EFFECT OF IRON AND SILICON IMPURITIES ON K_{Ic} OF ALUMINUM ALLOY D16

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It is known that the service life and reliability of structures depends mainly on the resistance of the material to crack propagation, particularly the fracture toughness K_{Ic} or K_c [1, 2].

Along with the development of alloys, production techniques, heat treatment, and thermoplastic hardening conditions it is necessary to increase the fracture toughness.

It is known that iron and silicon impurities form relatively brittle and insoluble phases in alloy D16. Reducing the quantity of these brittle phases or completely eliminating them may lead to an increase of the fracture toughness without substantial loss of strength properties [3].

We investigated the effect of the iron and silicon concentrations on the fracture toughness of extruded strips 65 × 200 mm in section of aluminum alloy D16. Strips with the normal concentrations of iron and silicon (~0.5%) and low concentrations (~0.1%) were tested in the naturally (D16T) and artificially (D16T1) aged conditions. The fracture toughness (K_{Ic}) was tested on samples for off-centered tensile tests (OCT) with a thickness of 65 mm. The fracture toughness tests were conducted by British standards; all the requirements for determining K_{Ic} of aluminum alloys were fulfilled [2].

The mechanical properties of the alloys are given in Table 1. For comparison, properties are also given for extruded strips of alloys AK4-1T1, V95T1, and a new American alloy X2048 intended for supersonic aircraft. It can be seen that the strength (σ_b and $\sigma_{0.2}$) and ductility (δ) are higher for alloy D16T of high purity than for the commercial alloy after natural (D16T) and artificial (D16T1) aging.

It is known that approximately the same concentration of iron and silicon (hundredths of one percent) in alloy D16 lead to formation of phases $(Al-Fe-Si)_\alpha$ and $(Al-Fe-Si-Mn)_\alpha$, which like other iron intermetallic compounds are almost insoluble in solid aluminum and lead to a reduction of ductility and especially the fracture toughness [5]. With a low concentration of iron and silicon the quantity of iron intermetallic compounds is negligible, in which case most of the manganese is in the form of dispersed particles of phase T ($Al_{12}Mn_2Cu$) and not in the form of $(Al-Fe-Si-Mn)_\alpha$ or $Al_6(Mn, Fe)$, which lower the ductility. Inclusions of manganese phase T have a positive effect on the properties of alloy D16, the strength even increasing somewhat [5, 6].

The fracture toughness of alloys D16T and D16T1 with high purity in terms of iron and silicon is considerably higher than that of the standard commercial alloy.

The fracture toughness of a material determines the maximum (critical) size of cracks that the material can withstand without fracture at stresses below the yield strength. When the applied stress is equal to the yield strength of the material, the size of the critical defect (a_{cr}) is proportional to $(K_{Ic}/\sigma_{0.2})^2$.

It is possible to compare alloys by the size of the critical defect a_{cr} at any stress. Let us assume that all materials investigated have a surface crack of depth (a) that is one-fifth the length at the surface. With tensile stress the critical size (critical depth) is determined by the formula [7]:

$$a_{cr} = K_{Ic}^2 \frac{Q}{1.21\,\pi\sigma^2},$$

where Q is a parameter depending on the geometry of the crack and the ratio of $\sigma/\sigma_{0.2}$; σ is the working stress.

Figure 1 shows the effect of the purity of the alloy in terms of iron and silicon on the variation of the breaking stress with the size of the semielliptical surface crack in alloy D16. The results for alloys V95T1, AK4-1T1, and X2048T851 are also shown.

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TABLE 1

Purity	Alloy	σ_b	$\sigma_{0,2}$	δ, %	K_{Ic}, kgf/mm$^{3/2}$	$K_{Ic}/\sigma_{0.2}$, mm
		kgf/mm^2				
Standard	D16T	52,1	34,6	13,7	120	12
	D16T1	50,1	35,1	9,1	100	8,1
High	D16T	54,7	36,6	14,5	148	16,3
	D16T1	51,9	43,1	9,9	140	10,5
Low Cu*	X2048T851	43,5	39,2	—	115	8,6
Standard	V95T1	58,6	51,5	8,4	95	3,4
The same	AK4-1T1	45,1	40,3	7,9	76	3,5

*Data from [4].

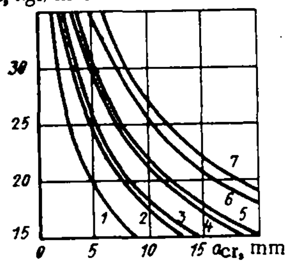

Fig. 1. Variation of breaking stress with size of the critical defect. 1) AK4-1; 2) V95; 3) D16T1; 4) X2048; 5) D16T; 6) D16T1, high-purity; 7) D16T, high-purity.

Analysis of the curves indicates that reducing the iron and silicon content of alloy D16 substantially increases the permissible size of cracks, while reduction of the copper content (alloy X2048) leads to an increase of fracture toughness in the artificially aged condition.

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