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STRENGTH AND PLASTICITY

Structural Changes in Bi–43 wt % Sn Eutectic Alloy under Superplastic Deformation

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Abstract—Methods of scanning electron microscopy have been used to study the microstructure of superplastically deformed samples of eutectic alloy Bi–43 wt % Sn. The observed specific features of the deformation relief of the samples reveal the active development of the viscous dislocation–diffusion flow under superplasticity conditions. The manifestation of the hydrodynamic mode of deformation has been revealed under these conditions. The opportunity of the realization of viscous mechanisms of the transport of substance and of the manifestation of the effect of superplasticity are explained by the appearance in the material of a state that is characterized by a high dislocation density and low strength properties. An additional increase in the dislocation density and softening under superplasticity conditions are attributed to the occurrence of structural and phase transformations stimulated by deformation, the relaxation of significant internal elastic stresses, and the instability of the structural state of the initially nonequilibrium alloy in the field of mechanical stresses. Factors responsible for the appearance of significant internal elastic stresses in the alloy are analyzed.

Keywords: superplastic deformation, viscous flow, hydrodynamic mode of deformation, internal elastic stresses, nonequilibrium phase state, eutectic alloy

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INTRODUCTION

The study of changes of the structure of a material under the conditions for superplastic deformation makes it possible to estimate the physical processes that occur in this case. The widely used method employed for such studies is a topographic analysis of the deformed samples. The most important result of these studies obtained to date is the establishment of a growth of grains and the retention of their equiaxed character after superplastic deformation. These facts usually serve as a basis for the conclusion that the main mechanism of the transport of substance under superplasticity conditions is grain-boundary sliding (GBS).

A characteristic feature of the deformation relief that appears in the superplastically deformed polycrystalline materials is also the absence of slip lines inside the grains. It is usually assumed that upon superplastic deformation the sources of dislocations are grain boundaries. As a result, the slip lines are not formed, since, in the process of deformation, grain growth occurs and, therefore, the positions of the dislocation sources change continuously [1].

In the overwhelming majority of cases, topographic studies are carried out on preliminarily polished surfaces of samples. Furthermore, specific features of the deformation relief that appears on such surfaces after insignificant degrees of additional deformation are studied. Upon large deformations, the nature of the deformation relief becomes relatively complex, and its study is difficult [1, 2].

At the same time, it has been shown in previous works [3–8] that the phase state of eutectic alloys under the conditions under which they manifest superplastic (SP) properties is nonequilibrium. As has been established in [6, 9], this nonequilibrium leads, in particular, to the dependence of the deformation characteristics of the alloys under superplasticity conditions on the method of preliminary mechanical treatment of the samples. For example, grinding and subsequent polishing lead to changes in the phase composition of the surface layers. The macrorelief that appears after preliminary polishing differs substantially from the relief that appears on the untreated surface. It has been revealed that the grinding and polishing prior to the tests lead to a noticeable change in the creep rate. The results of these observations indicate the need of conducting an analysis of the microstructure of the samples that are subjected to the action of only external mechanical

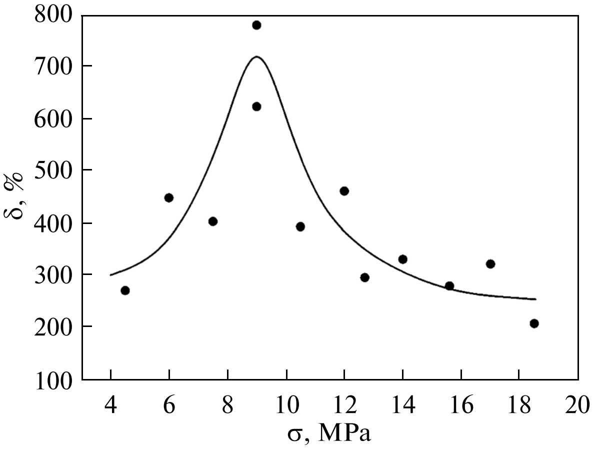

Fig. 1. Dependence of the elongation to fracture δ of the samples of the Bi–43 wt % Sn alloy on the applied stress σ.

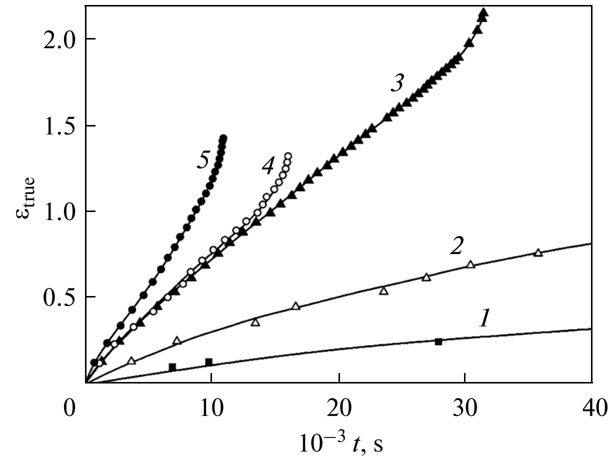

Fig. 2. Curves of creep of the samples of the Bi–43 wt % Sn alloy at σ (*1*) 67.5, 7.5 (*2*), (*3*) 9, (*4*) 15, and (*5*) 17 MPa.

stress in the process of the accumulation of significant relative elongations. This analysis seems to be important, since its results more correctly reflect the processes that cause SP flow of the material. These studies are carried out in the present work.

EXPERIMENTAL

The Bi–43 wt % Sn alloy was obtained by melting together chemically pure components with subsequent casting onto a massive copper substrate. The ingots obtained were preliminarily swaged to ~70% using a hydraulic press.

The mechanical tests were carried out in the regime of creep at a constant applied stress σ in the range from 4.5 to 18.5 MPa. The creep curves were constructed point by point based on the data on the relative elongation $\Delta l/l_0$ and the time of deformation *t*. The relative error in the determination of $\Delta l/l_0$ was approximately 5%. The true deformation ε_{true} of the samples was determined by the formula

$$\varepsilon_{true} = \ln(1 + \Delta l/l_0).$$

The experiments were carried out at room temperature. The studies of creep were performed on samples subjected to preliminary compressive deformation immediately after casting and after aging for no more than two weeks.

The microstructure of the surface of the deformed samples was studied using a JEOL JSM-6490 scanning electron microscopes (SEM) equipped with an EDAX/TSL system for the EDX analysis (performed at the Max Planck Institute for Iron Research GmbH); a JSM-840 SEM; and a JSM 7001F SEM equipped with an INCA ENERGY350 EDX analyzer. The studies were carried out no less than one year after the mechanical tests of the samples.

RESULTS AND DISCUSSION

Figure 1 displays the dependence of the elongation to fracture δ on the applied stress σ for the samples under investigation under the selected experimental conditions. As can be seen, this dependence takes a domelike shape characteristic of SP materials. The stress that is optimum for the manifestation of SP properties is σ = 9 MPa. The maximum value of δ in this case is 770%.

Figure 2 presents some creep curves obtained at different σ that are optimum for the manifestation of the effect of superplasticity, and also some curves obtained at stresses above and below the optimum stress. As follows from these data, the average rate of true strain at the stage of creep that excludes the appearance of a clearly pronounced neck directly before the rupture of the specimen at σ = 9 MPa is approximately 6.5×10^{-5} s^{-1}.

The microstructural studies were carried out at optimum σ. It should be noted that, under these conditions, the deformation of the samples is by no means always uniform. In a number of cases, their longitudinal section has the shape of a trapezium. In the sample brought to fracture (δ = 770%), the local deformation in the gage part varies from ~280% to ~1300%. The true stresses in the appropriate sections at the moment of fracture are equal to approximately 4 and 15 MPa, respectively. As can be seen from Fig. 1, in this range of stresses, the elongations at fracture are no less than 300%, i.e., the alloy behaves superplastically. Therefore, the changes in the microstructure that are observed with an increase in the local deformation reflect the changes in the microstructure in the process of the accumulation of the relative elongation under superplasticity conditions. A comparison of the results of these studies with the results obtained for samples with uniformly changing cross sections confirms the correctness of this approach.

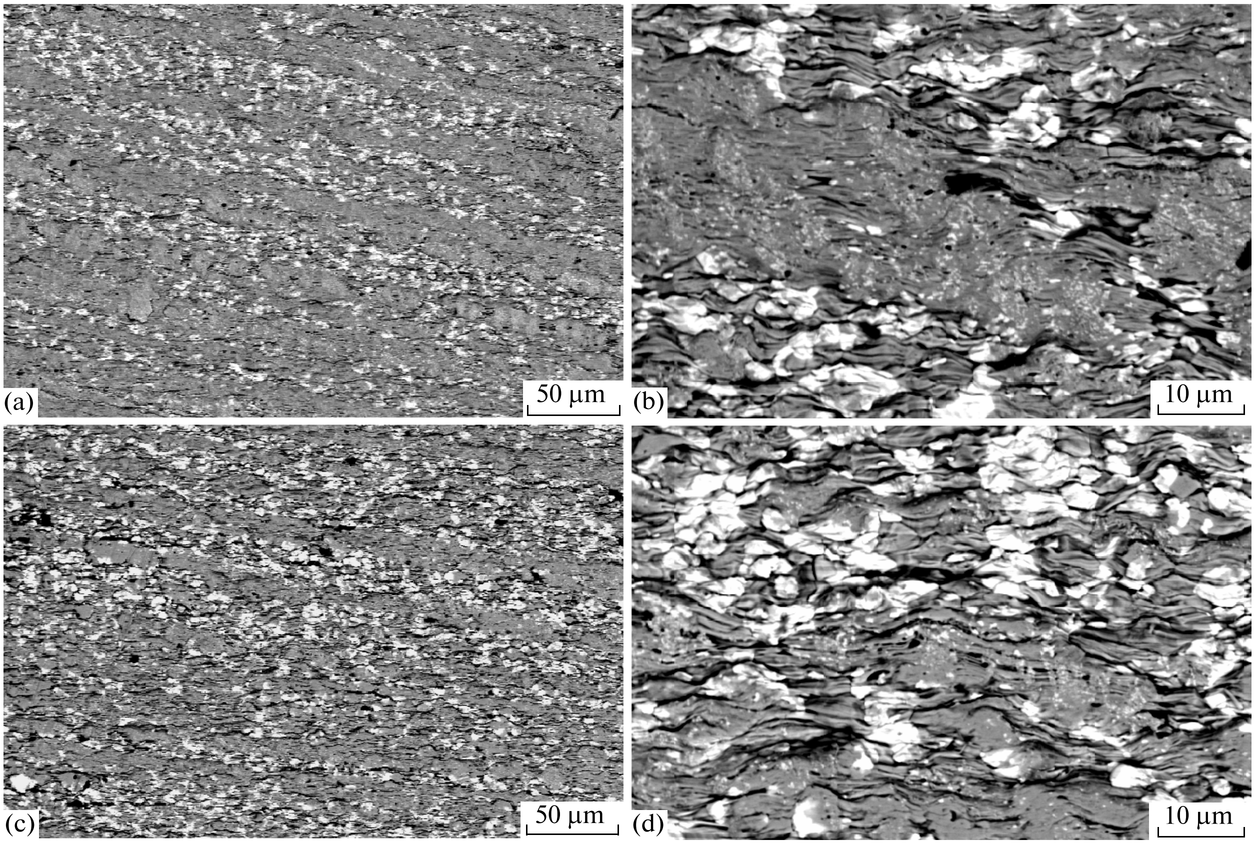

Fig. 3. SEM images (in reflected electrons) of the surface of the gage part of the tensile-test sample of the Bi–43 wt % Sn alloy at the relative elongations $\Delta l/l_0$ (a, b) ~340 and (c, d) ~510% at σ = 9 MPa. Direction of tension coincides with the horizontal.

The changes in the microstructure of the surface of the gage part of the deformed samples in the process of the accumulation of relative elongation are shown in Figs. 3–5. The studies were carried out in the regime of reflected electrons (in the composition contrast, dark regions correspond to the Sn-based phase and bright regions correspond to the Bi-based phase) and in the regime of secondary electrons.

As in the case of the previously investigated eutectic alloy Sn–38 wt % Pb [4], on the surface of the insignificantly deformed regions (ε_{loc} ~ 30%), there are revealed relatively wide (more than ten microns) mesobands of localized plastic deformation. The direction of these bands almost coincides with the direction of the maximum external shear stresses. These mesobands neighbor the bands of undeformed regions. The regions that did not undergo deformation can be identified by the presence of the surface layer enriched in tin with small inclusions of bismuth. It was shown in independent investigations that the aging of the investigated SP alloy is accompanied by a significant increase in the tin concentration in the surface layers of the samples [3].

The further development of the deformation process leads to the expansion of the bands of the localized plastic deformation into the region of the undeformed material. The orientation of the bands changes. Macrobands of localized deformation located at angles that are noticeably smaller than 45° with respect to the direction of σ prove to be connected to one another by bands oriented along the direction of the action of the maximum shear stresses. Gradually, the macrobands of the localized deformation become parallel to the direction of the action of the external stress (see Fig. 3). At a certain stage of flow, almost the entire material proves to be involved into the deformation process. However, even if the local deformation is about 1000%, separate small regions are observed in the surface layer of the sample that preserve the initial structure of the surface, i.e., regions of material that hardly participate in the deformation process (Fig. 4).

As early as at the moment when the first bands of localized deformation appear, the superplastic flow of the alloy has a viscous character (Fig. 5a). Explicit signs of the development of intragranular deformation are revealed. The grains have a banded fragmented structure (Figs. 3, 4). The grains have a striated structure. The striation is characteristic of the entire surface of the deformed part of the sample in contrast to the appearance of banded zones described in the literature that are periodically revealed in regions between two

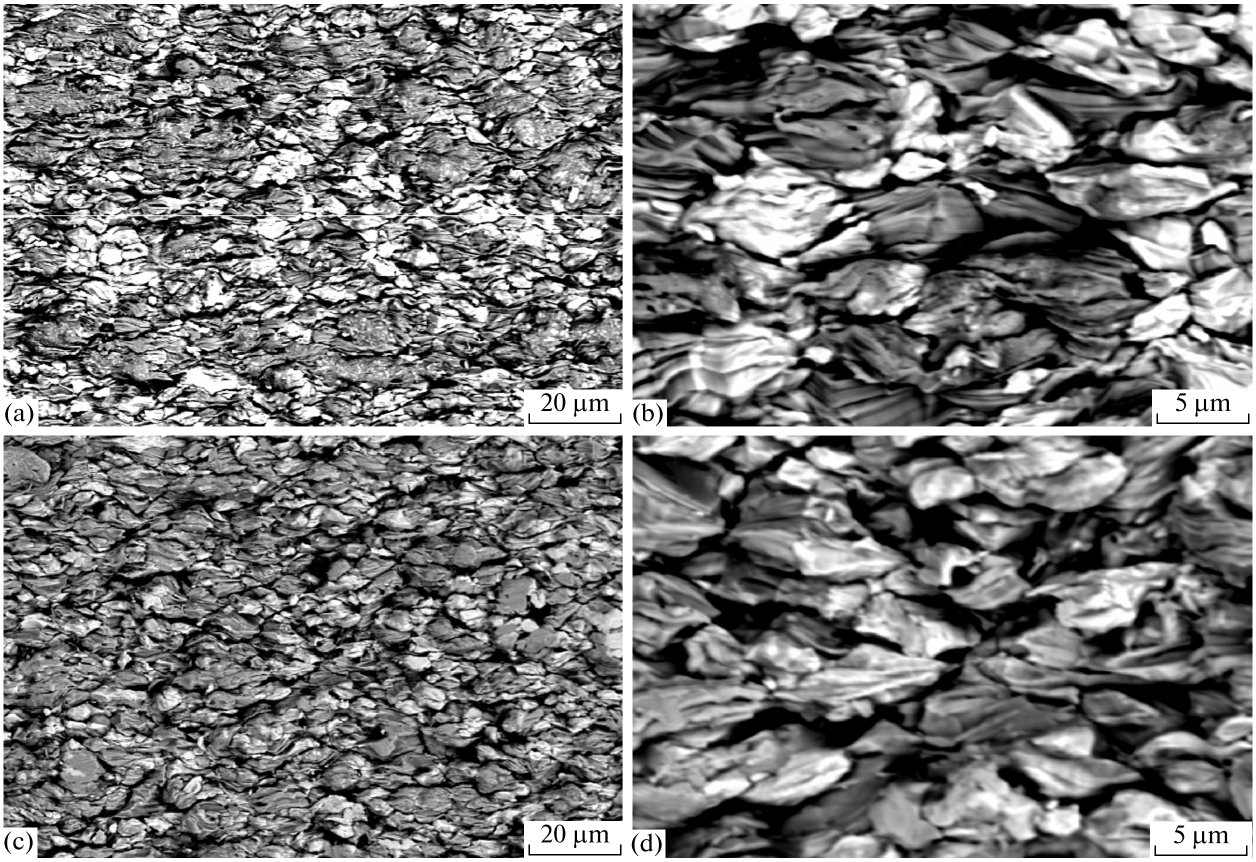

Fig. 4. SEM images (in reflected electrons) of the surface of the gage part of the tensile-test sample of the Bi–43 wt % Sn alloy at the relative elongations $\Delta l/l_0$ (a, b) ~1040 and (c, d) ~2500%; $\sigma = 9$ MPa. The direction of tension coincides with the horizontal.

adjacent grains. These zones are attributed to the development of diffusion creep under the conditions of superplasticity [1, 2]. The well-pronounced waviness is revealed in the deformation relief. These specific features of the deformation relief of the samples convincingly indicate the manifestation of the hydrodynamic mode of deformation under superplasticity conditions.

Another feature of the evolution of the shape of grains in the process of SP deformation should be noted. As can be seen from Figs. 3–5, the grains gradually become lenticular. The regions adjacent to the boundaries that are oriented perpendicularly to the direction of σ prove to be noticeably elongated in the direction of the action of the external tensile stresses. This specific feature of the shape of grains becomes clearly pronounced in the case of significant elongations (see Fig. 4). This fact can indicate the important role of the normal tensile stresses in the development of the structural state, which makes it possible to achieve a viscous flow of the material and to produce large plastic deformations.

An analysis of the surface of the significantly deformed regions (Fig. 4), just as in the case of the Sn–38 wt % Pb alloy [5], reveals the presence of a large number of discontinuities elongated in the direction of tension in the structure of the material. The alloy appears to be strongly stratified in the direction of tension. Many grains on the surface of these regions appear to be isolated from one another. This structure cannot be characteristic of the internal part of the sample, since the presence of discontinuities is catastrophic for the material. This would certainly lead to the destruction of the samples. The observed specific features of the surface layer can indicate only the output of this layer from the state of superplasticity and from the deformation process at all. It is possible to assume that this circumstance explains the role of the scale factor in the manifestation of SP properties. There are known data that indicate that the elongation upon fracture under superplasticity conditions depends on the dimensions of the cross section of the samples; i.e., the thicker the sample, the greater the elongation [10].

An analysis of the microstructure carried out in the regime of secondary electrons (Fig. 5) reveals that, in the case of significant elongations, protrusions and depressions are observed on the surfaces of the deformed samples. The structure of the material in the lower-lying layers differs significantly from the above-

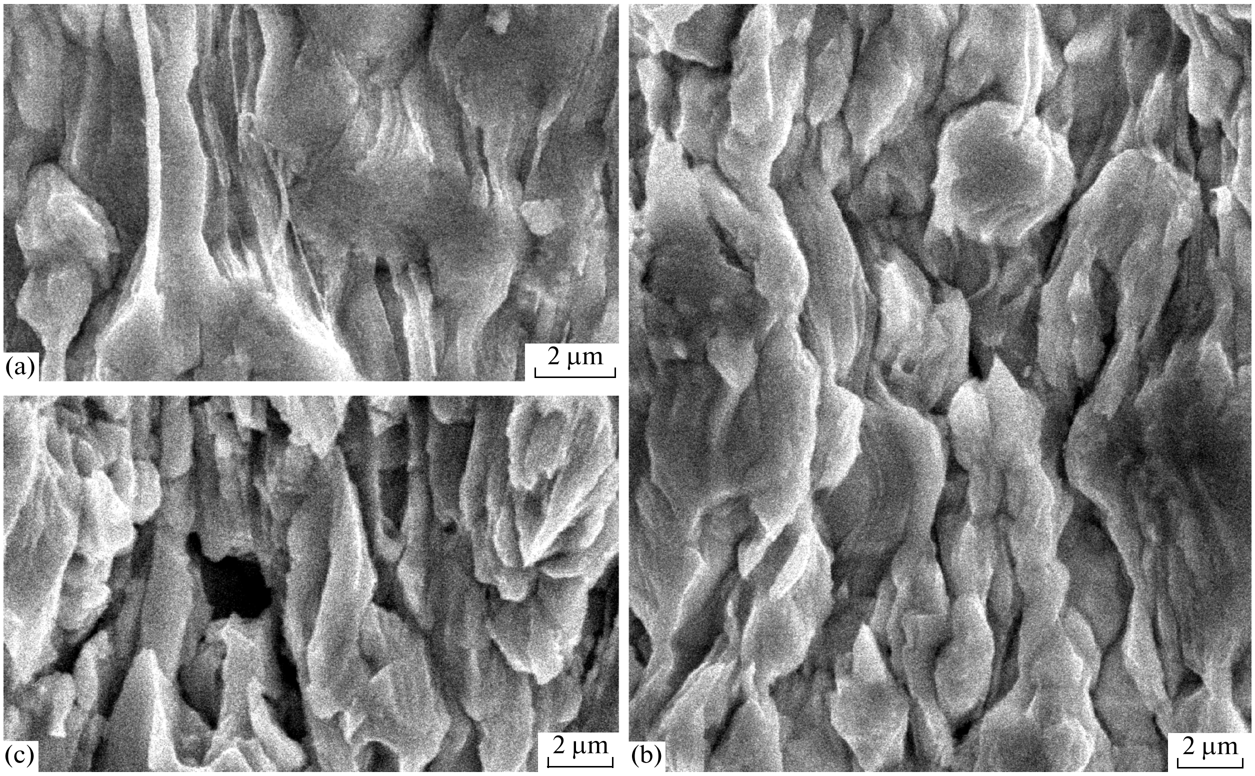

Fig. 5. SEM images (in secondary electrons) of the surface of the gage part of the tensile-test sample of the Bi–43 wt % Sn: (a) at the initial stage of flow; (b) at the stage of developed deformation; and (c) in the neck region; $\sigma = 9$ MPa. Direction of tension coincides with the horizontal.

described structure observed in the higher-lying layers. It is characterized by enhanced grain fineness and the noticeable elongation of grains in the direction of the action of the external stress. The structure of both coarser and smaller grains contains microscopic inclusions (Fig. 5b). These inclusions are most likely to represent dispersed bismuth precipitates in the tin matrix. This conclusion is supported by the excessive relative amount of the α(Sn) phase in the initial state of samples in comparison with the equilibrium amount. As follows from the performed analysis, the equilibrium state of the alloy at room temperature is characterized by the volume ratio of the α(Sn) and β(Bi) phases V_{Sn}/V_{Bi} close to 1 : 1. Passage from room temperature to higher temperatures is accompanied by an increase in the relative amount of the α(Sn) phase. At a maximum concentration of Bi in the Sn-based solid solution, which corresponds to the eutectic temperature, the V_{Sn}/V_{Bi} ratio in the equilibrium state is ~1.5. In the bulk of the ingots, the phase relationship differs significantly from this value. The V_{Sn}/V_{Bi} ratio proves to be different in different regions of the ingot; however, in all cases, it proves to be notably higher (it can reach 3.8). Furthermore, based on an analysis of the angular dependence of the intensity of the diffuse scattering of X-ray radiation, it has been shown in [3] that, under the conditions of SP flow in the Bi–43 wt % Sn alloy, regions of short-range phase separation are formed that can subsequently be transformed into precipitates of stable phases. The appearance of these regions is attributed to the initial stage of the phase separation of supersaturated solid solutions (the so-called stage of preprecipitation) stimulated by plastic deformation.

Figure 6 displays the microstructure of the fracture surfaces of the head and gage parts of a sample brought to failure. The fractures were performed at the temperature of liquid nitrogen in the plane approximately perpendicular to the direction of σ. A comparative analysis of these micrographs makes it possible to reveal some other changes in the microstructure of the samples arising as a result of SP deformation. First, it can be seen that the grain structure of the samples becomes more uniform. The fracture in the gage part in both phases is intercrystalline, whereas in the head, the grains of the Bi phase exhibit transcrystalline fracture. It can also be seen that the β(Bi) phase in the head region is characterized by a significant dispersion of the structure. There are both rather small and substantially coarser grains of this phase, while in the gage part, this phase appears fairly uniform. In particular, these changes in the microstructure indicate the occurrence of dynamic recrystallization in β(Bi) phase under the conditions for superplastic flow.

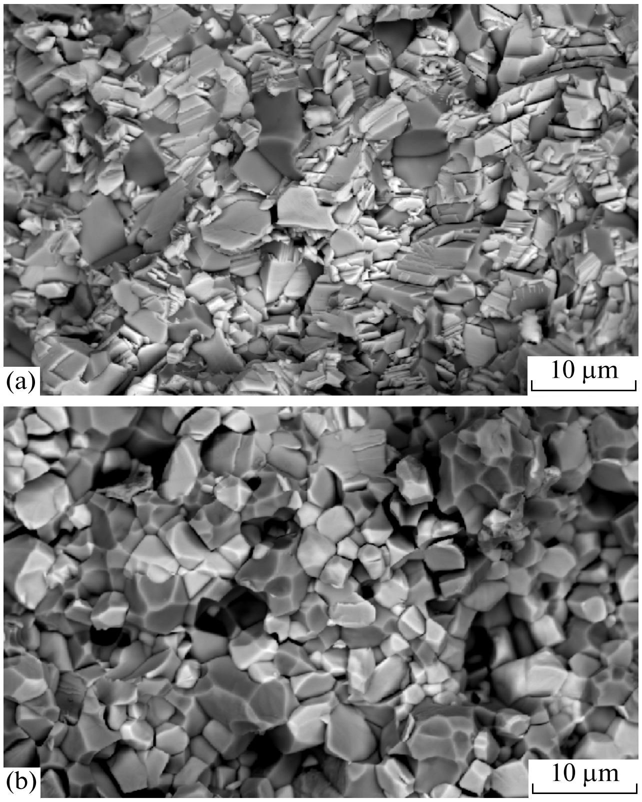

Fig. 6. SEM images (in reflected electrons) of the surface of the low-temperature fracture of the sample of the Bi–43 wt % Sn alloy: (a) in the region of the head; (b) in the region of the gage part; σ = 9 MPa.

It should also be noted that, as a result of the SP deformation, grains of the α(Sn) phase become fragmented. This fragmentation is rather clearly pronounced in the coarser grains. At the same time, in a number of cases, the observation of composition contrast makes it possible to identify the presence of small grains of this phase. However, in the head, the grains of the α(Sn) phase have approximately identical sizes and, in all cases, the fracture surfaces of the grains are smooth. Therefore, we can draw a conclusion regarding the dispersion of this phase under the conditions of the superplastic deformation caused by the fragmentation of grains. According to the existing concepts [11], the main cause of fragmentation in polycrystals is the presence of significant elastic stresses that appear at the grain boundaries and at grain junctions during plastic deformation.

Thus, the revealed specific features of the deformation relief indicate that the SP flow of the alloy has much in common with the flow of materials under the conditions of subsolidus superplasticity. By this term, the authors of [12] called the superplasticity that appeared in a number of aluminum-based alloys at temperatures equal to 0.95–0.98 T_m (temperature of their melting). In these alloys, in the presence of all signs of superplasticity and its high characteristics, sliding of the grain boundary introduces no more than 10–20% into the total deformation. The roles of dislocation creep and diffusion creep prove to be substantially enhanced, and the suppression of the elongation of grains and the retention of small grains at large elongations without a change in the neighbor grains occurs via dynamic recrystallization. In other words, there is active intragranular deformation and growth in the dislocation density in the elongated grains. After superplastic deformation, the dislocation density in these alloys exceeds 10^9 cm^{-2} upon tension at an optimum rate. Then, due to dynamic recrystallization, these elongated grains are transformed into chains of small grains. The grains elongated along the tensile axis become divided by transverse boundaries with the formation of equiaxed fragments. In many grains, signs of diffusion creep can be seen, i.e., regions near the transverse boundaries that are depleted of second-phase particles are observed. These processes occur repeatedly at different points of the sample subjected to tension. Elongations equal to hundreds of percents are achieved, not by the rearrangement of grains, as in the case of the determining contribution of GBS, but rather via local changes in their shapes and sizes due to the division and nucleation of new grains as a result of recrystallization [13].

The changes revealed in the microstructure of the Bi–43 wt % Sn alloy suggest that the conditions that are optimum for the effect of superplasticity to manifest can be different at different stages of creep. In particular, this may be connected with the dispersion of the initial structure of the alloy due to the above-mentioned structural and phase transformations that take place upon deformation due to a change in the phase state of the alloy in connection with the expected precipitation of bismuth from the α(Sn) phase, as well as due to the fragmentation of grains of the α(Sn) phase.

This assumption is confirmed by the phenomenological analysis of flow [1] carried out for relative elongations of 50, 150, and 300%.

Figure 7 shows the curves of the $\log\sigma = f(\log\dot{\varepsilon})$ dependence. In all cases, this dependence has a sigmoid shape characteristic of the SP materials, which is characterized by substantially different slopes in the different ranges of ε. The maximum values of the strain-rate sensitivity *m* of the flow stress evaluated from the slope of the $\log\sigma = f(\log\dot{\varepsilon})$ curves [14] are approximately 0.65, 0.7, and 0.6 for the curves *1*, *2*, and *3*, respectively. It can also be seen from the figure that the maximum of *m* is shifted toward the higher deformation rates for the structural–phase state that is formed at the stage of the flow where the relative elongation is about 300%.

Thus, the results of the above investigations indicate that the deformation process in the eutectic alloy considered is multistage and rather complicated under conditions that correspond to the manifestation of the effect of superplasticity. The superplastic flow from the very beginning occurs with the participation of dislocations, the density of which proves to be fairly high. This conclusion is confirmed by the observation of intragranular dislocation slip actively developed in the samples. This in turn indicates the presence of high internal elastic stresses, since the level of the applied external stresses is insufficient for the operation of sources of the dislocation multiplication in the grains. The presence of a high level of internal elastic stresses and high dislocation density in the material is also confirmed by the fragmentation of grains of the α(Sn) phase. The SP flow is accompanied by the dynamic recrystallization of the β(Bi) phase. Along with the decomposition of the supersaturated solid solution of bismuth in tin that is stimulated by plastic deformation, these processes lead to the dispersion of the initial structure of the alloy at a certain stage of deformation. As a result, the interval of the deformation rates that are optimum for the manifestation of the effect of superplasticity proves to be different for different stages of the flow; it shifts toward the greater values for the structural-phase state that is formed at relative elongations of about 300% compared with the state of the alloy in the initial stages of deformation.

The concepts of the hydrodynamic mode of deformation under superplasticity conditions have been considered earlier in the theoretical works [15]. Experimentally, the hydrodynamic mode of deformation under superplasticity conditions was for the first time revealed when studying the eutectic Sn–38 wt % Pb alloy [16]. The results obtained in the present work show that this mechanism of mass transfer is also achieved in other SP alloys of this type.

The authors of [15] attribute the appearance of the hydrodynamic mode of deformation to the attainment of a certain critical level of the deforming stresses τ_{cr} in the material. According to [15], the magnitude of τ_{cr} is equal to $(150–120)^{-1}G$, where G the shear modulus. Taking into account the literature data for the shear moduli of bismuth and tin (12 and 16–19 GPa, respectively) [17], the value of τ_{cr} for the α(Sn) phase is within the limits of 110–160 MPa. In the β(Bi) phase, the value of τ_{cr} is 80–100 MPa. This level of stresses is one order of magnitude greater than the value of the applied stresses σ. Hence, it follows that, just as in the case of the Sn–38 wt % Pb alloy [16], the manifestation of the hydrodynamic mode of deformation in the samples under investigation is caused by the internal stresses. In this case, the level of these stresses appears to be fairly high.

Now, a question arises about the origin of internal stresses in the alloy investigated.

One of the factors responsible for their appearance can be the nonequilibrium phase state of the alloy. This nonequilibrium already appears during the process of ingot crystallization, which follows from the relative amounts of tin- and bismuth-based phases in the ingots.

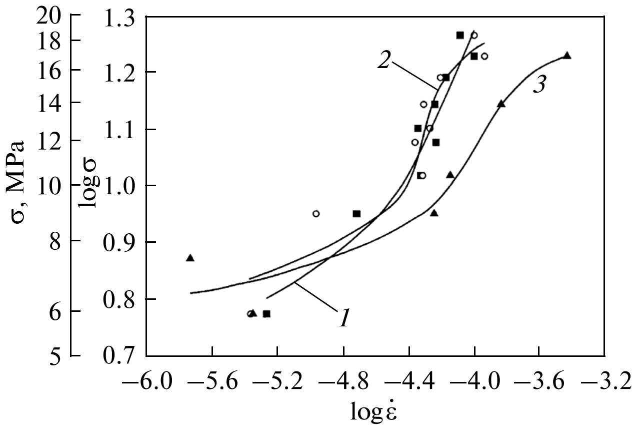

Fig. 7. $\log\sigma = f(\log\dot{\varepsilon})$ dependence for the samples of the Bi–43 wt % Sn at the relative elongation $\Delta l/l_0$ (*1*) ~50, (*2*) ~150, and (*3*) ~300%.

The nonequilibrium of the phase state causes the opportunity of the occurrence of kinetic phase transformations under the conditions of the action of external tensile stresses. The phase transformation that occurs upon deformation causes the appearance of significant internal stresses localized mainly at the grain boundaries. The interaction of the local sources of overstresses between themselves in the microvolumes forms an overall macroscopic field of internal stresses responsible for the deformation behavior of a polycrystal. The internal stresses lead to the appearance of additional dislocations, in particular, in connection with the activation of Frank–Read sources. Thus, the local dislocation density in the samples under investigation grows. In the places of significant local overstresses, which are primarily the grain boundaries and adjacent regions of grains, the dislocation density can reach anomalously large values. In the final account, this leads to the appearance of a dislocation structure that determines the cooperative character to the dislocation motion, which ensures the passage of the polycrystal into the state of superplasticity [15].

This reasoning also agrees with Kosevich's ideas concerning the behavior of a dislocation ensemble in the crystal at high external stresses [18]. As is noted in [18], the intensity of the multiplication of dislocations increases with an increase in the external stresses, and the average distance between the dislocations decreases. A dislocation structure arises that, in some cases, completely prevents the movement of dislocations. Then, a further increase in the load leads to the destruction of the crystal via the origin and propagation of microscopic cracks. In other cases, this structure gives a cooperative nature to the dislocation motion, which ensures very large plastic deformations. The crystal can pass into the state of superplasticity.

The dislocation density in the material can also increase as a result of the frequently observed sharp decrease in the shear modulus μ directly before the phase transformation [19]. Since the critical length of the activation of a Frank–Read source changes as μ/σ, the decrease in the shear modulus can lead to the situation where the shorter segments of dislocations will act as sources at the same stress.

On the other hand, the appearance of regions with a liquid-like and nanocrystalline structure due to the phase transformation leads to a significant increase in the diffusion coefficients in the material. As a result, in local regions of the polycrystal, conditions are created for intense diffusion-related nonconservative dislocation motion. This flow can be accompanied by the formation of cavities in the bulk or by a spatial redistribution of defect complexes in the material deformed, as well as by a recrystallization or the nucleation and growth of precipitates of a new phase and by the preceding formation of segregates of the alloy components at grain boundaries or clusters, etc. [20]. In this case, plastic deformation is a certain homogeneous process, which differs fundamentally from the deformation-related change in the polycrystal structure via grain-boundary sliding; rather, it resembles the viscous flow in a mixed amorphous–crystalline material.

One of the factors that cause the presence of internal compressive stresses in the crystallizing ingots and the metastability of the phase state of the alloy is an increase in the specific volume of bismuth upon the transition from the liquid into solid state. This has already been noted earlier [21].

The preparation of SP eutectic alloys under conditions that permit one to quench the high-temperature state can lead to the appearance of internal compressive stresses of other nature as well. The decomposition of the supersaturated solid solutions based on the alloy components can be accompanied by changes in the specific volumes of these solutions and of mixtures of proper phases that form instead of them. If the transition into the equilibrium state is accompanied by noticeable differences in the relative changes in the specific volumes for each of the phases, then at a certain stage of the decomposition one phase will begin to compress the other phase, thereby preventing the completion of the process of the decomposition. Preliminary estimations show that these differences in the eutectic alloy under consideration are significant. This problem is now at the stage of additional study.

A quite natural problem is also that of the preliminary deformation as the possible reason for the appearance of internal stresses in the polycrystalline materials that manifest SP properties, as well as the problem of the specific features of relaxation of these stresses. As far as is known, these problems connected with SP materials have remained unstudied until now.

As is known, the eutectic alloy investigated in this work is considered as a typical alloy that manifests structural superplasticity. The appearance of this effect is not attributed to the occurrence of some structural or phase transformations. The above-presented experimental results indicate the conditional character of the existing division of superplasticity into the structural superplasticity and superplasticity under special external conditions [1, 2], which some authors call "internal-stress superplasticity" [22]. It may turn out that, in all cases, the nature of the effect of superplasticity is identical. Based on the data obtained, it can be assumed that the prerequisite for the appearance of this effect is the existence of a state of material with specific structural and strength characteristics under deformation conditions. Such characteristics are, in particular, a high dislocation density and a low material strength. The additional increase in the dislocation density and softening under deformation conditions can be observed as a result of the occurrence of some structural and phase transformations in the material and the relaxation of significant internal elastic stresses. Softening may be due to the manifestation of the instability of the structural state of the initially nonequilibrium systems in the field of mechanical stresses.

CONCLUSIONS

The active development of viscous dislocation–diffusion flow and the manifestation of the hydrodynamic mode of deformation have been revealed in the eutectic Bi–43 wt % Sn alloy under superplasticity conditions. This indicates that, under these conditions, in contrast to the traditional concepts, the grain-boundary sliding is by no means always the basic mechanism of the mass transfer of substance.

The viscous flow in the alloy appears first in the localized plastic-deformation bands, whose direction nearly coincides with that of maximum external shear stresses and then develops gradually throughout the entire sample. This can indicate that the structural state that ensures the opportunity of the realization of the viscous mechanisms of the transport of substance is created as a result of the occurrence of structural and phase transformations stimulated by plastic deformation. The transformations begin in the places of the most probable nucleation of new grains, which are the bands of the localized deformation, and gradually propagate into the volume of the material in the process of deformation. This conclusion is confirmed by the data on the nonequilibrium of the initial phase state of the alloy and by the results of the previously performed X-ray diffraction investigations.

The superplastic flow of the eutectic Bi–43 wt % Sn alloy is accompanied by the decomposition of the supersaturated tin-based solid solution, by the dynamic recrystallization of the β(Bi) phase, and by the fragmentation of grains of the α(Sn) phase.

The active development of the viscous dislocation–diffusion flow and the manifestation of the hydrodynamic mode of deformation can be caused by the high level of internal elastic stresses and by the occurrence of kinetic phase transformations in the alloy under superplasticity conditions. The significant internal elastic stresses can appear during the crystallization of the alloy because of an increase in the specific volume of bismuth upon the transition from the liquid into the crystalline state.

It has been revealed that the deformation rates that are optimum for the effect of superplasticity to manifest is shifted toward the greater values in the case of the structural–phase state of the material, which forms at significant elongations of the samples compared with the state in the initial stage of tension. This can indicate a change in the phase state and dispersion of the structure of the alloy in the process of deformation under superplasticity conditions.

The manifestation of the effect of superplasticity in the Bi–43 wt % Sn is caused by the mutual influence of the processes of plastic deformation and structural–phase transformations in the initially nonequilibrium system, including the processes of the decomposition of supersaturated solid solutions and dynamic recrystallization.

The results of the performed investigations indicate that the manifestation of the effect of superplasticity is connected with the appearance (under the conditions of deformation) of a state that is characterized by a high dislocation density and by low strength of the material. An additional increase in the dislocation density and softening under deformation conditions can be observed as a result of the occurrence of structural–phase transformations in the material stimulated by plastic deformation and the relaxation of significant internal elastic stresses. The softening may be due to the manifestation of the instability of the structural state of the initially nonequilibrium systems in the field of mechanical stresses.

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