Internal Friction Measurements During Stress Induced Martensitic Transformation of Cu Zn Al Shape Memory Single Crystal

M. Perez and M. Morin

GEMPPM, UMR C5510, INSA de Lyon, Bât. 502, 20 av. A. Einstein, 69621 Villeurbanne cedex, France

Abstract : The shape memory alloys present, in the high temperature phase, a super-elastic behaviour : during a super-elastic test, the martensitic transformation is induced by the stress, and a large reversible deformation is observed. With a single crystal, the maximum super-elastic deformation reaches 8 to 10%. During the tensile test on a single crystal, only one variant of martensite is induced in the shape of many parallel needles.

Using a specific tensile machine, we have measured the friction due to the movement of the interfaces between the austenite and the martensitic phases. These measurements have been realised during a tensile test on single crystals of CuZnAl. The movement of the interfaces is obtained by a low sinusoidal stress that is superimposed to the tensile stress.

Results show that the interfaces are progressively pinned when the super-elastic strain is maintained constant. This pinning disappears when the strain is slightly increased.

1. INTRODUCTION

The thermoelastic martensitic transformation of the CuZnAl shape memory alloy is a first order phase transition proceeding by nucleation and growth of the product phase. This transformation consists mainly by a shear strain and can be induced by temperature or stress variation. When the transformation is temperature induced the obtained phase called martensite presents 24 different orientations or variants.

From a single crystal of the parent phase, only one variant of martensite can be stress induced. The microscopic observation of single variant formation shows the nucleation then the thickening of many needles of martensite. All these needles, and then all the interfaces between the parent and the martensitic phase have the same crystallographic orientation. For single crystals, F.C. Lovey [1] has shown that, for the low variations of stress, the hysteresis of these interfaces is very small.

Studies of the Internal Friction (IF) during the martensitic transformation [2, 3] have shown that the motion of the transforming interfaces gives rise to a large damping. However, all these studies have been realised during thermal martensite transformation.

In this paper, we have measured the internal friction due to the movement of the interfaces using a specific tensile machine. The advantage of this machine [4] is that inside the sample, stress is homogeneous. It is then possible, with this machine, to measure the internal friction during temperature or stress induced transformation.

The measurements have been realised during the stress induced transformation of a single crystal of CuZnAl alloy to a single variant.

2. THE EXPERIMENTAL TECHNIQUE

2.1 The tensile machine

The main characteristic of the specific tensile machine (fig.1) is that all the movements are obtained without friction. It is then possible to measure internal friction by superimpose a slow sinusoidal stress to the tensile stress. The strength is obtained by means of a pneumatic jack, and the guiding of the moving part by elastic steel wires.

Figure 1 : Pneumatic tensile machine

Figure 2 : Stress-strain loop used to measure internal friction (at $2 \cdot 10^{-4}$ of strain)

The sensors are a 500 N strength gauge and an extensometer. The machine can work in a stress or strain controlled regime by means of an electronic servo control.

The sample is immersed together with the extensometer in a thermally regulated bath of silicone oil to obtain a very stable and homogeneous temperature.

The internal friction δ is calculated as the ratio between the dissipated energy during one oscillation ΔW , which coincides with the area enclosed by the stress-strain loops, divided by the elastically stored energy (W) :

$$\delta = \frac{1}{2} \cdot (\Delta W / W)$$

Figure 2 shows a recorded stress-strain loop used to measure the internal friction for a strain IF amplitude of $2 \cdot 10^{-4}$. The resolution of the machine is better than $0.1 \mu\text{m}$ in displacement and 0.01N in strength.

2.2 The sample

The sample is a single crystal of Cu-Zn-Al obtained by a modified Bridgman method. The composition is Cu-15.5Zn-8Al wt %. The transformation temperatures are $M_s = 36^\circ\text{C}$, $M_f = 18^\circ\text{C}$, $A_s = 27^\circ\text{C}$, and $A_f = 44^\circ\text{C}$.

Samples of useful dimensions $14 \times 3 \times 1 \text{ mm}^3$ were cut from single crystal by electroerosion and chemically polished. The heat treatment consists of an homogenisation for 0.5 hour at 850°C , a quench into water at room temperature and an aging for 1 hour in boiling water.

3. INTERNAL FRICTION DURING SUPERELASTIC TEST

Internal friction measurements have been realised at 35°C , during a super elastic traction test. The figure 3 shows the obtained stress-strain curve. For each point of this curve, internal friction has been measured by superimpose a sinusoidal strain to the traction strain. The amplitude of this sinusoidal strain is about 5×10^{-4} .

Figure 3 : Superelastic curve at 35°C , measured during loading.

Figure 4 : Apparent modulus measured versus the stress induced transformation.

Figure 5 : Internal Friction (IF) measured versus the strain induced transformation. $\epsilon = 5 \times 10^{-4}$.

Figure 6 : Same as figure 6, but IF is draw versus the number of cycles, showing the decrease of IF with the measuring time.

Figures 4 and 5 presents the apparent modulus, and the internal friction versus the deformation of the sample :

- at zero deformation, the sample is in beta phase (parent phase). IF is low, and the modulus is high.
- between 0.5 % and 8 % of strain, the martensite phase is stress induced. The mobility of the interfaces between parent and martensite phases induces an increase of IF and a decrease of the modulus.
- near 8.5 % of strain, all the sample is transformed in a single variant of martensite phase. The interfaces have disappeared, then IF is decreased, and the modulus is increased again.

The figure 6 presents the same IF measurements as in figure 5, but versus the number of cycles. It appears that, for each deformation of the sample, the value of IF decreases versus the number of measuring cycles. This behaviour seems indicate a progressive pinning of the interfaces versus the time or the number of cycles. To confirm this hypothesis, we have realised several decreases at the same deformation, but separates by small jumps of stress $\Delta\sigma$ ($\Delta\sigma = 2\text{Mpa}$). Figure 7 presents the obtained results :

Figure 7 : IF (■) and apparent modulus (◇) versus the number of cycles at constant temperature and strain. Each decrease of IF is separate by a small jump (increase and decrease) of 2 MPa. Strain measurement = $5 \cdot 10^{-4}$.

Results of the figure 7 show that the apparent modulus varies inversely to IF : during the cycling, an increase in the modulus and a decrease of IF is observed. These effects can be due to the progressive pinning of the interfaces between the martensite and the parent phase. After each jump of the stress, IF and modulus are restored. The small increase and decrease of stress is sufficient to unpin the interfaces. It can therefore be noticed that the pinning of the interfaces is more and more efficiently when the number of cycles increases.

4. CONCLUSION

Using a new equipment for the IF measurement in traction, it has been possible to evaluate the damping due to the motion of the interfaces between the parent phase and the martensite during a super elastic test. We have showed that when the interfaces are presents inside the sample the IF is increased, and the apparent modulus lowered. The interfaces are progressively pinned during the IF measurement. This pinning disappears partially if the sample is submitted to a small variation of stress.

References

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