EFFECT OF CARBON ON THE MECHANICAL PROPERTIES AND STRUCTURE OF TITANIUM ALLOYS

O. P. Solonina and N. M. Ulyakova

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Data concerning the effect of carbon on the mechanical properties of titanium alloys (especially the heat resistance characteristics) are limited. It has been found [1] that carbon increases the strength of titanium considerably in solid solution but increases the strength very little in the form of carbide. The ductility of titanium decreases under the influence of carbon. Carbon, as any other α stabilizing element, raises the temperature of the $\alpha + \beta \rightleftharpoons \beta$ transformation. The presence of more than 0.1% C in titanium alloys induces precipitation of excess carbides that lead to embrittlement [1] due to the low solubility of carbon in α and β phases (0.48 and 0.15% respectively at 920°C).

We investigated the effect of carbon on the mechanical properties and structure of single-phase Ti 6.5Al 3Zr and two-phase Ti 6.5Al 3Zr 2Mo alloys.

Ingots weighing 6 kg alloyed with carbon were remelted in a consumable electrode furnace with use of TG-100 titanium sponge. Carbon was added in the form of titanium carbide, containing 19% C.

The ingots were forged to bars 12 mm in diameter and given two heat treatments: 1) 960°C 4 h + 600° 8 h; 2) 1000° 30 min + 600° 8 h.

The bars were cooled in air after holding at these temperatures.

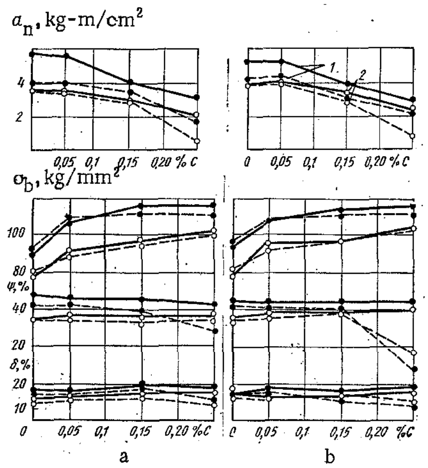

Fig. 1

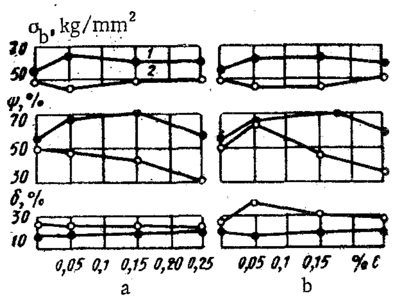

Fig. 2

Fig. 1. Effect of carbon on mechanical properties of Ti 6.5Al 3Zr 2Mo (1) and Ti 6.5Al 3Zr (2) at 20°C. a) 960°C 4 h + 600° 8 h; b) 1000° 30 min + 600° 8 h. ——) Original condition; — — —) after holding at 600° for 100 h.

Fig. 2. Effect of carbon on the mechanical properties at 600°C for alloys of Ti 6.5Al 3Zr 2Mo (1) and Ti 6.5Al 3Zr (2). a) 960°C 4 h + 600° 8 h; b) 1000° 30 min + 600° 8 h.

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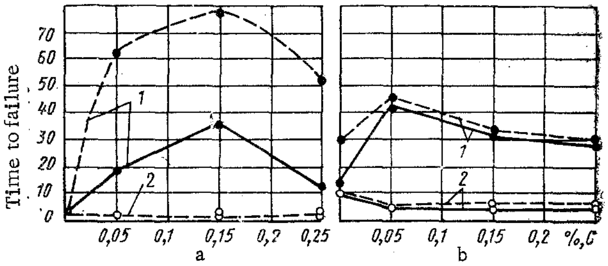

Fig. 3. Effect of carbon on the long-term strength of Ti 6.5Al 3 Zr 2Mo (1) and Ti 6.5Al 3 Zr (2) after heat treatment. a) 500°C, σ = 65 kg/mm^2; b) 600°, σ = 30 kg/mm^2. ——) 1000°C 30 min + 600° 8 h; — — —) 960° 4 h + 600° 8 h.

The temperature of the polymorphous transformation was determined by quenching the samples and examining the microstructure in a light microscope.

We investigated the mechanical properties of the alloys in tension at 20, 500, and 600°C, the long-term strength at 500 and 600°, and the thermal stability after holding the samples at 600° for 100 h and subsequent testing at 20°.

The mechanical properties at 20° in the original condition and after holding for 100 h are shown in Fig. 1.

Alloying with as much as 0.25% C raises the ultimate strength and lowers the impact toughness, with no change of the elongation or reduction in section. The greatest increase in strength (with almost no reduction of impact toughness) occurs as the carbon content is raised to 0.05%, i.e., within the limits of its solubility in α titanium, which agrees with data in the literature. The heat treatment conditions selected have an identical effect on the mechanical properties of the alloys investigated.

After additional holding at 600° for 100 h the strength of the alloys remains almost unchanged. The ductility of alloys with more than 0.15% C decreases, especially for the alloy with 2% Mo and to a greater extent after the second heat treatment. In alloys with less than 0.15% C the additional holding for 100 h lowers the toughness more in the two-phase alloys with Mo than in the single-phase alloys without Mo. For alloys with 0.15-0.25% C the reduction of the toughness is approximately the same for both types.

Short-term tests of the alloys at 600° (Fig. 2) showed that additional alloying with Mo raises the strength by 7-10 kg/mm^2 for the alloy with 0.05% C. Further increase of the carbon content does not lead to any increase in strength. The strength of the alloy without Mo decreases somewhat or remains the same with further increase of the carbon content. The reduction in section is higher for the alloys with Mo than the alloys without Mo, while the elongation is higher for the alloys without Mo.

The results of long-term strength tests are shown in Fig. 3. The long-term strength was calculated from the time to failure. Carbon raises the long-term strength of alloys with Mo. The long-term strength is highest for the alloys with Mo that contain 0.05-0.15% C.

At 500° and a stress of 65 kg/mm^2 the strength after the first heat treatment is highest for the alloy with 0.05-0.15% C (the life of the sample increases from 0 to 60-80 h). At 600° and a stress of 30 kg/mm^2 the long-term strength is somewhat lower than at 500° for the alloys with carbon. The addition of carbon to the α Ti alloy not containing Mo has almost no effect on the long-term strength.

TABLE 1

Alloy	% C	Temperature (°C) at $\alpha + \beta \rightleftharpoons \beta$ transformation
Ti – 6,5Al – 3Zr – 2Mo	—	990
	0,05	1040
	0,15	1070
	0,25	1090
Ti – 6,5Al – 3Zr	—	1000
	0,05	1050
	0,15	1080
	0,25	1110

The addition of 0.05% C to both alloys leads to a smaller grain size of α phase. With additions of as much as 0.25% C the grain size gradually increases. It should be noted that after the first heat treatment the grain size of α phase is larger than after the second, probably due to coalescence of α phase during prolonged holding (4 h) at 960°.

The results of determining the polymorphous transformation temperature (see Table 1) indicate that carbon, being an α stabilizing agent, raises the $\alpha + \beta \rightarrow \beta$ transformation temperature. The addition of 0.05% C raises the transformation temperature by 50°.

CONCLUSIONS

1. The addition of carbon to titanium alloys leads to an increase of the ultimate strength and decrease of the impact toughness at 20°, with no change in the ductility. The largest increase in strength (14-18 kg/mm^2) results from the addition of 0.05% C.

2. After holding for 100 h at 600° the ductility of the alloys with as much as 0.15% C is the same as in the original condition.

3. The addition of 0.05% C raises the ultimate strength of Ti 6.5Al 3Zr 2Mo by 7-10 kg/mm^2 at 600°. The strength of the alloy without Mo decreases or remains the same when carbon is added.

4. The addition of 0.05-0.15% C to Ti 6.5Al 3Zr 2Mo leads to an increase of the long-term strength at 500 and 600°. The long-term strength of the alloy without Mo remains unchanged when carbon is added.

5. The addition of 0.05% C also reduces the grain size of α phase and raises the $\alpha + \beta \rightarrow \beta$ transformation temperature.

LITERATURE CITED

1. L. S. Moroz et al., Titanium and Its Alloys [in Russian], Sudpromgiz, Leningrad (1960).