# Internal Friction Measurements During Martensitic Transformation in Cu Zn Al Alloys at kHz Frequencies

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## ABSTRACT

Early observations of internal friction during martensitic transformation in the low frequency range have shown a strong dependence on the thermal rate and measuring strain amplitude. The present results of internal friction in the kHz range confirm the amplitude dependence, but show that the internal friction spectrum is not influenced by the thermal rate between 0.8 K/min and 3.0K/min.

The amplitude dependent internal friction is analysed according to the Granato-Lücke model. It is shown that the results can be described by this model if one introduces an anisotropy factor to take into account the weakening of the shear elastic constant $(C' = C_{11} - C_{12})/2$.

## KEYWORDS

Internal friction ; martensitic transformation ; dislocation damping ; Cu Zn Al-β alloys ; shear elastic constant.

## INTRODUCTION

It has been observed that internal friction (IF) measurements during a martensitic transformation give a peak between the starting and finishing temperatures of the transformation, $M_s$ and $M_f$ ; and in general, the martensite phase IF is greater than that of the parent phase. The IF measurements performed at low frequencies, for instance, in Ti Ni alloys (Mercier and co-workers, 1979), in Co Ni (Postnikov and co-workers, 1968 ; Belko and co-workers, 1969), and in Cu Zn Al (De Jonghe and co-workers, 1975, 1976) have shown that the thermal rate and strain amplitude are very important parameters.

The results in the kHz range reported in the present paper differ from those obtained in the low frequency range. The observed differences may be useful for an understanding and interpretation of the IF mechanism in Cu Zn Al alloys.

## EXPERIMENTAL PROCEDURE

Cu Zn Al alloys with a nominal composition of 76 wt % Cu, 17 wt % Zn and 7 wt % Al were prepared by induction melting under an argon atmosphere. The casting was then treated at 800°C followed by water quenching. The $M_s$ temperature for this alloy is around 320 K.

The IF and frequency measurements were carried out in parallelepiped samples (2 mm x 4 mm x 40 mm) under flexural vibrations. The accuracy of the frequency measurements is higher than 99.9 % ; the dispersion of the IF is 2 % for $Q^{-1} = 5 \times 10^{-3}$ ; and the accuracy of the temperature measurement is ± 1 K (Stadelmann, 1978). All the measurements are recorded digitally, tape-punched, and afterwards read by computer.

## RESULTS

In order to establish a comparison with low frequency results, we have studied the influence of the temperature variation rate ($\dot{T}$) and the strain amplitude ( $\varepsilon$ ) on the IF spectrum.

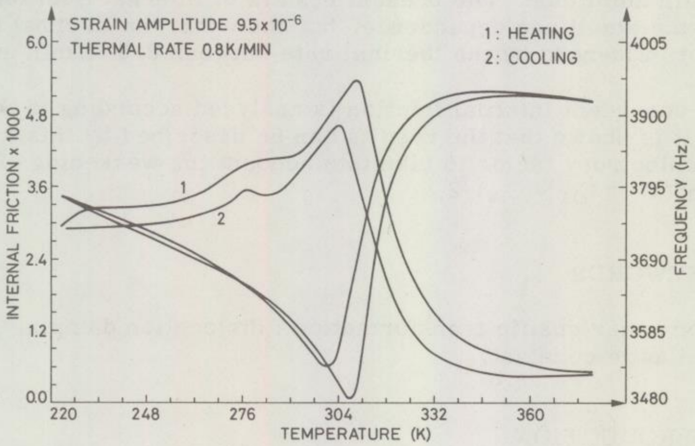


Fig. 1. Internal friction and frequency variations between 220 and 380 K.

Figure 1 shows the IF and frequency as a function of temperature at a constant cooling and heating rate. The maximum of IF is accompanied by a minimum in the frequency. The peak height is about 15 to 20 % higher on heating than cooling.

Figure 2 shows the behaviour of peak height (A) and martensite phase background (B) as a function of thermal rate for two strain amplitudes. It has been found that the thermal rate between 0.8 and 3.0 K/min has no influence on the IF spectrum. On the other hand, as shown in figure 3, the strain amplitude has a considerable influence. In fact the peak height varies from $6.3 \times 10^{-3}$ for $\varepsilon = 2.7 \times 10^{-5}$ to $2.0 \times 10^{-3}$ for $\varepsilon = 9.5 \times 10^{-7}$. This result is very important, for it implies that at very small strain amplitude the peak disappears ; and this in turn implies that the IF could be due to the dislocation mobility.

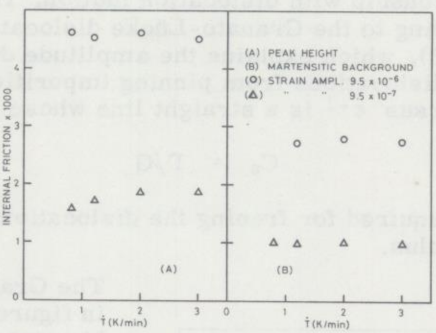


Fig. 2. Influence of $\dot{T}$ on peak height and martensite phase.

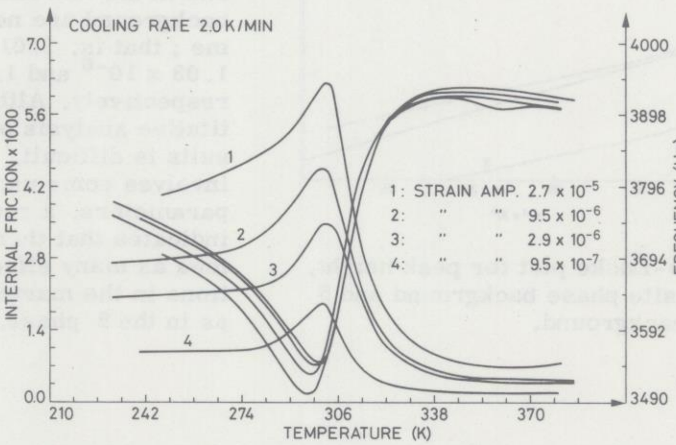


Fig. 3. Internal friction and frequency as function of temperature for different strain amplitudes.

## DISCUSSION

### (a) Dependence on temperature variation rate

The influence of the thermal rate observed in the low frequency range, which has not been observed in the present results, can be understood using De Jonghe's model (De Jonghe and co-workers, 1976). The dependence on $\dot{T}$ becomes negligible at high frequency (kHz range) owing to the $\dot{T}/f$ factor. This non-dependence on $\dot{T}$ is similar to the result reported by Mercier and co-workers (1979) in TiNi alloys measured in a static process, that is, with the temperature variation rate null. This behaviour is also predicted by Postnikov and co-workers (1976).

(b) Amplitude dependence

As pointed out in the previous section the dependence of IF on strain amplitude, fig. 3, can imply a relationship with dislocation motion. Therefore, these results were plotted according to the Granato-Lücke dislocation damping theory (Granato and Lücke, 1956), which explains the amplitude dependent IF as being caused by breakaway of dislocations from pinning impurities. This theory predicts that $\ell n\, Q^{-1} \times \epsilon$ versus $\epsilon^{-1}$ is a straight line whose slope is given by De Batist (1972) :

$$C_2 = \Gamma/G \quad (1)$$

where $\Gamma$ is the stress required for freeing the dislocation from its pinning points and $G$ is the shear modulus.

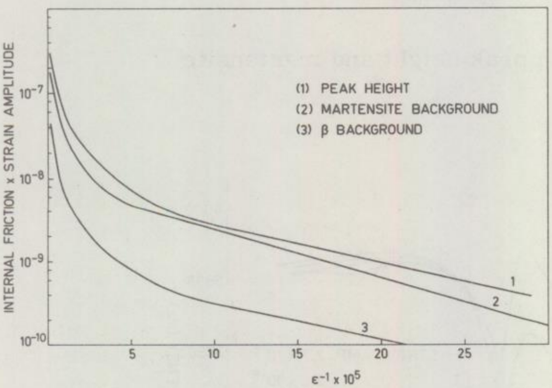


Fig. 4. Granato-Lücke plot for peak height, martensite phase background and β phase background.

The Granato-Lücke plot shown in figure 4 was corrected taking into account the fact that the strain amplitude is not maximum along the sample (Jalanti, 1975). The slopes in the β phase, in the peak height and in the martensite phase background are nearly the same ; that is, $1.01 \times 10^{-6}$, $1.03 \times 10^{-6}$ and $1.34 \times 10^{-6}$ respectively. Although a quantitative analysis of these results is difficult, because it involves some unmeasured parameters, a rough estimate indicates that there are 10 times as many effective dislocations in the martensite phase as in the β phase.

(c) Model

According to the observed amplitude dependence in figure 3 and 4, our results can be interpreted by the Granato-Lücke model of amplitude dependent IF, but with the addition of the anisotropy factor A, as used by Mercier and Melton(1976) for the amplitude independent case.

In general, to calculate the elastic energy of a dislocation line, one utilizes the isotropic medium approximation ; that is, the elastic energy depends on the average elastic constant $\mu$ . But in the case of an anisotropic material, one needs to utilize the matrix $C_{ijk\ell}$ . Foreman (1955) calculated the elastic energy per unit length of a dislocation line in an anisotropic medium, replacing each of the elastic constants $\mu$ by $\mu A$ (energy factor). The calculations of $\mu A$ are very complicated, but in most cases they are proportional to $(C_{11} - C_{12})^{1/2}$ .

The amplitude dependent IF is given by the expression (De Batist, 1972) :

$$Q^{-1} = \frac{C_1}{\epsilon} \exp\left(-\frac{C_2}{\epsilon}\right) \quad (2)$$

with $C_1 = \Omega \lambda \Delta_0 L^3/\pi^2 \ell G$ (3)

and $C_2 = \Gamma/G$ (1)

In equation (3), $\Omega$ is an orientation factor ; $\lambda$ is the dislocation density ; $\Delta_0 = 4(1-\nu)/\pi^2$ ; $\nu$ is Poisson's ratio ; L is the dislocation lenght, $\ell$ is the average distance between impurity pinning points ; and G is the shear modulus, where G will be replaced by $G^A$ to take the anisotropy into account.The stress required for freeing the dislocation from its pinning point can be written :

$$\Gamma = \pi F/4 a \ell \quad (4)$$

with

$$F = 4 G \epsilon^o a^4/d^2 \quad (5)$$

where $\epsilon^o$ is the Cottrell misfit parameter, d is the distance between the impurity atom and dislocation, and a is the interatomic distance.

From equations (1),(3),(4) and (5), the only term dependent on the elastic constant in equation 2 is $C_1$ through G. So that, one can rewrite equation 2 :

$$Q^{-1} = \frac{C_1(A)}{\epsilon} \exp\left(-\frac{C_2}{\epsilon}\right) \quad (6)$$

where $C_1$ now is a function of the anisotropy factor A. That is : $C_1 \alpha \frac{1}{G^A} \alpha (C_{11} - C_{12})^{-1/2} \alpha A^{1/2}$, since $A \equiv C_{44}/C'$. Now, if we take into account that the shear elastic constant $C' = (C_{11} - C_{12})/2$ diminishes ; and hence the anisotropy factor, A, increases at the martensitic transformations (Nakanishi, 1975 ; Guenin and co-workers, 1977), then $Q^{-1}$ also increases at the transformation ; and the frequency, which is proportional to $G^{1/2}$, diminishes. Thus, equation 6 would explain the IF during a martensitic transformation, as being caused by the enhanced mobility of dislocations when C' diminishes.

## CONCLUSION

In summary, the IF mesured in CuZnAl alloys during a martensitic transformation in the kHz range, does not exhibit a temperature variation rate influence. This behaviour has been predicted by De Jonghe and co-workers (1976) and Postnikov and co-workers (1976). On the other hand, the dependence of the whole IF spectrum on the strain amplitude can possibly be explained by dislocation mobility. The observed peak can be explained by dislocation breakaway, taking into account that the elastic shear constant C' decreases during martensitic transformation.

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