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THE INTERNAL FRICTION STUDY OF INTERFACE DYNAMICS OF NiTi ALLOY IN THE PROCESSES OF MARTENSITIC AND I/C PHASE TRANSFORMATION

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Abstract—Two internal friction peaks associated with martensitic and I/C(R) phase transformations were observed in the first thermal cycle for NiTi alloy. By utilizing the experimental data of IF (as a function of \( \frac{T}{\omega} \)), an explicit functional relationship of interface dynamics was obtained as \( V = V^* \exp\left(-\frac{\Delta G - \Delta G_a}{\Delta G - \Delta G_T}\right) \), and the expression of IF during the process of transformation as \( \frac{Q}{\omega} = C \cdot \Delta G^* (\frac{dF}{dT}) \frac{1}{\omega} (\Delta G - \Delta G_a)^4 \), where \( V \) is the average velocity of phase interface, \( \Delta G \) is the phase transformation driving force; and \( \Delta G_a \) is the transformation resistant force, which has the order of 5 kcal/mol, 8 kcal/mol and 10 kcal/mol for I/R, R/M and M/p transformations respectively. The "Soft Mode Effect" during the transformation processes has been discussed.

I-INTRODUCTION

The internal friction peak at low frequency in the process of martensitic transformation have been observed in many alloys such as FeMn (1), NiTi (2) and AuCd (3) et al. These IF peaks have characters of: 1) when the temperature variation rate \( \frac{T}{\omega} \) = 0, the peak height is proportional to \( \frac{T}{\omega} \) (\( \omega \) is angular frequency of measuring); 2) the IF is independent on the amplitude of measurement; 3) when \( \frac{T}{\omega} = 0 \), the characterizing IF associated with the transformation process disappears. There are some models attempted to interpret the damping mechanism of martensitic transformation (4, 5, 6, 3). Recently, an interface dynamic model has been proposed by one of the authors (7), and the IF was considered to be a Maxwell-type viscous damping resulted from the motion of interfaces in the process of transformation.

In this paper, we report a IF study of interface dynamics of NiTi alloy in the process of martensitic and I/C(R) phase transformation.
II-EXPERIMENT

The IF, elastic modulus ($f^2$) and electric resistance ($\Delta R$) were measured during linear heating and cooling processes on an improved KÅ's torsional pendulum. All three parameters were measured simultaneously on the same specimen, with temperature variation rate $\Upsilon=0.25-5K/min$ and frequency of measuring $f=1Hz$. The NiTi alloy used has a nominal composition of Ni-49.7 at%Ti, and cold rolled to a thin plate. Specimens were taken to the dimension of $35x2.5x0.25(mms)$ and were annealed for 1 hour at $500^\circ C$ before measurement. All the measurements of IF, $f^2$ and $\Delta R$ were carried out in the first thermal cycle for the IF is dependent sensitively on thermal cycles (8).

III-RESULTS AND DISCUSSIONS

Two IF peaks which separated clearly were observed in the descending process even for the first thermal cycle (fig.1). The first one peak accompanied by a sharp minimum of modulus ($f^2$) and an abnormal change in electric resistance ($\Delta R$) is resulted from the incommensurate to commensurate (I/R) phase transition. The second peak accompanied by the decrease of electric resistance is caused by the martensitic transformation (R/M). While in the process of ascending, only one IF peak associated with the reverse martensitic transformation (M/P) was observed.

The peak heights of I/R, R/M and M/P transformation are proportional to $(\Upsilon/w)$ (fig.2), but they are not a good linear relationship as reported(1).

Considering the motion of phase interfaces in the process of transformation under action of transformation driving force $\Delta G$, and also the existence of resistant force $\Delta G_R$, there exists a relationship between the average moving velocity of the interfaces $V$ and the effective driving force $\Delta G'=\Delta G-\Delta G_R$ as $V=\psi(\Delta G-\Delta G_R)$. From this consideration, a interface dynamic model related to IF and $\Delta M/M$ (the modulus minimum of measuring) in the process of phase transformation has been established as

$$Q= \left(\frac{n^2}{2}\right) \cdot \frac{d \log \psi(\Delta G')}{d \Delta G'} \cdot dF/dT \cdot \Upsilon / w \quad (1)$$

$$\Delta M/M= n \xi \cdot d \log \psi(\Delta G') \cdot dF/dT \cdot \Upsilon / w \quad (2)$$

where $n$ is the coupling factor, $\Upsilon$ is the shear modulus, $dF/dT$ is the transformation rate of new phase and $\xi$ is the transformation strain. This expression can explain reasonably all the three characteristics of IF during I/R and M/P transformation mentioned above.

Eqn. (1) could be rearranged as

$$\psi(\Delta G')=C \cdot d \log \psi(\Delta G')/d \Delta G' = Q^\prime w/(\mu \Upsilon \cdot dF/dT) \quad (3)$$

All the parameters in the right hand side of eqn. (3) can be measured by experiments. So, by utilizing eqn. (3) and experimental data, an explicit functional relation of $V=\psi(\Delta G')$ can be obtained.

For the first order phase transformation, the variation of enthalpy $\Delta H$ with temperature can be ignored, then the chemical driving force can be written as

$$\Delta G=\Delta H \cdot (T-T_0)/T_0 \quad (4)$$

where $T_0$ is the balance temperature between two phase, and $\Delta H$ was measured by DSC-IIC (PERKIN-ELMER).

Taking $\Delta G_R$ as a parameter to be determined, and using the linear analyse method, we get (fig.3)

$$d \log \psi(\Delta G-\Delta G_R)/d \Delta G' = \Delta G^*/(\Delta G-\Delta G_R) \quad (5)$$
and 
\[ v = \Phi(\Delta G - \Delta G_R) = v^* \exp(-\Delta G^*/\Delta G - \Delta G_R) \]  
(6)

where \( v^* \) is a limited velocity, \( \Delta G^* \) is a characteristic force, corresponding to \( v = v^*/e \); and the resistant force \( \Delta G_R \) has the order of 5 cal/mol, 8 cal/mol and 10 cal/mol for I/R, R/M and M/P transformations, respectively.

Put equ.(5) into equ.(1), we obtained the expression of IF during phase transformation as

\[ Q' = \left( \frac{n^2}{2} \right) \mu \cdot \frac{dF}{dT} \cdot \frac{\Delta G^*}{w(\Delta G - \Delta G_R)^2} \]  
(7)

The \( (\Delta M/M)-(\dot{T}/w) \) curve was shown in fig.4. By comparison fig.4 with equ.2, it is clear that the extrapolated value of \( \Delta M/M \) at \( \dot{T}/w=0 \) is not zero, and is associatead with the soft of sonic mode. The experimental value of \( \Delta M/M \) in the processes of I/C and M/P phase transformation was composed of the soften of sonic mode and the modulus defect resulted from the motion of interfaces.

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Fig. 1 - Plots of internal friction modulus and resistance vs temperature.

Fig. 2 - The $Q''$-$\gamma$/w curves for I/R, R/M, and M/P transformations.

Fig. 3 - Log $\gamma$($\Delta G - \Delta G_R$) - Log($\Delta G - \Delta G_R$) curve of I/R transformation.

Fig. 4 - The $\Delta M/M$-$\gamma$/w curve of I/R transformation.