HIGH DAMPING RELATED TO ANELASTICITY OF MN-CU-ALLOYS

Stoyan Parshorov[1*], Stefan Valkov[2], Maria Ormanova[2], Ivan Parshorov[1]

[1]*Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre "Acad. A. Balevski", Bulgarian Academy of Sciences, 67 "Shipchenski prohod" Blvd, 1574 Sofia, Bulgaria, e-mails: st.parshorov@gmail.com, parsh@ims.bas.bg*

[2]*Institute of Elektronics "Acad. E. Djakov", Bulgarian Academy of Sciences, 72 "Tzarigradsko chaussee" Blvd, 1784 Sofia, Bulgaria, e-mails: stsvalkov@gmail.com; maria_mecheva@abv.bg*

Abstract. The dynamic relaxation spectrum of tree Mn-Cu alloys for a broad temperature interval – 293-973K is investigated in order to determine the micro-plastic behavior of the material at levels of relative deformation at the range of 10^{-4}-10^{-2}. The amplitude dependence of internal friction (IF) shows presence of tree zones of deformation amplitudes and possible dislocation mechanism of hysteretic damping and micro-plasticity in material.

Keywords: micro-plasticity, internal friction, background of internal friction.

1. INTRODUCTION

In real bodies, at stress values of the order of 10-4-10-2 [1, 2], far below the yield strength of the material, the condition of instantaneousness under ideal elasticity is not fulfilled according to Hoog's law and in the material occur micro plastic acts. Such a condition is defined as micro plastic.

From a physical point of view, the micro plasticity of the material is determined by the connection of stress and deformation with certain, internally occurring processes, performing work, during which a certain amount of energy is spent. Such are the transfer of material through atomic relaxation mechanisms, mainly related to diffusion processes, drift processes of impurity atoms and irreversible dislocation creep when the dislocation segments break away from the attachment points [1, 2].

[*]Corresponding author.

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The main method for obtaining information about the micro plastic behavior of the material is the internal friction (IF) method.

A periodically time-varying torsional strain is applied to a specimen. The phase shift angle between them – φ, called the "loss angle", is determined as a result of the balance of input W and dissipated energy W during one cycle during the experiment per unit volume of the material:

$$\operatorname{tg}\varphi \approx \varphi = \frac{W}{2\pi\ W} = Q^{-1}. \tag{1}$$

In the literature, the symbol Q^{-1} is adopted and means energy loss, and its magnitude is called IF.

2. MATERIAL AND RESEARCH METHODOLOGY

Three Mn-Cu alloys with chemical composition shown in Table 1 are the subject of research.

Table 1. Chemical composition – weight. %

No	Designation	Mn	Cu	Zn
1	Mn75Cu25	75	25	–
2	Mn65Cu35	65	35	–
3	Mn75Cu23Zn3	75	22.5	2.5

It is characteristic of alloys 1 and 2 that they have maximum damping ability and the presence of zinc – alloy 3, increases their mechanical properties [3–5].

Test samples for IF with dimensions – $0.5 \times 0.5 \times 50$ mm were made from the material by electrosparking. After closing the samples in vacuum ampoules, they are subjected to a standard mode of heat treatment – quenching and aging, in the following standard mode: tempering temperature – 800 °C, holding time 10 min, cooling in water, aging temperature 400 °C – melts 1 and 3, melt 2 – 490 °C, retention time 120 min.

To study the temperature dependence of IF, an automated and computerized apparatus for IF research was used, built on the principle of the inverse, balanced pendulum, at the operating frequency – 1–2 hertz and 12 measurement amplitudes, according to which 12 degrees of the relative deformation in the range 2.10^{-4}–5.10^{-4}. The IF values of the samples were taken in the temperature range 293-973K, at a heating rate of 1.5°/min.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 1 shows the dependence of IF on temperature, for the minimum and maximum values of relative strain, of a sample of Mn65Cu35 alloy. It is characterized by several main effects: a low-temperature and a high-temperature background of IF, which are a function of all relaxation processes occurring in the material and a resonance maximum. The increase in IF values with an increase in the deformation amplitude including the dissipated energy from the occurrence of the first microplastic acts in the material, characteristic of the hysteresis mechanism of relaxation. The resonance maximum will not be commented on due to lack of direct connection with the phenomena we are investigating.

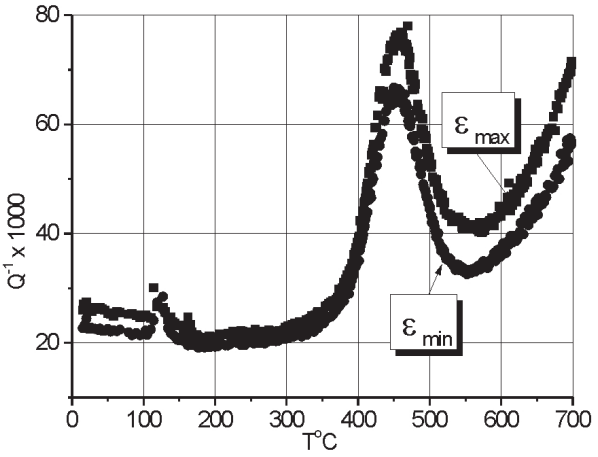

Fig. 1. Dependence of VT on temperature for the minimum and maximum values of relative deformation-alloy Mn65Cu35

The temperature characteristics of IF for all studied alloys are shown in Fig. 2–4 in coordinates:

– Value of IF – degree of relative deformation in studied temperature range. In order to exclude additional energy losses of a resonant nature, the IF values from relaxation maxima were subtracted from them.

Their analysis showed that:

– The presence of three characteristic zones of relative deformation is established:

I – zone – amplitudes up to values of the order of 2.10^{-4}, in which a strong amplitude dependence is observed.

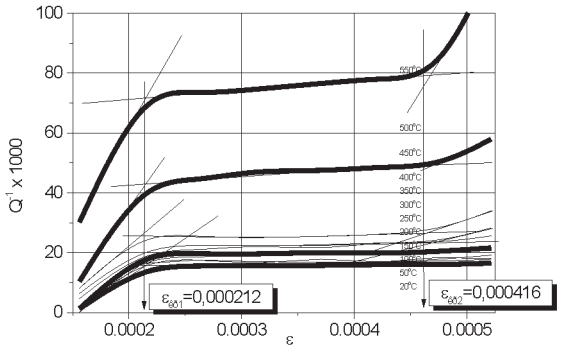

Fig. 2. Dependence of IF on the relative deformation – Mn-25%Cu alloy

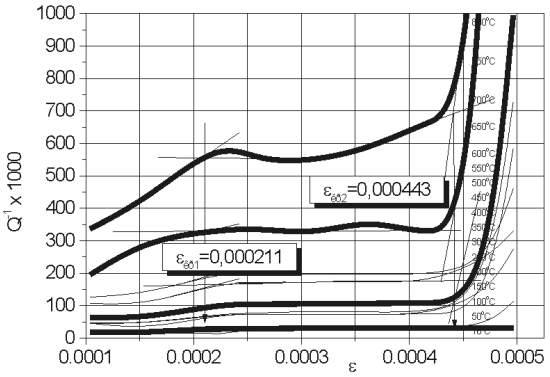

Fig. 3. Dependence of IF on the relative deformation – Mn-35%Cu alloy

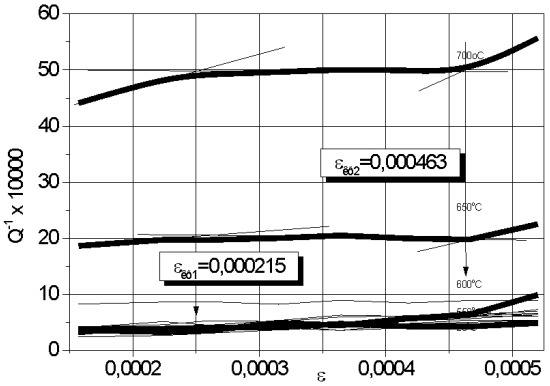

Fig. 4. Dependence of IF on the relative deformation – Mn-Cu-Zn alloy

II – zone – amplitudes of the order of 2-5.10^{-4}, in which the amplitude dependence is weakly expressed.

III – zone – amplitudes of the order of 5.10^{-4}, in which a strong amplitude dependence is observed.

- At constant temperature, damping grows strongly with increasing relative strain.
- For all studied alloys, the amplitude dependence is most pronounced at elevated temperatures, in the zone of the high-temperature background of internal friction.
- The Mn-35%Cu alloy has the most pronounced amplitude and temperature dependence, followed by Mn-25%Cu and the weakest in the Mn-Cu-Zn ternary alloy.
- The general appearance of the amplitude dependences of the individual alloys is similar, but they differ in the values and ranges of the individual parameters.

For the first time Reid [3], and after him other authors [4, 5, 6], established the relationship between the microplastic behavior of the material and the critical value of the stress. According to him, the basis of mechanical hysteresis is primarily the processes of irreversible dislocation creep of the material and, more precisely, microplastic acts at higher degrees of deformation.

This particularly strong mechanism applies to the studied Mn-Cu alloys, since in them at cooling takes place a phase transition of γ-manganese with a metastable wall-centered cubic lattice into a cubic-tetragonal one, which has a martensitic character, as a result of which the structure is non-equilibrium and with a large amount of structural defects, respectively dislocations [7, 8].

The mechanism describing the hysteresis processes occurring in the studied range of deformations is known as the Granato-Luke theory [1, 5], schematically shown in Fig. 5. This theory rests on the following: The dislocation line with a total length L (dislocation segment) is fixed at both ends immovably,

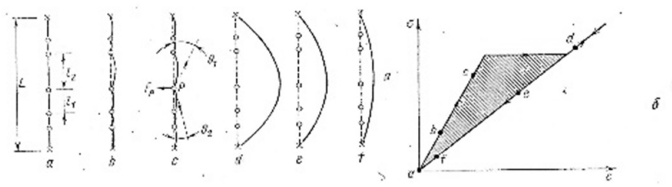

Fig. 5. Scheme of the process of detachment of the dislocation segment from the attachment points under cyclic loading and hysteresis diagram of the relationship between stress and strain.

and in the middle with solute atoms or other defects at a distance l (dislocation segment). When an external, critical stress is applied, the dislocation line can break away from the anchor points.

Then the IF is described by the equation:

$$Q^{-1} = \left[C_1.\Lambda.L^3/l^2.A_{Amplitude}\right] . \exp\left[-\pi.f_m/4.b.l.A_{Amplitude}\right],$$

where: C_1 – constant, Λ – density of dislocations [cm^{-2}], $A_{Amplitude}$ – supercritical amplitude of deformation (relative deformation), b – Bürgers vector [cm], f_m – maximum force of connection of impurity atoms with the dislocation line.

Therefore, the value of IF at supercritical deformation depends on the density of dislocations, the concentration of impurity atoms on them, the length of the dislocation segments, the number and strength of connection of their attachment. IF increases with strain amplitude as an increasing number of dislocation segments participate in energy losses.

In order to interpret the results in light of the theory of Granato-Luke, they were presented into coordinates $\ln(Q^{-1}.A_{Amplitude}) - 1/A_{Amplitude}$.

In Fig. 6–8 present the obtained results in the above coordinates. They show that above a certain critical amplitude of deformation, a strong amplitude effect is observed, which confirms the theory of Reed and Granato-Luecke.

The established deviation from the assumed linear dependence of this theory, also obtained by other authors [9, 10], shows that there is at least one more mechanism of hysteresis energy dissipation, which has other energy parameters and develops in a certain range of amplitudes.

The segment of the ordinate axis "M" and the tangent of the resulting line N, according to the above equation, are described by the dependencies:

$$M = C_1.\Lambda.L^3/l^2 \quad \text{and} \quad N = \pi.f_m/4.b.l \ ,$$

where: C_1 – constant, Λ – density of dislocations [cm^{-2}], $A_{Amplitude}$ – supercritical amplitude of deformation (relative deformation), b – Bürgers vector [cm], f_m – maximum force of connection of impurity atoms with the dislocation line.

Given that the value of L/l represents the concentration of anchor points or the concentration of defects along the line of dislocations, the coefficient M is effectively proportional to the dislocation density and more precisely to the square of the defect concentration.

In Fig. 9 shows the temperature variation of the coefficients M from the equation of Granato and Luecke, from which it can be seen that:

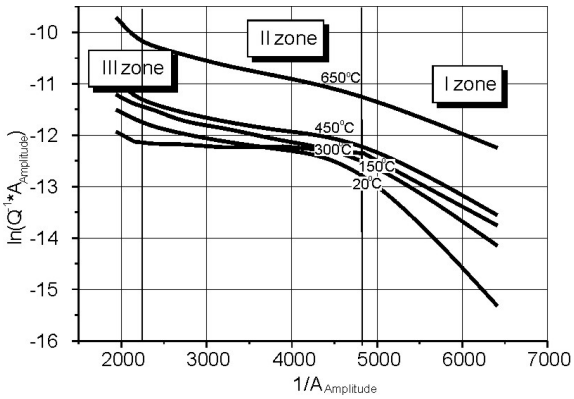

Fig. 6. Dependence of $\ln(Q^{-1}.A_{Amplitude}) - 1/A_{Amplitude}$ at different temperatures – alloy Mn-25%Cu

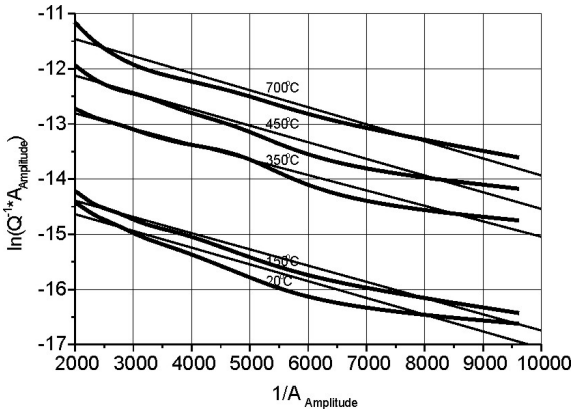

Fig. 7. Dependence of $\ln(Q^{-1}.A_{Amplitude}) - 1/A_{Amplitude}$ at different temperatures – alloy Mn-35%Cu

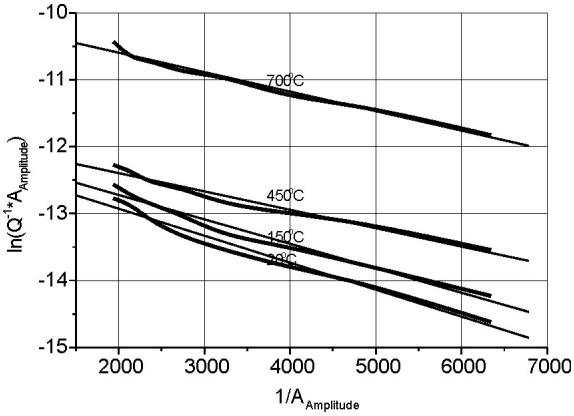

Fig. 8. Dependence of $\ln(Q^{-1}.A_{Amplitude}) - 1/A_{Amplitude}$ at different temperatures – alloy Mn-Cu-Zn

– As the temperature increases, the dislocation density and defect concentration decrease slightly.
– The greatest dislocation density and concentration of defects is found in the Mn-35%Cu alloys.

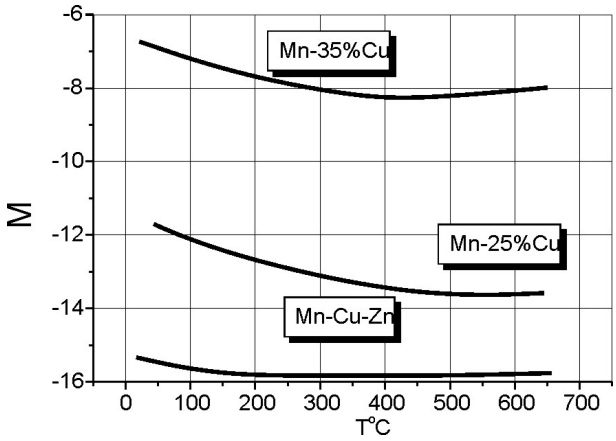

Fig. 9. Dependence of the coefficient M on temperature

The coefficient N is proportional to the strength of interaction between the defects and the line of dislocations. The temperature variation of the N coefficient – Fig.10 shows that:
– There is a temperature minimum of the interaction energy, after which it

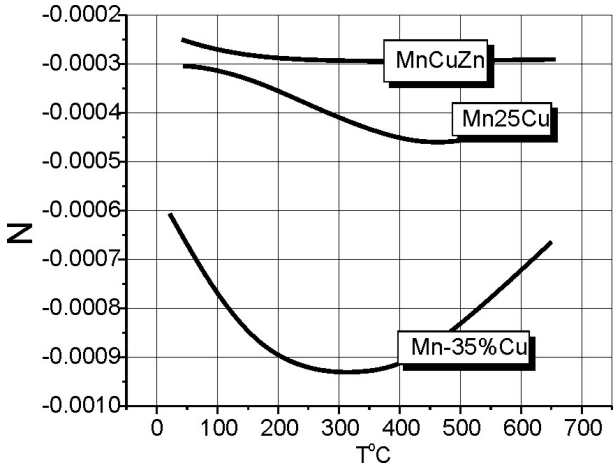

Fig. 10. Dependence of the coefficient N on temperature

begins to grow, probably due to the additional anchoring of the dislocation lines, not only by the impurity atoms, but also by the presence of separated phases along the dislocations in the solid solution.
– The strength of interaction between defects and dislocations is greatest in the Mn-Cu-Zn alloy and weakest in Mn-35%Cu.
– There is a temperature minimum in the interaction energy, after which it begins to grow, probably due to the additional anchoring of the dislocation lines, not only by the impurity atoms, but also by the presence of additional detachments along the dislocations in the solid solution.

Considering our results and those obtained by Xie, Morelli and Schaller [11], we can generalize and create the following model view of hysteresis energy losses in Mn-Cu alloys, and probably applicable to all aging fuels: The dislocation lines are anchored by the alloying atoms in the solid solution. During the formation processes in the solid solution, secondary phases are separated, according to the mechanisms published in the literature, namely - initial formation of a modulated structure, Guinet-Preston zones and subsequent formation of separations of the second phase along the dislocations, as places with the most -high surface energy.

When applying a cyclic deformation, with an amplitude above a certain critical value – zone 1, the increase in the damping effect is due to a gradual detachment from the attachment points by the alloying atoms. In zone 2, this process slows down because firmly attached dislocation segments of the separated secondary phase remain. In zone 3 there is a process of detachment of dislocations from separations along the dislocation lines. Then the entire segment is torn catastrophically from the attachment points.

4. CONCLUSIONS

– In the range of relative deformations, characteristic of the microplasticity of Mn-Cu alloys, three zones are observed that are strongly temperature-dependent, and this dependence is most strongly expressed in the zone of the high-temperature background of IF.
– There are two mechanisms of attachment of dislocation lines - that of impurity atoms and that of separations at high temperatures. When cyclic deformation with a supercritical amplitude is applied, the dislocation lines are gradually detached from the alloying atoms, and at higher temperatures and deformations, from the cluster formations in the material.
– The deviation from the assumed linear dependence in the theory of Granato and Luecke shows that there are several mechanisms of hysteresis energy

dissipation, which have different energy parameters and develop in a certain range of microdeformations.

It was established that the high energy losses in the studied material are determined by the presence of a high concentration of structural defects and a low value of their strength of connection with the dislocation lines.

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