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Austenitic–martensitic interface damping measured in shape memory alloys by a cyclic tensile machine

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Abstract

A tensile machine has been constructed to test shape memory alloys. With this machine it is possible to measure the internal friction anywhere in the stress–strain plot. The minimum strain amplitude for the measurements is near 10^{-4} and the maximum frequency is 0.6 Hx.

In this paper we present some preliminary results obtained on single crystals of Cu–Zn–Al shape memory alloys. The internal friction *vs.* temperature has been measured at various cooling–heating rates (from 0 to 1 K $\min^{-1}$). We have also measured the internal friction *vs.* deformation during a superelastic test (at T above A_f). This last experiment shows that the internal friction depends on the number of interfaces between the martensitic and austenitic phases.

1. Introduction

In the martensitic phase shape memory alloys present a high damping. In another paper [1] we have shown that for high amplitude (about 10^{-4}) measurements this damping is due to the movement of the interfaces between the different variants of martensite.

During the martensitic transformation the internal friction comprises two principal contributions [2]. The first is due to the orientation of thermal martensite by the measurement stress [3, 4]. This contribution depends on the cooling–heating rate and on the frequency of measurement. The second contribution is probably due to the movement of the two kinds of interfaces present in the sample: the interfaces between the variants and the interfaces between the martensitic and austenitic phases. This second part is independent of the cooling–heating rate [5].

All previous measurements at high amplitude (about 10^{-4}) have been made using a torsional pendulum. This mode of excitation allows easy and accurate measurements, but within the sample the stress and strain are not homogeneous. To characterize the role of the various interfaces existing within shape memory alloys, we have constructed a tensile machine which operates without external friction. With this machine we can measure the internal friction during the formation of a single variant of martensite and thus with only one kind of interfaces, *i.e.* the interfaces between the martensitic and austenitic phases.

In this paper we give details of the tensile machine and present some preliminary measurements obtained on single crystals of Cu–Zn–Al shape memory alloys.

2. The tensile machine

The tensile machine (Fig. 1) has a pneumatically controlled moving part and is driven by a computer. All chap guidings are elastic to avoid friction. The sensors are a strength gauge that works between 0 and 500 N, a classical linear velocity displacement transducer (LVDT) that records displacements up to 5 mm and an extensometer attached to the sample.

The machine can work in a stress or strain-controlled regime. By means of the computer it is possible to apply a sinusoidal stress or strain to the sample anywhere in the stress–strain curve. The internal friction δ is calculated as the ratio between the dissipated energy ΔW, which coincides with the area enclosed by the stress–strain loops, and the total energy W:

$$\delta = \frac{\Delta W}{2W}$$

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

The characteristics of this machine are a maximal strength of 2000 N, a maximal displacement of 8 mm,

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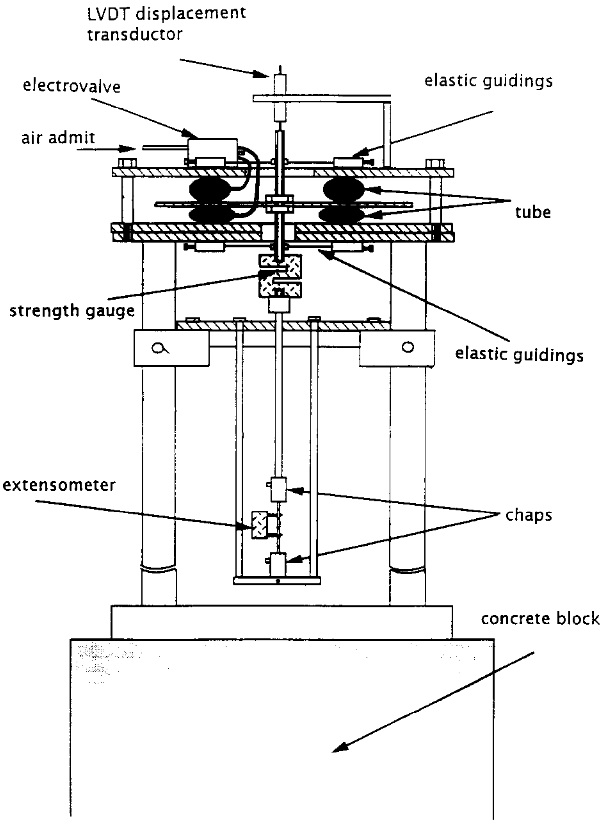

Fig. 1. Pneumatic tensile machine.

a strength resolution of 0.1 N, a displacement resolution of 0.5 μm, a maximal frequency during a sinusoidal cycle of 0.6 Hz and a temperature between −40 and 200 °C with silicone oil.

3. The samples

The samples are single crystals of Cu–Zn–Al obtained by a modified Bridgman method. The composition is Cu–15.5Zn–8Al by weight. The transformation temperatures turned out to be $M_s = 36$ °C, $M_f = 18$ °C, $A_s = 27$ °C and $A_f =$ 44 °C.

Samples of dimensions $20 \times 4 \times 1$ mm^3 were cut from single crystals with a diamond blade saw and chemically polished. The heat treatment consisted of homogenization for 1 hour at 850 °C, quenching into water at room temperature and aging for 1 h in boiling water.

4. Internal friction vs. temperature data

The internal friction and Young modulus have been measured as a function of temperature with the tensile machine. Figure 2 shows the results obtained during a cooling run at a cooling rate of $dT/dt = 1$ K min^{-1}, a deformation level of 5×10^{-4} and a null middle stress. These results are similar to those obtained using a classical torsional pendulum. Three regimes can be distinguished in the temperature dependence of the internal friction.

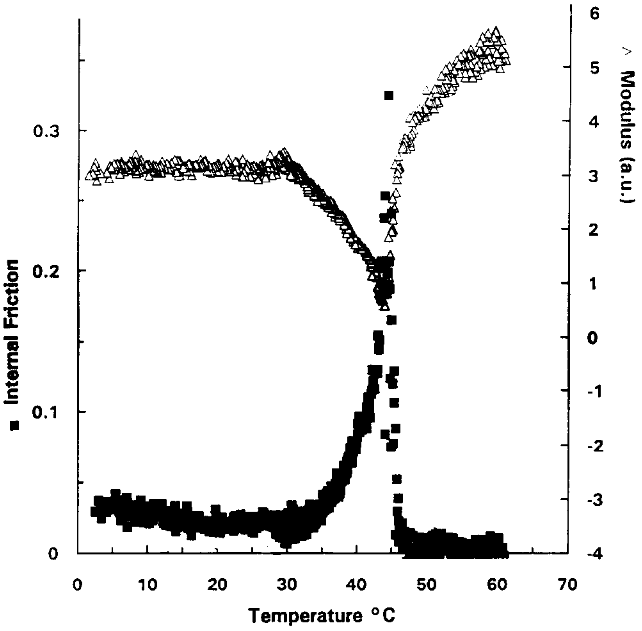

Fig. 2. Internal friction *vs.* temperature; frequency 0.2 Hz, amplitude 5×10^{-4}, cooling rate 1 K min^{-1}.

(1) At high temperature in the austenitic state the internal friction is very low.

(2) At low temperature in the martensitic state the internal friction is high, near 3×10^{-2}. In this state the Cu–Zn–Al alloy can be used as a high damping material.

(3) A high maximum of the internal friction and a deep minimum of the Young modulus are associated with the martensitic transformation. The internal friction maximum depends on the cooling rate as shown in Fig. 3, where the plotted data were obtained under the same conditions as those for Fig. 2 but taken during steps of temperature changes ($dT/dt = 0$ K min^{-1}).

5. Internal friction measurement during a superelastic test

Figure 4 presents a tensile curve obtained at a temperature higher than A_f in the austenitic phase ($T = 45$ °C).

(1) At first a linear relationship between stress and strain is observed (from A to B).

(2) The deformation of the sample at an approximately constant stress (from B to C) results from the stress-induced martensitic transformation. During this stage only one variant is formed and therefore the interfaces present are only those between the martensitic and austenitic phases.

(3) The part of the diagram from C to D is obtained when the stress is decreased and is a consequence of the hysteresis of the transformation.

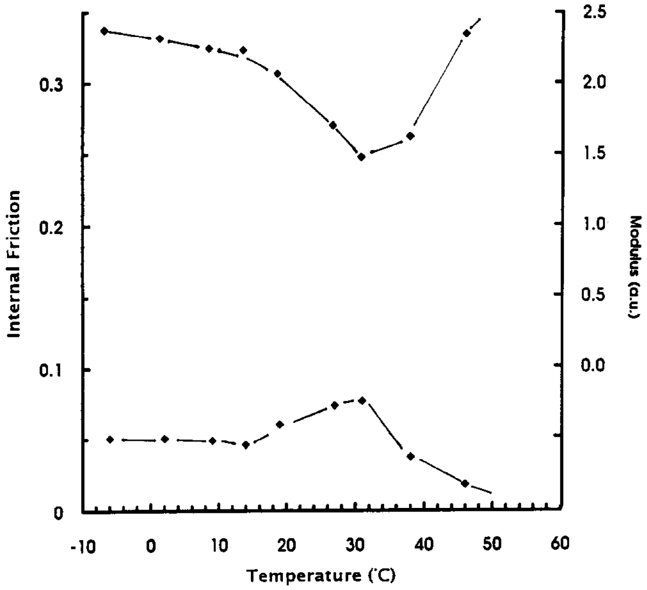

Fig. 3. Internal friction *vs.* temperature; frequency 0.2 Hz, amplitude 5×10^{-4}, cooling rate 0 K min^{-1}.

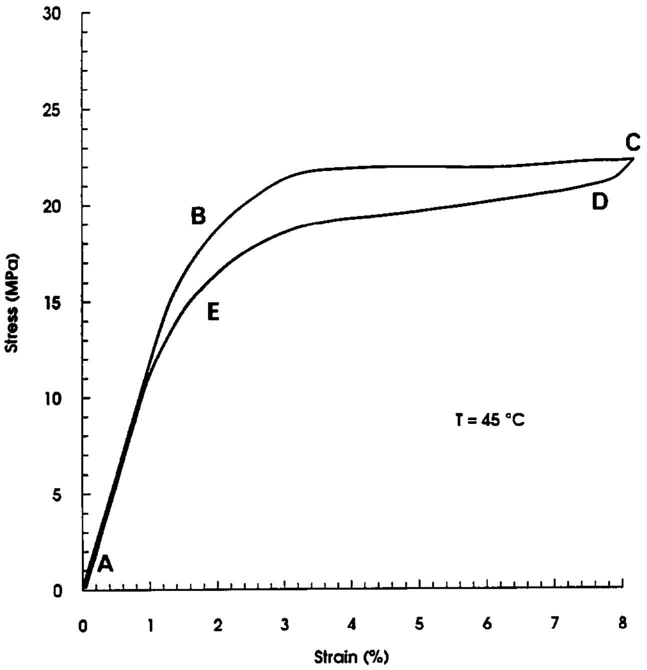

Fig. 4. Superelastic tensile curve measured at 45 °C.

(4) The part of the diagram from D to E corresponds to the inverse martensitic transformation.

During this test it was verified optically that only one variant of martensite was present and numerous interfaces between the martensitic and austenitic phases were examined. At first small needles of martensite (with the same orientation) appear. During the deformation of the sample the number of these needles increases, also inducing an increase in the number of interfaces. Subsequently the needles grow larger to overrun the sample and the number of interfaces decreases to reach a null value when the entire sample is in the martensitic state.

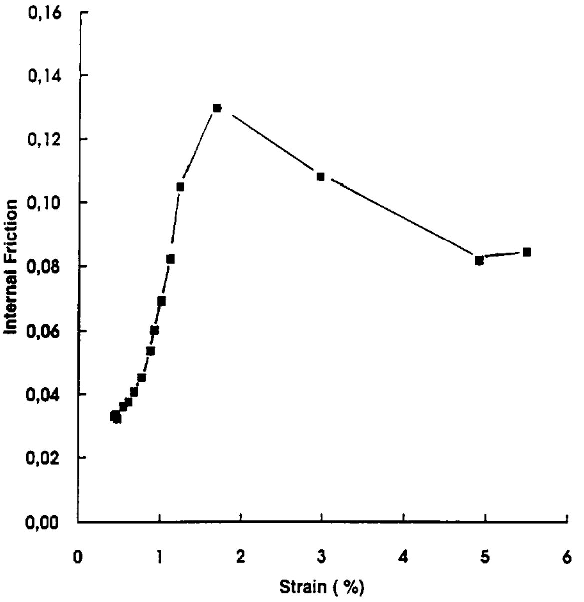

Fig. 5. Internal friction measured during superelastic test at 45 °C; frequency 0.5 Hz, amplitude 5×10^{-4}.

It is possible with our tensile machine to superimpose on the quasi-static strain a sinusoidal strain of small amplitude (5×10^{-4}) to measure the internal friction. Figure 5 presents the result obtained under these conditions. We can see that the internal friction first increases as the strain increases, and then decreases. The maximum of the internal friction corresponds approximately to the situation where the number of interfaces between the martensitic and austenitic phases also reaches its maximum value.

6. Conclusions

A tensile machine has been built which allows us to measure the internal friction of shape memory alloys. The main advantage of this machine is that it allows internal friction measurement in traction under homogeneous stress and strain conditions, in contrast with the classical measurement in torsion.

The internal friction can be measured anywhere in the stress–strain plot. In the case of a superelastic test the stress inducing the martensite is in the same direction as the internal friction stress measurement.

Internal friction *vs.* temperature spectra measured with this machine are in substantial agreement with those obtained using a classical torsion pendulum. The internal friction measured during a superelastic test is found to be related to the number of interfaces between the martensitic and austenitic phases present within the sample.

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