OPTIMIZATION OF THE COMPOSITION OF HEAT TREATABLE ALUMINUM BRONZE

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UDC 669.71.717

The method of planned experiments was used to determine the effect of alloying elements on the mechanical properties of aluminum bronzes as-cast [1]. The regression equations obtained for the yield strength and elongation

\[
\sigma_{0.2} = 25.41 + 4.91X_1 + 3.36X_2 + 6.12X_3 + 0.93X_1X_2 - 1.6X_1X_3;
\]

\[
\delta = 29.4 - 11.22X_1 - 10.14X_2 - 9.39X_3 + 1.06X_1X_2 + 3.32X_1X_3 + 7.18X_2X_3;
\]

where

\[
X_1 = \% \text{Al} - 8; \quad X_2 = \% \text{Ni} - 2.5; \quad X_3 = \% \text{Fe} - 1;
\]

made it possible to determine the range of optimal composition of aluminum bronze with the best possible mechanical properties as-cast.

To determine the effect of heat treatment on the mechanical properties of aluminum bronzes in the same range of composition we used the irregular fraction replica 3/4 of the complete factorial experiment $2^4$ [2]. This makes it possible to construct an incomplete quadratic model of the variation of mechanical properties with composition for different heat treatment conditions. The experimental data and the matrix are given in Table 1. From the planning matrix we determined the mechanical properties of alloys of different compositions quenched from 850°C in water and tempered at 500, 600, and 700°C. The best combination of mechanical properties for all the alloys was obtained by tempering at 600°C. On the basis of the experimental data obtained, we plotted the variation of yield strength and elongation with the concentrations of alloying elements for the heat treatment selected:

\[
\sigma_{0.2} = 31.86 + 6.04X_1 + 5.93X_2 + 3.73X_3 + 1.68X_4;
\]

\[
\delta = 26.65 - 9.05X_1 - 15.49X_2 - 3.18X_3 + 8.22X_1X_2 - 4.39X_1X_3 - 4.94X_1X_4 + 7.1X_2X_3 - 1.33X_2X_4,
\]

Calculation of the regression coefficient and the analysis of variance were conducted with the Minsk-22 computer, using the common formulas of regression analysis [2].

The adequacy of regression equations (3) and (4) was calculated by Fisher's criterion for the 5% significance level.

It follows from comparison of the regression coefficients of Eqs. (1)-(4) that heat treatment substantially changes the variation of the mechanical properties with the composition, as compared with the as-cast condition. The regression coefficients in Eq. (3) at $X_1$ and $X_2$ are almost 50% larger than in Eq. (1), and at $X_3$ only one-half. This means that after heat treatment the hardening effects of aluminum and nickel increase sharply, while the
The effect of hardening due to an increase of the manganese content decreases. The positive effect of the interaction of aluminum and nickel [coefficients at \( X_1 X_2 \) in Eq. (4)] increases eight times, which is due to precipitation of intermetallic compounds of nickel and aluminum from the \( \alpha \) solid solution as the result of heat treatment. X-ray analysis* showed that after quenching from 850° and tempering at 400-500° the distortion of the lattice of the \( \alpha \) solid solution decreases sharply in the alloy with 8.86% Al, 3.93% Ni, 3.86% Mn, and 1.30% Fe. This variation of second-order stresses with the tempering temperature indicates disruption of coherent bonds and formation of a new intermetallic phase after tempering at temperatures above 500° (Fig. 1).

In contrast to the as-cast condition, the interaction of aluminum with manganese [coefficient at \( X_1 X_3 \) in Eq. (4)] has a negative effect, i.e., in alloys with more than 8% Al an increase of the manganese concentration lowers the ductility. This is the reverse of the effect of aluminum and manganese on the ductility of the alloy as-cast. It is explained by the intensive grain growth at 800-900° in alloys with more than 8% Al and more than 8% Mn. Figure 2 shows the fracture of a sample with 9% Al and 10% Mn after quenching in water from 850°. To explain the reason for the effect of manganese on the mechanical properties after quenching and tempering we conducted dilatometric studies of alloys with 9% Al and 2, 5, and 8% Mn. The dilatometric data were used to plot the variation of the \( \beta \rightarrow \alpha + \beta \) transformation temperature with the manganese concentration (Fig. 3). Raising the manganese concentration greatly affects the \( \alpha \) transformation temperature. With quenching from 850° an increase of the manganese concentration raises the inflection above the \( \beta \) transformation temperature, and therefore grain growth occurs, which also impairs the mechanical characteristics. Figure 4 shows the microstructure of the alloy with 9% Al and 11% Mn after quenching from different temperatures. After quenching from 700° the alloy has a homogeneous structure consisting of \( \beta \) solid solution (Fig. 4a); quenching from 850° leads to considerable grain growth (Fig. 4b). Thus, the optimal quenching temperature depends on the manganese and aluminum concentrations.

Equations (3) and (4) make it possible to find the composition of aluminum bronze with the mechanical

*Made by N. A. Likhacheva.