Effect of local chemical composition of grain boundaries on corrosive resistance and mechanical properties of ultrafine-grained titanium alloys

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Industrial alloy PT3V composed of Ti-4.73wt.%Al-1.88wt.%V formed the target of this research. The ultrafine-grained (UFG) structure in the alloy was obtained through equal channel angular pressing (ECAP) at the temperature of 723-743 K.

In its initial state (before ECAP) the alloy structure is characterized by heterogeneous distribution of grains by size from 10-20 μm to 100 μm. The analysis of diffraction patterns obtained from some grains of a coarse-grained alloy shows that these are α-Ti grains. The energy-dispersive analysis reveals two types of grain boundaries (GB) in the structure of coarse-grained alloys. First, there are 'clean' GB that form an absolute majority in the alloy structure. The aluminum concentration in such GB is 3.8±0.9 wt.%, whereas the average vanadium concentration is 1.9±0.2 wt.%. The aluminum concentration in surrounding GB is 3.6±0.9 wt.%, whereas the vanadium concentration is ~1.4±0.2 wt.%. Second, these are grain boundaries the vanadium concentration in which may reach 10 wt.%. The average aluminum concentration in the titanium lattice close to such GB is ~4 wt.%, whereas the vanadium concentration is ~1.6 wt.%. Such grain boundaries are limited in number.

The average grain size in alloy after N=4 ECAP cycles is 0.2-0.5 μm. Grains are mainly elongated in shape, but there are a lot of equiaxed grains as well. Grain boundaries are clean with no excess vanadium segregations similar to those observed in a coarse-grained alloy. The results of the energy-dispersive analysis show that the spread in aluminum and vanadium concentrations between separate grain boundaries is insignificant.

With the increase in the number of ECAP cycles to N=4 there is an increase in the macroelasticity strength, yield strength and hardness from 420 to 750 MPa, from 620 to 1020-1050 MPa and from 1.9-2.0 to 3.5-3.6 GPa, respectively. Along with high strength, the UFG alloy at room temperature is characterized by high ductility δ_{max}=47.5-50%. Ductility grows from 225 to 475% in the UFG alloy with the deformation temperature growing 873 to 1073 K. In coarse-grained alloys, a similar rise in the deformation temperature leads to ductility growing from 85 to 220%. Fractures in coarse-grained and UFG samples are ductile in nature.

Hot salt corrosion tests performed on alloy in the original state show that the corrosion-affected layer after 500 h of tests at T=523 K is L_{cor}=500-600 μm deep. Corrosion is intercrystallite. Similar tests on the UFG alloy show that the nature of corrosion processes does not change with corrosion propagating primarily along grain boundaries. However, the depth of the corroded layer in the UFG alloy does not exceed L_{cor}~100-150 μm. Thus, the results of the tests prove a significant increase in corrosion resistance of UFG alloys as compared to coarse-grained materials.

It was shown that a simultaneous increase observed in corrosion resistance, strength and ductility may be related to diffusion-controlled atomic rearrangement of alloying elements (aluminum, vanadium) along the GB of a alloy during ECAP. Along with the formation of new GB during ECAP at elevated temperatures, there is a diffusion redistribution of atoms of alloying elements from 'old' GB to 'new' ones. Vanadium with high concentration along the original GB of a coarse-grained alloy balances the concentration and diffuses along the boundaries to 'clean' grain boundaries formed during ECAP. At the same time the local concentration of vanadium atoms along the GB decreases due to a significant increase in the overall area of grain boundaries.

It shall be noted that a decrease in the concentration of alloying elements along the GB of the UFG alloy contributes to 'easier' movement of lattice dislocataions through GB and reduces the defect accumulation rate along the grain boundaries. Consequently, the intensity of junction disclinations leading to microcracks along the GB is drawn down. This increases the ductility of the UFG alloy.

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