We studied the structure and mechanical properties of stainless maraging steels of the following types: Cr-Ni-Mo, Cr-Ni-Co, Cr-Ni-Co-Mo, Cr-Ni-Co-Mo-Ti (all with 12-13% Cr and 6-7% Ni). These chromium and nickel concentrations in low-carbon steels provide fairly high corrosion resistance under atmospheric conditions and make it possible to obtain a martensite matrix even in the case of substantial additions of alloying elements to induce aging. It is very important to keep the carbon concentration to the minimum, since it has a great effect on $M_s$, the hardness of the steel after quenching, the corrosion resistance, and the ductility.

The chemical composition of the steels is given in Table 1. Heats 1 and 2, weighing 8 kg, were melted in a vacuum furnace. The others (25 kg) were melted in an open induction furnace, followed by electroslag remelting. The ingots were forged to rods 14 mm in diameter and rolled to strips 1-1.2 mm thick.

The possible structure of the steels according to Schaeffler's diagram was considered in adding Mo, Co, and Ti to the basic Cr-Ni steel.

Not one of the steels corresponded to the martensite region of Schaeffler's diagram — the martensitic heat 3 is located in the austenitic-martensitic region of the diagram; heats 8, 9, and 10, containing no more than 13% retained austenite, are at the boundary of the austenitic region; the martensitic heat 4 and the austenitic-martensitic heats 5 and 6 correspond to the austenitic region.

Schaeffler's diagram was reliable only for the martensitic-austenitic heats 1 and 2 and the austenitic heat 7.

Hammond's diagram* was of limited use in predicting the structure of the alloys: neither cold hardening at -70°C for 3 h nor cold working (rolling) with 50% reduction eliminated the retained austenite in heat 5, with cobalt,

Fig. 1. Effect of cobalt on the hardness after aging (500°C 8 h) of steel with 12% Cr and 7% Ni.

Fig. 2. Variation of hardness with aging time at 500°C. The heat numbers are given on the curves.

Fig. 3. Effect of molybdenum on the hardness after aging (500°C 8 h) of steel with 12% Cr, 7% Ni, 7% Co.

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Comparison of the effect of cobalt and molybdenum on the stability of austenite indicates that molybdenum increases the stability to a greater extent than cobalt despite the fact that it is a ferrite-forming element. To obtain martensite in steel with 12–13% Cr and alloyed with molybdenum without using cold hardening or cold working it is necessary to reduce the concentration of nickel and other austenite-forming elements.

On the basis of this conclusion we corrected the concentration of nickel, cobalt, and molybdenum; as the result, we obtained steels with almost no retained austenite (heats 8, 9, and 10).

The hardening effect of cobalt on Fe–7Ni–12Cr is shown in Fig. 1. Raising the cobalt content from 5 to 10% results in considerable hardening during aging.

Interesting results were obtained from comparing the effect of cobalt on the mechanical properties of Ni and Cr–Ni steels with a martensite matrix. The mechanical properties after aging of 18% Ni [1] and 13Cr–7Ni steels are given in Table 3. The compositions of these steels were selected so that the total concentration of Cr and Ni in the Cr–Ni steels was approximately equal to the nickel content of the Ni steels.

At the same strength in the quenched condition the plasticity of the Ni steels is higher than that of the Cr–Ni steels.

Steels with 5% Co did not harden notably after aging, although the plasticity increased. With 10% Co in the 18% Ni steel there was a slight increase in the strength after aging, while for the Cr–Ni steel the increase in strength was fairly substantial: $\Delta\sigma_b = 26 \text{ kg/mm}^2$. The plasticity changed negligibly.

As was found in [1], further increase in the cobalt content makes it possible to obtain high strength also in nickel steels. The authors explained this strengthening by the possibility of ordering during aging of Ni–Co steels. We did not investigate the strengthening mechanism of Cr–Ni steels alloyed with cobalt.

The hardening of these steels when molybdenum is added is negligible at concentrations up to 2% [2], but is notable at 4%. The hardening induced by molybdenum is greatly affected by the higher alloying of the solid solution.

The variation of the hardness during aging of heats 2, 4, and 9 is shown in Fig. 2. Co–Mo steels are hardened more during aging than would be expected from simple addition of the increase in hardness after aging of steels separately alloyed with cobalt and molybdenum. The hardening effect of molybdenum on steel containing 7% Co is shown in Fig. 3.

Fig. 5. Effect of crack length on the ultimate strength of steel 00Kh12N7K7M4. a) Through crack; b) surface crack. 1) Longitudinal samples; 2) transverse samples.