T - T - T diagrams are commonly used to determine the stability of the supercooled solid solution, which affects the hardenability of aluminum alloys and their properties after cooling in air before quenching [1-4]. However, data are lacking on the stability of the solid solution during deformation heat treatment (DHT).

C - C - T diagrams, which are of greater practical use than T - T - T diagrams, were plotted. The diagram shows graphically the effect of the continuous cooling rate on transformation temperature. By means of diagrams with cooling curves during quenching or cooling curves in air it is possible to determine the extent of the transformation quantitatively. The use of T - T - T diagrams requires calculations and assumptions that are not always well founded.

Alloy AK6 contained 2.2% Cu, 0.56% Mg, 1.03% Si, and 0.53 Mn. This alloy was selected because it is widely used commercially and also because of several characteristic features — the narrow temperature range of homogeneity and low stability of the solid solution. It was concluded that these characteristic features would facilitate demonstrating the effect of the cooling rate and cooling time during DHT on its properties.

The C - C - T diagram was constructed by means of determining the loss of strength due to high-temperature decomposition. This method is of the greatest practical interest and is fairly sensitive to changes in structure. Cylindrical pieces — crushers 45 mm in diameter and 70 mm high with conical recesses in the ends (to ensure even deformation) — were subjected to DHT; heating to quenching temperature of 520°C, holding for 60 min, 15% upsetting in a press, and cooling in still air, in oil, and in paraffin heated to 100°C. Cooling in oil and in paraffin simulated cooling of parts of small section in air. After a given time, continuous cooling was interrupted with cooling in water at a temperature of 20°C.

In the standard treatment the pieces were upset at 450–460°C with 15% deformation, cooled in air, and heated to quenching temperature of 520°C. The subsequent cooling conditions were the same as during DHT. The deformed and quenched pieces were then aged at 160°C for 12 h. Samples were then cut for mechanical tests. The test results (four samples for each experimental point) were used to plot the loss of strength in relation to the cooling time (Fig. 1). The ultimate strength of the quenched pieces (not cooled in air) was taken as 100%; the ultimate strength was 50.6 kg/mm² after DHT and 49.6 kg/mm² after the standard treatment.

The C - C - T diagram (Fig. 2) was plotted from the cooling time corresponding to 5 and 10% loss of strength for each cooling rate.

The accuracy of the diagram plotted in coordinates of temperature and time depends mainly on the error in determining the temperature during cooling in air before final cooling in water for plotting the loss of strength curves. The error was calculated as the rms error due to inaccurate recording of the instrument, unstable cooling conditions due to variations in the temperature of the cooling medium and changes in the dimensions of the piece, inaccurate determination of the cooling time in air, the temperature differential through the height and section of the piece, and cooling of the piece during transfer into the cooling medium and into the quenching bath. The total error during cooling in paraffin was 9°C. This is the largest error, since it corresponds to the maximum cooling rate investigated. The diagram plotted with this degree of accuracy is sufficiently reliable for practical purposes.

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Fig. 1. Variation of ultimate strength of alloy AK6 with cooling time in air (A), in oil (O), and in paraffin (P): ---) standard treatment; _____) DHT.

Fig. 2. C - C - T diagram for alloy AK6: ---) standard treatment; _____) DHT.

Fig. 3. Nomogram for determining time (curves 1 and 2) and temperature (3, 4) of cooling in air inducing 5% (dashed lines) and 10% loss of strength (solid lines).

At temperatures above 420°C the 5% loss of strength curves coincide for the two treatments, which is due to even high-temperature decomposition.

DHT slightly accelerates decomposition during cooling to temperatures below 420°C, which is manifest in the slight shift of the respective curves on the diagram.

Samples cooled in oil to 370°C, with a 10% loss of strength, were examined in light and electron microscopes.* No differences in structure were observed after either treatment. The x-ray analysis showed no difference in the structure of samples before and after cooling, accompanied by 4% loss of strength (the lattice constant was determined, the misorientation of regions of coherent scattering, the relative microdistortion). Neither recovery nor recrystallization occur during cooling.

Thus, the loss of strength during cooling is due to high-temperature decomposition. The slight difference in the strength of samples subjected to different treatments can be explained by the small differences in structure.

To determine the permissible cooling (in air) for parts of different size before quenching we constructed a nomogram (Fig. 3) on which were drawn the cooling curves in air for the surface layers of cylinders differing in diameter.

From the nomogram one can determine the cooling time before quenching in which the loss of strength in the most rapidly cooled surface layer is 5 or 10%.

It can be concluded that in most cases of DHT used in production (cylinders over 10 mm in diameter) the cooling during transfer from the furnace to the press and then to the quenching tank should not affect the ultimate strength — the loss should not exceed 5%. This agrees with the results from an analysis of scattering of the characteristic mechanical properties after standard and thermomechanical treatments [6]. For alloys with low stability of the solid solution it may be dangerous to delay quenching. Cooling at this time should be held to the minimum — the dies should be heated to pressing temperature and ejectors should be used.

CONCLUSIONS

1. C - C - T diagrams for alloy AK6 and a nomogram for determining the permissible cooling temperature and time were constructed.

2. The stability of the supersaturated solid solution of alloy AK6 after DHT at temperatures above 420°C is the same as, and at temperatures below 420°C somewhat lower than, after standard treatment.

3. Cooling below 105°C during quenching has no effect on the ultimate strength of alloy AK6.

LITERATURE CITED


*Electron microscopic and x-ray analyses were made after natural aging of the samples.