Fracture toughness criteria of small-sized samples with ultrafine grain structure

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Mesomecanics of fracture toughness for the small-sized samples with nano- and ultrafine grain is considered. The small-sized samples with chevron notch for commercial titanium VT1-0 and VT6-alloy with ultrafine grain (UFG) structure obtained by severe plastic deformation have been investigated experimentally. The average grain size made 200 nm. In square samples of 18 mm in length with a square side of 6 mm, a crack of 0,21 mm in thickness was applied in the form of a chevron notch. According to the specifically developed technique, the following characteristics of fracture process were determined, which are necessary to calculate fracture toughness of the test material: Young's modulus E, dynamics of crack opening μ, change in crack length Δl under loading.

A qualitative type of the «load-displacement» diagrams for the materials with UFG structure essentially differs from those of the same materials with coarse-grained (CG) structure. A specific feature of alloys with UFG structure is the three-stage character of loading diagrams after a stage of elastic loading.

The moment of crack nucleation at the end of a chevron notch is clearly fixed in the form of the stretched relaxation «tooth». When achieving the certain length Δl_1, a drop in external loading stops and the second stage starts where the crack propagation occurs practically under constant external loading. At the third stage of catastrophic fracture of the sample, the external loading drops to zero. A complex of experimental and calculation data allows one to determine a specific energy of free surface formation of the crack G and stress intensity factor K_{Ic} (SIF) as fracture toughness criteria. These fracture toughness characteristics for the studied materials are presented in the table.

Table. *Effect of UFG structure on mechanical characteristics of VT1-0 and VT6*

Mechanical characteristics	BT1-0		BT6	
	CG	UFG	CG	UFG
Yield strength $\sigma_{0.2}$, MPa	270-350	700-960	850-900	1044-1450
Ultimate strength $\sigma_в$, MPa	460	1100	970-1100	1250
K_{Ic}, Pa·m$^{1/2}$	98-150	62.8	84-110	56.2
G, kJ ·m^{-2}	240	35.55	200	28.44

As seen from the table, the formation of UFG structure causing increase in yield strength and ultimate strength of the material is accompanied by drop in its fracture toughness. It is quite logical. According to mesomechanics, crack nucleation and opening is the rotational deformation mode at the macroscale level. In compliance with of angular momentum conservation law, thus, the rotational deformation modes of the reverse sign should be developed at a mesolevel. The formation of such rotational modes (in the form of mesovortices) correlates with specific energy G of free surface formation of the crack. When forming the UFG structure, the value of G is considerably decreased. It is due to the strong thermodynamic nonequilibrium of UFG material, decrease of couple stresses at formation of accommodative mesovortices, high level of deforming stresses. Experimental data are presented in the paper to confirm the developed concept of fracture mesomechanics.