THE PROPERTIES AND HEAT TREATMENT
OF Ti - Cr AND Ti - Cr - A1 ALLOYS

V. N. Moiseev

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We have investigated binary Ti-Cr alloys containing up to 15% Cr and Ti-Cr alloys containing 3% Al. This concentration of Al was chosen to ensure high plasticity of the alloy, which is rolled into sheets.

The alloys were prepared from titanium sponge TG00 (σb = 38 kg/mm²), electrolytic refined chromium, and aluminum А00. The alloys were smelted in a vacuum arc furnace with expendable electrodes by the double remelting method. The ingots were 120 mm long and 120 mm high and weighed about 5 kg. The chemical composition of the alloys is given in the table. The concentration of impurities was 0.03-0.05% Fe, 0.04-0.06% Si, 0.03-0.04% C, and 0.080-0.011% O₂.

Rods 12 mm in diameter and sheets 1.2 mm thick were prepared from the ingots. Forging was begun in the temperature range of the β-region and it was terminated at temperatures in the α + β-region. The sheets were rolled at 700-900°C and then at 550-750°C. Alloys containing 12-15% Cr were rolled at temperatures no lower than the limit of eutectic transformation.

The mechanical properties of the alloys were determined on Gagarin rod samples, and on flat samples cut from the sheets in a direction perpendicular to the direction of rolling. The width of the working part of the sample was 10 mm. Welded samples 15 mm wide were subjected to bending tests according to the standard method; the bending radius was equal to the thickness of the sheet.

The resistance to rupture and the yield point increase, while plasticity decreases with increasing concentrations of chromium (up to 12%) (Fig. 1). The addition of 3% aluminum increases the strength of the alloy by about 20 kg/mm², although the plasticity decreases somewhat.

The binary alloy containing 15% Cr becomes brittle after annealing at 700-800°C. Possibly this is due to the eutectic decomposition or preservation of the ω-phase resulting from the slow cooling after heating to 700°C and higher. However, X-ray analysis fails to indicate the presence of intermetallic compounds, obviously because of the initial decomposition state or the small amount of eutectic. The addition of 3% Al prevents the eutectic decomposition, and the annealed alloy is very plastic.

We also determined the mechanical properties of the alloys after quenching (Fig. 2). The bars were heated 1 h at the desired temperature and then quenched in water (at room temperature).

In Ti-Cr and Ti-Cr-Al alloys in which the β-phase does not stabilize on quenching, the strength and the flow limit in the α + β-region increase with increasing concentrations of Cr (up to 4%) and increasing quenching temperatures, while the plasticity decreases. This is due to the formation of the metastable α'-phase (titanium martensite) as a result of quenching. This phase is the product of the diffusionless transformation of the β-phase. The amount of α'-phase increases with increasing quenching temperatures, while increased concentrations of Cr increase the supersaturation of chromium in this phase. An increase in quenching temperature in the β-region does not affect the mechanical properties in any significant way.

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Binary alloys with a concentration of chromium near the critical concentration (9% Cr) are brittle when quenched, due to the formation of the $\omega$-phase. Addition of Al to the alloy eliminates the formation of the $\omega$-phase.

The mechanical properties of alloys with concentrations of Cr higher than the critical concentration (12-15%) are not significantly affected by increased quenching temperatures. In these alloys quenching stabilizes the plastic $\beta$-phase, and the brittle $\omega$-phase is absent. The slight increase of plasticity with increasing quenching temperatures (700-800°C) can be explained by more complete annealing, while the decrease of plasticity (particularly the decrease of the cross section) resulting from quenching from temperatures above 800-900°C can be explained by intense growth of grains at high temperatures.

In quenched alloys of titanium with chromium and alloys of titanium with other elements martensitic transformation of the metastable $\beta$-phase into the $\alpha'$-phase occurs as the result of stress. This transformation favors plastic deformation at lower stresses. Deformation of the alloy containing unstable $\beta$-phase leads to an increase in the difference between the ultimate strength and the yield point.

Figure 3a represents the mechanical properties of sheets (1.2 mm in thickness) of Ti-Cr and Ti-Cr+3% Al quenched from 800 and 850°C in water. One can see the region in which the difference between the ultimate strength and the yield point is high. In alloys containing aluminum there is no martensitic transformation and there is not such a difference between $\sigma_b$ and $\sigma_{0,2}$ (Fig. 3b).

It must be noted that quenching rods of the alloy containing 9% Cr from 800°C or higher in water induces brittleness as the result of the formation of the $\omega$-phase. Sheet samples (1.2 mm thick) of the same alloy quenched from the same temperatures are highly plastic, which indicates the absence of the $\omega$-phase. Thus, one can eliminate brittleness in the rods of the alloy containing 9% Cr by increasing the rate of cooling.

Strengthening heat treatments (quenching and aging) have substantial effects on the mechanical properties of the alloys investigated. The samples were cut from rods 12 mm in diameter and were quenched in water from temperatures 50°C above and below the limits of the $\alpha + \beta \rightarrow \beta$-transformation (Fig. 4).

The samples were then subjected to aging at 300, 400, 500, and 600°C for 0.25, 1, 4, 16, and 64 h, and were subsequently cooled in air.

The variation of the hardness of the Ti-Cr and Ti-Cr-Al alloys as a function of the quenching temperature and aging conditions is represented in Fig. 5. The variation of the mechanical properties of the bars quenched from temperatures 50°C or more below the limit of the $\alpha + \beta \rightarrow \beta$-transformation as a function of the aging temperature (for 4 h) is represented in Fig. 6.

Alloys containing 9% Cr and quenched from the $\alpha + \beta$- and $\beta$-regions are very hard. Aging at 300 and 400°C increases this hardness only slightly, while aging at 500 and 600°C either does not affect the hardness, or decreases it.

In alloys containing 2% and 4% Cr the strength first increases and then decreases with increasing aging temperatures. Alloys containing 2% Cr which are aged at 300°C have the maximum strength, while in alloys containing 4% Cr...