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# STRESS RELAXATION AND STRESS RECOVERY OF TiNi SHAPE MEMORY ALLOY IN STRESS-CONTROLLED SUBLOOP LOADING

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## 1. Introduction

Since the shape memory alloy (SMA) has the superior functions as intelligent materials, the application of the SMA has drawn the worldwide attention. In the case of the subloop in which strain, temperature and stress vary in the range prior to the martensitic transformation (MT) completion, the starting and finishing conditions of the MT prescribed in the full loop are not satisfied. If the condition of the MT to progress is satisfied, stress relaxation and stress recovery occur under constant strain and the load to hold the position varies.

In the present study, the transformation-induced relaxation and stress recovery in the stress-controlled superelastic subloop loading under a constant strain are discussed by the tension test for the TiNi SMA.

## 2. Stress-strain relationship in the stress-controlled subloop loading

The stress-strain curve and variations in stress $\sigma$ and strain $\varepsilon$ with time $t$ obtained by the test under a stress rate $d\sigma/dt = 5$ MPa/s till a point $H_1$ at a strain $\varepsilon_1 = 6\%$ followed by holding the strain $\varepsilon_1$ constant and thereafter unloaded under a stress rate $d\sigma/dt = -5$ MPa/s till a point $H_3$ at a strain $\varepsilon_3 = 2\%$ followed by holding the strain $\varepsilon_3$ constant are shown in Figs. 1 and 2, respectively.

As can be seen in Fig. 1, in the strain holding process at $\varepsilon_1 = 6\%$, stress decreases from $\sigma_1$ to $\sigma_2$, resulting in stress relaxation $\Delta\sigma = \sigma_2 - \sigma_1$. In the strain holding process at $\varepsilon_3 = 2\%$, stress increases from $\sigma_3$ to $\sigma_4$, resulting in stress recovery $\Delta\sigma = \sigma_4 - \sigma_3$.

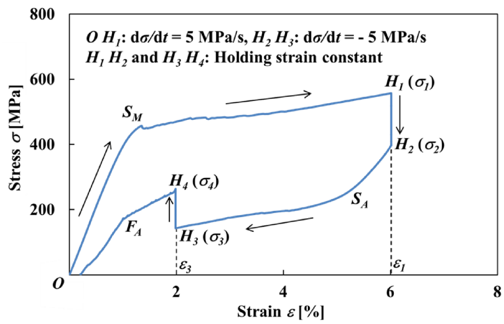


Fig. 1. Stress-strain curve.

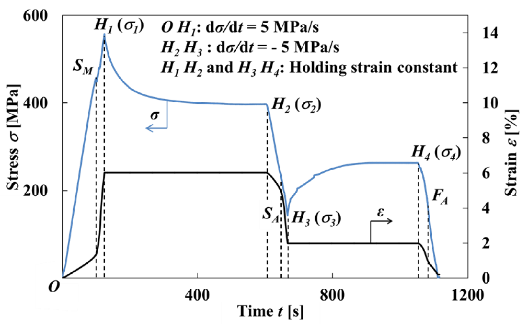


Fig. 2. Variation in stress and strain with time.

As can be seen in Fig. 2, after the strain holding start point $H_1$, stress decreases rapidly in the early stage and thereafter decreases gradually. The stress $\sigma_2$ at a point $H_2$ after relaxation is 397 MPa. Similarly, in the unloading process, after the strain holding start point $H_3$, stress increases rapidly in the early stage and thereafter increases gradually. The stress $\sigma_4$ at a point $H_4$ after recovery is 263 MPa.

### 3. Behavior of transformation band

Figure 3 shows the photographs of specimen surface at various strains taken by a microscope during the test. In the loading process under a constant stress rate of 5 MPa/s, strain rate increases from a strain of 2% to 3%, and the transformation bands appear on the whole specimen surface. After a strain of 3%, the interfaces of the appeared transformation bands propagate and strain increases. In the strain holding stage from the point $H_1$ at a strain of 6% to the point $H_2$, the MT progresses and the region of the martensite-phase expands a little. In the unloading process after stress relaxation (point $H_2$), the reverse transformation progresses from the initiation location at the interfaces of the transformation bands and strain decreases. In the strain holding stage from the point $H_3$ at a strain of 2% to the point $H_4$, the reverse transformation progresses and the region of the parent-phase expands a little.

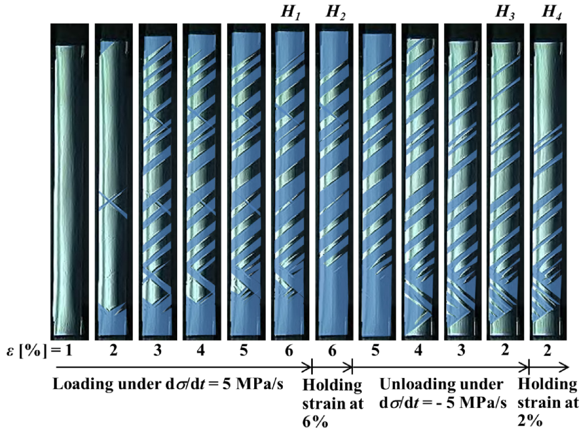


Fig. 3. Photographs of specimen surface at various strains $\varepsilon$.

### 4. Temperature change due to transformation

Figure 4 shows the temperature distributions on specimen surface at various strains during loading and at various stresses during holding strain constant obtained by the thermography. Figure 5 shows the relationship of stress $\sigma$ and temperature change $\Delta T$ between the average temperature on the specimen surface and the atmosphere temperature with time $t$ during loading and holding strain constant.

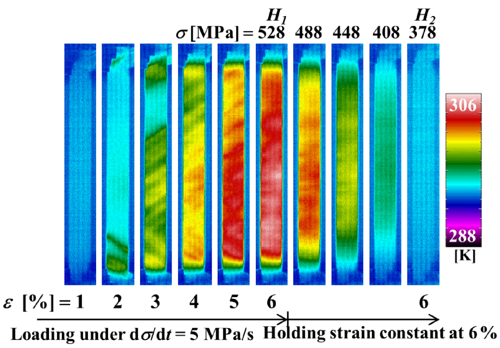


Fig. 4. Thermograms of temperature distribution on specimen surface at various strains $\varepsilon$.

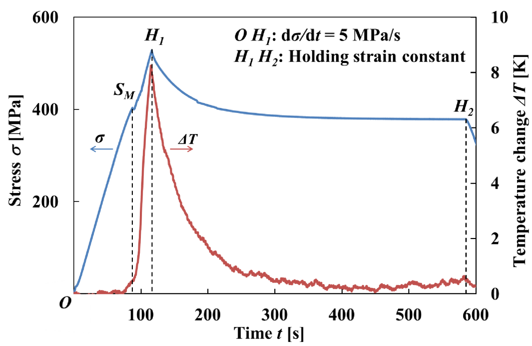


Fig. 5. Variation in stress $\sigma$ and average temperature change $\Delta T$ on specimen surface.

As can be seen in Figs. 4 and 5, in the loading process from the MT start point $S_M$ to the point $H_1$, strain rate becomes high as shown in Fig. 2 and there exists less time for the heat generated due to the exothermic MT to transfer to the atmosphere air, resulting in an increase in temperature of the specimen. In the strain holding stage from the point $H_1$ to the point $H_2$, temperature decreases by the air and the condition for the transformation to progress is satisfied, resulting in the progress of the MT. As a result, stress relaxation appears during holding strain constant.