THERMOELASTIC CHARACTERIZATION OF SINTERED TiNi MATERIALS

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Abstract. - The equiatomic TiNi compound has been extensively studied because of the shape memory effect. In principle, this intriguing effect is associated with thermoelastic martensitic transformation and reverse transformation. This specific thermal behavior is most interesting for examination, from aspects of thermoelasticity. The incoming of thermal energy in the temperature region of the transformation changes the feature of elasticity. For this reason, the registered values of the velocities and attenuation of ultrasound in region of transformation are changed. This phenomenon is the most important for studying the nondestructive thermoelastic behavior in examined materials.
Using the relationship from theory of elasticity (from values of the density and velocities of ultrasound) it is possible to obtain the values of elastic moduli. In this case it is possible to obtain information about elastic (i.e., thermoelastic) state.

1. Introduction

The type of transformation which occurs in the shape memory alloys is known as a martensitic transformation and changes the material from the high temperature form, called austenit (A), to the low temperature form called martensitic (M). For a given alloy composition in a given annealed condition, the transformation occurs at a very predictable, repeatable temperature. The transformation occurs because either one phase or the other is thermodynamically more stable than the other at that temperature. Also, because the material can change from one phase to another one with a simple shearing motion of the atoms within the crystal structure and no diffusion or large movements of the atoms is required, the transformation can occur virtually instantly. That is, as fast as heat energy can be put into or taken out of the material, the transformation (and memory) will occur.

The influence of composition and thermomechanical processing of the functional properties is well understood and described earlier in the literature. The basic concept to remember is that in order to avoid plastic deformation during shape memory or pseudoelastic loading, the martensitic and the β-phase have to be strengthened. NiTi alloys have the significant advantage, that these techniques can be easily applied due to good ductility and a very interesting, but complicated precipitation process [1].

2. Experimental procedure

The samples for examination were prepared by pressing and sintering [2], [3], from powder mixture of metal (Ni-99.8%-pure and Ti-99.5%-pure; produced in MERCK- Company). The diameter of the prepared cylindrical samples was 17.5 and the length was about 18mm. The maximum value of the pressure was 400MPa. The samples were sintered in argon atmosphere at the temperature of 1073K for the time of 3.6 ks. The experimental values of the velocities and attenuation were obtained in interval of temperature from 290 to 425K.

The market effect of the shape memory materials is conversion of the low temperature of thermal to mechanical energy. Without the elastic deformation by using ultrasound it is
possible to register the elastic (i.e. thermoelastic) changes through the austenit/martensit and reverse temperature transformation. In this region the values of velocities and attenuation showed hysteresis behaviour. These results are most important for determination of the interval of the temperature transformations, for to decrease or increase the hysteresis form, for shift this hysteresis and for more other aspects.

![Fig. 1. Selected 1 and 2 echoes](Up velocities, down attenuation)

The velocities and attenuation of longitudinal and transverse ultrasonic waves were measured by Pulse-echo overlap method and technique detailed described earlier [4] [5]. A typical used echo patterns (up for velocities, down for attenuation) are shown in Fig. 1. The velocities of ultrasonic waves were measured at 6MHz, and attenuation at 3MHz.

3. Experimental results and discussion

The transparency of ultrasound is in direct correlation with the elastic state of the examined materials. This is most important for obtaining information about thermoclastic state in materials with shape memory effect. For this purpose it is proposed to investigate the transparency of ultrasound with warming and cooling through interval of M/A and reverse transformation.

![Fig. 2. The diagrams of the longitudinal (vL) and transverse (vT) ultrasonic waves as a function of temperature](VL-0/1073 K, VT-0/1073 K)

The obtained diagrams of velocity waves in examined material are presented:

Depending on the quality of the equipment and scattering – R, magnetoelectric effect –

The values of attenuation of longitudinal and transverse waves in temperature interval from attenuate [5]. The diagrams for a

![Fig. 3. The diagram of attenuation](Alin-1, 3)

where the subscript "l" refers to the longitudinal wave, and the subscript "t" refers to the transverse wave. The values of attenuation were measured at 3MHz and plotted as a function of temperature.
The obtained diagrams of velocities of longitudinal ($v_l$), and transverse ($v_t$) ultrasonic waves in examine material are presented in Fig 2.

Depending on the quality of the material, its structural conditions and its ultrasonic frequency there may be more different absorption mechanisms

$$\alpha = \Sigma \alpha_i$$  \hspace{1cm} (1)


The values of attenuation of longitudinal ($\alpha l$) and transverse ($\alpha t$) ultrasonic waves in tinny compound in temperature interval from 290 to 425 K were obtain from measurement by earlier described equipment [4]. The values of attenuation ($\alpha$ in dB) were measured directly from attenuate [5]. The diagrams for attenuation are present in the Fig. 3.

**Fig. 3.** The diagrams of the attenuation of the longitudinal ($\alpha l$) and Transverse ($\alpha t$) ultrasonic waves

The elastic state of the examined material is presented in Fig. 4. It is proposed to investigate the $\alpha l$ and $\alpha t$ through interval of $M/A$ and reverse $\alpha l$ and $\alpha t$.

**Fig. 4.** The diagrams of the diagrams of the Bulk modulus ($K$) and the Young modulus ($E$)
From the previous figures it is evident that the diagrams of velocities and attenuation have a hysteresis form in same interval of temperature i.e. interval of transformation.

By standard relationships from the theory of elasticity [6], using the values of the density ($\rho$) of the sample and velocities ($v_l$ and $v_t$) of the ultrasonic waves, the bulk modulus ($K$) and Young modulus ($E$) were determined by following relationship:

$$K = (3\rho v_l^2 - 4\rho v_t^2)/3$$

$$E = \rho \frac{v_l^2 (3v_l^2 - 4v_t^2)}{v_l^2 - v_t^2}$$

where the $v_l$ and $v_t$ are values of the longitudinal and transverse ultrasonic waves, respectively.

All presented diagrams (Fig 2-5) are typical transformation curve for materials with shape memory effect. The critical point in the transformation, which is shown are the martensite starting temperature during cooling ($M_s$), and martensite finish temperature ($M_f$), the austenite starting temperature during heating ($A_s$), and the austenite finish temperature ($A_f$). The minimum values of the velocities, attenuation and elastic moduli at $M_f$-point can indicate pseudoeelastic state of the examined materials.

4. Conclusion

The propagation of ultrasonic waves and attenuation in this paper is utilized for examination of elastic and thermoelastic behaviour in TiNi materials with shape memory effects. The examined samples were prepared from powder particle of Titanium and Nickel, by earlier described method of powder metallurgy. The velocities of ultrasound were measured by the pulse echo overlap method, and total values of attenuation were obtained directly from ultrasonic equipment. The elastic moduli were calculated by relationship from theory of elasticity. With thermal treatment trough the temperature of transformation were obtained information about thermoelastic behaviour. From analyze and compared obtained hysteresis curves in materials with shape memory effect it is possible to determine most important thermoelastic behaviour in interval of temperature transformation.

References


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LATTICE DYNAMICS

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The Lattice dynamical calculations are performed. We assume ion-ion interaction within the CGW model. The theory has been applied to the ultrasonic frequency spectra and lattice specific heat. The results show good agreement with the experimental data.

1. INTRODUCTION

The alkaline-earth metals exhibit a variety of crystal structures. At room temperature, they transform to bcc structure above 830-870 K. Mg, Ca, and Sr transform to fcc structure above 830 K, and Ba transforms to bcc structure above 1040 K. These metals have a pronounced pressure for this metal at room temperature.

In the last two decades, the lattice dynamics of this class of materials has been studied extensively, both experimentally and theoretically. The theory is based on the pseudopotential theory, the Molière potential, and the pseudopotential approach [7] and a realistic model [8].

In this paper, we will use the first-order dynamical matrix approach proposed by Clark-Gazit and the classical model [9], as well as the second-order dynamical matrix approach [10].

2. THEORY

2.1 Dynamical Matrix for fcc and bcc Structures

By following the approach of Moore and Upadhyaya, we obtain the elements of dynamical matrix for ion-ion and atom-phonon interactions, as follows:

Fcc:

$$D_{ij} = 2(a_1 + a_2 \xi)^2 C_{ij} + C_{ij}^3 + 4(a_1 + a_2 \xi)^3 C_{ij} + C_{ij}^3$$

$$+ 8(a_1 + a_2 \xi)^4 C_{ij} C_{2ij} - C_{ij} C_{2ij} - C_{ij} C_{2ij}$$

$$- 4C_{ij} C_{2ij}^3 + 8\sqrt{3} \xi C_{ij} C_{2ij} C_{ij} C_{2ij}$$

where $a_1$, $a_2$, and $\xi$ are the lattice constants, the interatomic potentials, and the displacement of the ion, respectively.