DEFORMATION CAPACITY OF HEAT-RESISTING ALLOYS WITH INTRAGRANULAR HARDENING

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The service life of machine parts and units depends not only on the strength of the material but also on its deformation capacity.

Studies of Cu–Be alloys have shown that the creep rate of the metal depends not on intergranular processes but on the creep resistance of the grain bodies [1]. At the same time, the plasticity of the metal under high-temperature strain is determined by discontinuities occurring in the grain boundaries and the rate of their development, which depends on the extent to which deformation of the grain boundaries is localized [2].

The use of special stepped heat treatments for precipitation-hardening heat-resisting materials permits the plasticity to be increased considerably under high-temperature deformation conditions [3, 4]. These heat treatments affect mainly the structure and strength of the grains, and therefore there is probably a relationship between the magnitude of intragranular strengthening and the rate at which the grains slip with respect to each other during high-temperature deformation.

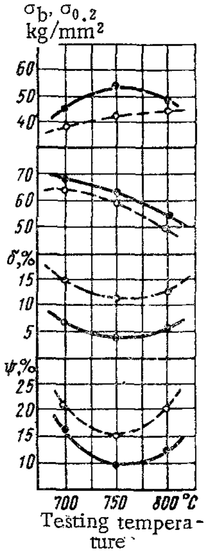

Fig. 1. Mechanical characteristics of alloy ÉI 893 after different heat treatments at temperature of reduced plasticity (v_{def} = 4%/h). —) After treatment 1; - - -) after treatment 2.

To determine the relationship between structural strengthening of the grains and the extent to which deformation is localized and the deformation capacity of the grain boundaries, which determines the high-temperature plasticity of the metal, we investigated the mechanism of deformation and failure of the commercial nickel alloy ÉI 893 (0.06% C, 16.02% Cr, 1.28% Ti, 1.23% Al, 4.62% Mo, and 8.09% W) after the following heat treatments: 1) 1180°C for 2 h, 800°C for 12 h; 2) 1180°C for 2 h, 1000°C for 4 h, 900°C for 8 h, and 850°C for 15 h.

Treatment 1 resulted in precipitation of a nodular dispersed phase with a particle size of 0.02 μ and an average distance of 0.06 μ between particles; after treatment 2 the particle size was 0.07 μ, with a distance of 0.19 μ between particles. The difference in the size and amount of dispersed phase in the grain boundaries was negligible and the grain size was grade 2 in both cases.

The mechanical properties of the metal after the two heat treatments at a constant rate of 4%/h at the temperatue of the maximum reduction of plasticity are shown in Fig. 1. The strength was almost identical after the two heat treatments, while the specific elongation was 250-300% higher after treatment 2.

The variation of the strain relief in tension was investigated with the VTU-TsKTI apparatus and the MII-4 and MIM-8M microscopes.

To remove the cold-worked layer the samples were electropolished in a reagent consisting of 250 ml H_3PO_4 + 70 ml H_2SO_4 + 80 ml H_2O.

The mechanism of deformation and failure was investigated at 650 and 800°C, i.e., near the temperatures at which the values of δ are lowest.

In deformation at 650°C the intragranular deformation is considerable after the stepped heat treatment (Fig. 2, a-d). After treatment 1 the strain relief is weakly developed even in the area of the main crack (Fig. 2e). The variation of the microhardness in the intragranular areas also indicates the more substantial development of shear accompanying the strengthening of the metal after treatment 2 (Fig. 3a).

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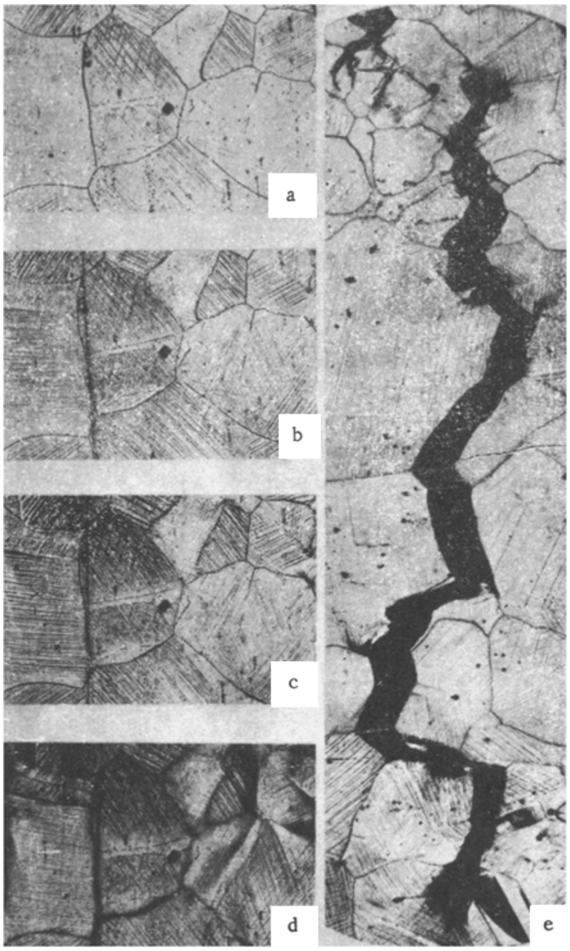

Fig. 2. Microstructure at 650°C and $v_{def} = 4\%/h$ of the ÉI 893 alloy after heat treatment. a) $\varepsilon = 3.2\%$; b) $\varepsilon = 5.6\%$; c) $\varepsilon = 9\%$; d) $\varepsilon = 13.8\%$; a-d) × 150; e) × 300; a-d) heat treatment 2; e) treatment 1.

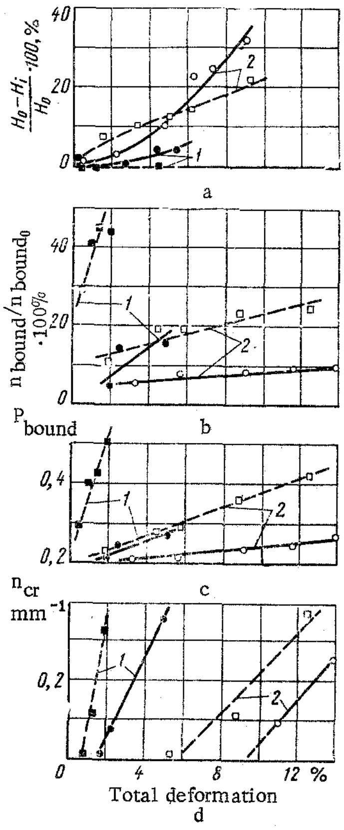

Fig. 3. Variation of intragranular hardening, intergranular slip, and deformation capacity with high-temperature strain. a) Relative microhardness of intragranular areas; b) number of grain boundaries in which slip is observed; c) average value of intergranular slip; d) number of cracks in grain boundaries. ———) Tested at 650°C; - - - -) tested at 800°C. The numbers on the curves are heat treatment numbers.

The deformation is more localized in the grain boundaries after treatment 1. At $\varepsilon_{tot} = 3\%$ slip is observed in only 5% of the boundaries after treatment 2, but in 10% of the boundaries after treatment 1 (Fig. 3b). At the same strain the magnitude of intergranular slip (P_{bound}) is 0.02 and 0.08 μ respectively (Fig. 3c).

It should be noted that, other conditions being equal, the highly strained boundary area is wider after treatment 2, i.e., the extent of local deformation in the boundary is lower in this case.

The higher rate of the intergranular slip process after treatment 1 is responsible for the higher damage (the number of cracks per unit length of the sample, n_{cr}) during deformation [2]. Thus, discontinuities appear after only about 2% total deformation following treatment 1 and after 9% deformation following treatment 2 (Fig. 3d). The average crack length after treatment 2 is one-third to one-half that after treatment 1 (at $\varepsilon_{tot} = 14\%$).

It can be seen from Fig. 3c that $P_{bound}/\varepsilon_{tot} = \text{const}$, which agrees with the results in [5]. This ratio should decrease with increasing stress [6], but it increases more than seven times in spite of a slight increase of the flow stress (by a few per cent) at 800°C after treatment 1. Thus, the sharp increase of P_{bound} cannot be due to the effect of stress.

It can be assumed that the rate of intergranular slip is determined by the character of intragranular deformation, which depends on the structural hardening of the grains. At a given rate of high-temperature deformation greater structural strengthening of the grains (treatment 1) leads to a sharp increase of the ratio $P_{bound}/\varepsilon_{tot}$, i.e., a higher rate of intergranular slip, which is responsible for the rapid development of damage in the grain boundaries. The plasticity becomes lower in this case.

CONCLUSIONS

1. The rate of intergranular slip during high-temperature deformation depends on the condition of the intragranular areas. The intergranular slip increases with the hardening of the grains at a given degree of deformation.

2. The structural condition of the ÉI 893 alloy after the stepped heat treatment creates conditions for the reduction of the intergranular slip rate. The development of discontinuities in the grain boundaries is reduced substantially, which increases the plasticity during high-temperature deformation by comparison with the alloy subjected to the simple heat treatment.

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