Chemistry

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Abstract

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THE EFFECT OF ALUMINUM ON THE STABILITY OF THE BETA PHASE IN TITANIUM –MOLYBDENUM–IRON ALLOYS

In recent years a number of works have been published devoted to the study of complex-alloyed titanium alloys with additions of aluminum. However, from the data of these works it is difficult to judge the nature of the effect of aluminum on the stability of the quenched β-phase and on the kinetics of its decomposition, since their results are to a considerable extent contradictory. Thus Kessler and Hansen (^{1}) report that, upon introducing aluminum into titanium—molybdenum alloys, the temperature of the martensitic transformation decreases and the rate of decomposition of the β solid solution increases. The hardness of quenched alloys increases with increasing aluminum content. In the work of Grist et al. (^{2}) it was established that the presence of aluminum in quenched titanium—manganese alloys slows the decomposition of the β-phase. At the same time, the ω-phase lines on the X-ray diffraction patterns of the ternary alloy are considerably weaker than on the X-ray diffraction patterns of the binary titanium—manganese alloy. Kontorovich and Semenchenkov (^{3}) found that alloying titanium —molybdenum alloys with aluminum leads to a decrease in hardness. For the investigation, alloys of the titanium—molybdenum—iron system were selected, previously studied by N. V. Ageev and Z. M. Rogachevskaya (^{4}). This made it possible to compare the results obtained with the data of the cited work.

For preparing the alloys, iodide titanium TG-00, Mo powder, and electrolytic iron were used. The charge was pressed and melted in a vacuum arc furnace with a tungsten electrode in an atmosphere of argon or helium. To obtain an ingot more homogeneous in composition, melting was repeated 3–4 times. The change in ingot weight relative to the initial charge (30 g) did not exceed 0.3 g. Control chemical analysis gave the following results (Table 1). The ingots obtained were rolled

Table 1

Chemical composition of the alloys

Mo content, %, by charge	Mo content, %, by analysis	Fe content, %, by charge	Fe content, %, by analysis	Al content, %, by charge	Al content, %, by analysis	Carbon impurity, %
13.5	15.0	6	4.64	1	1.22	0.071
13.5	13.76	6	5.45	2	1.78	–
13.5	20.50	6	5.60	3	3.32	0.028

into rods; forging was carried out in the temperature range 950-750°. The rods were annealed for two hours at 900° with subsequent furnace cooling. The annealed alloys were quenched from temperatures of 700-1000°.

Methods of microscopic and X-ray analysis, as well as hardness measurement, were used in the work. X-ray diffraction patterns were taken···

was carried out in the RKD chamber by the polished-section method in copper radiation with a nickel filter. Hardness was determined on a Vickers instrument under a load of 10 kg.

Stability of the β-phase on heating

All the alloys studied, with the exception of alloys containing 6.7% molybdenum, 2.2% iron, and 1, 2, and 3% aluminum, had a single-phase structure of the solid solution β already after quenching from 700° (Table 2). The alloys Ti—6.7 Mo—2.2 Fe—1 Al and Ti—6.7 Mo—2.2 Fe—2 Al were quenched to the β-phase from 900°, and Ti—6.7 Mo—2.2 Fe—3 Al from 1000°. The alloy Ti—6.7 Mo—2.21 Fe studied in work (4), when quenched from temperatures up to 1000°, had a two-phase $\beta + \omega$ structure.

Table 2

Composition of the alloys studied (in percent)

Al	Fe	Mo	Ti	Al	Fe	Mo	Ti
1	9	7	bal.	3	10	12	bal.
2	9	7	»	1	6	13.5	»
3	9	7	»	2	6	13.5	»
1	10	9	»	3	6	13.5	»
2	10	9	»	1	2.2	6.7	»
3	10	9	»	2	2.2	6.7	»
1	10	12	»	3	2.2	6.7	»
2	10	12	»				

The quenched alloys were aged in the temperature range 200—600° for 0.25—144 h. Figure 1 shows the effect of temperature and holding time during aging on the

Figure 1. Stability of the β phase during aging. I —Ti—9Mo—10Fe—1Al alloy; II —Ti—9Mo—10Fe—2Al; III —Ti—9Mo—10Fe—3Al; IV —Ti—13.5Mn—6Fe—1Al; V —Ti—13.5Mn—6Fe—2Al; VI —Ti—13.5Mn—6Fe—3Al. a —β phase, —$\beta + \alpha$ phase.

Figure 1: Figure 1. Stability of the β phase during aging. I —Ti—9Mo—10Fe—1Al alloy; II —Ti—9Mo—10Fe—2Al; III —Ti—9Mo—10Fe—3Al; IV —Ti—13.5Mn—6Fe—1Al; V —Ti—13.5Mn—6Fe—2Al; VI —Ti—13.5Mn—6Fe—3Al. a —β phase, —$\beta + \alpha$ phase.

stability of the β-phase. The least stable was the β-phase in the alloys Ti—6.7 Mo—2.2 Fe with 1, 2, and 3% aluminum. Already after 15 min of heating at 200° the β-phase decomposes with precipitation of the ω-phase, and the increase in hardness accompanying the appearance of the ω-phase is the greater, the higher the aging temperature.

On heating to 200—300° the ω-phase is stable for 100 h. At 400°, after 25 h, in the alloys Ti—6.7 Mo—2.2 Fe and 1, 2, and 3% aluminum, the transformation $\beta + \omega \rightarrow \beta + \alpha$ occurs, accompanied by a certain decrease in alloy hardness. Increasing the aluminum content does not affect the stability of the β-phase in the alloy Ti—6.7 Mo—2.2 Fe. However, the hardness of the aged alloys changes regularly with increasing aluminum content (Fig. 2). The higher the aluminum content, the greater the values attained by the hardness during decomposition of the β-phase and the smaller the change in hardness during the transformation of the ω-phase into the α-phase.

In all the other alloys studied, decomposition of the β-phase proceeded with precipitation of the α-phase. Formation of the ω-phase was not observed. At 300° the β-phase was stable for 100 h in all alloys. In the alloys Ti—12 Mo—10 Fe with 1, 2, and 3% aluminum at 400° the β-phase did not decompose over 144 h. In the alloys Ti—9 Mo—10 Fe and 1, 2, and 3% aluminum the β-phase decomposed after 121, 25, and 16 h, respectively. At 500°, in the alloys Ti—13.5 Mo—6 Fe and 1% aluminum, Ti—9 Mo—10 Fe and 1% aluminum, the β-phase is stable for 1 h, while in the alloys Ti—9 Mo—10 Fe with 2 and 3% aluminum and Ti—7 Mo—9 Fe and 1, 2, and 3% aluminum, for 15 min.

For some alloys the stability of the β-phase during aging after quenching from 800° was studied. The results obtained indicate that decomposition of the β-phase of alloys quenched from 800 and 900° proceeds analogously (Fig. 3).

A study of aging of quenched alloys of the titanium—molybdenum—iron system with different aluminum contents showed that, as the amount of aluminum in the alloy increases, the stability of the β-phase decreases and decomposition proceeds more intensively (Fig. 2).

If the alloys studied are compared with ternary alloys of the Ti—Mo—Fe system previously investigated by N. V. Ageev and Z. M. Rogachevskaya (4), it may be noted that aluminum makes it possible to retain the β-phase in alloys

Figure 2. Effect of Al on aging of titanium alloys. I —Ti—6.7Mo—2.2Fe; II —Ti —7Mo—9Fe. 1 —1% Al, 2 —2% Al, 3 —3% Al.

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Figure 3. Effect of quenching temperature on the stability of the β phase in the Ti—7Mo—9Fe—1Al alloy during subsequent aging. a —quenched from 800°, —from 900°.

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Fig. 1. Stability of the β phase during aging. **I** —Ti—9Mo—10Fe—1Al alloy; **II** —Ti—9Mo—10Fe—2Al; **III** —Ti—9Mo—10Fe—3Al; **IV** —Ti—13.5Mn—6Fe—1Al; **V** —Ti—13.5Mn—6Fe—2Al; **VI** —Ti—13.5Mn—6Fe—3Al. **a** —β phase, —$\beta + \alpha$ phase.

Fig. 2. Effect of Al on aging of titanium alloys. **I** —Ti—6.7Mo—2.2Fe; **II** —Ti —7Mo—9Fe. **1** —1% Al, **2** —2% Al, **3** —3% Al.

Fig. 3. Effect of quenching temperature on the stability of the β phase in the Ti—7Mo—9Fe—1Al alloy during subsequent aging. **a** —quenched from 800°, —from 900°.

at a lower total content of transition metals. As little as 1% aluminum suppresses the formation of the metastable ω-phase during decomposition. Although, as the Al content increases from 1 to 3%, the stability of the β-phase during aging decreases, in alloys with 1% aluminum it is nevertheless more stable than in ternary Ti—Mo—Fe alloys without an aluminum addition. This is due to the fact that aluminum, being generally an α-stabilizer, in an amount up to $\sim$ 1% does not change the temperature of the $\alpha \rightleftarrows \beta$ transformation in titanium.

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REFERENCES

[1] H. D. Kessler, M. Hansen, Trans. ASM, **46**, 790 (1954). [2] A. J. Griest, J. R. Doig, P. D. Frost, Trans. Met. Soc. AIME, **215**, 4, 627 (1959). [3] I. E. Kontorovich, A. T. Semenchukov, Izv. vyssh. uchebn. zavedenii, Metallurgiya, No. 6, 144 (1960). [4] N. V. Ageev, Z. M. Rogachevskaya, ZhNKh, **4**, No. 10, 2323 (1959).

Note: Figure translations are in progress. See original paper for figures.