CONCLUSIONS

1. The mechanical properties of alloy VT9 after deformation under conditions of superplasticity are not inferior to the properties of alloys after HTMT. The ultimate tensile strength, fatigue limit, and fracture toughness are higher than after the standard treatment.

2. Deformation of alloy VT9 under conditions of superplasticity makes it possible to shorten the process, excluding the holding time during heating before deformation and annealing. Deviations from the optimal conditions of superplasticity with use of the shortened heat treatment lead to an increase of the strength, but the ductility decreases and the thermal stability of the alloy is also impaired.

3. Superplastic deformation practically eliminates the structural and chemical heterogeneity of the alloy and increases the evenness of the mechanical properties through the section of the piece.

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MICROALLOYING OF TITANIUM ALLOYS

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Metals and alloys are modified by seeding with refractory materials, which increases the number of crystallization nuclei, or with surface-active elements, which are adsorbed on the faces of crystals and prevent their growth [1].

Rhenium has a higher melting point (3180°C) than titanium, and therefore can be used for refractory seeding to increase the number of crystallization nuclei. The analogs of titanium -- zirconium and hafnium -- have a higher affinity for oxygen than titanium. It is assumed that they play the role of surface-active elements, while their refractory oxides are crystallization centers. The affinity for oxygen and the negative value of the isobaric potential of oxide formation (∆H) are 219 kcal/mole for TiO₂, 259 kcal/mole for ZrO₂, and 272 kcal/mole for HfO₂ [2, 3]. Rare-earth metals (REM), which are very promising for microalloying of titanium alloys, form very high-melting compounds with oxygen (tₘ ~ 2800°C). The REM have a high negative value of the isobaric potential of oxide formation (420 kcal/mole for Y₂O₃, 428 kcal/mole for GdO₃, 462 kcal/mole for Dy₂O₃), and therefore these oxides have high stability [4].

The addition of as much as 0.02% Re and 0.1% Zr to α + β alloys VT14 and VT16 increases the ductility of weldments by 50-100% [5].

This work concerns the effect of microalloying of α + β and β titanium alloys with elements of groups III (Y, Gd, Dy), IV (Zr, Hf), and VII (Re).

These and other alloying elements were added as shavings to the electrode, which was subjected to double remelting in an argon arc furnace. The ingots obtained were forged to bars and then rolled to sheets.

The addition of as much as 1% Zr to alloy VT15 increases the ductility in the heat-treated condition by 50-100%, with retention of the same strength.

This effect becomes more evident as the oxygen content of the alloy increases. Zirconium is evidently a deoxidizer in this case. The positive effect of 1% Zr on β alloys VT1 and TS6 has also been noted, which makes it possible to consider the possibility of adding zirconium to all β alloys [6].

A substantial improvement in the mechanical properties of alloy VT15 was observed with the addition of 0.2% Hf to the base metal and 0.2-1% Hf to the seam metal, which had a coarse structure (Fig. 1). Due to the high cost of hafnium, it is expedient to add ~ 0.02-0.1% Hf to the base metal and ~ 0.5-1.5% Hf to the welding wire.

The effect of 0.02, 0.1, 0.5, and 1.5% Gd, Y, and Dy (each) on the mechanical properties of α + β alloy VT23 and β alloy VT15 was investigated.*

The addition of 0.02-0.1% REM has almost no effect on the mechanical properties of annealed alloy VT23 with a fine-grained structure (σ_b = 110-115 kgf/mm^2, δ = 15-16%, ψ = 55-60%); at higher concentrations of REM the ductility decreases somewhat: δ = 13-14% (Fig. 2a-d).

The addition of REM improves the coarse structure of alloy VT23 overheated at 1000° for 1 h — the grain size of the alloy with 0.02% REM is two to three times smaller and the intragranular platelets are considerably shorter and thinner. The thinner boundaries of the primary grains in the alloy with REM point to a lower concentration of impurities in the boundary.

The low sensitivity to overheating of alloy VT23 should be emphasized. After heating at 1000° for 1 h and subsequent annealing the mechanical properties are high: σ_b = 105-108 kgf/mm^2, δ = 12%, ψ = 35%. The

Fig. 1. Effect of hafnium on the mechanical properties of alloy VT15 in the heat-treated condition. a) Base metal; b) weld seam. ——— Overheated at 1000° for 1 h; ———— not overheated.

Fig. 2. Effect of 0.2% REM on the mechanical properties of alloy VT23 (a-d) and VT15 (e-h). a, b) Annealing at 750°; c, d) quenching from 800° and aging at 550° for 10 h; e, f) annealing at 800°; g, h) quenching from 680° and aging at 480° for 25 h + 560° for 15 min; a, c, e, g) without preliminary overheating; b, d, f, h) preliminary overheating at 1000° for 1 h. Crosshatched columns: Alloys without REM; light columns: alloys with REM.

* L. G. Mukhina and I. P. Zheligina took part in this work.