NONFERROUS METALS AND ALLOYS

EFFECT OF MAGNESIUM ON THE STRUCTURE AND PROPERTIES OF Al–Ni–Si–Mn BRONZE

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Small additions of magnesium improve the strength of precipitation-hardening (beryllium) and strain-hardening (tin–phosphorus, silicon–manganese, etc.) spring bronzes [1-3]. The effect of magnesium is explained by its adsorption influence, reducing the mobility of structural defects. This changes the processes of phase and intraphase transformations, on which the properties of the alloys depend after heat treatment.

This work concerns the effect of magnesium on the structure and properties of bronze ANKMts 6-6-1-2 from a group of new precipitation-hardening bronzes based on the Cu–Ni–Al–Si–Mn system. A series of alloys was melted in a vacuum furnace, containing 0.05%, 0.09%, and 0.13% Mg, and also without Mg. The magnesium additions were made to the same heat, containing 5.85% Al, 5.73% Ni, 0.88% Si, and 1.86% Mn. The ingots were subjected to hot and cold deformation by 40% (with intermediate quenching) to obtain bands 0.3 mm thick, from which the samples were cut.

The elastic limit, hardness, and electrical resistivity of all the bronzes were identical after quenching from 900°C (σ0.002 = 27 kg/mm², HV = 180, ρ = 0.240 · 10⁻⁴ Ω·cm). After quenching, the structure of all the bronzes consisted of a solid solution with inclusions of second phases. These inclusions inhibit grain growth due to the barrier effect. At temperatures above 900-950°C substantial grain growth occurs in the bronze without magnesium due to partial solution of excess phases, and therefore a quenching temperature of 950°C is unacceptable, although the hardening effect during aging increases due to the high supersaturation of the solid solution.

When magnesium is added the grain growth that occurs when the quenching temperature is raised from 900 to 950°C (Fig. 1) slows down, which confirms the assumption that magnesium is a surface-active element in these alloys. The slowing of grain growth makes it possible to raise the quenching temperature of bronzes with magnesium as compared with the standard bronze and to increase the concentration of the solid solution with no danger of grain growth. During subsequent aging of bronzes with magnesium the hardening effect increases. However, 900°C is the optimal quenching temperature for most samples of the ANKMts 6-6-1-2 alloy.

Fig. 1. Microstructure of bronze ANKMts 6-6-1-2 quenched from 950°C. a) Without Mg; b) with 0.13% Mg.
Fig. 2. Properties of ANKMts 6-6-1-2 bronze. a) Quenched + aged at 450°C; b) strain hardened 40% + aged at 400°C. ○) Without Mg; □) 0.05% Mg; ●) 0.09%; Δ) 0.13%.

Fig. 3. Relaxation resistance of ANKMts 6-6-1-2 bronze after quenching from 900°C and aging at 425 and 450°C for 3 h (a,b), and after quenching from 900°C, 40% cold deformation, and aging at 375°C for 5 h (c) and 400°C for 3 h (d). a,b) σ₀ = 57 kg/mm²; c,d) σ₀ = 87 kg/mm². ○) Without Mg; □) 0.05% Mg; ●) 0.09% Mg; Δ) 0.13% Mg.

Aging was conducted at 425, 450 and 500°C. The rapid development of decomposition of the solid solution, accompanied by lowering of the resistivity and an increase in strength, was observed at 425°C. The highest strength (σ₀ = 57 kg/mm², HV = 320) of all the alloys investigated regardless of the magnesium content was reached after 3 h and practically matched the highest degree of decomposition of the solid solution at this temperature. The character of the changes in these properties during aging was similar for all the alloys investigated.

Aging at 450°C (Fig. 2) accelerates decomposition of the solid solution. The highest elastic limit (58 kg/mm²) is reached in 2 h, and the maximum hardness in 3 h. The alloys with magnesium are strengthened somewhat more than the alloy without magnesium. The degree of decomposition corresponding to the maximum increase in strength at this aging temperature is higher than at 425°C.

With aging at 500°C the elastic limit (58 kg/mm²) and hardness (330) are highest after 1 and 2 h respectively. The maximum hardening matches a lower value of the resistivity.

Fig. 4. Relaxation resistance of ANKMts 6-6-1-2 bronzes under cyclic load after quenching and aging at 450°C for 3 h (a), and after quenching, cold deformation, and aging at 400°C for 3 h (b). a) σ₀ = 49 kg/mm²; b) σ₀ = 88 kg/mm². ○) Without Mg; □) 0.05% Mg; ●) 0.09% Mg; Δ) 0.13% Mg.