THE INVESTIGATION OF PSEUDOELASTIC NITI WIRES FOR DAMPING USES

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Abstract

Some shape memory alloys like NiTi show noticeable high damping property in pseudoelastic range. Due to its instinct characteristics, a NiTi alloy is commonly used for passive damping applications, in which the energy may be dissipated by the conversion from mechanical to thermal energy. Previous researches found the NiTi wires own higher damping property than the bars; therefore the wire form is adopted in this study. A loss factor is introduced for measuring the damping property of the NiTi wires. The experimental observation shows the mechanical behaviors of NiTi wires are dependent on temperature, strain rate and strain amplitude. Moreover, it is found the first several decades of loading-unloading cycles can obviously influence the property of NiTi wires under the same working conditions.

Key Words: Shape memory alloy, Pseudoelasticity, Damping, Martensite, Austenite

INTRODUCTION

Shape memory alloy (SMA) materials have the unusual ability to recovery large deformation (up to 15%) without inducing the permanent residual strain. This distinct recovery ability of shape memory alloys like shape memory effect (SME) and pseudoelasticity effect (PE, also known as superelastic effect), as shown in figure 1, makes them more attractive than conventional materials [1].

The pseudoelasticity effect of SMA shows a phenomenon to recover the deformation by releasing the stress without change of temperature, resulting from the phase transformation above austenite finished temperature A_f. When the applied stress reaches a critical value, the austenite SMA material begins to transform to martensite phase; once the loading is released, the stress induced martensite SMA returns to austenite phase without residual strain [2].

Moreover, shape memory alloys also show conspicuous damping property [3]. The closed stress-strain curve is observed to form a hysteresis loop, which denotes the energy dissipation during loading-unloading behavior [4-5]. The inherent characteristics of SMAs like large recovery deformation, high energy dissipation capacity and high fatigue resistance make them conspicuous among all damping materials.

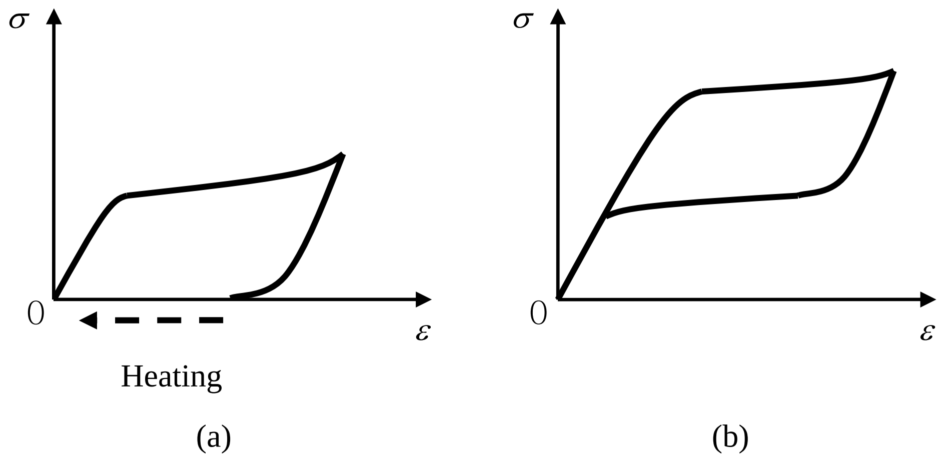


Figure 1 – The mechanical behaviors of shape memory alloys: (a) Shape memory effect; (b) Pseudoelasticity effect

Due to the fabrication technology and low cost, a Nickel-Titanium (NiTi) alloy has become the most prevalent shape memory alloy for commercial applications [6]. And many investigations have been exploited to find out the influence of environment conditions to the mechanical behavior of NiTi alloys [7-9]. In this study, a series of experiment work are observed and the phenomena reveal the damping property of NiTi wires is dependent on the temperature, strain rate, strain amplitude and cycle numbers.

SPECIMEN AND EXPERIMENT

The NiTi wires with nearly equiatomic composition are selected for experiment investigation here. The diameter of SMA wires is chosen as 1 mm in this experiment investigation. The unidirectional tensile load is applied to the SMA wire specimen in all the tests. The mechanical behaviors of wires are observed in various temperatures, strain rates, strain amplitudes and cycle numbers.

(1) Test at various temperatures

This test was conducted at temperature 293, 303, 313 K respectively with constant strain rate 1×10-2 s^{-1}. The surface temperature is kept constant during the test.

(2) Test on various strain rates

The different strain rates, 1×10^{-2}, 1×10^{-1} and 1 s^{-1}, were applied to the specimen at the constant temperature 313 K. The wires are not pre-cycled before the tests.

(3) Test at various strain amplitude

The maximum deformations of the wires are chosen as 2%, 4% and 6% in the tests to investigate the influence of strain amplitude on the wires. The temperature is 313K and the strain rate is in low strain rate 1×10^{-2} s^{-1} during the test.

(4) Test with various loading cycles

The mechanical behaviors of NiTi wires subjected to different loading-unloading cycles are exploited. The applied loads were completely unloaded to observe the influence of cycle numbers on the damping property of wires as well as their residual strain.

RESULTS AND ANALYSIS

To investigate the damping property of SMA wires, we introduce a parameter, loss factor, for analysis. The loss factor η is defined as the specific damping capacity per radian of the damping cycle [8].

$$\eta = \frac{\Delta W}{2\pi W} \quad (1)$$

where ΔW is the dissipated energy and W the strain energy. The schematic stress-strain diagram of dissipated energy and strain energy is shown in figure 2

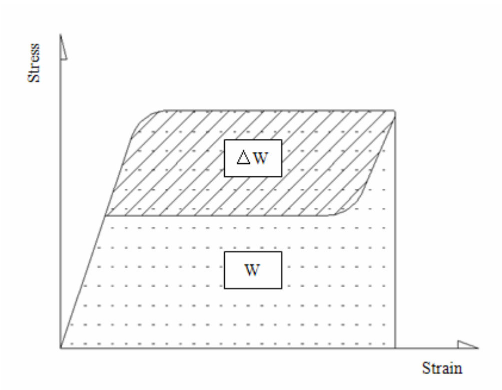
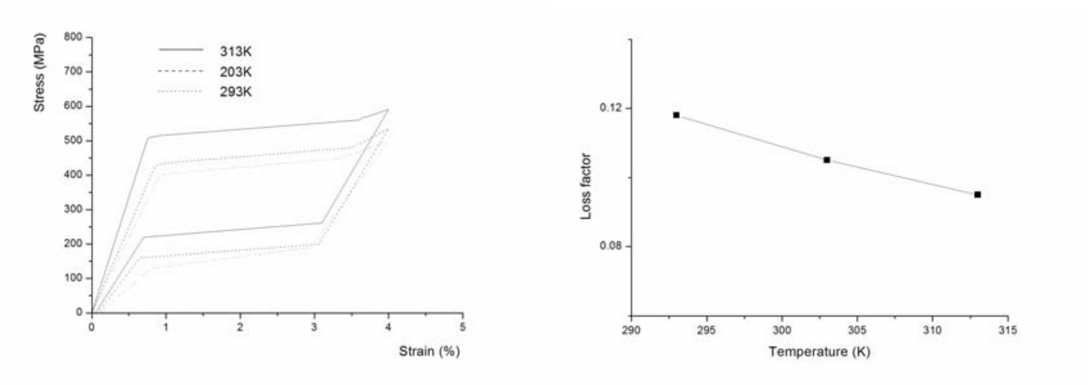


Figure 2– Schematic stress-strain diagram of dissipated energy and strain energy

3.1 Effect of temperature

The influence of temperature on the mechanical behavior of SMA wire is shown in figure 3. It is observed the transformation stress occurs when the strain reaches 0.75% around and large hysteresis loops appear during whole loading-unloading process. The higher the temperature, the higher transformation stress may yield. This phenomenon reveals the transformation stress from the austenite to martensite phase increases with temperature. Though the residual stress accumulates as temperature increase, it is neglectable compared with the whole large deformation. The loss factor can be obtained by equation (1) and is observed to decrease as temperature increases, as shown in figure 3(b). Correspondingly, that will cause the reduction of the damping performance.

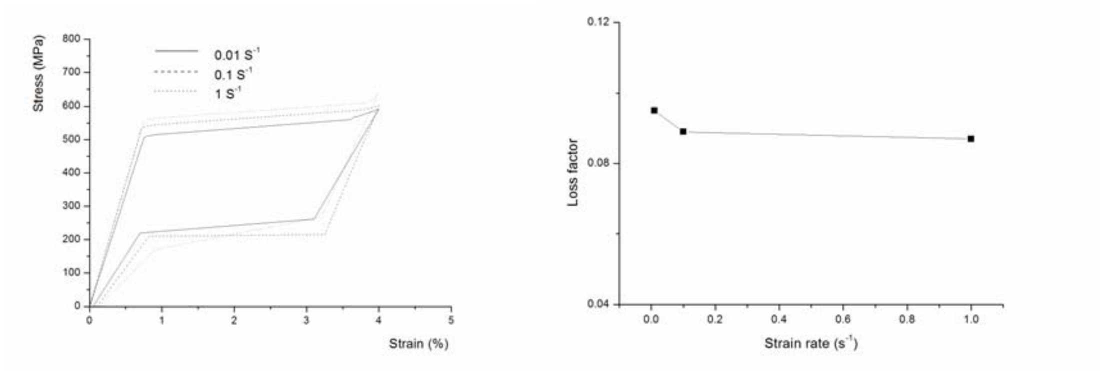


(a) (b)

Figure 3 – The influence of various temperatures on the NiTi wires: (a) The stress-strain curve; (b) The loss factor

3.2 Effect of strain rate

The wires are applied by tensile loads under different strain rates. Figure 4(a) shows the effect of strain rates on the mechanical behavior of the wires. As it is seen, the wires exhibit similar stress-strain contour. It is revealed by figure 4(b) that the loss factor of the wire change slightly as the strain rates range from 0.01 ~ 1 s^{-1}. Hence the mechanical properties can be ignored in this strain rates extent.

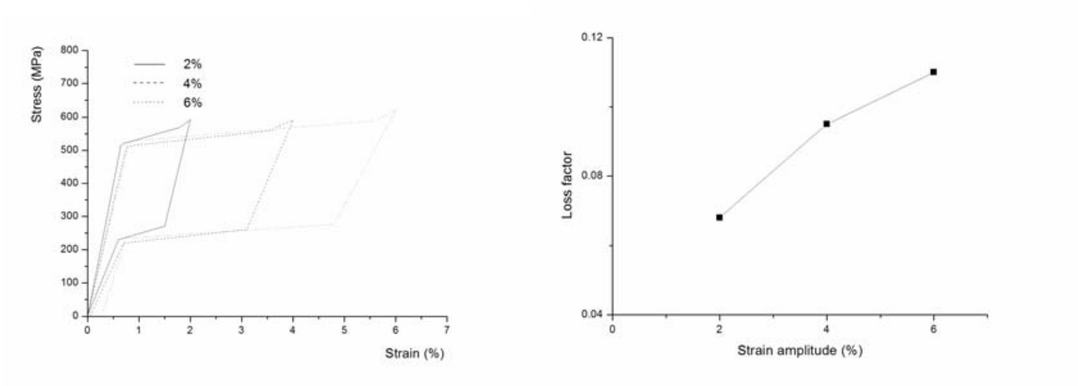


(a) (b)

Figure 4 – The influence of various strain rates on the NiTi wires: (a) The stress-strain curve; (b) The loss factor

3.3 Effect of strain amplitude

Figure 5(a) shows wires may keep similar loading-unloading contour with the variation of the strain amplitudes, whereas the width of hysteresis loops changes simultaneously. In addition, this phenomenon results in the severe change of loss factors, i.e. the damping property of the wires. Observed from figure 5(b), the wires with larger strain amplitude may dissipate more energy. While the residual strain turns considerable and cannot be ignored. Hence how to adjust the strain amplitude of SMA wire to obtain high damping performance with ignorable residual stress should be considered for practical applications.



(a) (b)

Figure 5 – The influence of various strain amplitudes on the NiTi wires: (a) The stress-strain curve; (b) The loss factor

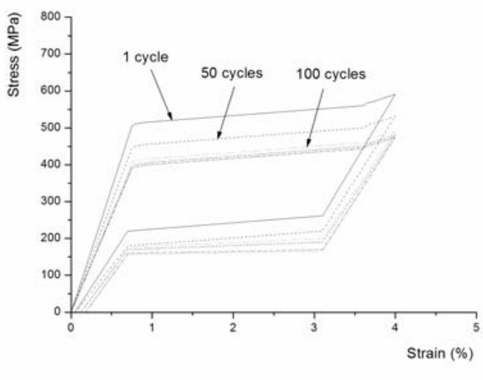


Figure 6 – The stress-strain curve with various loading cycles

3.4 Effect of cycle number

It is also observed that the pre-cycle will influence the mechanical behavior of SMA wires. Figure 6 shows that the stress-strain curve may change obviously in the first 100 cycles, while it turns static without obvious change as the loading-unloading cycle number increases. Based on the stress-strain plot, it can be deduced the cycle number, especially after 100 cycles, has no obvious influence on the loss factor.

CONCLUSIONS

The mechanical behavior of NiTi wire is observed to find out its potential damping uses for practical applications. A series of the tests are conducted under different working conditions. A loss factor is introduced for damping measurement of the SMA wires. The experiment results show that the damping properties of NiTi wires are strongly dependent on temperature and strain amplitude. The strain rate may slightly influence its damping property during 0.01 ~ 1 s^{-1}. The loading-unloading cycles don't affect the mechanical property obviously if the wire has been pre-cycled with 100 cycles.

REFERENCES

[1] L. C. Brinson and R. Lammering, 1993, "Finite element analysis of the behavior of shape memory alloys and their applications", *Int. J. Solids Struct.*, Vol. 30, No. 23, pp. 3261-3280

[2] R. Wang, C. Cho, C. Kim and Q. Pan, 2006, "A proposed phenomenological model for shape memory alloys", *Smart Mater. Struct.*, Vol. 15, pp. 393-400

[3] J. V. Humbeeck and S. Kustov, 2005, "Active and passive damping of noise and vibrations through shape memory alloys: applications and mechanisms", *Smart Mater. Struct.*, Vol. 14, pp. S171-S185

[4] E. Pieczyska, S. Gadaj, W. K. Nowacki, K. Hoshio, Y. Makino and H. Tobushi, 2005, "Characteristics of energy storage and dissipation in TiNi shape memory alloy", *Sci. Technol. Adv. Mater.*, Vol. 6, pp. 889-894

[5] C. W. deSilva, 2000, "Vibration: Fundamentals and Practice", CRC Press.

[6] M. V. Gandhi and B. S. Thompson, 1992, "Smart Materials and Structures", Chapman & Hall.

[7] A. Yawny, M. Sade and G. Eggeler, 2005, "Pseudoelastic cycling of ultra-fine-grained NiTi shape-memory wires", *Z. Metallkd*. Vol. 96, No. 6, pp. 608-618

[8] M. C. Piedboeuf and R. Gauvin, 1998, "Damping behaviour of shape memory alloys: strain amplitude, frequency and temperature effects", *J. Sound Vibr.*, Vol. 214, No. 5, pp. 885-901

[9] R. DesRoches, M. Asce, J. McCormick and M. Delemont, 2004, "Cyclic properties of superelastic shape memory alloy wires and bars", *J. Struct. Eng.*, Vol. 130, No. 1, pp. 38-46