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DAMPING CHARACTERISTICS OF CU-ZN-AL SHAPE MEMORY ALLOYS

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Abstract A Cu-19.03Zn-13.14Al at % shape memory alloy has been investigated using: a) I.F. and Young's modulus measurements in the KHz range; b) tension-compression cycling at 0.5 Hz; c) calorimetric measurements. From a) and b) the damping characteristics of the alloy have been determined, whereas from c) the friction work during beta-martensite transformation has been calculated as 10 J/mol.

1.- Introduction.

It is well known that CuZnAl alloys show high damping features in the martensitic transition region and in the martensitic state at temperatures lower than Mf (1-4). The damping properties are frequency and strain-amplitude dependent (1,5), they are affected by the microstructure as well. It is generally accepted that in the martensitic state the elastic energy dissipation arises from the stress assisted motion of interfaces between variants, while the nature of the frictional forces acting on the interfaces are not yet known. At the martensitic transition an internal friction (I.F.) maximum usually occurs, which is associated to stress-assisted motion of β-martensite interfaces, that is to martensite formation and reversion. The appearance of this maximum is sensitive to the thermal hystory of the material and to the cooling and heating rates. At the martensitic transition usually a decrease is observed in the Young's modulus, which is larger than expected from the anelasticity theory. On approaching the reversion temperature As from the low temperature side, a gradual non linear decrease is displayed by the Young's modulus; such a decrease starts far below As. The nature of such softening is not yet known.

Several calorimetric studies have been performed to get a better understanding of the various phenomena linked to the martensitic transition, however only recently the complexity of such experiments has been realized. Thus the deduction of the free enthalpy associated with the transition requires a rather sophisticated analysis of the data, involving separation of the various contributions to the free energy, one of which has to do with energy dissipated as irreversible work associated to the frictional motion of the interfaces (6,7).In order to to gain more insight on the nature of the energy dissipative motion of the interfaces, an investigation was undertaken, which combined I.F.measurements, mechanical cycling and calorimetric observations in one CuZnAl alloy.

2.- Experimental

2.1.-Alloy preparation

The atomic composition of the alloy used in the present experiments was 67.83 Cu, 19.03 Zn, and 13.14 Al. This composition was selected to minimize possible variations in DO_3 order parameter in the temperature range of our tests (233 - 313 K). After melting, the material was homogenized at 800 °C for 12 h, then extruded into bars of 20 mm diameter. Specimens of suitable dimensions and shape were machined from the rod and, prior to any measurement , they were treated at 780 °C for 20 min, then quenched into boiling water, where they were aged for 30 min , to be finally quenched into water at RT. This state of the material was selected to avoid quenched-in vacancies and related effects on martensite stabilization.

2.2.- Internal friction experiments

The specimens used were three rectangular strips , 1.5, 2.0, 3.0 mm in thickness, respectively, 50mm in length and 5 mm in width. For the I.F. measurements they were supported along nodal lines by thin thermocouple wires.Their free-free resonant flexural modes were excited electrostatically and the I.F.were deduced from the decay of the free oscillations. The resonant frequencies were 2010, 2610 and 3890 Hz,for the three samples, respectively, whereas the strain amplitudes were in the range of 10^{-7}.

2.3.- Mechanical cycling experiments

The samples tested were standard tensile round specimens, 8 mm in diameter and 70 mm in gauge length, which were cycled in an Instron tensile-compression machine operated at 0.5 Hz and at selected strain amplitudes in the range of 10^{-3}, in the temperature range from 233 to 313 K. The strain was measured by means of extensometers of 50 mm measuring length.

2.4.- Calorimetry measurements

The specimens in this case were chips cut from the core of the extruded bars; their masses ranged from about 50 to about 100 mg. The calorimetric measurements were performed at different scan rates through the martensitic transition region, both on heating and cooling, by using a Perkin-Elmer differential scanning calorimeter.

3.- Results

3.1.- Internal friction data

A typical heating-cooling measurement run between 100 and 400 K is illustrated in fig. 1-a, where the temperature dependence of the Youngs modulus E of specimen B (2.0 mm thick) is shown. As evident, in the parent β phase (T > 277 K), E linearly increases with decreasing the temperature. Below 277 K, E decreases reaching a minimum at about 272 K, then it increases non linearly over a wide temperature range (272 - 160 K). A linear behaviour is resumed at around 160 K.
On heating , E shows a behaviour similar to that observed on cooling, with a minimum at 284 K and a region of steep increase (between 284 and 289 K) displaced of about 12 K.
A wide hysteresis loop is observed with extreme temperatures of about 210 and 300 K.

The I.F.of specimen B, which was measured simultaneously to the Young's modulus at a strain amplitude in the 10^{-7} range, is shown in fig 1-b. The main features of this are : a) higher level of I.F. in the martensitic than in the parent β phase, b) well evident asymmetric maxima in the region of direct (β-M) and inverse (M-β) transitions, c) a hysteresis loop with temperatures similar to those for the E(T) curves.The level of I.F. peak at the transition is $Q^{-1} = 3.5*10^{-3}$, a factor of 8 higher than in the β phase and a factor of 2 higher than in the martensite.

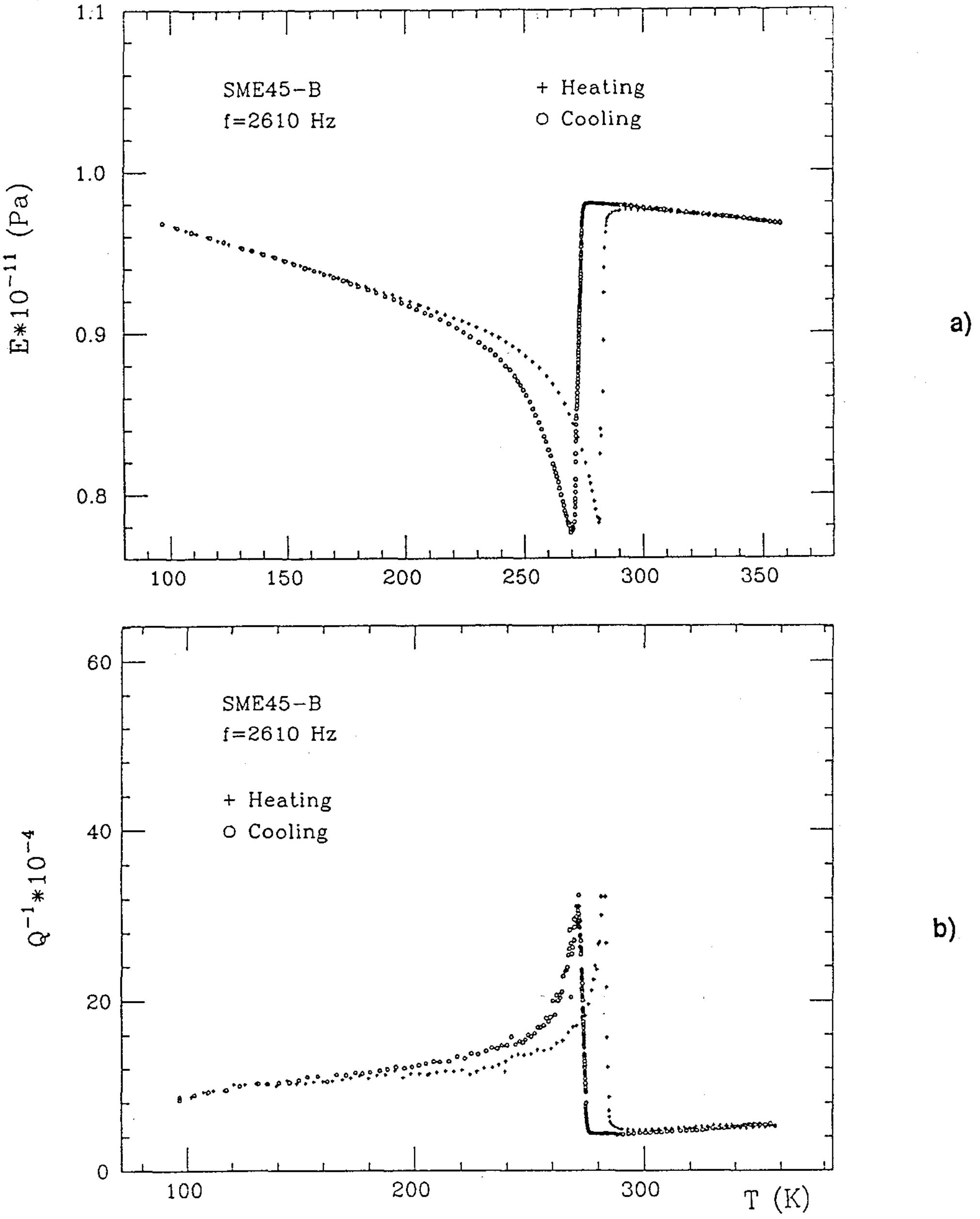


Fig. 1 Young's modulus (a) and I.F. (b) vs. temperature

3.2.- Mechanical cycling

Several sets of sequential isothermal tension-compression deformations cycles from 233 to 313 K, were taken at progressively increasing strain amplitudes, from ± $1*10^{-3}$ to $\pm 5*10^{-3}$. As an example, Fig. 2 shows the set of curves obtained at 268 K.

Hysteresis loops both in the martensitic and in the β phase became stable after only one cycle and remained perfectly reproducible in the subsequent ten cycles..

From the obtained stress-strain loops, the specific damping capacity (S.D.C.), $\Delta U/U$, namely the energy ΔU dissipated per cycle of deformation energy U, has been calculated.

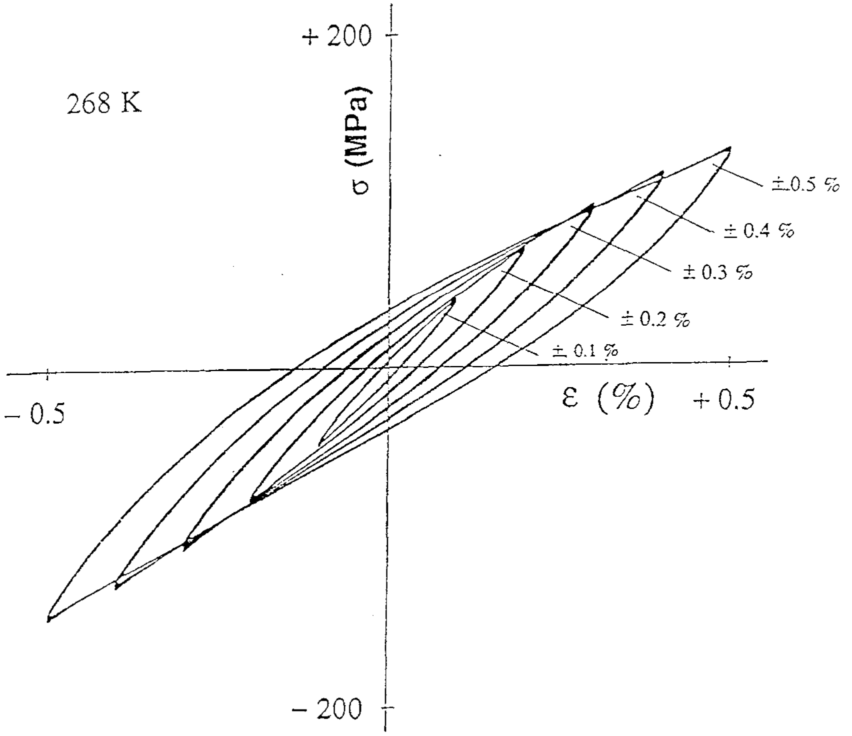


Fig. 2 Tension-compression deformations cycles at 268 K for various stress amplitudes

The temperature dependence of S.D.C. at various strain levels is shown in fig.3. As evident, the position of the peak in the S.D.C. vs. T curves is independent of the strain amplitude and strictly corresponds to the peak of I.F. vs. T curves of fig. 1-b. The level of energy dissipation at the peak is however much higher, reaching now values of $\Delta U/U$ up to 57 %, corresponding to $Q^{-1} = \Delta U/2\pi U = 9*10^{-2}$; furthermore, very high values are preserved in the martensitic phase below the transition temperature.

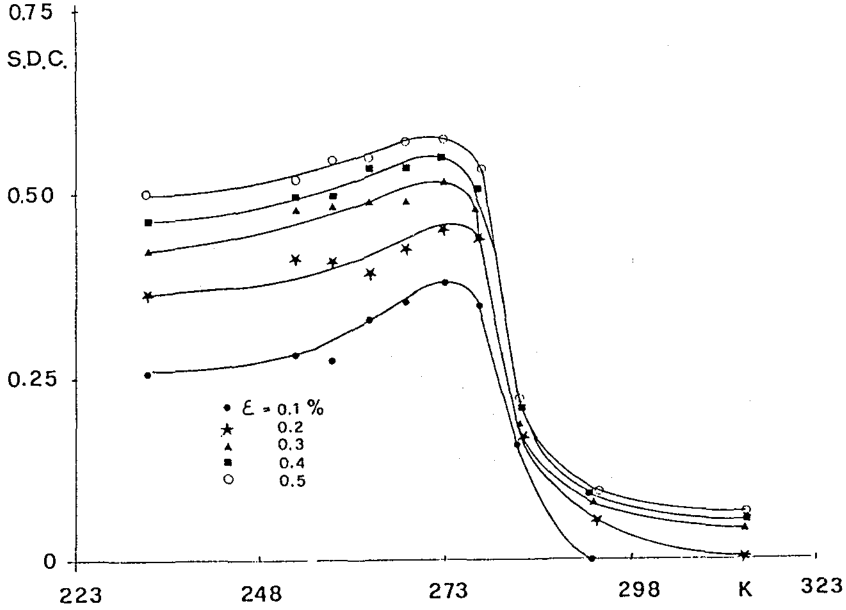
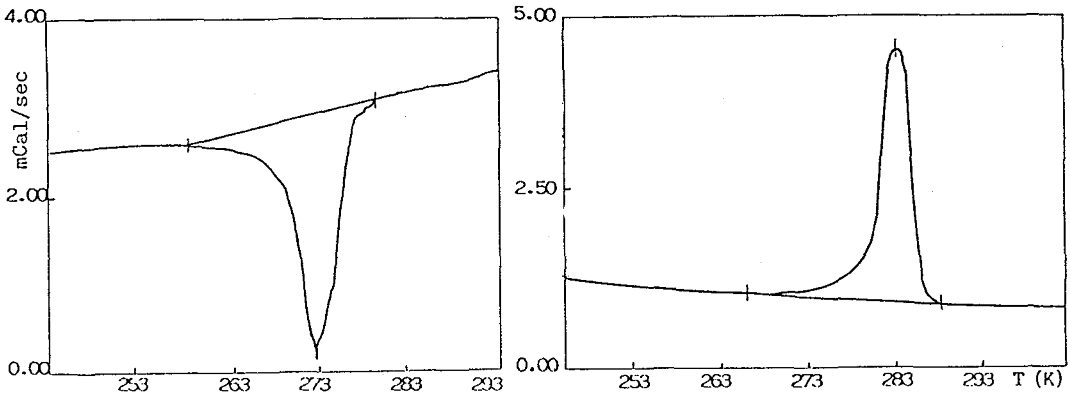


Fig. 3 S.D.C. vs. temperature for various stress amplitudes

3.3.- Differential scanning calorimetry.

A detailed calorimetric investigation of a set of CuZnAl alloys was carried out in the framework of thermodynamic analysis of martensitic transformations, a complete description of which will be given elsewhere (8). Fig 4 shows the calorimetric curves concerning the present alloy taken at a scan rate of 10 k/min.



a)

b)

Fig. 4 Calorimetric curves for direct (a) and indirect (b) β-martensite transformation

The results can be summarized as follows:

a) upon thermal cycling from 233 to 313 K a stable condition for the thermodynamic potentials is observed after few cycles, in agreement with the results of section 3.2. The

temperature of the heat absorbtion and heat evolution peaks are 284 ±1 and 272 ±1 K, respectively, in good agreement with the position of the peaks of fig. 1-b and 3. Values of characteristic transformation temperatures are: Ms = 284 ±1 K, Mf = 258 ±1 K, As = 264 ±1 K, Af = 289 ±1 K. The hysteresis is considerably smaller than observed for for I.F. curves;
b) the enthalpy changes for the forward (fig. 4-a) and reverse (fig. 4-b) transformations, measured from the area under the calorimetric peak, are $Q_{\beta\text{-}M}$ = 314 J/mol and $Q_{M\text{-}\beta}$ = 334 J/mol, respectively;
c) The frictional work, calculated according to (6) from $(Q^{M\text{-}\beta} - Q^{\beta\text{-}M})/2$, is 10 J/mol.

4.- Discussion

A number of features coming from the present investigation need some further comment.
First, results at section 3.2 confirm that strain amplitudes of the order of 10^{-3} are necessary to achieve elevated damping levels, as pointed out in ref. (5).
Second, for such strain amplitudes, high values of the S.D.C. are observed not only at the transition temperature, but also in the martensitic phase, a feature which is of interest for possible applications of SME alloys for damping.
Third, the importance of both alloy composition and thermal treatment on the stability of hysteresis loop upon thermal and mechanical cycling through the β phase-martensite transformation is emphasized. In the present experimental conditions, excellent reproducibility of hysteresis loops was observed for a few cycles, which allowed the evaluation or reliable S.D.C. data and was the prerequisite (6) for the determination of frictional work from calorimetric measurements. However the fatigue behaviour, which is the main parameter for practical applications, is still unknown and will be the object of further investigations.
Fourth, the friction work computed from calorimetric data, is the energy irreversibly dissipated in forms other than heat (6,7), for example as ultrasonic waves. The value obtained in the present investigation favorably compares with data reported in the literature (6,9).
As a final comment, by comparing the I.F. vs T curve of Fig. 1 - b to the S.D.C. vs T curve of Fig. 3, the absence of a sharp peak in the latter, in correspondence of the transition temperature is well evident. This effect is correlated to the forementioned high level of damping in the martensitic phase, which, for large stress amplitudes, reaches values comparable to those observed in the β - M transition region, as pointed out in (5).

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