New Aspects of Internal Friction during Martensitic Transformation of a Cu–Zn–Al Alloy

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Alloys with a thermoelastic martensitic transformation generally exhibit high mechanical damping in the martensitic phase. Further in this type of alloy a strong internal friction maximum versus temperature is observed during transformation. This maximum is heating rate dependent.

This work is concerned with the decrement measurement in a Cu–Zn–Al alloy at zero heating rate. In this case, and at temperatures below $M_s$, it has been shown that internal friction decreases with the number of measuring oscillations, and recovers after a few minutes’ rest. The residual internal friction after a large oscillation number does not exhibit any peak at transformation temperature and is stress dependent in the martensitic region. This behavior is qualitatively explained in terms of a very simple model.

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I. Introduction

The alloys with a thermoelastic martensitic transformation generally exhibit high mechanical damping in the martensitic phase. Further a strong internal friction maximum (I.F.) is observed during the transformation in such a kind of alloy (Fig. 1); this maximum is heating rate dependent(1)–(3)(6).

This work is concerned with the decrement measurement at zero heating rate.

II. Experimental Conditions

A polycrystalline Cu–Zn–Al alloy ingot was obtained by melting with an induction furnace in argon atmosphere. The samples were cut from the ingot, $40 \times 3 \times 1 \text{ mm}^3$ in size, sealed in a quartz tube, and water quenched after $3.6 \text{ ks}$ homogenization at $1100 \text{ K}$.

The composition 69.4 at% Cu–13.6 at% Zn–17 at% Al gives a $M_s$ temperature near room temperature(4).

Two pendulums were used for the measurements of internal friction:

—A classical torsion pendulum which allows damping measurements during free decay of oscillations at a frequency of 1 Hz. Approximately 10 oscillations are necessary to measure the decrement.

—A forced oscillation torsion apparatus operating at a 0.05 Hz frequency and allowing the damping measurement as soon as the first oscillation(5) is completed.

Fig. 1 Changes in internal friction and modulus with temperature.

—Frequency: 1 Hz
—Relative strain amplitude: $5 \times 10^{-5}$
—Heating rate: $dT/dt=0.021 \text{ K/s}$
—Classical torsion pendulum

The constant temperature steps were realized by use of a high inertia furnace. (Temperature stability within 0.1 K). The measurements were done after 1.8 ks from the beginning of the step. The present results are related to increasing temperature steps.

III. Results

1. Internal friction

For temperature steps below $A_t$, we observed a strong decay of the damping with the number of measuring oscillations. This proves that the oscillations during measurement affect the damping process. This behavior is shown in Fig. 2. This decay is observed during the transformation as well as in the stable martensitic phase. The effect is less pronounced at low temperature. If the excitation of the sample is interrupted for 3.6 ks, the damping is partially restored (Fig. 2).

On the other hand Fig. 3 shows the damping-spectrum against temperature measured on the classical pendulum (zero heating rate: steps, measured after approximately 10 oscillations during constant temperature steps:

- Frequency: 1 Hz
- Relative strain amplitude $\epsilon$: $10^{-4}$ and $2.5 \times 10^{-5}$
- Classical torsional pendulum
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A remaining transformation peak is observed but with a very small intensity compared with that obtained by non-zero heating rate (Fig. 1). The same spectrum is drawn in Fig. 5 for measurement after 120 oscillations. In this case it is seen that the transformation maximum has completely disappeared.

From these results it can be summarized that the large internal friction peak observed during transformation at non-zero heating rates (Fig. 1) is extremely weakened at zero heating rate (Fig. 3) and has completely disappeared after a large number of measuring oscillations (Fig. 4).

2. Modulus effect
A strong modulus effect is observed during transformation (Fig. 1) at non-zero heating rate. At zero heating rate (Fig. 4) this modulus effect remains, being however a little weaker, whereas the internal friction peak completely disappears.

3. Strain amplitude dependence
A strong strain amplitude dependence is observed. In Fig. 5 are drawn curves of internal friction versus temperature for three different strain amplitudes in the same conditions as in Fig. 4.

IV. Discussion

Principal experimental characteristics of I.F. during martensitic transformation are now relatively well known (Fig. 6). The I.F. spectrum may be divided into three parts:

— a weak I.F. in the high temperature matrix phase (C domain)
— a high I.F. in the martensitic phase (A domain)
— an I.F. peak at the transformation (B domain).

From the present results it is seen that the situation is more complex and leads us to consider three components of I.F. in A and B domains.

(1) An internal friction (I.F. 1) which does not depend on heating rate and number of oscillations but is only strain amplitude dependent. I.F. 1 does not exhibit any peak during the transformation (Figs. 4 and 5).

(2) An internal friction (I.F. 2) which decreases with the number of measuring oscillations and which presents a small maximum during the transformation (Figs. 2, and 3).

(3) An internal friction (I.F. 3) which depends on the heating rate in B domain during the transformation.

The internal friction peak has been widely studied for several alloys without separation in I.F. 2 and I.F. 3, but the results are valid in the first approximation. It is demonstrated that:
—The peak intensity increases linearly with the heating rate
\[ \dot{T} = \frac{dT}{dt}, \]
where \( T \) is the temperature and \( t \) is the time.

—The peak intensity decreases with increasing measuring frequency and increases with strain amplitude.

Two models explain these peak characteristics:

—Belko’s model\(^1\) is built on the basis of the fact that the measuring stress reduces the nucleation energy for favorably oriented nucleus. This leads to the expression of I.F.

\[ Q^{-1} = \frac{Gba^2 \dot{m}}{\omega kT} \]

where \( G \) = shear modulus
\( a \) = transformation strain
\( \dot{m} = (dm/dt) \) = transformation rate
\( \omega \) = angular frequency
\( T \) = temperature

Delorme’s model\(^6\) is a more phenomenological one. No particular hypothesis is done on the nucleation process, but it is supposed that the measuring stress gives the orientation of a definite fraction of martensite thermally produced.

Hence the expression for I.F. is:

\[ Q^{-1} = K \frac{\dot{m}}{\omega} \]

where \( K \) is a constant.

If we except the term \( T \) the two models give the same results.

Initially the term \( \dot{m} \) was considered only temperature dependent. Recently De Jonghe and co-workers\(^2\) introduced the stress dependence

\[ \frac{dm}{dt} = \frac{\partial m}{\partial \sigma} \frac{\partial \sigma}{\partial t} + \frac{\partial m}{\partial T} \frac{\partial T}{\partial t}. \]

This expression, with Delorme’s model, leads to:

\[ Q^{-1} = K \left\{ \frac{\partial m}{\partial T} \frac{1}{\partial t} \frac{\partial T}{\partial t} + \frac{6}{4\pi} \frac{\partial m}{\partial \sigma} \frac{\partial \sigma}{\partial t} \left[ 1 - \frac{\sigma_e}{\sigma_0} \right]^3 \right\} \]

(1)

where \( \sigma_e \) is the stress at which interfaces martensite-matrix or martensite-martensite begin to move, \( \sigma_0 \) is the maximum stress of the internal friction measurement:

\[ \sigma = \sigma_0 \sin (\omega t). \]

The first term is identical to the initial model and the second is the stress dependent term. This improvement enables us to explain:

—The strain dependent part of the I.F.
—The I.F. in the martensitic region where \( (\partial m/\partial T) = 0 \), but where the orientation of martensite variants with stress is possible.

In the case of temperature steps only the second term of expression (1) is operative and may be used to explain qualitatively I.F. 1 and I.F. 2

\[ Q^{-1} = \frac{4K}{\delta \sigma_0} \frac{\partial m}{\partial \sigma} \left[ 1 - \left( \frac{\sigma_e}{\sigma_0} \right)^3 \right] \]

The model explains the strain dependence and seems to be adapted for I.F. 1. To explain the decay of the internal friction with the number of oscillations (I.F. 2) it must be supposed that \( \partial m/\partial \sigma \) decreases or \( \sigma_e \) increases. This implies that interface mobility is lowered with the number of oscillations.

Physically this would be explained if it is supposed that an imperfect glissile interface leaves some “defects” behind it. These defects may disturb the interface when it comes back affecting its mobility. These “defects” must vanish rather easily when the interface is at rest to restitute the initial mobility. Annealing kinetics will be done at different temperatures in the martensite in order to explain these “defects”.

V. Conclusion

Internal friction at temperature steps were measured in a Cu–Zn–Al alloy. It has been shown that the internal friction decreases with the number of measuring oscillations and is restored after a few minutes of rest. The remaining I.F. after a large number of oscillations does not represent any peak at transformation temperature and is stress dependent in the martensitic region. This behavior is qualitatively explained with a very simple model.
REFERENCES