ON THE NATURE OF THE RESONANCE RELAXATION MAXIMUM IN HIGH DAMPING ALLOYS

Stoyan Parshorov[1*], Stefan Valkov[2], Maria Ormanova[2], Stoyko Gurov[1] and 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; s_gyurov@ims.bas.bg; parsh@ims.bas.bg;*

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

Abstract. The present paper investigates the nature of the resonant relaxation maximum in high-damping alloys. The main parameters of the relaxation process are determined. It was found: (i) The solute atoms present in the substitutional solid solution together with the vacancies create cluster formations; (ii) The nature of the internal friction resonance maximum is related to the interaction of the applied measuring voltage with the stress field of the crystal lattice created by impurity atoms; (iii) The resonance maximum and the high-temperature background are two sides of the same process, reflecting the mechanism of aging processes.

Keywords: high damping alloys, internal friction, dynamic relaxation spectra, parameters of relaxation maxima, relaxation constant, activation energy.

1. INTRODUCTION

The purpose of the present article is to study the nature of the resonance relaxation maximum in connection with the damping properties of the three alloys.

[*] Corresponding author.

DOI: 10.7546/EngSci.LX.23.02.02

2. MATERIAL AND METHOD

The subject of investigation are two high damping manganese alloys 75%Mn-25%Cu and 65%Mn-35%Cu, produced at the Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre "Acad. A. Balevski", BAS by standard technology, and beryllium bronze EN CW103C with a certified chemical composition given in Table 1.

Table 1. Chemical composition of the beryllium bronze (in weight %)

Designation according to EN	Be	Ni	Co	Cu
CW103C	0.59	1.14	1.05	rest

The specimens (1×1×50 mm) are made using an electro-eroding machine. They are heat-treated under standard conditions in vacuum glass tubes – quenching and ageing: quenching after 10 min at a temperature of 800 °C and ageing for two hours at 400 °C for the manganese alloys, and for beryllium bronze – quenching at 940 °C and ageing at 480 °C, 120 min. Quenching medium is water.

The manganese-copper alloys find larger application as alloys of high damping properties of internal friction [1–3]. It is well-known that the value of internal friction at a certain frequency, relative deformation and temperature is directly proportional to the damping properties of the alloys at these conditions [4–5].

The temperature dependencies of the internal friction (dynamic relaxation spectra) are recorded. Fully automated and computerized apparatus is used for investigation, built on the principle of an inverted balanced pendulum at an operating frequency of 0, 5–7 Hz. The relaxation spectra of the specimens are recorded in the temperature range of 20–650 °C, at a heating rate of 3°/min. At each studied temperature the values of internal friction are recorded for ten amplitudes per relative operation from 2×10^{-2} to 1×10^{-6}.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The dynamic relaxation spectra of the specimens are shown in Figs 1–3. The dependencies refer to the maximum degree of relative deformation in the amplitude-dependent area of the internal friction, Amplitude-Dependent Internal Friction (ADIF) 2×10^{-2}, and the minimum in the amplitude-independent area of internal friction, Amplitude-Idependent Internal Friction (AIIF) 1×10^{-6}.

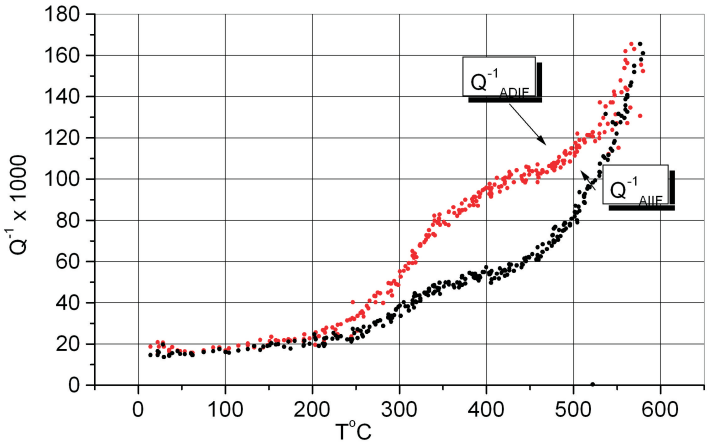

Fig. 1. Dynamic relaxation spectra of the beryllium bronze

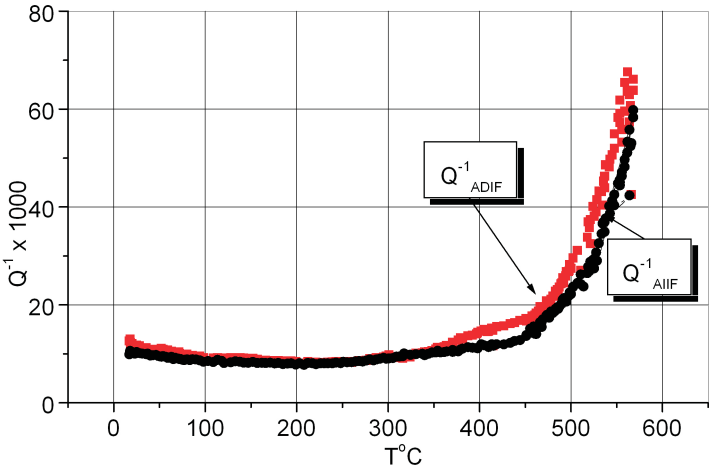

Fig. 2. Dynamic relaxation spectra of the Mn-25%Cu alloy

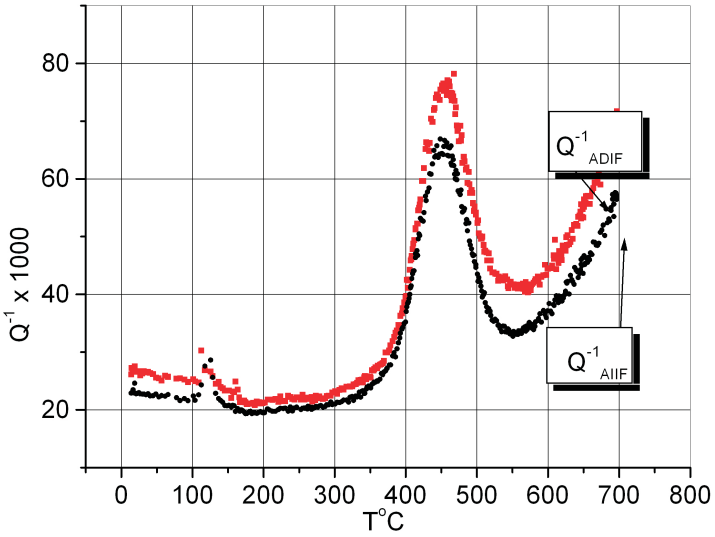

Fig. 3. Dynamic relaxation spectra of the Mn-35%Cu alloy

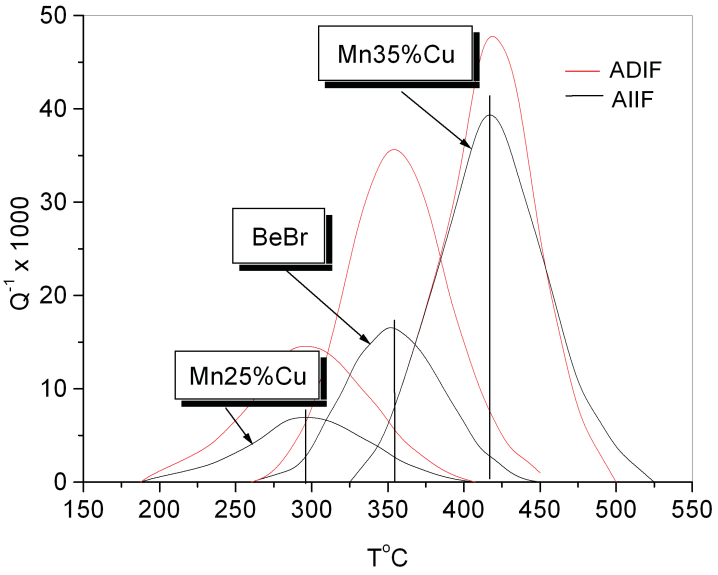

Fig. 4. Relaxation maxima of internal friction
in the studied alloys after background subtraction

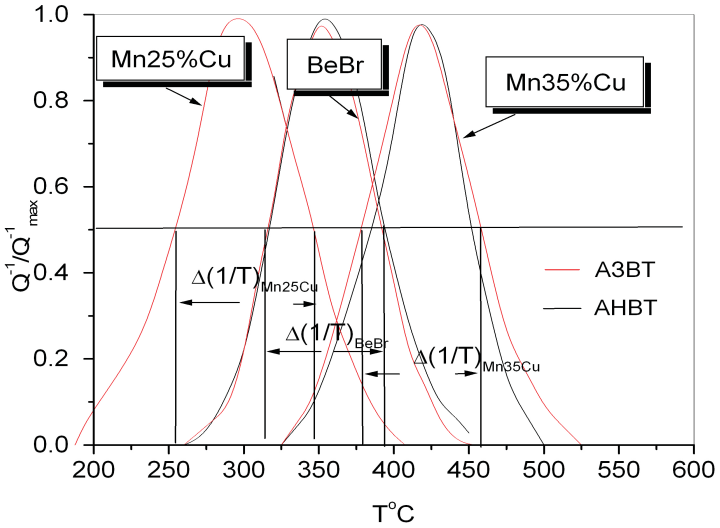

Fig. 5. Normalized relaxation maxima of the internal friction in the investigated alloys

For all studied alloys, maxima of internal friction with resonance nature can be observed on the temperature dependence of the relaxation spectra, Figs 1–3.

These maxima separated from the background are shown in Fig. 4, and in a normalized form in Fig. 5.

The main parameters that unambiguously determine the relaxation process are:

- relaxation constant, τ_0 [sec];
- activation energy of the process, H [kcal/mol];
- distribution parameter of relaxation times, β;
- the form-factor of the defect, $\delta\lambda$.

3.1. Relaxation constant

The relaxation constant τ_0 is a linear function of the inverse temperature of relaxation maximum $1/T_{\max}$ and of the ratio of the Planck constant "h" and Boltzmann constant "k" according to the theory of C. Wert [5]:

$$\tau_0 = h/kT_{\max},$$

$K = 1.38 \times 10^{-16}$ [erg/°], $h = 6.625 \times 10^{-27}$ [erg.sec].

The obtained values of the relaxation constant indicate the presence of a relaxation process that takes place at a relatively lower speed, compared to that of ferrite $\left(\tau_0 \times 10^{-15} \text{ sec}\right)$ and martensite $\left(\tau_0 \times 10^{-13} \text{ sec}\right)$ [5].

3.2. Activation energy

For the cases where the relaxation processes have a low activation energy, Wert and Marx give a dependence connecting the activation energy, the value of the operating frequency ν [Hz], and the relaxation time τ_0 [6–7]:

$$H = R.T_{\max} \ln\left(1/2\pi\nu\tau_0\right),$$

where R is the gas constant – 1.986 [cal/mol.grad].

The approximation of this method lies in the uncertainty of the relaxation constant τ_0, for which a reasonable value is taken from the literatura, for example 10^{-13} sec, or from the calculated values given in Table 2.

The values of the activation energy of the process calculated by the two methods, Table 2, are close to the value obtained by J. Robert and P. Barand 33 kcal/mol [8]. The authors propose the hypothesis that the basis of the process lies in the grain boundary diffusion of dissolved atoms, i.e. of copper in manganese. The activation energy of the relaxation maxima calculated by their width is also given in Table 2. The value is proportional to the differences of the inverse temperatures of the half-width of the maximum $\Delta\left(1/T\right)$ and the gas constant R:

$$H = 2.643R/\Delta\left(1/T\right) \text{ [kcal/mol]}.$$

Table 2. Parameters of the relaxation máxima

No	Designation	$\tau_0.10^{10}$ [sec]	H, [kcal/mol] by Wert	H, [kcal/mol] along the width of the maximum	β	$\delta\lambda$
1	Mn75Cu25	2.73	22.72	23.95	3.02	0.0249
2	Mn65Cu35	3.42	28.52	31.00	3.75	0.1094
3	BeBr	3.01	25.12	29.60	3.11	0.0257

3.3. Distribution parameter of relaxation times β

The representation of the relaxation maxima in the coordinates of Novick and Berry allows calculating the distribution parameter of the relaxation times, as shown in [5]:

$$x' - Q_{\max}^{-1},$$

where $x' = H/R\,(1/T - 1/T_{\max})$.

The methodology assumes a normal distribution of the logarithm of the relaxation times $\ln \tau/\tau_{\max}$, which most accurately describes the experimental relaxation maxima. For each individually studied case, the calculated values for the distribution parameter β are given in Table 2.

In all studied alloys, the width of the maxima is larger than that corresponding to one relaxation time, i.e. the distribution parameter β is larger than zero. The values of the distribution parameters for the different alloys are approximately in the range of 3.02–3.11, which indicates that there is a large energy diversity in the relaxation processes that are characteristic of martensitic structures and mechanisms [11–12].

3.4. Form factor $\delta\lambda$

The deformations along the two main symmetry axes of the relaxation defect are calculated according to the equation [5]:

$$(\delta\lambda)^2 = k.T_{max}.S.C_0.G.v_0.$$

The value of the form factor $(\delta\lambda)$ corresponding to the mean difference in Table 2 is calculated for the studied alloys at the preset values: $a = 2/9$ for tetragonal effect, $G = 8.13 \times 10^{11}$ din/cm^2, $k = 1.38 \times 10^{-16}$ erg/°, $v_0 = 7.25$ cm^3/mol. The values of relaxation dipole form factor differ significantly from each other for the studied alloys, being the largest for the Mn-35%Cu alloy. This indicates the presence of differences in the defect structure of the studied alloys.

4. CONCLUSION

The nature of the resonance relaxation maximum of internal friction during inelastic deformation is related to the interaction of the applied measurement voltage with the stress field of the crystal lattice created by impurity atoms, which causes their resonance jumps. On this basis, we can give the following generalized hypothesis of the physical nature of the investigated maxima:

- The solute atoms present in the substitutional solid solution together with the vacancies create cluster formations.
- The dislocation structure is stable up to temperatures at which diffusion processes occur weakly.

- Relaxation processes occur with increasing the high-temperature background of internal friction, when there is temperature instability of the dislocation substructure and mass creep of dislocations in adjacent crystallographic planes.
- Therefore, the resonance maximum and the high-temperature background are two sides of the same process, reflecting the mechanism of ageing processes.

ACKNOWLEDGEMENTS

The authors are grateful to the Bulgarian National Science Fund at the Ministry of Education and Science for the financial support, contract No KP06H67/7/12.12.2022/.

All equipment and experimental units used in this article are funded by the European Regional Development Fund within the framework of the "Science and Education for Smart Growth 2014–2020", Project COE "National center of mechatronics and clean technologies", No BG05M2OP001-1.001-0008-C08.

REFERENCES

[1] U. Fastos, *et al.*, Metal Science of High Damping Alloys, *Metallurgy* (1988) (in Russian).

[2] Rui Zhu, Baoquan Mao, and Hua Li, Dynamic Characteristics of Mn-Cu High Damping Alloy Subjected to Impact Load, *Advances in Mechanical Engineering* (2021) **13** (4), https://doi.org/10.1177/16878140211013616.

[3] F. K. Nagai, K. Watanabe, and K. Kawahara, The Damping Behaviour of Ni Added Mn-Cu Damping Alloys, *Materials Transactions* (2003) **44** (9) 1671–1674.

[4] W. Riehemann, Metallische Werkstoffe mit extremer innerer Reibung und deren Messung, *Habilitationsschrift*, Papierflieger, Clausthal-Zellerfeld (1996), ISBN 3-931443-73-6.

[5] A. Nowick and B. Berry, *Anelastic Relaxation in Crystalline Solids*, Academic press, New York and London (1972).

[6] C. Wert and J. Marx, *Acta Metallurgica* (1953) **1** 113.

[7] C. Wert, *Acta Metallurgica* (1954) **2** 361.

[8] J. Roberts and P. Barrand, Interpretation of the Damping Behaviour of Copper-Nickel Alloys, *Scripta Metallurgica* (1968) **2** (9) 501–506, https://doi.org/10.1016/0036-9748(68)90182-8.

[9] V. A. Kulagin, A. Rodin, and B. Bokshtein, *Russian Metallurgy* (2020) 1055–1059 (in Russian).

[10] Y. Zhong, F. Yin, T. Sakaguchi, K. Nagai, and K. Yang, Dislocation Structure Evolution and Characterization in the Compression Deformed Mn-Cu alloys, *Acta Materialia* (2007) **55** (8) 2747–2756, https://doi.org/10.1016/j.actamat.2006.12.012.

[11] S. Zhang, Q. Tian, Y. Qi, Y. Li, and C. Li, Tuning Ultra-high Damping Capacity of Mn-Cu Alloy to Fit Wide-range Service Temperature, *Materials Science* and Technology (2022) **38** (5) 157 299–307, https://doi.org/10.1080/02670836.2022.2043028.

[12] G. Edwards, K. Stiller, G. Dunlop, and M. Couper, The Precipitation Sequence in Al-Mg-Si Alloys, *Acta Materialia* (1998) **46** (11) 3893–3904. https://doi.org/10.1016/S1359-6454(98)00059.

Received April 05, 2023