HYDROGEN EMBRITTLEMENT OF TITANIUM ALLOYS WITH DIFFERENT STRUCTURE

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Several investigations have shown that hydrogen embrittlement of technically pure titanium and α-titanium alloys is due to the precipitation of the hydride phase [1, 2].

No hydride phase precipitates in alloys with a two-phase α + β structure, metastable β'-structure, or the stable β-structure.

The lack of investigation of the effect of hydrogen on phase transformation in titanium alloys with the α + β, β', and β structures makes it impossible to explain the mechanism of their embrittlement. The present investigation is a generalization of the results of experimental studies of Ti-O-N, Ti-Al-H, Ti-Cr-H, and Ti-Mo-H alloys.

Alloys with the α, α + β, β, and β' structures were saturated with hydrogen, using the universal apparatus described in [2]. Oxygen in the form of titanium dioxide was introduced into the alloys during smelting. In an experimental investigation of the effect of hydrogen on the Ti-O alloy [3], metallographic analysis confirmed that the solubility of hydrogen in titanium decreases with increasing concentrations of oxygen in the alloy. The amount of the hydride phase increases with increasing concentration of oxygen in titanium (Fig. 1). The microhardness of the hydride phase changed from 450 to 565 kg/mm² when the concentration of oxygen was varied from 0.1 to 1.2%.

A metallographic study of Ti-Al alloys and of the stable β-structure showed that the solubility of hydrogen in titanium increases with increasing amounts of aluminum in the alloy (Fig. 2). It should be noted that the solubility of hydrogen in the alloy containing 5% Al does not exceed 0.5%, according to our results.

The solubility of hydrogen in this alloy was found to be 0.018% in [4] and 0.031% in [5]. This difference in the solubility of hydrogen in the alloy containing 5% Al is explained by the difference in the degrees of purity of the initial titanium.

It can be assumed to be established fact that hydrogen embrittlement of two-phase titanium alloys is manifest in the decrease of ductility under the effect of low deformation rates and premature brittle fracture in tests of resistance to prolonged exposure to high temperatures. The study of the effect of hydrogen on the resistance to creep of binary and multicomponent alloys showed that hydrogen increases the creep rate in all alloys. Oxygen increases the resistance to creep. However, the increase in oxygen concentration leads to a sharp decrease of thermal stability and to brittle fracture. Simultaneous increase in the concentrations of hydrogen and oxygen in alloys have a particularly great effect on embrittlement as the result of the decrease of the solubility of these gases in titanium.

It should also be noted that we show here for the first time that two-phase titanium alloys become particularly susceptible to tearing under the effect of hydrogen.

A study of the effect of hydrogen on the structure of Ti-Cr and Ti-Mo alloys [6] showed that the solubility of hydrogen in titanium increases with increasing concentrations of chromium. In an alloy containing 5% Cr the solubility is 0.025%, while in an alloy containing 7% Cr it is 0.050%. It was shown that hydrogen accelerates the eutectoid decomposition of the β'-phase in the Ti-Cr alloy with simultaneous precipitation of the chemical compound TiCr₂. The amount of TiCr₂ depends on the concentration of hydrogen in the alloy (Fig. 3).

The β-solid solution becomes increasingly stable with increasing amounts of chromium and hydrogen in the alloy. However, the β-solid solution is metastable and decomposes at high temperatures with precipitation of TiCr₂.
Fig. 1. Microstructures of titanium alloys containing 0.5% hydrogen and different amounts of oxygen. 
\[ \times 800. \] a) 0.4% oxygen; b) 1.2% oxygen.

Fig. 2. Microstructure of titanium alloys containing 0.5% hydrogen and different concentrations of aluminum. 
\[ \times 800. \] a) 3% Al; b) 8% Al.

Fig. 3. Microstructure of titanium alloys containing 15% Cr and different concentrations of hydrogen. 
\[ \times 800. \] a) 0.0005% hydrogen; b) 0.05% hydrogen; c) 0.5% hydrogen.