INFLUENCE OF PHASE DISEQUILIBRIUM ON CHANGES IN ELASTIC PROPERTIES OF SUPERPLASTIC EUTECTIC ALLOYS CAUSED BY PRIOR PLASTIC DEFORMATION AND AGING

V. F. Korshak[1], Y. O. Shapovalov[2], P. P. Pal-Val[2], L. N. Pal-Val[2]

[1]V. N. Karazin Kharkiv National University, 4 Svobody Sq., Kharkiv, 61022, Ukraine

[2]B. Verkin Institute for Low Temperature Physics and Engineering of NAS of Ukraine, 47 Scientific Ave., Kharkiv, 61103, Ukraine

The report presents the results of the first systematic study on changes in Young's modulus E of superplastic eutectic alloys Sn-38wt.%Pb and Bi-43wt.%Sn under conditions of pre-plastic deformation, prolonged natural aging, and creep at room temperature at external stress σ, which is optimal for the manifestation of the superplasticity effect.

The studied cast alloys were obtained under conditions of rapid crystallization under super-cooling, which reached 34 °C and 17 °C for the Sn-38wt.%Pb and the Bi-43wt.%Sn alloys, respectively. Preliminary deformation was performed by compression on a hydraulic press by ≈ 70–75 %. Mechanical tests were carried out at a constant stress of σ = 4.5 MPa and σ = 9.0 MPa for Sn-38wt.%Pb and Bi-43wt.%Sn alloys, respectively – see Fig. 1 and Fig. 2.

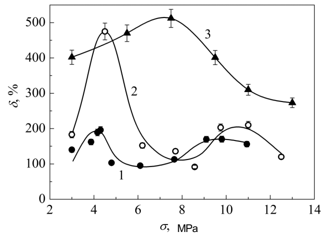

Fig. 1 Dependence of maximum elongation δ on stress σ for Sn-38wt.%Pb alloy samples after precompression on a press (1), after aging a compression-deformed ingot for 1.5 months (2), and after annealing a compression-deformed ingot (3). T ≈ 20 ºC

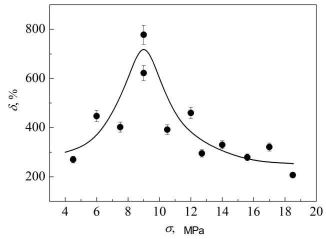

Fig. 2 Dependence of elongation δ on the applied stress σ for Bi-43wt.%Sn alloy samples. T ≈ 20 ºC

Young's modulus was determined from acoustic measurements using the composite piezoelectric vibrator method. The longitudinal vibration frequencies were ≈102 kHz and ≈113kHz, and the amplitude of ultrasonic deformation was $\varepsilon_0 \sim 10^{-7}$.

It was found that compression increases the Young's modulus of both alloys. The modulus also increases during aging in both cast and compressed samples – see Fig. 3, Fig. 4 and Fig. 5.

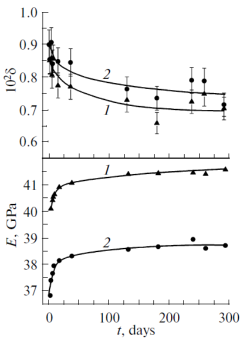

Fig. 3 Relationship between decrement δ and dynamic Young's modulus E for cast Sn-38wt.%Pb alloy subjected to an aging process of duration t. *1* is the ingot area in bordering the atmosphere; *2* is the ingot area borders the substrate

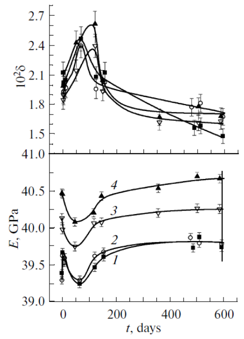

Fig. 4 Relationship between decrement δ and dynamic Young's modulus E for compressed (by hydraulic press) Sn-38wt.%Pb alloy subjected to an aging process of duration t. The duration of aging after compression is 18 days for samples 1 and 2 and 26 days for samples 3 and 4

Experimental data presented in Fig. 3 – 5 were analyzed taking into account the information about the volumetric ratio of phases V_{Sn}/V_{Pb} (Sn-38wt.%Pb alloy) and V_{Sn}/V_{Bi} (Bi-43wt.%Sn alloy) and the results of a theoretical assessment of the change in Young's modulus during its transition from the initial metastable state which is in equilibrium at pre-eutectic temperature to the equilibrium state at room temperature. The results from calculations performed according to the mixtures rule in the Voigot (E_V) and Reuss (E_R) approximations are presented in the table 1.

Table 1

Theoretical estimation of the value of Young's modulus E of the alloys Sn-38wt.%Pb and Bi-43wt.%Sn for different volume ratios of phases

Sn-38wt.%Pb	V_{Sn}/V_{Pb}	E_V, GPa	E_R, GPa	Bi-43wt.%Sn	V_{Sn}/V_{Bi}	E_V, GPa	E_R, GPa
The equilibrium phase ratio corresponding to room temperature	2.45	44.7	37.9	The equilibrium phase ratio corresponding to room temperature	1	43.5	41.4
The equilibrium phase ratio corresponding to the eutectic temperature	1.67	43.3	37.9	The equilibrium phase ratio corresponding to the eutectic temperature	1.5	41.5	40.5

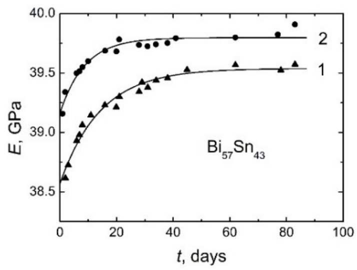

Fig. 5 Dependences of the dynamic Young's modulus E of the Bi-43wt.%Sn alloy on the aging time t. 1 – in the cast state; 2 – after plastic deformation by compression by ≈ 70%.

As a result of the performed analysis following conclusions were made. The increase in Young's modulus during aging is associated with the transition of alloys from the metastable to the equilibrium phase state at room temperature. The increase in E due to compression is caused by the emergence of internal stresses in the material.

The superplastic deformation of the alloys is accompanied by a noticeable decrease in Young's modulus as the relative elongation accumulates from 0 to ≈ 150%: by ≈ 15 % in the Sn-38wt.%Pb alloy (Fig. 6) and by ≈ 8 % in the Bi-43wt.%Sn alloy. Upon further elongation, the modulus experiences a periodic increase followed by a decrease.

Taking into account the results of X-ray diffraction studies, it is shown that the decrease in E under superplastic flow conditions results from the combined effects of the deformation and decomposition of supersaturated solid solutions formed in alloys under the selected crystallization conditions, as well as relaxation of internal elastic stresses. The periodic increase in Young's modulus amidst its predominant decrease indicates the periodicity of phase formation processes in the studied metastable eutectic alloys under superplastic deformation conditions.

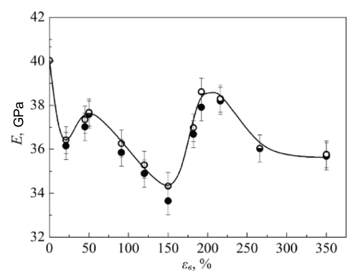

Fig. 6 Dependence of Young's modulus E of the Sn-38wt.%Pb alloy on the relative elongation ε_b under superplasticity. ○ - E value in 1 hour after unloading. ● - E values obtained by extrapolating the dependence $E = f(t)$ to the time $t = 0$

Based on the results of the performed experiments, it is shown that the level of internal stresses arising as a result of compression is sufficient to activate the additional Frank-Read dislocation sources and ensure a noticeable increase in the dislocation density of under the action of external mechanical stress. The presence of significant internal stresses can be the reason for the manifestation of the hydrodynamic mode of deformation in conditions of superplasticity, which was first discovered by the authors – see Fig. 7 and Fig. 8. As known, it is generally accepted that the main mechanism of deformation in superplasticity is the movement of grains as a whole by grain-boundary slip.

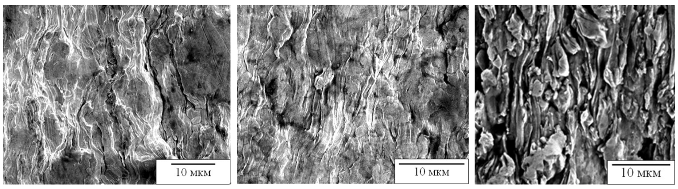

Fig. 7 Strain relief of Sn-38wt.%Pb alloy samples deformed under superplasticity conditions. T ≈ 20 °C. SEM image (in the secondary electron mode). The tensile direction coincides with the vertical

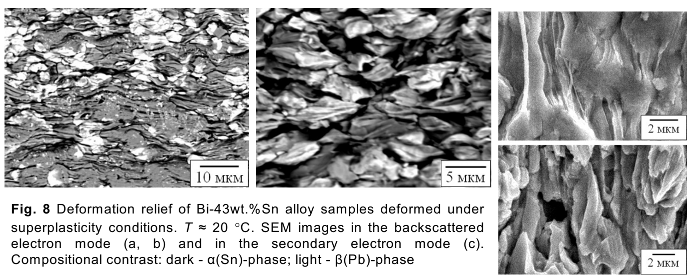

Fig. 8 Deformation relief of Bi-43wt.%Sn alloy samples deformed under superplasticity conditions. T ≈ 20 °C. SEM images in the backscattered electron mode (a, b) and in the secondary electron mode (c). Compositional contrast: dark - α(Sn)-phase; light - β(Pb)-phase

The scientific results presented in the paper have been partially published in [1-4]:

1. V. F. Korshak, Yu. A. Shapovalov, P. P. Pal'-Val', and P. V. Mateichenko, *Bulletin of the Russian Academy of Sciences. Physics*, **75**, No. 10: 1345 (2011). https://doi.org/10.3103/s1062873811100200
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