EFFECT OF PROLONGED LOADING ON THE STRUCTURE AND PROPERTIES OF ALLOY KhN77TYu

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Creep of heat resistant alloys is due to changes in structure in the grain boundaries and within the grains. These changes refer to the morphology of hardening phases, dislocations, and also signs of failure in the grain boundaries. Creep is usually regarded as a process in which signs of hardening and failure are balanced with a preferential accumulation of damage in the grain boundaries, which leads to failure. The effect of hardening during creep is large and one would expect a substantial improvement of the properties due to preliminary creep under certain conditions [1]. Hardening is especially effective with overloads in the first stage of creep: with proper selection of the time and magnitude of the overload the time to failure under working conditions can be increased several times [2, 3]. Since hardening in the first stage of creep is usually explained as a process associated with the formation of substructure, it appears possible to use the elements of the substructure for additional hardening of alloys. The effectiveness of this treatment for precipitation-hardening alloys has been demonstrated with the use of polygonization annealing after deformation (before aging) [4].

We investigated the effect of preliminary creep on the structure and properties of precipitation-hardening heat resistant alloy KhN77TYu. The treatment includes quenching, deformation under creep conditions at a temperature considerably below the aging temperature, and subsequent aging.

Hardening of the alloy is associated with the selection of the temperature, stress, and time of creep. The temperature at which creep occurs should not be higher than the temperature of intensive aging but should not be so low as to induce the harmful effect of cold plastic deformation [2]. Also, the time required for the formation of substructure at low temperatures is very large. It should be kept in mind that the structure approaches the equilibrium condition much more rapidly with slow deformation than during heating of the previously deformed metal to the same temperature [5]. The magnitude of the stress also determines the perfection of the substructure formed. High stresses may induce intensive generation of dislocations without reinforcement by diffusion processes, i.e., the stability of dislocation arrays will be low. The low stress requires a long time for the formation of substructure. It should be kept in mind that with increasing stress during creep the size of the subgrains decreases [6].

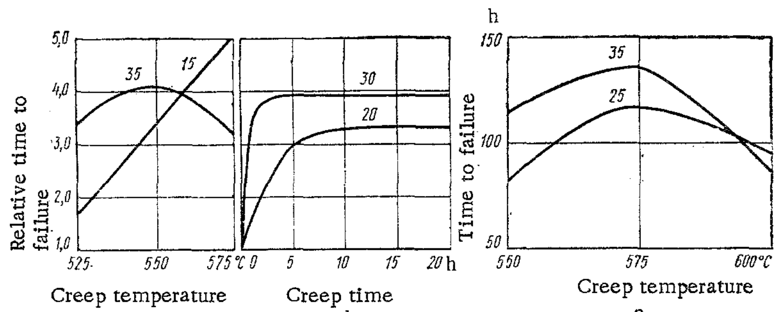

Fig. 1. Effect of preliminary creep conditions on time to failure of alloy KhN77TYu at 700°C, $\sigma = 40$ kg/mm^2 (a, b) and at 800°C, $\sigma = 18$ kg/mm^2 (c). a, c) Creep time 1 h; b) creep temperature 550°C. The stress (kg/mm^2) is given on the curve.

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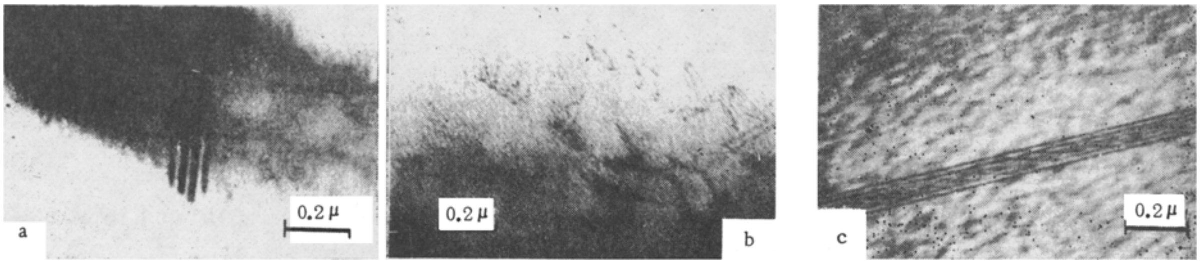

Fig. 2. Electron micrographs of alloy KhN77TYu. a, b) After preliminary creep of the quenched alloy at 550°C with $\sigma = 20$ kg/mm^2 for 5 h; a) stacking faults; b) coplanar distribution of dislocations; c) after preliminary creep and aging at 700°C for 16 h.

Before being subjected to creep the pieces for samples were solutioned at 1080°C for 8 h, producing a homogeneous structure. The samples were subjected to creep at temperatures of 500-600°C. The time matched a deformation not exceeding 0.7%, since with deformation ≥2% no hardening occurs. After deformation, the samples were aged at 700°C for 16 h.

The results of creep tests at 700 and 800°C for samples subjected to this treatment are shown in Fig. 1. The optimal temperature of the treatment varies with the stress level in preliminary creep – it is ~550°C at a stress of 35 kg/mm^2 and >550°C at a stress of 15 kg/mm^2 (Fig. 1a). The largest effect of preliminary creep is achieved in the first 5-10 h at 550°C, and the higher the stress level during creep, the more rapidly the maximum hardening is attained and the larger the effect. Under the preliminary creep conditions selected the time to failure increases by a factor of 3-4. The results of long-term tests of alloy KhN77TYu at 800°C and $\sigma = 18$ kg/mm^2, shown in Fig. 1c, indicate that the optima conditions for preliminary creep are 575°C for 1 h.

Parallel tests were made to determine the effect of low-temperature tempering at 550-600°C for as long as 100 h without application of stress on the heat resistance of alloy KhN77TYu. Some improvement of the heat resistance was noted, but no more than 30%, and therefore the reason for the increase of the heat resistance is the creep, and the effect of the K state is not the main factor [7].

Electron microscopic studies of the fine structure were made after solutioning, preliminary creep, aging, and creep tests for 62 h at 700°C with $\sigma = 40$ kg/mm^2. The study was made by the disk method with the Hitachi 200 electron microscope. After solutioning at 1080°C for 48 h the alloy consisted of the solid solution with no particles of γ' phase, but $Cr_{23}C_6$ carbides were observed in the grain boundaries. After preliminary creep the solid solution decomposes with precipitation of fine particles of γ' phase. Plastic deformation in the presence of the ordered particles occurs with cutting of the particles by dislocations, with formation of stacking faults and coplanar distribution of complete dislocations (Fig. 2a, b). During subsequent aging the stacking faults, limited by dislocation segments, are retained (Fig. 2c), as are the more stable dislocation arrays, but the complete dislocations disappear (evidently annihilated due to the prolonged effect of temperature), and the particles of γ' phase increase slightly in size. After prolonged testing dislocation loops appear around particles of γ' phase. The fine structure of the alloy after long-term tests without preliminary creep differs sharply from that described – coplanar disruption of dislocations is observed, which butt against the grain boundaries. Evidently the dislocation pile-ups promote large stresses in boundary areas, due to which the samples fail considerably earlier than the samples subjected to preliminary creep. Also, dislocations running to the grain boundaries lead to damage in these areas due to the run off of vacancies and other defects.

CONCLUSIONS

When alloy KhN77TYu is subjected to preliminary creep dispersed particles of γ' phase appear in the structure, and consequently plastic deformation occurs by cutting of the particles by dislocations, with formation of stable stacking faults, which are retained during subsequent aging and strengthen the structure. After long-term strength tests the structure contains dislocation loops evenly distributed through the grains, with no coplanar distribution of dislocations in grain boundaries. All these changes in the fine structure lead to an increase of the service life of alloy KhN77TYu.

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