induced motion of interphase boundaries of R phase [9]. The Q^{-1} in N/I transition at different frequencies and heating rate was measured (fig. 6(a)) and the linearity of Q_m^{-1} to $\dot{T}/f$ is obtained (Fig. 6(b)). The non-zero intercept of the longitudinal axis implies the Q^{-1} under isothermal condition. Magnitude of

Fig. 6 - (a) Internal friction as function of temperature at different measuring frequency and heating rate.
(b) Q^{-1}_{max} vs $\dot{T}/f$

Q^{-1} at $\dot{T} = 0$ is approximately equal to plateau between the two peaks which does not change with $\dot{T}$ and f . Actually phonon relaxation does not contribute to Q^{-1} at $f = 1$ Hz. The Q^{-1} proportional to $\dot{T}/f$ being common to first order phase transition, the mechanism of Q^{-1} is considered to be similar to that of martensitic transformation suggested by one of the authors [10]. When an object under constant surface traction is subjected to change of elastic stiffness due to phase transition, the elastic energy will also changes, half of the work done by applied stress is turned into elastic energy, and the other half dissipated [11]. Since the measurement of sound velocity shows a steep change in the vicinity of T_1 and applied stress can be treated as

constant in the instance of change, half of work done by applied stress is dissipated which give rise to internal friction. The larger the change of elastic constant in a vibration period, the larger the internal friction, namely $Q^{-1} \propto \dot{T}/f$. Because the height of the Q^{-1} plateau at the lower temperature side of the I/C transition peak does not change either with $\dot{T}$ or f , we consider it to be the static hysteresis loss due to the existence of discommensuration in this temperature range. In the NiTi(Fe)/1/ alloy, the lattice and incommensurate modulation lock-in and become commensurate principally through the rhombohedral distortion due to the abrupt expansion along $\langle 111 \rangle$ direction about T_C and the number of discommensurations almost remain unchanged in the incommensurate phase. So a stable Q^{-1} plateau appears. We intend to observe the relation between Q^{-1} and the lattice images of discommensuration by means of high resolution electron microscopy. Mercier's /3/ investigation of Q^{-1} in NiTi (Fe) with similar content at KHz range shows no obvious peak at T_1 and a broad protrusion in the region of N/I transition, it may be attributed to the increase of frequency much more than 1Hz so that make $\dot{T}/f$ tend to zero. It is also easy to explain that why the Q^{-1} peak of N/I transition measured at 3.69KHz is much lower than that obtained at 0.5KHz in TaSe₂ /6/.

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