9. S. A. Saltykov, Stereometric Metallography [in Russian], Metallurgiya, Moscow (1970).
10. V. N. Gridnev, Strength and Ductility of Cold Worked Steel [in Russian], Naukova Dumka, Kiev (1974).

EFFECT OF SUPERPLASTIC DEFORMATION ON THE STRUCTURE OF HEAT-RESISTANT NICKEL ALLOY ZhS6KP

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It is often impossible to observe changes of any kind in the structure of samples subjected to superplastic deformation even after deformations as large as 1000%. Retention of the equiaxed shape of the grains is generally a characteristic feature. Sometimes there are changes in the sizes of grains or in the mutual positions of particles in biphase alloys. The basic results of structural studies were generalized in [1].

Most of these studies were made with the "traditional" superplastic alloys – Zn–Al and Al–Cu. Grain growth during superplastic deformation has been observed in titanium alloys [2].

The structural changes occurring under conditions of superplasticity in heat-resistant nickel alloys have been investigated very little.

This work* concerns the changes in the structure of heat-resistant nickel alloy ZhS6KP after elongation under superplasticity conditions. Samples for the tests were prepared from hot extruded rods with a grain size of 10-12 μ. The tests were made at 1100-1180°C at a pull rate of 0.5-10 mm/min.

The maximum deformation, ~ 500%, was obtained at a pull rate of 0.5 mm/min at 1150°C. The sensitivity factor (m) of the flow stress to the strain rate was determined by the graphic method and was equal to 0.5. The structure was examined on samples tested under optimal conditions of superplasticity which fractured after 500% deformation and also on samples deformed 200%, when the test was stopped.

The samples were cut in the direction of deformation and the structure was examined in the deformed section as well as in the undeformed head.

Figure 1 shows the microstructure of these sections of the sample after 500% deformation. Substantial differences in the structure of the head and the deformed section are observed both at a magnification of 1800 × and 7000 ×. At a magnification of 1800 × the head has individual large primary precipitates of γ' phase located in the grain boundaries, the basic structure consisting of finely dispersed γ' phase (Fig. 1a).

In the deformed section of the sample finely dispersed γ' phase is observed as separate islets (Fig. 1c) that occupy about 50% of the total area of the microsection. At a magnification of 7000 × it can be seen that the particles of γ' phase in the head of the sample are tetragonal, while the particles in the deformed section are oval, the size of the particles being considerably smaller in the deformed section (Fig. 1b and d). Thus, the deformed section is characterized by considerable solution of γ' phase, which is not observed in the head of the sample under the same temperature conditions.

The characteristic feature of the deformed section of the sample is the bands elongated in the direction of deformation in which a large number of fine branching cracks is observed (Fig. 2). The distribution of the bands with cracks resembles that of carbide stringers in the rods. It can be seen in Fig. 1c that the cracks are located at the boundary of the matrix with primary carbides or titanium carbonitrides. The carbide stringers are due to the manufacturing process.

*A. A. Fedorov and L. S. Balyura took part in this work.

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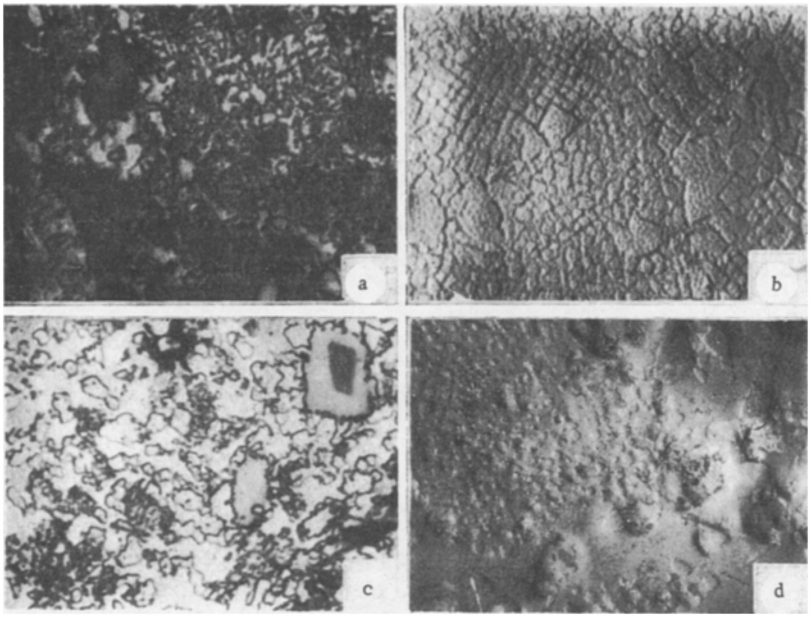

Fig. 1. Structure in the head (a, b) and the deformed section (c, d) of the sample. a, c) 1800 ×; b, d) 7000 ×.

It should be noted that cracks were observed only in sections free of precipitates of dispersed γ' phase. The cracks do not induce premature failure of the sample, since the stress concentrations at the ends of the cracks are not sufficient for crack growth due to the low stresses at which superplastic deformation occurs (2-3 kgf/mm^2). There are data [6] indicating that sensitivity to stress concentrators does not occur under conditions of superplastic deformation. In this case the sample fractures not because of crack growth but as the result of the accumulation and consolidation of microcracks to sizes commensurate with the size of the sample.

This mechanism of fracture is responsible for the large plastic deformation attained before fracture under conditions of superplasticity.

A thin network of cracks is observed in the sample after very slight etching; stronger etching leads to removal of the layer containing cracks in continuous voids oval in shape similar to those observed previously [3]. It was concluded in [3] that these "caverns" originate in vacancies.

It is difficult to agree with this conclusion. Even rough calculations indicate the impossibility of vacancies growing to such dimensions [4].

It is more probable that the cracks formed in superplastic deformation result from the matrix breaking away from the surface of carbide inclusions, as observed in ordinary ductile fracture [5]. The development of

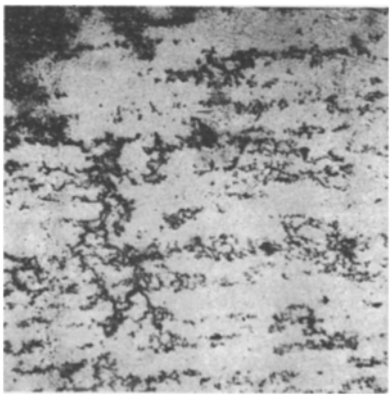

Fig. 2. Bands with cracks in the deformed section of the sample.

fracture depends on the degree of deformation. In the sample deformed 200% and removed from the test at that time the cracks are not in the form of continuous bands but occur in small sections constituting about 10% of the area of the band with accumulations of cracks observed in the sample deformed 500% (up until fracture).

In samples tested under conditions of superplasticity in compression with ~ 90% deformation no cracks or centers of fracture are observed.

CONCLUSIONS

1. Deformation of heat-resistant nickel alloy ZhS6KP in tension under conditions of superplasticity leads to changes in the quantity and size of γ' phase, which can be explained by the intensification of diffusion processes during superplastic deformation.

2. The formation of centers of fracture in samples of alloy ZhS6KP during superplastic deformation is due to carbide stringers.

LITERATURE CITED

1. V. M. Grabskii, Structural Superplasticity of Metals [Russian translation], Metallurgiya, Moscow (1975).
2. L. A. Elagina et al., "Superplasticity of $\alpha + \beta$ titanium alloys," Tekhnol. Legkikh Splavov, No. 11, 30 (1975).
3. V. G. Osipov, A. S. Tikhonov, and M. Kh. Shorshorov, "Mechanism of superplasticity of a nickel–chromium alloy of eutectic composition," Fiz. Khim. Obrab. Mater., No. 6, 76 (1970).
4. D. McLean, "Point defects and mechanical properties of metals and alloys at high temperatures," in: Vacancies and Point Defects [Russian translation], Metallurgizdat, Moscow (1960), p. 303.
5. R. W. Honeycombe, Plastic Deformation of Metals, St. Martin (1968).
6. V. G. Osipov, "Forming and fracture of superplastic materials," Fiz. Khim. Obrab. Mater., No. 2, 91 (1972).