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Effects of thermomechanical cycling on the shape memory behavior and transformation temperatures of a Ni50.2Ti49.8 alloy

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Abstract

The effects of thermomechanical cycling on the shape memory behavior and transformation temperatures of a Ni50.2Ti49.8 alloy under a constant applied stress of 300 MPa were investigated. It is believed that thermomechanical cycling induces defects such as dislocations, which evidently affect the shape memory behavior and transformation temperatures. The recovery strain decreases with increasing number of thermomechanical cycles, whereas the irreversible plastic strain increases, especially in the initial few cycles. The stored elastic strain energy has an important influence on transformation temperatures, the A_s^σ decreases and the M_s^σ increases with increasing number of thermomechanical cycles. The recovery strain, irreversible plastic strain, A_s^σ, and M_s^σ reach a saturation value after several cycles.

Keywords: shape memory alloy; TiNi; thermomechanical cycling; recovery strain; transformation temperature

1. Introduction

TiNi-based shape memory alloys are well known for their excellent shape memory behaviors and mechanical properties. Thus, they are potential candidates for various technical applications [1-2]. TiNiCu ternary alloys have been attractive because of their high performance in cyclic shape memory properties, less composition sensitivity to transformation temperatures, smaller temperature hysteresis, and quicker actuation response when compared with the TiNi binary alloy [3-5]. For practical applications, thermal cycling is always involved, especially for the shape memory alloy actuators. The actuators are expected to perform the desired operation repeatedly without any deterioration in the recovery strain. The stability of shape memory characteristics and transformation temperatures is very important during thermomechanical cycling. Unfortunately, a large variation in the shape recovery strain and transformation temperatures occurs during thermomechanical cycling, therefore it is necessary to understand these changes for the successful implementation of shape memory alloy actuators.

Many researchers have studied the effect of thermal cycling on the memory characteristics and transformation temperature of TiNi and TiNiCu [6-8]. M_s decreased and A_s increased because of defects/dislocation induced during thermal cycling. Dislocations may obstruct the movement of the boundary between the parent phase and martensite phase, which results in the decrease of recovery strain magnitude. The effects of thermomechanical cycling on the shape memory behavior and transformation temperatures are scarcely documented in literatures. In this article, the shape memory behavior and transformation temperatures of Ni50.2Ti49.8 submitted to a constant stress of 300 MPa have been investigated during the initial 10 thermomechanical cycles.

2. Material and experimental

The nominal composition of the Ni50.2Ti49.8 (at.%) alloy ingot was prepared using a high frequency induction vacuum furnace. The as-cast ingot was hot-forged and hot-drawn, followed by cold-drawing and intermediate annealing alternately, and the final product was in the form of a wire with a diameter of 0.2 mm. The samples were sealed in an evacuated quartz tube and annealed at 500°C for 30 min, followed by air cooling. Samples for thermomechanical cycling test (120 mm in gauge length) and differential scanning calorimeter (DSC) measurement (3 mm in length) were cut from the wires. The DSC measurement was carried out at a thermal cycling rate of 10°C/min. The phase transfor-

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mation temperatures after annealing and prior to any thermomechanical cycling were M_f = 19.9°C, M_s = 28.6°C, A_s = 31.3°C, A_f = 45.0°C. The stress-strain curve of the Ni50.2Ti49.8 alloy tested at room temperature is shown in Fig. 1. The critical stress, which induced martensite transformation (σ_{SIM}), was 255 MPa, and the tensile strength was 1175 MPa. A constant stress of 300 MPa was chosen in the next thermomechanical cycling.

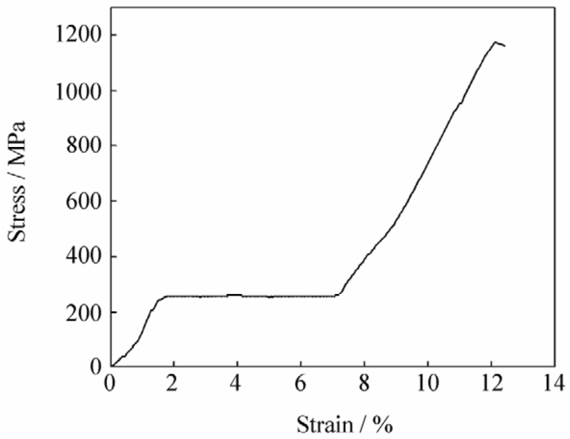

Fig. 1. Stress-strain curve of the Ni50.2Ti49.8 alloy at room temperature.

The thermomechanical cycling test was carried out with the self-assembly equipment as shown in Fig. 2. The furnace used a resistive heating coil for heating and a compressor for cooling. The thermal cycling rate during the thermal cycling was approximately 3°C/min. The temperature of the sample was measured with Platinum-resistance sensor, and the displacement was measured using a linear variable differential transformer (LVDT). The sample was elongated to obtain a strain of 7.02% when loaded with 300 MPa at room temperature, and then the sample was heated to a temperature above the finish temperature of reverse transformation (the first heating), cooled below the finish temperature of forward transformation (the first cooling) with a constant applied stress of 300 MPa, with repeated heating and cooling sequentially. The strain-temperature curves during different cycles were obtained.

A typical example of the strain-temperature curve recorded during thermomechanical cycling is depicted in Fig. 3. The tangential extrapolation method is used to determine M_s^σ, M_f^σ, A_s^σ, and A_f^σ, which denote phase transformation temperatures when the sample is under constant stress. Strain recovery is accompanied with rise in temperature when it reaches A_s^σ and fully recovers at A_f^σ. The recovery strain ε_r is present. During cooling, the sample is elongated when the temperature reaches M_s^σ and ends at M_f^σ. ε_t denotes the total strain after cooling completely, and ε_p is the irreversible plastic strain.

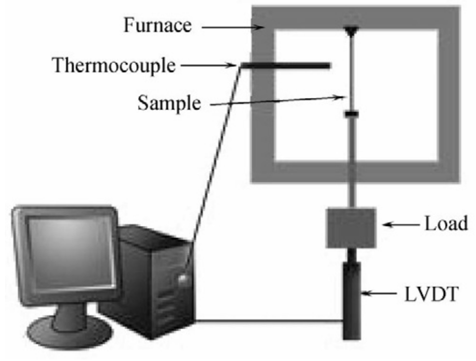

Fig. 2. Schematic of the thermomechanical cycling setup.

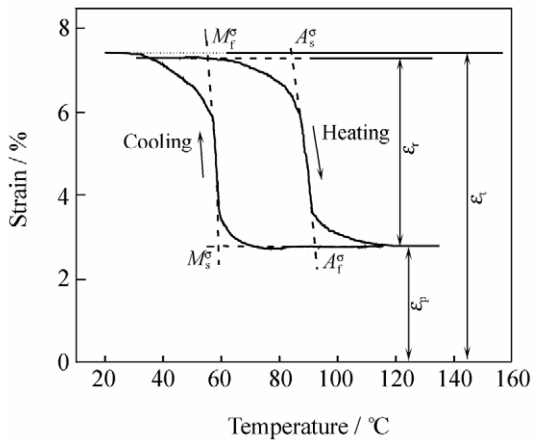

Fig. 3. Typical strain-temperature curve of the Ni50.2Ti49.8 alloy during cooling and heating with a constant applied stress.

3. Results and discussion

3.1. Effect of thermomechanical cycling on shape memory behavior

To reveal the effect of thermomechanical cycling on shape memory behavior, the strain-temperature curves under different number of cycles were obtained. Fig. 4 shows the strain-temperature curves during thermomechanical cycling (n = 1, 2, 5, 10). The recovery strain ε_r decreased with increasing number of cycles, especially in the initial few cycles. In the first cycle it was 5.82%, and it then drastically dropped to 5.19%, 3.86%, and 3.25% in the 2nd, 5th, and 10th cycles, respectively. On the contrary, the irreversible plastic strain ε_p increased with increasing number of cycles. From 1.2% in the beginning to 2.11%, 3.65%, and 4.32% in the 2nd, 5th, and 10th cycles. Another phenomenon observed in Fig. 4 is that the total strain ε_t was slightly increased with increasing number of cycling. The relationship of ε_r, ε_t, and ε_p could be approximately expressed as the equation of $\varepsilon_r + \varepsilon_p = \varepsilon_t$. The tendency of ε_r, ε_t, and ε_p is more clearly described in Fig. 5. The changes are significant in the initial few cycles and reach a saturated magnitude after 8-10