THE EFFECT OF RECRYSTALLIZATION ON ALUMINIUM ALLOYS CRACK RESISTANCE

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ABSTRACT

In the work presented, specimen thickness and structure dependence of fracture toughness of high strength 2024 and 7075-type aluminium alloys has been studied. Thin semiproducts with non-recrystallized structure and thickness of < 10 mm have usually an advantage, but in the case of thicker semiproducts (> 10 mm) materials with recrystallized structure have superiority over thin semiproducts. The results of the studies on specimen thickness and structure dependence of crack resistance allow one to design laminated composites. In comparison with the corresponding monolithic materials, fracture toughness of these composites can be improved by 32-35%.

KEYWORDS

Fracture toughness, recrystallized structure, non-recrystallized structure, laminated composites.

Semiproducts with non-recrystallized structure show improved strength and slightly lower, but sufficiently high, ductility as compared to products with recrystallized structure (Dobatkin, 1962, 1965; Dobatkin et al., 1965; Miklyaev and Freedman, 1969, 1986; Miklyaev and Volozneva, 1973). Detailed investigations carried out by V. I. Dobatkin (1962, 1965, Dobatkin et al., 1965) allowed us to determine the higher strength of semiproducts with non-recrystallized structure (polygonized structure). This strengthening named "structural strengthening" (Dobatkin, 1965) has a great potentiality for improvement in semiproduct strength, but for the present its usage in practice is absolutely insufficient. It is related, firstly, to the fact that up to now anisotropy of properties was evaluated as a negative phenomenon which was to be suppressed, and recrystallization considered as one of the effective means for improvement in isotrophy of wrought semiproducts and, secondly, to the absence of classified information about the effect of recrystallization on crack resistance.

This work is focused on determination of the effect of the recrystallization degree of 2024 and 7075-type aluminium alloy semiproducts on their crack resistance.

The results of testing of specimens from 2024 alloy extruded shapes with 2.3 mm wall thickness show that at plane stress conditions semiproducts with non-recrystallized structure have higher fracture toughness K_c at higher strength properties (0.2 YS, UTS) and at lower values of ductility (see Table 1).

During investigation of semiproducts with some other thicknesses and various structures contradictory results were obtained (Table 1). So, 5 mm thick specimens of strip with non-recrystallized structure have slightly lower fracture toughness than those with recrystallized structure. 8 mm thick specimens of extruded strip with non-recrystallized structure show sufficiently higher K_c value in comparison with those of plate with recrystallized structure, but as for 2 mm thick specimens relation of fracture toughness values is reverse.

Hence, in evaluating δ the effect of the structure on fracture strength at plane and combined stress conditions the thickness of specimen or semiproduct should be taken into account.

In view of complex δ dependence of K_c, comparison of fracture strength of different structure materials was carried out according to the results obtained during tests of 2024T3 specimens with various thickness extruded at various temperatures with the above dependence being plotted. The results of testings (see Table 2 and Fig. 1) show that fracture toughness of non-recrystallized strips is higher than that of recrystallized ones at thickness up to ~10 mm. Fractographic analysis of specimens after K_c testing gives evidence that both transgranular plastic fracture and intergranular, less plastic, fracture take place (Fig. 2). Table 2 shows average values of transgranular fracture F determined by 10 fractographs for each specimen. It is clear that F value for specimens of both thicknesses is higher in case of non-recrystallized structure. The thicker the specimens, the more share of transgranular fracture. The larger share of transgranular fraction in specimen from the strips with non-recrystallized structure can be explained by the fact that energy necessary for propagation of the crack on the very developed surface of non-recrystallized grains becomes higher than energy necessary for propagation of the crack through the grain boundaries.

Different specimen thickness dependence of F for various structures results in non-equidistance of the left portions of the 1st and 2nd curves (Fig. 1). An increase in share of transgranular fracture in thicker specimens leads to an increase of K_c (max) value for both structures and to their shift in direction of thicker thicknesses in comparison with

Table 1. Mechanical Properties of 2024 and 2124 Alloy Semiproducts with Recrystallized and Non-recrystallized Structure

Alloy	Semiproduct	Structure[1)]	Direction	Mechanical Properties						
				UTS MPa	0.2 % YS MPa	El %	RA %	KCU kJ/m^2	KCT kJ/m^2	K_c MPa$\sqrt{m}$
2024T3	Shape with 2.3 mm wall thickness (0.69 Mn)	R	L	440	350	21.3	-	-	-	55.1 [2)]
		N/R	L	490	402	12.7	-	-	-	71.2 [2)]
2024T3	5x100 mm strip (0.71 Mn)	R	L	455	355	20.4	28.0	218	127	80.5 [2)]
			T	473	350	10.0	14.7	177	108	-
		N/R	L	518	385	14.5	20.2	218	147	77.5 [2)]
			T	509	346	16.5	18.3	196	127	-
	5x100 mm strip (0.49 Mn)	R	L	445	346	15.7	28.3	206	118	66.3 [2)]
			T	465	340	11.6	14.3	157	88	-
2124T3	Rolled plate (40 mm)	R	L	430	313	19.4	24.3	235	-	70.3/75.0 [3)]
			T	430	302	13.0	13.5	167	-	-
	50x150 mm extruded strip	N/R	L	526	394	12.3	19.2	186	-	95.0/71.2 [3)]
			T	452	325	10.7	21.9	88	-	-

1) R - recrystallized; N/R - non-recrystallized. 2) 100 mm wide specimens with the thickness equal to that of semiproducts and 30 mm long central crack are used. 3) 150 mm wide longitudinal specimens with 8 mm (numerator) and 2 mm thickness (denominator).

Table 2. Structure Dependence of Mechanical Properties and Data of Fractographic Analysis of Specimens of 20x100 mm² 2124T3 Alloy Strip on Structure

Structure	Direction	Tension test properties: UTS MPa	0.2% YS MPa	El %	RA %	Fracture toughness K_c, MPa$\sqrt{m}$ at specimen thickness, mm: 2	6	Share of intercrystalline failure F, % at specimen thickness, mm: 2	6
non-recrystallized	longitudinal	539	417	15.5	20.5	90	99	50	85
	transverse	480	348	14.0	18.0	-	-	-	-
recrystallized	longitudinal	422	284	19.5	24.0	81	91	18	50
	transverse	387	270	18.0	21.5	-	-	-	-

the case of isotropic structure (certain directivity of structure elements preserves also after recrystallization).

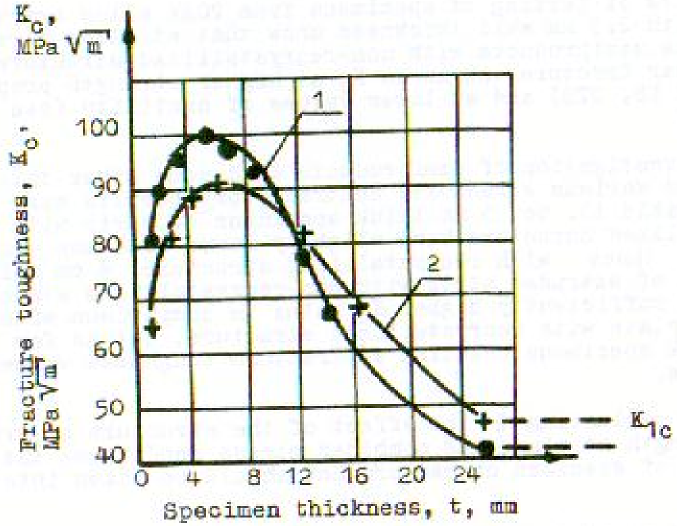
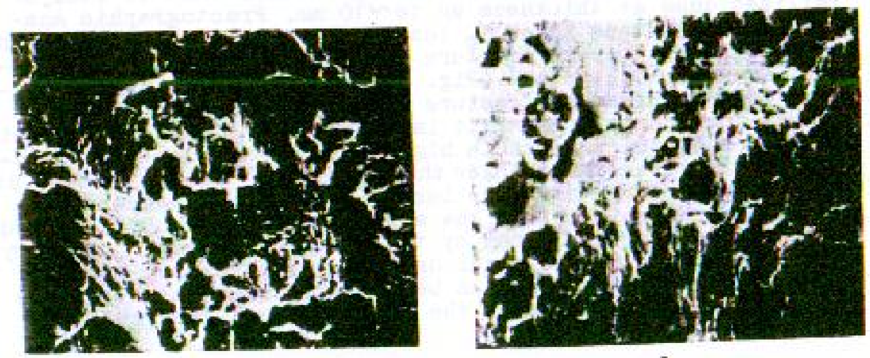


Fig. 1. Specimen thickness dependence of fracture toughness (K_c) of 2124T3 alloy strips with non-recrystallized (1) and recrystallized (2) structure.



1 2

Fig. 2. Electron fractographs of fracture zone of 2124T3 extruded strip specimens at plane stress conditions (after K_c tests): 1 - non-recrystallized structure; 2 - recrystallized structure. x 500

At thicknesses $t_o<t<t_{1c}$ fracture takes place under conditions of combined stressed state. With an increase of t, fracture zone growths in the centre of the cross-section of the specimen during plain strain and, as $K_{1c}<K_c$, energy of fracture reduces. However, rate of reduction in fracture toughness in case of non-recrystallized structure becomes higher due to the lower K_{1c} value. At t>12 mm K_c value of specimens with non-recrystallized structure becomes lower than K_c of specimens with recrystallized structure. When $t=t_{1c}$ fracture occurs completely under conditions of plain strain. At testing of thicker specimens, difference in K_{1c} values between specimens with different structure does not change, but recrystallized structure has an advantage. This advantage, apparently, should diminish with improvement of alloy purity as to impurities due to improvement of alloy ductility. However, this assumption requires additional experimental check.

The effect of structure on specimen thickness dependence of K_c was noted earlier during study of Al-Zn-Mg alloy sheets (Thompson and Zinkhman, 1975). The authors of the present paper studied specimen thickness and structure dependence of fracture toughness in 7075-type alloy sheets. Fig. 3 (1st curve) shows that K_c values for sheets with non-recrystallized structure are substantially higher than those of 7175T73 sheets with recrystallized structure, i. e. at 5 mm thickness, K_c of these samples is 161 MPa$\sqrt{m}$ and 103 MPa$\sqrt{m}$, and yield strength is 473 MPa and 468 MPa, respectively.

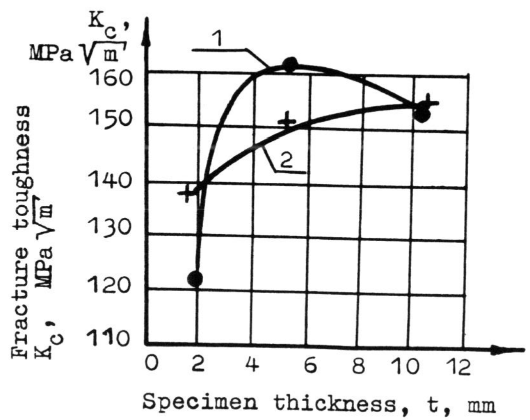


Fig. 3. K_c of 7475T73-type Zr-bearing alloy sheets as a function of specimen thickness and structure: 1 - non-recrystallized; 2 - recrystallized.

The results of the studies on specimen thickness and structure dependence of crack resistance allow one to design laminated composites. In comparison with the corresponding monolithic materials, fracture toughness of these composites can be improved by 32-55 % (Table 3) at practically equal strength properties (UTS, YS, El).

Table 3. Mechanical Properties of 5 mm Thick Sheets from 7075-type Alloys and from 7475T6+1145+7475T6 Composite

Material	UTS MPa	0.2 % YS MPa	El %	K_c MPa$\sqrt{m}$
7075T6	542	492	11.8	87
7175T6	560	497	9.1	88
7475T6*	543	466	11.9	102
7475T6+1145+7475T6	536	505	15.4	135

* Neshpor et al., 1982.

CONCLUSIONS

1. The development of non-recrystallized structure is an important source for improvement in strength and crack resistance of aluminium alloy semiproducts.

2. In designing critical structures, specimen thickness and structure dependence of material crack resistance should be taken into account.

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