FUSIBILITY DIAGRAM OF THE Ti-Cr-Mo SYSTEM

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A characteristic peculiarity of the components of the triple Ti-Cr-Mo system is their chemical activity at high temperatures. Metallic molybdenum, stable in air up to 400°, forms the oxide MoO₃ above 600°. Titanium possesses great affinity with oxygen and nitrogen. Interacting with them, it forms limited solid solutions and compounds. It follows from the phase diagram of Ti-O (1) and Ti-N (2) that oxygen and nitrogen considerably raise the temperature of the polymorphic α→β conversion of titanium, expanding the area of existence of the α-phase. Hydrogen also dissolves in titanium, considerably lowering the temperature of its polymorphic conversion (3, 4).

The Ti-Cr system (Fig. 1, I) has been investigated by a number of authors (5-11). It has been established that in the primary crystallization process β-titanium and chromium form a continuous series of solid solutions. On the solidus curve a minimum melting point is observed for alloys with a content of about 50% Cr by weight. When the temperature is lowered, there is a decomposition of the solid solution with secretion of an intermetallic compound.

The question of the composition of the compound has been solved in different ways by various investigators (5-7). According to radiographic data (7) the compound corresponds to the formula TiCr₂ and has a cubic face-centered lattice of the MgCu₂ type with period a = 6.929 Å. Further investigations (12, 13) have revealed a high-temperature modification of the compound TiCr₂ with a lattice of the MgZn₂ type.

The high-temperature modification, having a hexagonal lattice (a = 4.922 KX, c = 7.945 KX, c/a = 1.614) exists above 1300°, while the low-temperature one with a cubic face-centered lattice (a = 6.929 Å) occurs at temperatures below 1000°. In the interval 1000-1300° the co-existence of the two modifications is possible.
In stabilizing the $\beta$-phase of titanium, chromium lowers the
temperature of its polymorphic conversion. In the titanium-
rich area of the Ti-Cr system a eutectoid conversion $\beta \rightarrow \alpha +$
TiCr$_2$ is observed. According to the data of (1) the eutectoid
point is determined at 600° and 13 at. % Cr. The lower limit of
the temperature of the eutectoid conversion, the composition of the
eutectoid point and the solubility of chromium in $\alpha$-titanium at
different temperatures are apparently to be explained by the different
degrees of contamination of the alloys with oxygen and nitrogen,
and are also, as shown in (14), the consequence of too slow a cooling
of the alloys in hardening.

In the Ti-Mo system (Fig. 1, II (16-17)) titanium and moly-
bdenum form between each other a continuous series of solid solutions.
Increasing the molybdenum content results in a continuous rise in the
melting point of alloys. Molybdenum, like chromium, lowers the
temperature of the polymorphic $\alpha \rightarrow \beta$ conversion of titanium, and
increases the stability of the $\beta$-phase.

The solubility of molybdenum in the $\alpha$-phase increases with
decreasing temperature and does not exceed 0.83 at 600°; at this
temperature, the boundary between the phase areas $(\alpha + \beta)/\alpha$ runs near
22.5 Mo.

Radiographic investigations of alloys (17) hardened from 800°
have shown that titanium increases the period of the molybdenum
lattice, but no linear dependence of the period upon the composition
is observed. In the radiographs of alloys with 60, 70, 80 and 90° Mo
additional lines appear, the nature of which has not been ascertained
by the authors. Because of the extreme slowness of the diffusion
processes at temperatures below 600° the alloys of the Ti-Mo system
have not been studied by the classic methods of physico-chemical
analysis and consequently there is no certainty that no conversion
takes place in the solid state at lower temperatures. As shown by
a study of the Hall constant (18), the formation from the solid
solutions of chemical compounds having the composition Ti$_4$Mo,
Ti$_3$Mo or TiM, is possible in the system.

In the Cr-Mo system (Fig. 1, III (19-21)) in the solid state
the alloys form a continuous series of solid solutions. On the
solidus line a minimum is observed at 1700° and a 25° Mo content.
The melting point of chromium is 1770°. Investigation (22) has
established the presence of a polymorphic conversion of chromium
at 1430°, while the melting point of pure chromium is fixed at 1429°.
With the presence of a polymorphic conversion in chromium, the phase
diagram of Cr-Mo given in (21) cannot be regarded as complete, and
additional investigations are required to refine it.

Work (23) gives data on the thermal analysis in the investi-
gation of the Cr-Vo system. The results of the thermal analysis
show that the minimum on the liquidus curve is observed at a higher
| temperature (1860°) and with a higher chromium content (about |
80% by weight). In the solid state there are a number of points which are apparently connected with the conversion in the solid state. These data agree with earlier works (24).

The triple system Ti-Cr-No has not been sufficiently investigated. In (25) a limited area of alloys with a rich titanium content has been studied in the temperature interval between 500 and 1300°. The phase boundaries have been determined by the parametric method (26), the application of which is favorable because of the presence of an extensive area of the B-phase. Characteristic of the Ti-Cr-No system in the titanium-rich area is the repression of the eutectoid reaction \( \beta \rightarrow \alpha + TiCr_2 \) taking place in the dual system Ti-Cr, and the enlargement of the area of \( \beta + TiCr_2 \). The work gives the isothermal cross-sections at 600, 750 and 700°, the isotherms of the \( \beta \)-surface, the isotherms of the \( \beta (\beta + TiCr_2) \) surface and the vertical sections with contents of 4 and 7% Cr, 4 and 8% Cr and 90, 80 and 70% Ti. The solidus surface has been constructed the isotherms of the surface of incipient melting of the area investigated have been represented.

Works (27 and 28) are devoted to the study of the mechanical properties of various triple and quadruple alloys. The literature contains references to unpublished works (12) concerning the alloys of the Ti-Cr-No system.

It can be seen from a review of the literature that no complete investigation has been made of the triple system Ti-Cr-No. The present work is devoted to the study of the interaction of the components in the triple system Ti-Cr-No and the construction of a phase diagram of them.

The diagram of the fusibility of the system studied was investigated for 2 days; 5 days for the molybdenum base. Homogenization completely eliminated liquation in the composition.

The microstructure of the alloys was investigated after various regimes of thermal treatment. To ascertain the structure of the alloys of the triple system Ti-Cr-No from the aspect of the chromium and molybdenum angles, electrolytic etching was applied in 5% oxalic and 2% hydrofluoric acid, respectively. To etch the titanium-angle alloys a reagent of the following composition was used: 60 parts of glycerine + 20 parts of concentrated nitric acid + 20 parts of hydrofluoric acid.

Some characteristic microstructures of alloys are shown in Fig. 2. The alloy with 55% (by weight) Ti, 36% Cr and 9% No after hardening from 1200° has the structure of a solid titanium solution. The microstructure of the two-phase alloy consisting of a mixture of \( \beta \)-titanium and TiCr_2 is shown in Fig. 2, b. According to the X-ray analysis data, the TiCr_2 after hardening from 1200° is found in two modifications: cubic face-centered and hexagonal. Fig. 2, c, d, e shows the microstructures of alloys which are one-phase after hardening from 1200°. In the alloy with
15% (by weight) Ti, 68% Cr and 17% Mo, decomposition of the solid chromium solution with secretion of TiCr₂ is observed after hardening from 900° (Fig. 2, f).

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Fig. 1. Surface of Incipient Melting

1. Author's data
CONCLUSIONS

1. The solidus surface of the Ti-Cr-Mo is constructed; the solidus surface corresponds to the formation of a continuous series of solid solutions.

2. The decomposition of the solid solutions with secretion of the chemical compound TiCr₂, which takes place in the dual system Ti-Cr, is also observed in the triple system Ti-Cr-Mo.

Fig. 2. Microstructures of the alloys of the system (x200).
(all percentages by weight)

a. 55% Ti, 36% Cr, 9% Mo, hardened from 1200°, solid solution of β-titanium;
b. 40% Ti, 50% Cr, 10% Mo, hardened from 1200°, β-titanium and TiCr₂;
c. 15% Ti, 68% Cr, 17% Mo, hardened from 1200°, solid solution of chromium;
d. 40% Ti, 20% Cr, 40% Mo, hardened from 1200°, solid solution;
e. 10% Ti, 10% Cr, 80% Mo, hardened from 1200°, solid solution of molybdenum;
f. 15% Ti, 68% Cr, 17% Mo, hardened from 900°, decomposition of solid chromium solution with secretion of TiCr₂.

LITERATURE


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