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THE INFLUENCE OF AGEING IN THE MARTENSITE PHASE ON THE INTERNAL FRICTION IN Cu-Zn-Al ALLOYS

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Abstract.
During ageing below $A_s$, the damping capacity of Cu-Zn-Al martensite goes through a maximum as a function of the ageing time. This process is found to be thermally activated. The observed effect is called the peaking effect of the second kind while referring to the peaking effect of the first kind already described earlier.

I - INTRODUCTION

The martensitic phase of the Cu-Zn-Al alloys exhibits a very high damping capacity which makes this alloy very attractive for industrial applications. Alloys thus investigated have martensitic transformation temperatures $M_s$ and $A_s$, well above room temperature. This condition however, requires special heat-treatments if one wants to conserve the high damping for a prolonged time. In recent publications /1,2/ it is demonstrated that the heat-treatment of the alloy should be such that the excess vacancies retained after quenching the high temperature beta-phase anneal out in the beta-phase prior to transforming to martensite. This is done by retaining the samples a sufficiently long time at low temperatures in the beta-phase /3/.

Also recently large interest has been given to the stabilisation of the martensitic phase resulting from ageing. During stabilisation the martensitic phase becomes more stable relative to the $\beta$-phase and thus the reverse transformation temperatures $A_s$ and $A_f$ increase. This stabilisation is a thermally activated process/4,5/ and not yet completely understood/6/. The aim of the present paper is to show whether or not a study of the internal friction could contribute to the understanding of the stabilisation phenomenon. In addition it shows the effect of ageing on the damping capacity.

II - EXPERIMENTAL PROCEDURES

In order to investigate a broad temperature range for ageing experiments, an alloy with high transformation temperatures was chosen. The composition in atomic percent is: 70.35 % Cu; 12.43 % Zn and 17.21 % Al. The $A_s$ temperature of the alloy is 383K. The 31 x 7 x 3 mm$^3$ samples are solution heat-treated at 1023K for 15 min. subsequently quenched in an oil bath at 423K and held there for 10 min. The samples are then air-cooled to room temperature. Different sets of samples were stored in oil baths at respectively 313K, 333K, 353K and 373K, for 2, 6, 20, 60 and 120 days and put on the internal friction equipment immediately. The internal friction was measured at room temperature for three hours under continuous vibration at resonance frequency on an apparatus DMA (Dynamic Mechanical Analyser) described elsewhere /1/.
III - EXPERIMENTAL RESULTS.

When the internal friction is measured continuously for some hours a peaking effect is observed (fig.1)/2,7/. The present study describes the most important items of the damping curve as a function of the ageing parameters, time and temperature as schematically indicated in fig.1. \( \eta_0 \) is the start value of the internal friction, \( \eta_{\text{max}} \) the peak-value, \( t_{\text{max}} \) the time when \( \eta_{\text{max}} \) is reached, \( \eta_1 \) the damping after one hour vibration and \( f_0 \) the initial resonance frequency (\( f_2 \) being proportional to the Young's modulus). The most important result is the occurrence of a new type of peaking effect. Indeed each of the defined \( \eta \)-values, \( \eta_0, \eta_{\text{max}} \) and \( \eta_1 \) are found to show a maximum as a function of ageing time (figures 2, 3 and 4). The kinetics of this peaking effect are found to be temperature dependent: the higher the temperature the faster the maximum is reached and the faster the decrease afterwards. In order to distinguish this peaking effect from the previous one, we will call it the "peaking effect of the second kind", while the other will be called the "peaking effect of the first kind". As also shown in the figures 2, 3 and 4, the peaking effect of the second kind is only observed at the ageing temperature of 333K. The maximum of internal friction at 313K is not yet reached at maximum ageing time, whereas the maximum at the ageing temperatures 353K and 373K occurs too soon to be detected within the experimental conditions. From fig.5 one can conclude that the time at which the peaking effect of the second kind occurs also goes through a maximum while the kinetics are temperature dependent. Another important result is that the resonance frequency and thus the elastic modulus increases with ageing time. This process accelerates with increasing ageing temperature as illustrated in fig.6. Finally, fig.7 shows the behaviour of the ratio \( \eta_{\text{max}}/\eta_0 \) as a function of ageing time and temperature.

DISCUSSION

The main difference between the "peaking effect of the first kind" (PE1) and the "peaking effect of the second kind" (PE2) is that the internal friction in the case of PE1 is easily restored by interruption of the vibration or an amplitude discontinuity /7/, while PE2 cannot be restored unless the material is heated to temperatures above \( A_f \) and cooled again below \( M_f \). A second important difference is the time scale at which both phenomena occur. For PE1 the maximum is reached within minutes while it takes some days for PE2. In both cases the role of the vacancies and their interaction with the interface boundaries cannot be denied. Indeed, the vacancy concentration in the martensitic state is higher than its equilibrium concentration. This can be deduced from two observations: 1. The formation energy for vacancies in martensite is higher than in the B-phase and thus its concentration will be higher than the equilibrium concentration calculated from this formation energy, since the vacancy-concentration in the B-phase prior to the transformation is retained upon quenching /4/. 2. Positron annihilation studies revealed that vacancies are produced during the transformation /8/. Also by positron studies it was found that the total defect concentration in the martensitic state was not significantly altered after long term ageing (up to six months) even at high temperatures, but below \( A_S/3 \). It is not clear at this moment how the vacancies influence the mobility of the interface dislocations either in the case of PE1 as in that of PE2. For PE1 a dragging model was proposed to be responsible for the effect but then the vacancies should be mobile enough to evaporate when the dislocations are displaced from their steady-state positions /2/. In the case of PE2 one should now also consider the matrix structure to be able to change due to the ordering process that is considered as responsible for the stabilisation /5/. In this re-ordered martensite structure the vacancies loose their mobility and dragging can be excluded. But if they are able to concentrate at the (interface-) dislocations they can act as firm or weak pinning points. The increased elastic-modulus is a good indication for this. Especially the binding force between the point defects and the dislocations and the distance between weak and firm points will largely determine the damping capacity as is proposed by the Granato-Lücke model. Also, the influence of the matrix-structure should be considered when the mobility of the dislocation is discussed. The occurrence of very small precipitates at the interfaces after long term stabilisation may complicate the problem and reveal more information. Further research in this area is needed.
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/7/ Van Humbeeck, J. and Delaey, L., Journ. de Phys. 43, (1982), C4-691.

Schematic representation of the internal friction and resonance frequency as a function of time during continuous vibration at room temperature. The parameters under investigation are indicated on the figure.

Figure 1.

The initial value of the internal friction $\eta_0$ at room temperature as a function of the ageing time at the indicated temperatures.

Figure 2.

The maximum value of the internal friction $\eta_{max}$ at room temperature as a function of ageing time at the indicated temperatures.

Figure 3.
Figure 4: The value of the internal friction after 1 hour vibration at room temperature, $\eta$, as a function of ageing time at the indicated temperatures.

Figure 5: The time at which the maximum described in fig.1 occurs as a function of ageing time at the indicated temperatures.

Figure 6: The value of the initial resonance frequency, $f_0$, at room temperature after ageing for 2 days(*) and 120 days (+) as a function of the ageing temperature.

Figure 7: The ratio $\eta_{max}/\eta_0$ (fig.3 and fig.2) as a function of the ageing time at the indicated temperatures.