Article ID: 1003－7837(2005)02,03－0350－05

Relationship between mechanical property and microstructure of NiTi shape memory alloy

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Abstract: The relationship between mechanical property and microstructure of NiTi shape memory alloy has been studied. It was founded that with increasing prestrain the memory recovery rate decreased, but the recovery stress and the recovery strain increased first and then decreased. The recovery stress and the recovery strain reached maximum at about 11% prestrain. The TEM(Transmission Electron Microscope) results of the alloy indicated that the microstructures with different prestrain of the alloy had obvious characters. At 9% prestrain, the martensite anamorphosis of the alloy still presented self-cooperation configuration, and some martensites have become thick obviously because of tropism. When the prestrain was 11%, the martensite anamorphosis has become completely thick and tropism became consistent. As the prestrain increased to 13%, the microstructures of the alloy have become disordered, the tropism became inconsistent and the interface became blurry.

Key words: recovery rate; recovery stress; recovery strain, microstructure; martensite anamorphosis

CLC number: TG139.6 **Document code:** A

1 Introduction

NiTi shape memory alloy had superordinary superelasticity, shape memory property, biocompatibility, corrosion resistance and they have been applied extensively in aeronautics, aerospace, medical apparatus and instruments, and many other fields[1]. The transformation behavior, shape memory effect, superelastic of NiTi shape memory alloy have been studied[2]. It was founded that shape memory alloy had not only shape recovery but also recovery stress. However, studies of microstructure and the correlation between mechanical properties and microstructures of NiTi shape memory alloys were very few.

The mechanical properties including relationships between prestrain and memory recovery stress and memory recovery strain, martensite shapes under different prestrains of NiTi shape memory alloy, and the relationship between mechanical properties and microstructures of NiTi shape memory alloy have been studied in this paper.

2 Experimental method

High-purity raw materials were smelted in vacuum inductance and were cast to ingot. Ingot was heat

Received date: 2005－07－27

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treated in order to reaching composition uniform, then was forged, swaged and drawn into wire. In the present study, $Ti_{49.8}Ni_{50.2}$ (No.4 alloy) and $Ti_{49.6}Ni_{50.4}$ (No.6 alloy) alloys were objects of mechanical property and $Ti_{49.6}Ni_{50.4}$ (No.6 alloy) was the object of microstructure. After heat treatment, wires were studied of mechanical property and microstructure. The mechanical property, strain, memory recovery rate, memory recovery strain, memory recovery stress were carried out on the universal electronic machine of Sintech-65/g model. The gauge length of the tensile sample was 25 mm and the strain speed rate was 1.67×10^{-2} mm/s.

First the samples were loaded to different strain capacities, then unloaded and hold the tensiometer immobile, after loosing one-end of the sample, finally the sample in gauge length was heated by home-made device. The memory recovery rate η was $(L_2-L_3)/(L_1-L_0)\times 100\%$. L_0 was the gauge length of the sample before deforming. L_1 was the total gauge length of the sample a0fter deforming. L_2 was the gauge length of the sample after deforming and unloading. L_3 was the gauge length of the sample after heat-treating and recovering. The memory recovery rate was the ratio of the memory recovery capacities after unloading reflected by tensiometer and heat-treating and total strain capacities before deforming. Predeforming capacities of the sample ξ was $(L_1-L_0)/L_0\times 100\%$, the same as the total strain capacities including elastic recovery before unloading. The measurement of the recovery stress was also carried out on the universal electronic machine of Sintech−65/g model. The microstructure of the alloy was observed by Transmission Electron Microscope (TEM).

3 Experimental results

3.1 The mechanical property of the NiTi shape memory alloy

The tensile experiment of the $Ti_{49.6}Ni_{50.4}$ (No.6) alloy was carried out under different deforming capacities. Fig.1 was the deforming curves. The rule of the No.4 alloy was similar to that of the No.6 alloy.

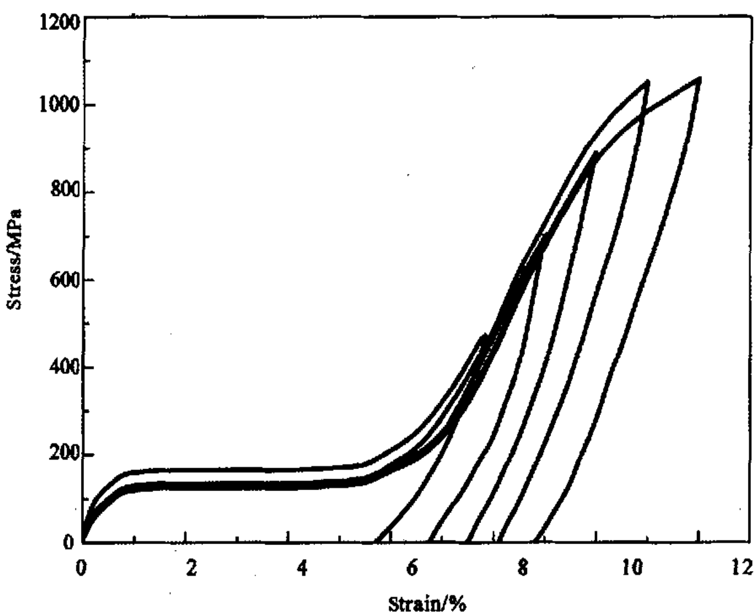

Fig.1 Stress-strain curves of No.6 ($Ti_{49.6}Ni_{50.4}$) alloy under different prestrains

Fig.1 showed that this series of deforming curves had such rules that the yield point jogs were very proximate. These results declared that the smelting technology was feasible, the composition uniform was good, the mechanical properties were proximate and the lengths of these yield point jogs were also proximate. From curves in Fig. 1, we could qualitatively observe that under 10% deforming capacity, the alloy didn't reach the secondary yield point jog, which declared that the alloy didn't enter the plastic deforming stage. While the deforming capacity was 11% or 12%, the alloy appeared the secondary yield point jog so that the alloy had partial plastic deformation.

Figs. 2(a−c) individually showed that the relationship between prestrain of TiNi shape memory alloy and the memory recovery rate, the memory recovery strain and the memory recovery stress. Fig. 2(a) indicated that the memory recovery rate of the alloy exhibited nonlinear decreasing tendency with increment of the prestrain. With the prestrain gradually increasing, the stability of the martensite increased and the reversibility decreased.

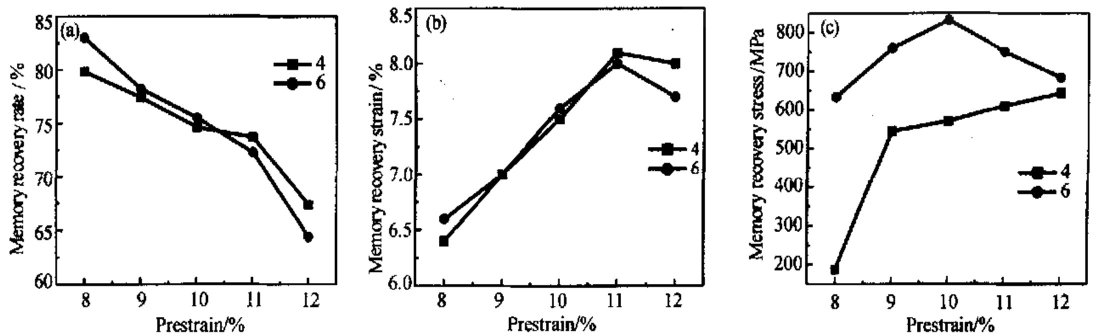

Fig. 2 Relationship between prestrainε_0 and memory recovery rate η(a), memory recovery strain ε(b) and memory recovery stress σ(c) for No. 4 ($Ti_{49.8}Ni_{50.2}$) and No. 6 ($Ti_{49.6}Ni_{50.4}$) alloys

The memory recovery strain was the important index of the memory recovery character of the shape memory alloy, which was the unified expression of the quality of the alloy. Fig. 2(b) showed that the memory recovery strain ε ($\varepsilon = \varepsilon_0 \times \eta$, the product of the total strain and the memory recovery rate) gradually presented increasing tendency with increment of the prestrain. When the prestrain value was 11%, the memory recovery rate appeared peak value and after the peak value it presented decreasing tendency. The memory recovery rate was not objective real measuring value but calculating value, in order to more visually reflect the memory recovery character of the alloy, which reflected the physical meaning of the total strain and the memory recovery rate in engineering application.

Fig. 2(c) indicated the variable process in that the memory recovery stress of the alloy first increased, then decreased with increasing the prestrain. When the deforming capacity was less than the critical value, the deforming capacity increased so that the recovery stress increased. While the deforming capacity was more than the critical value, the deforming capacity increased so that the recovery stress decreased significantly. These results were related with the martensite interface structure and the deformation mode of the alloy.

3.2 Microstructure of the TiNi shape memory alloy

Fig. 3 was the martensite Transmission Electron Microscope microstructures of the $Ti_{49.6}Ni_{50.4}$ (No. 6 alloy) alloy under 9%, 11% and 13% prestrain. Fig. 3(a) was the martensite pattern of the sample of 9% prestrain at room-temperature. In this figure, the martensite anamorphosis in A zone presented self-cooperation configuration, while the martensite anamorphosis in B zone have become thick obviously because of tropism, so that this pattern was generally titled "self-cooperation + anamorphosis thickness".

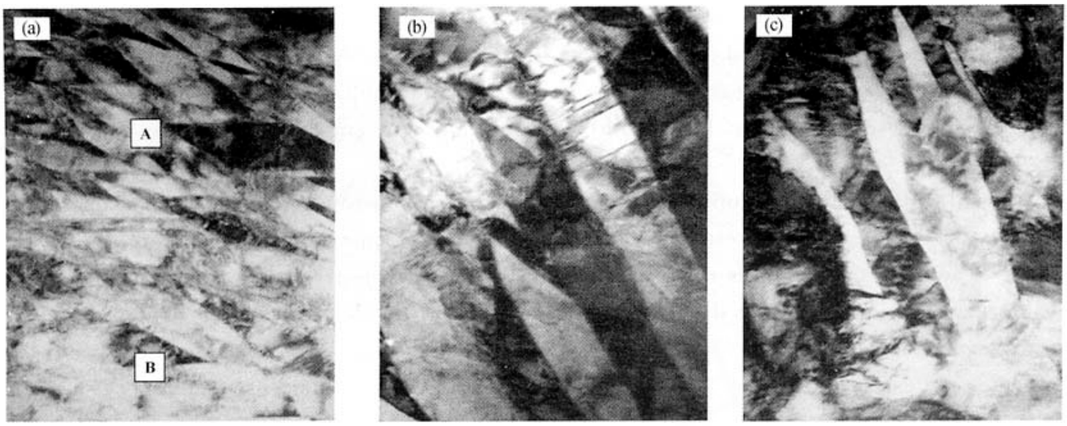

Fig.3 The microstructure of No.6 ($Ti_{49.6}Ni_{50.4}$) alloy under 9%(a), 11%(b) and 13%(c) prestrain

When the deforming capacity reached 11%, the martensite anamorphosis almost completely lose self-cooperation configuration and the total martensite anamorphosis became thick and the orientation was comparitively uniform which distributed along the tensile stress direction. The typical pattern showed as Fig.3(b). When the deforming capacity was 13%, the microstructure of the martensite became more disordered, the tropism became inconsistent and the interface became blurry as showed in Fig.3(c).

3.3 Experimental results and discussion

The super-ordinary shape memory effect of the TiNi shape memory alloy originated from the reversibility between the B2 order structure parent phase and B19 type monocline structure martensite phase (M).

In the deforming process, the fair coherent relationship between interfaces of martensite anamorphosis and twin boundaries in martensite anamorphosis was the structure assurance of obtaining high memory recovery rate and memory recovery stress. Observed from the relationship between the prestrain capacity and the memory recovery rate, the memory recovery rate gradually decreased while the memory recovery strain first increased then decreased with increment of the prestrain. In the deforming process, with increment of the strain capacity, the microstructure of the alloy changed from the martensite self-cooperation to plastic deformation. The plastic deformation led to the martensite interface structure changing from flat and fair coherence to appearing pedestal sit and distorted layer on the interface and loosing partial coherence. When the deforming capacity was increased further, the turbulent layer appeared on the interface and obviously lost coherence. Because of plastic deformation, the distorterence on the martensite interface and damaging coherence of original interface resulted in stabilization of martensite, decreasing of martensite reversibility, badness of the recovery property and decreasing of the memory recovery rate[3].

The memory recovery stress first increased then decreased with increasing the deforming capacity. When the deforming capacity was less than the critical value, the deforming capacity increased so that the recovery stress increased. While the deforming capacity was more than the critical value, the deforming capacity increased so that the recovery stress decreased significantly. These results were related with the martensite interface structure of the alloy. Because of the self-cooperation effect of the martensite, with increasing the prestrain, the single martensite quantity of the alloy increased and the recovery stress obviously increased when recovering at high temperature. With further increasing the deforming capacity, because of leading-in dislocation, the martensite of the same orientation formed easily. Otherwise consolidation of dislocation to matrix caused increment of the recovery stress. When the deforming capacity was more than the critical value, because plastic deformation resulted in changing on martensite twin boundary, turbulent layer appeared on the interface and coherence lost. Because of plastic deformation, the distorterence on the martensite interface and damaging coherence of original interface resulted in stabilization of martensite, decreasing of martensite reversibility, badness of the recovery property and decreasing of the memory recovery stress[4].

Observed from the high resolution Transmission Electron Microscope, the martensite anamorphosis induced from the stress interfaces were flat and distinct, which was coherent interface. On the martensite anamorphosis induced from the lower stress interfaces, there were few pedestal sit and distorted layer, so that the coherence of the interface was damaged. With increment of the deforming strain, the pedestal sit and distorted layer gradually changed to turbulent layers, so that the martensite anamorphosis interface completely lost coherence, which resulted in strain recovery character of the martensite induced strain decreased rapidly.

4 Conclusions

(1) From the studies of prestrain influence upon the memory recovery character of the NiTi shape memory alloy, it was founded that with increment of prestrain the memory recovery rate decreased, but the recovery stress and the recovery strain increased first and then decreased. The recovery stress and the recovery strain reached maximum at about 11% prestrain.

(2) The TEM(Transmission Electron Microscope) results of the alloy indicated that the microstructures with different prestrain of the alloy had obvious characters. At 9% prestrain, the martensite anamorphosis of the alloy still presented self-cooperation configuration, and some martensites have become thick obviously because of tropism. When the prestrain was 11%, the martensite anamorphosis has become completely thick and tropism became consistent. As the prestrain increased to 13%, the microstructures of the alloy have become disordered, the tropism became inconsistent and the interface became blurry.

(3) There were direct and corresponding relationship between the mechanical property and the microstructure of NiTi shape memory alloy.

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