Effect of external mechanical stresses on the heat of phase transformation in two-component metastable alloys

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INTRODUCTION

The study of the influence of external mechanical stresses on certain physical properties of superplastic (SP) materials is important for understanding the nature of structural-phase state of these materials and mechanisms of SP deformation. Literature analysis shows that among a huge number of experimental studies related to the problem of superplasticity, studies of changes in the physical properties of SP materials caused by the action of external stress are practically absent.

The poster presents the results of studying the effect of external mechanical stress (σ) during heating on the melting specific heat of superplastic eutectic alloys Sn-38wt.%Pb and Bi-43wt.%Sn [1, 2]. The research was carried out using the Differential Thermal Analysis (DTA) method.

MATERIALS & METHODS

The alloys are obtained from chemically pure components by casting on a solid copper substrate under laboratory conditions. Cast ingots were compressed on hydraulic press by ~75% and ~65% in case of Sn-38wt.%Pb and Bi-43wt.%Sn alloys, respectively. The samples for DTA had the form of rectangular parallelepiped with the height of ~1.4 and ~2.0 mm with the base area of 25÷50mm^2. The samples were loaded by means of a specially manufactured device, which was immersed in the furnace together with the sample. After reaching a temperature close to the eutectic one, the load was removed. The furnace temperature and the temperature difference between the tested and reference samples were determined using copper-constant thermocouples. The sensitivity of the furnace temperature recording is 20 K/cm. The sensitivity of the temperature difference recording is 0.5 K/cm. The average sample heating rate is ~1.2 K/min for Sn-38wt.%Pb and ~1.7 K/min for Bi-43wt.%Sn. A pure lead sample was used as a reference. The area of endothermic peaks was determined using the Origin 6.1 program. To calibrate the measurement system, differential thermal analysis of tin samples under the same conditions as the alloy samples was performed.

The value of applied external stresses σ was chosen taking into account the obtained data on stresses optimal for development of properties of the SP alloys at room temperature.

RESULTS & DISCUSSION

The Sn-38wt.%Pb alloy was studied in the aged after compression for ~1.5months state. The maximum elongation for this state of alloy is 475% at σ = 4.5 MPa.

Fig. 1 shows the DTA curves of the Sn-38wt.%Pb alloy normalized per unit of mass (1 g) at different values of σ. The abrupt change in the background at pre-melting temperature is caused by temporary thermal imbalance in the furnace associated with the load removal.

The results of DTA for samples of tin used to produce an alloy are demonstrated in **Fig. 2**. The deviation of the values of the area of these peaks from the mean value was taken as the experimental error in determining the peak area. The relative error of peak area determination for alloy samples with this approach is about 6 %.

Fig. 3 shows the dependence of specific melting heat of Sn-38wt.%Pb alloy on the value of applied external stress. As can be seen, this dependence has non-monotonous character, which was discovered for the first time.

We carried out the theoretical estimations of changes in specific heat of alloy melting based on the additive values of melting heat obtained for the phase states determined by equilibrium phase diagram and corresponding to the room and eutectic temperatures [3].

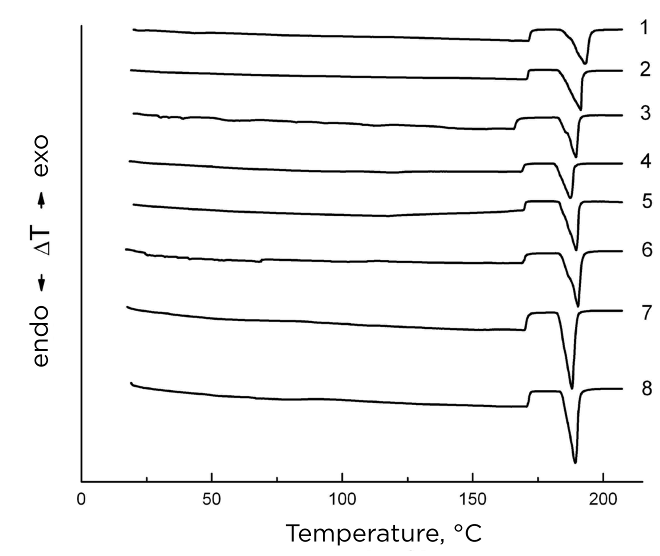

Fig. 1. DTA curves of samples of Sn-38wt.%Pb superplastic alloy at values of external compressive stress σ: 1-0.02; 2-0.5; 3-1.3; 4-2.5; 5-3.2; 6-3.4; 7-4.5; 8-5.7 MPa.

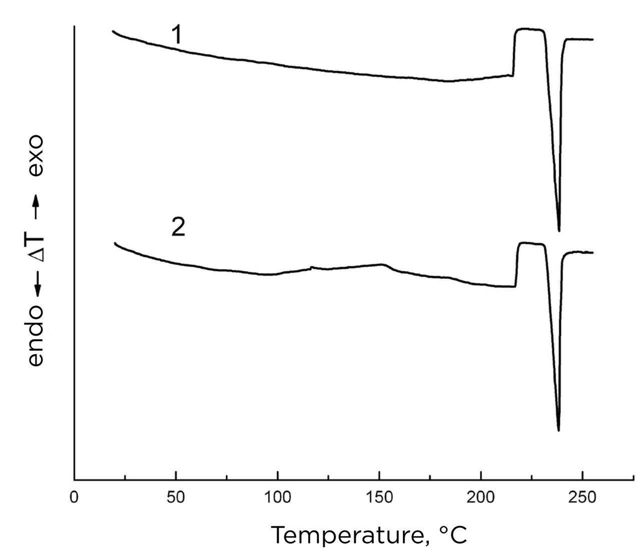

Fig. 2. DTA curves of tin samples at values of external compressive stress σ: 1-0.02; 2-2.7 MPa.

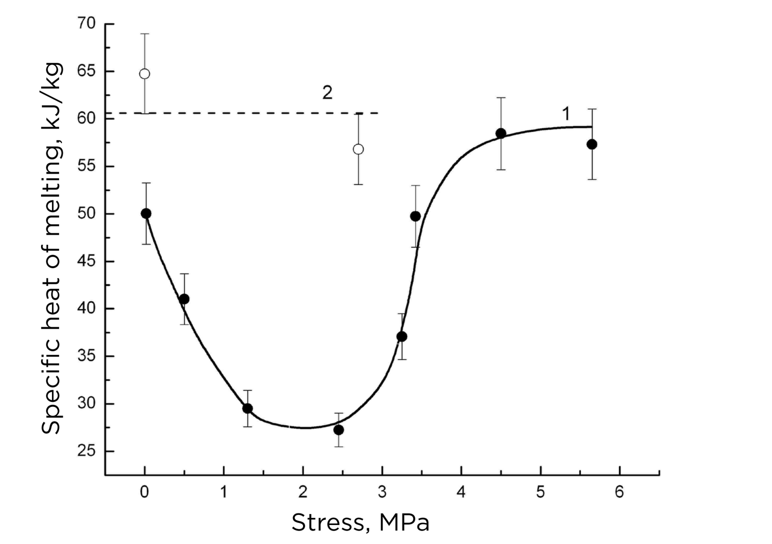

Fig. 3. Dependence of specific melting heat of Sn-38wt.%Pb superplastic alloy on the value of external compressive stress σ (curve 1). The dashed line (2) corresponds to the specific melting heat of tin.

Data on phase melting point change due to dissolution of other component are taken from [4].

The results of these estimates and the non-monotonous dependence of melting heat on σ allow us to conclude that both the initial phase state and the phase state at the moment of melting do not correspond to the equilibrium phase diagram of Pb-Sn system. This conclusion is confirmed by the results of phase state studies of the alloy carried out earlier in [5].

The presence of a descending branch on the dependence of the melting specific heat on the value σ can be caused, among other things, by the processes associated with the initial stage of decomposition of supersaturated solid solutions. The emergence of the ascending branch can be connected with the release of excess tin, which specific heat of melting significantly exceeds that of lead [1], from α(Pb)-phase.

The Bi-43wt.%Sn alloy was studied approximately 7 months after compression. The maximum elongation of the samples in this state reached 300% at stresses of ~5 MPa.

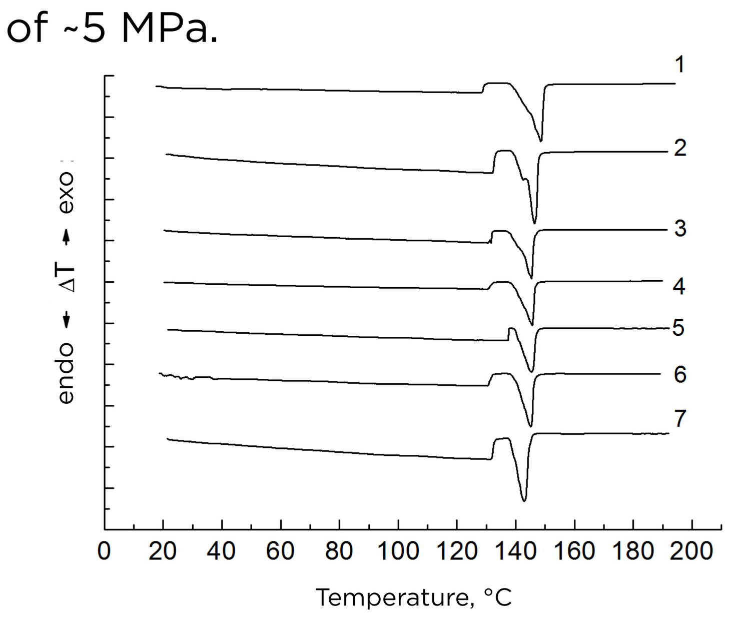

Fig. 4. DTA curves of samples of Bi-43wt.%Sn superplastic alloy at values of external compressive stress σ: 1 - 0.03; 2 - 0.5; 3 -1.6; 4 - 2.8; 5 - 3.8; 6 - 4.4; 7 - 7.5 MPa.

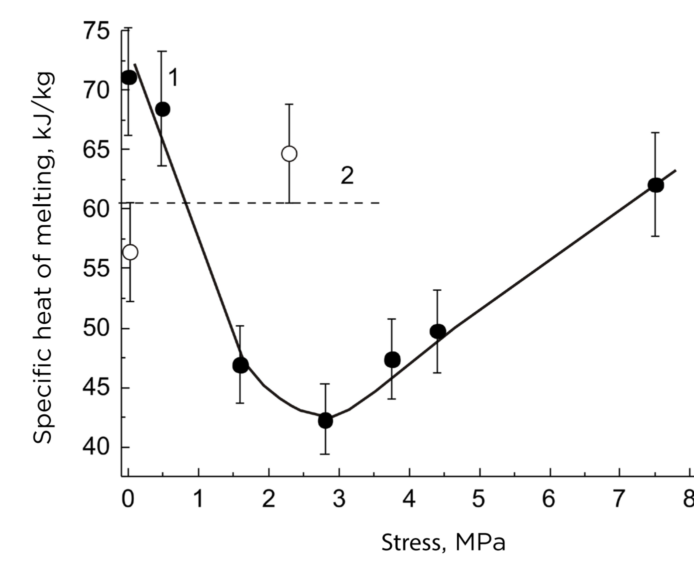

Fig. 5. Dependence of the specific melting heat of the Bi-43wt.%Sn alloy on the value of the external compressive stress σ (curve 1).

The DTA curves of this alloy normalized per a unit mass (1 g) at different values of σ are presented in **Fig. 4**. The dependence of the specific heat of melting on the value of the applied external stress is shown in **Fig. 5**. As you can see, in this case, this dependence is also non-monotonous.

Estimates using literature data [3, 6] show that the observed decrease in the specific heat of melting of the alloy is determined, among other things, by a change in the concentration and relative share of phases in the alloy due to temperature rise. The increase in the specific heat of melting may be caused by the release of Bi from the supersaturated Sn-based solid solution.

CONCLUSIONS

* It was found for the first time that the specific heat of melting of superplastic eutectic alloys Sn-38wt.%Pb and Bi-43wt.%Sn nonmonotonically depends on the value of the external stress applied during heating from room temperature to pre-eutectic temperature.

* This dependence is associated with the metastability of the phase state and the stimulating effect of plastic deformation on the processes that ensure the transition of the alloy to the equilibrium state corresponding to the temperature increase under experimental conditions.

* The presented results are important for understanding the physical nature of the superplasticity effect, as well as the mechanism of melting of eutectics.

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