

## DEFORMATION BEHAVIOR OF TiNi SMA OBSERVED BY LOCAL STRAIN, THERMOGRAPHY AND TRANSFORMATION BAND

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### 1. Introduction

In shape memory alloys (SMAs), strain of 6% is recovered by heating or unloading: shape memory effect (SME) or superelasticity (SE), respectively. In the loading process, strain appears due to the stress-induced martensitic transformation (SIMT) and diminishes due to the reverse transformation (RT) by heating or unloading. The deformation properties due to the SIMT differ depending on temperature and loading rate. The loading rate is designated by strain rate and stress rate. In the present paper, the influence of loading rate on the deformation behaviors is investigated for TiNi SMA. The deformation behaviors are observed by local strain, temperature variation by the thermography and transformation band on the surface of specimen.

### 2. Dependence of deformation behavior on loading rate

The stress-strain curves obtained by tension tests for an SME-NT wire under various strain rate at temperature  $T=353\text{K}$  are shown in Fig.1. As can be seen, the overshoot and undershoot and stress plateau appear clearly in the case of strain rate  $d\varepsilon/dt=1.67 \times 10^{-4}\text{s}^{-1}$ . These phenomena do not appear in the case of  $d\varepsilon/dt$  higher than  $1.67 \times 10^{-3}\text{s}^{-1}$ . The MT stress increases and the RT stress decreases with an increase in strain rate. The MT is exothermic and the RT endothermic process. Therefore, temperature of the specimen increases in the loading process and decreases in the unloading process with increasing strain rate. In the case of high strain, there is not enough time for temperature to be constant, and deformation processes, resulting in large variation in the MT stress.

### 3. Behavior of local strain

The relation between local strain  $\Delta l/l$  and accumulated total axial strain  $\Sigma|\Delta L/L|$  obtained by tension test for an SE-NT wire at strain rate  $d\varepsilon/dt=8.33 \times 10^{-5}\text{s}^{-1}$  is shown in Fig.2. The local strain expresses a ratio of variation  $\Delta l$  to gauge length  $l$  at each divided position ①-⑩ in the specimen. The

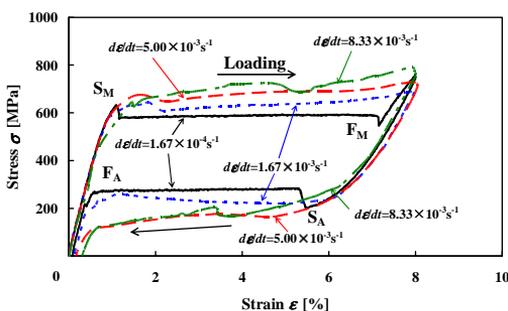


Fig.1. Relation between stress and strain under constant strain rates in SE-NT wire at  $T=353\text{K}$

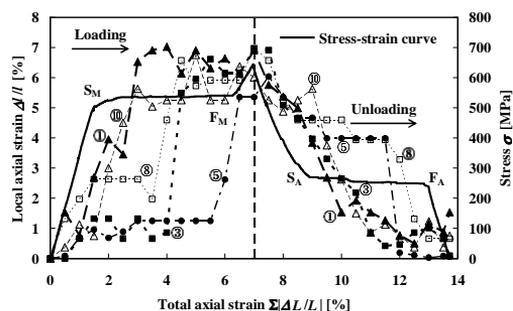


Fig.2. Relation between local strain and accumulated total axial strain in the SE test

accumulated total axial strain expresses the sum of absolute value of variation in total axial strain  $\Delta L/L$  in the loading and unloading process. In Fig.2, the stress-strain curves in the loading and unloading processes are shown by the solid lines. As can be seen Fig.2, local strain  $\Delta l/l$  in one end position ① increases markedly at total strain  $\Sigma|\Delta L/L|=1.5\%$ , and  $\Delta l/l$  in another end position ⑩ increases by 4.5% at  $\Sigma|\Delta L/L|=2.0\%$ . The variation of  $\Delta l/l$  appears in turn into central part of the specimen thereafter. The variation in  $\Delta l/l$  finishes in the central part ⑤ at  $\Sigma|\Delta L/L|=6\%$ . In the unloading process,  $\Delta l/l$  in both ends ① and ⑩ of the specimen decreases by 4.0% at  $\Sigma|\Delta L/L|=9\%$  where the RT starts. The variation in  $\Delta l/l$  during the unloading process appears in the similar order as the loading process.

#### 4. Transformation behavior observed by thermography

The temperature distributions on the surface of the SE-NT tape (width of 10mm and thickness of 0.7mm) through the images obtained by an infrared camera in tension test at strain rate  $d\varepsilon/dt = 1.67 \times 10^{-3} \text{ s}^{-1}$  are shown in Fig.3. As can be seen Fig.3, a transformation band with high temperature due to the MT appears in an upper end of the specimen at strain of 1.83% (Fig.(a)). The transformation bands appear in a bottom end and the central part of the specimen at strain of 2.15% (Fig.(b)). Temperature increases thereafter in many parts of the specimen (Fig.(d)), and the MT grows in the whole parts of the specimen till maximum strain (Figs.(e)-(l)). The reason why the temperature rise is small in both ends of the specimen is heat flow from the specimen into the grippers. The lowest temperature in the unloading process is 283K and maximum temperature change is -12.2K.

#### 5. Transformation band on the surface of the specimen

The photographs on the surface of the SE-NT tape obtained by the tension test under strain rate  $d\varepsilon/dt=1.67 \times 10^{-4} \text{ s}^{-1}$  are shown in Fig.4. As can be seen, variation does not appear on the surface of the specimen till strain of 1%. The band due to the SIMT occurs in an upper end of the specimen at strain of 2%. The transformation band grows thereafter from the upper part into the central part and occurs also in a bottom part at strain of 4%. The martensitic phase band occurred in both ends of the specimen grows toward the central part with an increase in strain. At strain of 8%, the parent phase with a narrow band remains in the central part of the specimen.

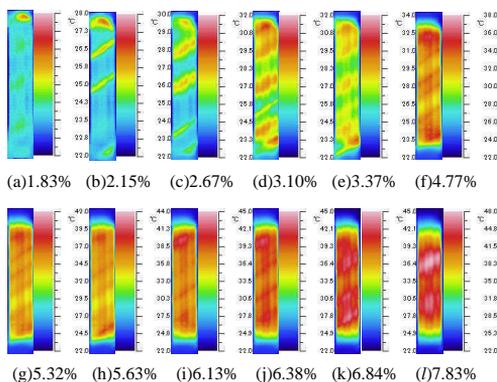


Fig.3. Temperature distributions on the tape specimen in the loading process during tension test

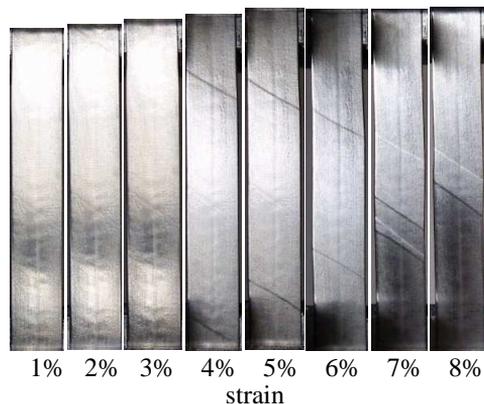


Fig.4. Deformation patterns on the surface of the tape specimen due to phase transformation in the loading process