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THE INFLUENCE OF STRAIN-RATE, AMPLITUDE AND TEMPERATURE ON THE HYSTERESIS OF A PSEUDOELASTIC Cu-Zn-Al SINGLE CRYSTAL

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Abstract. - The hysteresis loop, described during the formation of stress-induced pseudoelastic martensite in a Cu-Zn-Al betaphase single crystal, was studied as a function of strain-rate, deformation amplitude and temperature. The σ^{D^m} , the stress at which the transformation starts at a given constant temperature, is strain-rate independent but the hysteresis described by the stress-strain curve shows a maximum at intermediate strain-rates ($3.3 \times 10^{-3} \text{ sec}^{-1}$). For very low strain rates ($3.3 \times 10^{-5} \text{ sec}^{-1}$) the relative energy-loss ($\Delta W/W$) was independent of amplitude. The amplitude-dependence was the strongest at intermediate strain-rates. The absolute hysteresis, i.e. energy loss, measured at constant strain-rate seems to be independent of temperature in the region (M_S+60, M_S+110). The change in hysteresis as a function of strain-rate can be attributed to the heating and cooling of the sample due to the exothermic character of the beta-martensite transformation and the reverse endothermic transformation. At very low strain-rates the transformation occurs isothermally so that nearly no hysteresis is found. Only at very high strain-rates the sample is deformed adiabatically.

Introduction. - The beta-to-martensite transformation in Cu-Zn-Al alloys is associated with a damping peak and the internal friction in martensite is much higher than in the beta-phase (1). However, this behaviour was only measured when the temperature rate was different from zero. However, at dT/dt equal to zero, this is at constant temperature, a relaxation occurs so that the internal friction in the martensitic phase decreases with time and even the internal friction peak nearly disappears with time (2,3). This effect was also already noticed in Cu-Al-Ni (4) and Ti-Ni alloys (5). It is generally accepted that in the martensitic state the movement of interfaces greatly contribute to the energy loss (1), however the influence of these movements on the crystal structure is not clear yet. In the transformation region, the internal friction is due to the growing or disappearing of one phase into the other and, due to the measuring technique, combined with an alternating movement of the interfaces between the two phases. Above the temperature A_f the martensitic phase can also be induced by stress or strain. At this temperature, the beta-phase is stable in a stress free sample, upon removing the stress, the stress-induced martensite will disappear. This SIM gives rise to large elastic deformations. This pseudoelastic effect is more pronounced in single crystals and is much lower in polycrystals (6). The study of the hysteresis loop, described by a pseudoelastic curve of a β single crystal may reveal

important information concerning the mechanism and energy dissipation during the stress-induced growth of martensite.

Experimental procedure. - A Cu-Zn-Al alloy with composition 67.24 at % Cu, 21.66 at % Zn and 11.10 at % Al was made by induction furnace melting an eighth kilogram ingot to get a good homogenisation. The ingot was hot extruded to a bar of 12 mm diameter, a sample of 250 mm length was taken for inclusion in an evacuated quartz-tube to make a single crystal with the modified Bridgmen-technique. A heat-treatment of 10 min at 800°C followed by water-quenching was applied to the single crystal. The transformation temperatures, $M_s = -42^\circ\text{C}$, $M_f = -52^\circ\text{C}$, $A_s = -50^\circ\text{C}$, $A_f = -22^\circ\text{C}$, were determined by DSC and resistivity measurements. A tensile sample was made from the single crystal with the following dimensions : length 150 mm, diameter of the grips 12 mm, gauge length 40 mm, gauge diameter 6.25 mm. The sample was tested in an Instron-25 Ton tensile machine with a heating/cooling chamber. The strain rates applied to the sample were between $3.3 \times 10^{-5} \text{ sec}^{-1}$ (0.05 mm/min) and $6.7 \times 10^{-2} \text{ sec}^{-1}$ (100 mm/min). The strain was measured by a 25 mm/50 % extensometer. A chromel-alumel thermocouple was pressed against the sample. The orientation of the tensile axis was determined by the Laue back reflection method and is shown in the insert of fig.1.

Results. - Figure 1 gives the stress-strain curve at room temperature for complete stress-induced transformation, with a pseudoelastic elongation of 8.65 %. The stress necessary to induce martensite, σ^{p-m} , is temperature-dependent (6). This relationship is shown in figure 2 and is determined at a strain rate of $1.3 \times 10^{-4} \text{ sec}^{-1}$. The line is calculated by the linear regression method. $\sigma^{p-m} = 1.93T - 442$ with σ in MPa and T in K. At three different temperatures, 293 K (RT), 323 K and 353 K, pseudoelastic loops were described at different amplitudes (1, 2, 4 and 8 % deformation) and different strain rates. Figure 3 shows the curves taken at room temperature for four different strain rates and 8 % deformation. From an analysis of all these curves it can be concluded that : 1. σ^{p-m} is strain-rate independent. The transformation starts always at the same stress and strain. 2. The hysteresis described by the loops shows a maximum at intermediate strain rates. Figure 4 shows the change of the relative hysteresis, which is the area enclosed by the hysteresis loop divided by the area under the "horizontal" part of the loading curve, as a function of the natural logarithm of the strain rate at 8 % deformation and at two temperatures. 3. The loading curve shows a strain hardening effect increasing with increasing deformation rate. 4. The hysteresis H, as defined by Otsuka et al. (7), being the difference between the stress at e^{p-m} of the loading and unloading curve, is first increasing but decreases again at higher strain rates. 5. The hysteresis, proportional to the area of a closed loop, seems, within the experimental error, and at the same strain rates to be temperature independent.

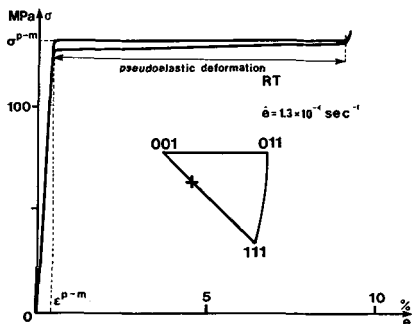


Figure 1
The total pseudoelastic loop at room temperature and at $\dot{\epsilon} = 1.3 \times 10^{-4} \text{ sec}^{-1}$. The orientation of the tensile axis is shown in the insert.

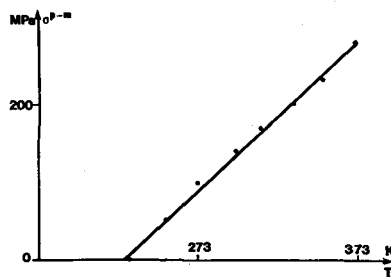


Figure 2
The linear relationship between σ^{p+m} and temperature.

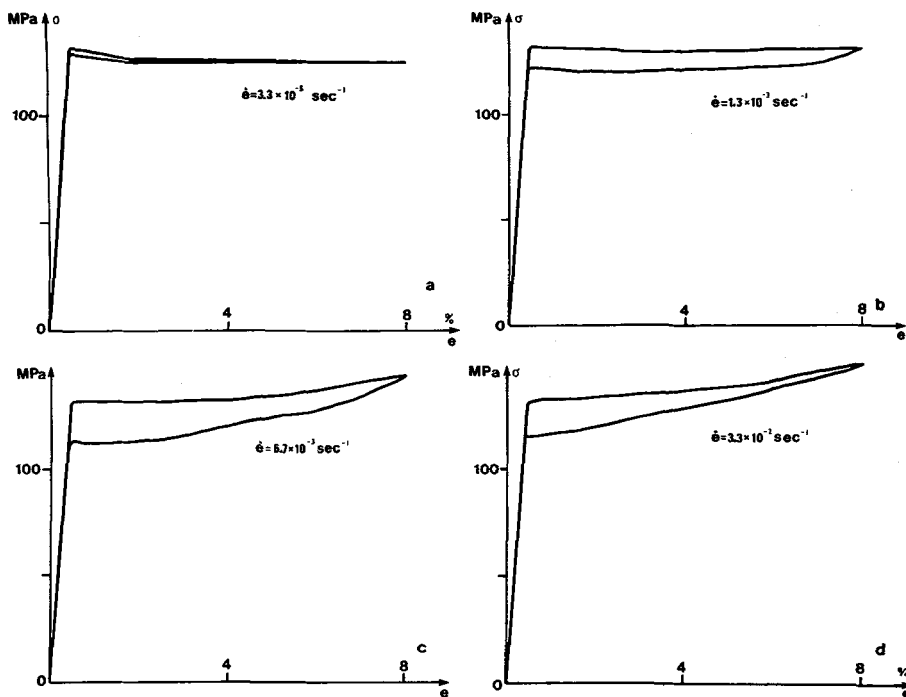


Figure 3 $\sigma - e$ curves at 8 % deformation and room temperature for four different strain rates.

At very low strain rates no amplitude dependence is observed, while at higher strain-rates $\Delta W/W$ reaches a maximum. Summarizing the results, figure 5 shows the relative energy loss as a function of the two parameters, the amplitude and the strain rate, $\ln \dot{\epsilon}$.

Discussion. - The change in hysteresis area can be explained by the heating and cooling effect due to the exothermic β -to-martensite and to the endothermic martensite to β transformation, as already pointed out earlier (1). The hysteresis in the stress-strain curves behaves similar as the temperature-deformation curves (fig. 3 and 6). A very low strain-rates, the heat produced during the beta to martensite transformation can easily flow away to the surroundings, especially to the grip ends. The heat loss at the air is already at moderate strain-rates neglectable in comparison to the heat loss at the grip ends (6). In figure 6, the dashed line being temperature of the environment, shows clearly that the increase in temperature increases with increasing strain rate due to decreasing heat loss. During unloading the transformation occurs endothermic. At very slow strain rates, the heat flow to the sample is large enough for "isothermal" transformation. However, at increasing strain rate, the heat-flow from the environment to the sample is not large enough. The sample will cool and its temperature will be lower than that of the environment at the end of transformation. This gives rise to a great temperature difference at a fixed deformation percent between the loading and unloading curve. Due to the increase in temperature during the loading cycle, the stress needed to proceed the transformation will become higher (fig. 2) so that the curve reveals an "apparent" strain-hardening. During unloading a similar but inverse effect occurs so that a large hysteresis area appears. At higher strain-rates the heat produced during loading can be nearly totally recuperated during cooling so that the sample temperature will not change or will drop only slightly under room temperature. This is the adiabatic behaviour. Such a temperature increase during deformation at increasing strain-rate was already measured in Cu-Al-Ni (8) and Cu-Zn-Sn (9). However, no relation was made with the "internal friction peak" as a function of strain-rate. Also, the conclusion that the energy loss during stress-induced transformation is proportional to the amount of martensite formed (10) is thus only valid at very low strain rates. The "strain-hardening" effect at higher strain-rates is due to the heating of the sample which influences the stress needed to proceed the transformation (fig. 2). So it can be concluded that the pseudoelastic hysteresis is temperature- and amplitude independent for low strain rates. The strain-rate dependency is only attributed to heating and cooling effects, which is due to the exo- and endothermic beta to martensite transformation and its reverse.

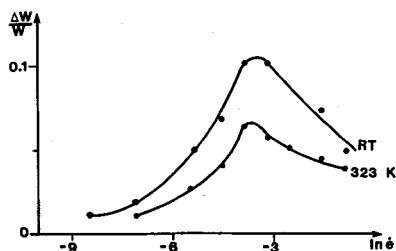


Figure 4 The relative energy loss during cycling as a function of the natural logarithm of the strain rate at two different temperatures.

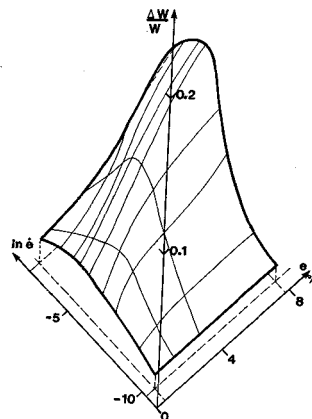


Figure 5 The relative energy loss as a function of strain of deformation amplitude and strain-rate.

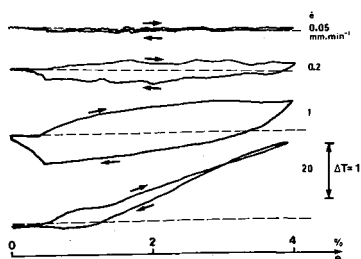


Figure 6 The temperature change at the surface of the sample as function of deformation at different strain rate (min/max)

References.

1. W. Dejonghe, L. Delaey, R. De Batist and J. Van Humbeeck, *Metal Science*, Nov. 1977, p. 523-530
2. M. Morin, G. Guenin, S. Etienne, P.F. Gobin, submitted to *Trans. JIM*, personal communication
3. J. Van Humbeeck, L. Delaey, to be published
4. I.A. Arbusova, V.S. Grivil-Yuk and L.G. Khandros, *Fiz. Metal. Metalloved* 30 n° 1, 1970, p. 181-185
5. O. Mercier, K.N. Melton and Y. De Préville, *Acta Met.*, Vol 27, pp. 1467-1475, 1979
6. J. Van Humbeeck, L. Delaey and A. Deruyttere, *Zeit. für Met.*, Bd 69 (1978), H. 9, S. 575-580
7. K. Otsuka, C.M. Wayman, K. Nakai, H. Sakamoto and K. Shimizu, *Acta Met.* Vol 24, pp. 207-226, 1976
8. C. Rodriguez and L.C. Brown, *Met. Trans. A*, Vol 11A, Jan 1980, p. 147
9. L.C. Brown, submitted to *Met. Trans.* Jan 1981
10. M. Ahlers, R. Pascual and R. Rapacioli, *Met. Sc. and Eng.* 27 (1977), p. 49-55

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