STRUCTURE-SENSITIVE MODEL FOR THE EVALUATION OF FRACTURE TOUGHNESS CHARACTERISTICS FOR TITANIUM ALLOYS

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Fracture toughness of a plastic titanium alloy containing from 0.05 to 0.35% of oxygen and nitrogen has been studied using the J-integral-based approaches. Optimal content of nitrogen and oxygen have been defined which ensure a sufficient level of fracture toughness and strength. The relationships have been proposed for the calculation of the micro-cleavage resistance stresses by the structure geometrical parameters in the case of plate-shaped α-phase. This allowed the alloy fracture toughness to be estimated accurately enough by the empirical relationships in the whole range of additive content variation.

INTRODUCTION

Classical fracture mechanics studies the influence of crack-type macroscopic defects on the brittle fracture process based on the principle of continuum giving no consideration to the factors of the material inner structure.

Meanwhile the investigations in the field of physics of strength and physical metallurgy, which have been progressing rapidly during the last years, testify to an appreciable influence on the processes of the material deformation and fracture at the crack tip of a number of factors, such as the type of lattice, the presence of defects in it, the grain size in a polycrystalline metal, the presence of dispersed particles of the second phase, etc. Ignoring those results does not allow to analyze the factors associated with the material inner structure and determining to a great extent the resistance to brittle fracture, thus making it impossible to solve the problem of predicting the ways of enhancing the materials fracture toughness.

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The paper gives the analysis of the results of the investigation into the influence of the structural factors on the fracture toughness of plastic titanium alloys containing different amount of impurities inducing embrittlement.

EXPERIMENTAL PROCEDURE AND MATERIALS

The investigations were carried out on a titanium alloy of the Ti-2Al-1.5V type in which the content of the nitrogen and oxygen varied within 0.05...0.35%. The verification of the established regularities was performed using the Ti-6Al-4V type titanium alloy. For those materials which are used in aircraft and ship building industries the enhancing of their brittle fracture resistance is an urgent problem.

Compact tensile specimens of 25 mm thickness were tested in tension. All precracks were fatigue ones and were grown in accordance with the existing standards. The fracture toughness characteristics were determined using load and energy approaches. J-integral was used as an energy criterion and the values obtained were recalculated into fracture toughness K_{IC}.

In order to establish quantitative dependencies between the fracture toughness characteristics and geometrical parameters of the titanium alloys microstructure, metallographic analysis was carried out with subsequent statistical processing of its results. The analysis also involved measurements of individual α-plates and α-colonies.

To evaluate the degree of phase dispersion the magnitude of the relative specific α-phase surface S_α was calculated, the latter being the most universal measure of the structure dispersion. The following relationship was used for the calculation:

$$S_\alpha = \frac{\Sigma S_\alpha}{\Sigma V_\alpha} \qquad (1)$$

where ΣS_α - total α-phase particles surface in unit volume, ΣV_α - total α-phase microparticles volume in unit volume.

Fractographic analysis was made on the specimens fracture surfaces in order to define the mode of fracture.

RESULTS AND DISCUSSION

The results of the fracture toughness investigation for the titanium alloy considered and their dependence on the nitrogen and oxygen content are shown in Fig.1. The analysis of the data presented reveals that fracture toughness of the Ti-2Al-1.5V alloy changes unambiguously with an increase in the content of the nitrogen and oxygen. A change of the content of the additives within 0.05% induces no noticeable changes in the K_{Ic}, but when the concentration of the nitrogen reaches 0.09% and that of oxygen 0.18% and continues to grow this leads to a rapid decrease in the alloy fracture toughness.

In order to predict the K_{Ic} values the empirical relationship obtained by Hahn G.T. and colleagues was used:

$$\sigma_c/\sigma_y = \alpha\,(K_{IC}/\sigma_y)^{\beta} \qquad (2)$$

where σ_y - yield point, σ_c - cleavage fracture stress.

There is no possibility to obtain experimental data on the cleavage fracture stresses σ_c for the given material over the whole range of additives content variation.

After corresponding manipulations the Hahn dependence can be presented in the following way:

$$K_{IC} = \frac{1}{\sigma_y^2}\left(\frac{R_{mc}}{7.43}\right)^3 \quad \left[\mathrm{MPa}\,\sqrt{\mathrm{m}}\right] \qquad (3)$$

where R_{mc} - resistance to microcleavage fracture at the yield point.

Since microcleavage is a process of an ideally brittle growth of a submicrocrack in small areas of a crystal with a perfect lattice, the R_{mc} value can be estimated using the existing theoretical dependencies involving the data of microstructural investigations. Thus the R_{mc} calculation was performed using data on the magnitude of such structural parameter as the α-plate thickness presented in Fig.2. The analysis of the data reveals that the maximum R_{mc} value corresponds to the minimum α-plate thickness $b\alpha$.

The obtained R_{mc} values were further used for the estimation of K_{Ic} by eq.(3). The analysis of the data in Fig.1 shows that the experimental and calculated K_{Ic} values agree within 15...20%.

CONCLUSION

The application of the structural fracture mechanics approaches to evaluate the K_{Ic} of titanium alloys allows one to predict the fracture toughness of those alloys with an error within 20...30% without fracture tests.

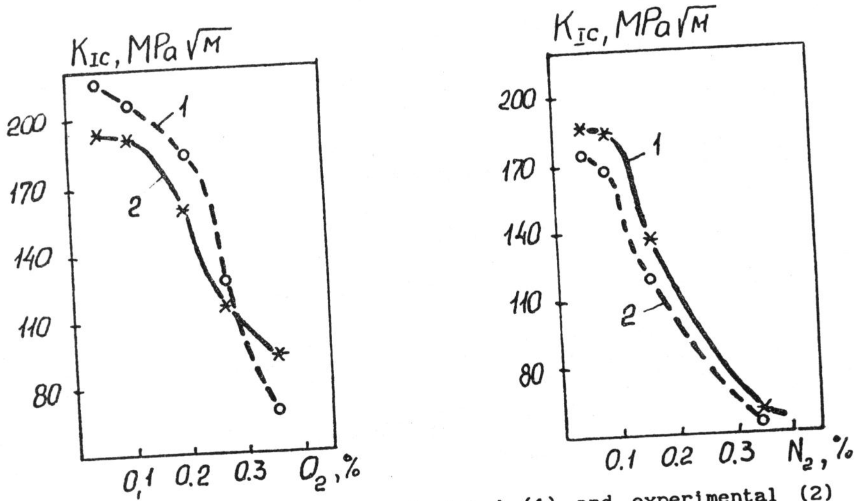

Figure 1 Comparison of the calculated (1) and experimental (2) dependencies: $K_{Ic}=f(O_2)$ and $K_{Ic}=f(N_2)$.

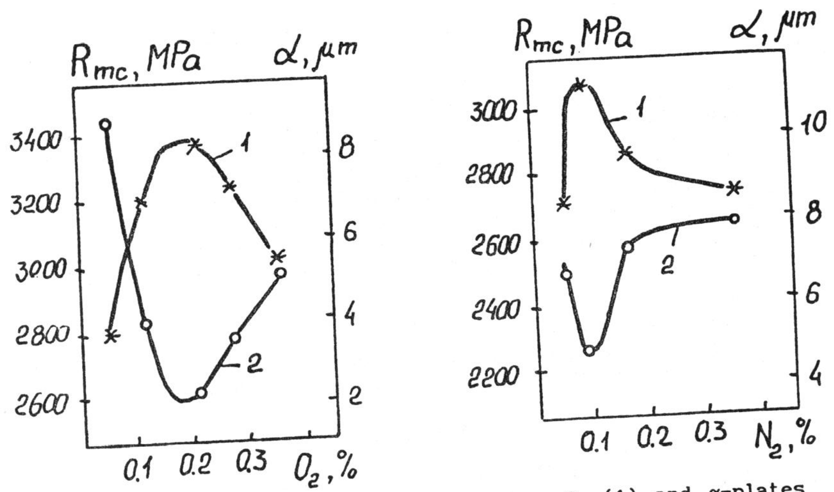

Figure 2 Dependence of microcleavage stress R_{mc}(1) and α-plates thickness b_α(2) on the oxygen (a) and nitrogen (b) content.