THE THRESHOLD OF STRESS INTENSITY RANGE IN ALUMINIUM ALLOYS

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The threshold of stress intensity range and the threshold of effective stress intensity range was investigated in a recrystallized and cold rolled aluminium (pure), a 6061, 7020 and 7075 aluminium alloy. A special technique to determine $\Delta K_{eff\ th}$ very accurately was applied. The measured $\Delta K_{eff\ th}$ value was about 0.8 MPa√m in all alloys. Neither the difference in the yield strength - it varies between 30 and 630 MPa - nor variations in the chemical composition does influence $\Delta K_{eff\ th}$, only the contribution of crack closure is changed.

INTRODUCTION

A comparison of the threshold value of aluminium alloys in the literature permits two different interpretations of the results. One group shows that the change of threshold is caused by a change of $\Delta K_{eff\ th}$ and a change of the contribution of contact shielding (mainly crack closure). In these studies $\Delta K_{eff\ th}$ varied between 0.4 - 3 MPa√m (see, for example, Venkateswara Rao and Ritchie (1), Bailon et al. (2), Suresh et al. (3) and Petit (4)). The second group shows that $\Delta K_{eff\ th}$ is not significantly changed by the microstructure and the chemical composition, where the determined $\Delta K_{eff\ th}$ is about 1 MPa√m (examples are presented by Herman et al. (5) Detert et al. (6) and Marci (7).

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They explained the variation of ΔK_{th} by a change of the contribution of crack closure. A reason for the discrepancy in the literature may be caused by the great uncertainty in the determination of the contribution of crack closure (Allison and You, (8)). The purpose of the present study is to decide which explanation for the changes of threshold is the correct one. Very different alloys are used, the differences in the mechanical properties and chemical composition are extremely large.

Remarks about the local variation of the threshold

The different mechanisms which influences ΔK_{th} can be categorised into different groups (Ritchie (9) and Suresh (10)), where each group of mechanisms gives a certain contribution to the threshold. The three most important contributions are the intrinsic threshold and the crack tip shielding due to fracture surface contacts (closure, bridging and friction) and crack tip shielding due to the crack deflection and branching. The sum of the intrinsic threshold and the contribution of crack deflection and branching is denoted as the effective threshold $\Delta K_{eff\ th}$. From the microscopical point of view these different contributions to the threshold may depend on the position of the crack tip in the microstructure. For example, the intrinsic threshold may depend on the orientation of the grain or on the distance between the crack tip and the next grain boundary. For a simplified two dimensional description a possible variation of the different contributions is schematically depicted in Fig. 1. The observed macroscopic ΔK_{th} is then given by the maximum of the microscopic value. In other words, the crack stops to grow at the strongest obstacles. This possible local variation of the contribution to the threshold is considered also in this study.

Experimental procedures and materials

In order to determine the effective threshold and the contribution of crack closure with sufficient accuracy a special technique was applied (Pippan et al. (11)). The idea of this technique is simple. One starts the fatigue crack growth experiments on pre-cracked specimens without crack closure. Such pre-cracks were produced in cyclic compression (details see (11)). The experiments were performed in aluminium alloys with extreme differences in both, the yield stress and the chemical composition. Tables 1 and 2 give the mechanical properties and the chemical composition. Standard compact tension specimens were used. The fatigue crack propagation test were conducted at room temperature in laboratory air and the frequency used was about 100 Hz.

RESULTS AND DISCUSSION

Table 3 presents the determined upper and lower bound for the measured $\Delta K_{eff\ th}$ and ΔK_{th} values. The thresholds were determined by increasing the load amplitude in steps at constant stress ratio until one reaches the long crack threshold. At load amplitudes which correspond to ΔK values which are smaller than $\Delta K_{eff\ th}$ the crack does not grow. Since at the beginning of the test no crack closure occurs, the crack will start to propagate if $\Delta K > \Delta K_{eff\ th}$ and stops when the contribution of crack closure has risen a point where $\Delta K_{eff} = \Delta K_{eff\ th}$. This gives us the upper and lower bound for $\Delta K_{eff\ th}$. During the further increase of the load amplitude the crack stops till ΔK is larger than the long crack threshold ΔK_{th} . This permits us to determine an upper and lower bound for ΔK_{th} (11). The crack length was measured by a potential drop technique. In order to control the potential drop results and to improve the accuracy of the determined $\Delta K_{eff\ th}$ additional specimens were fatigued somewhat below and somewhat above the expected $\Delta K_{eff\ th}$ .The compression pre-cracked specimens were subjected to a constant load amplitude test of about 10^7 cycles.

Table 1: Mechanical properties (in MPa) and heat treatment

Material		$R_{0.2}$	R_m
pure Al	cold rolled	115	117
pure Al	c.r.+recryst.330°C/1h	28	60
6061	T6	295	328
7020	T5	400	435
7075	heat treatment of AMAG	625	655

Table 2: Chemical composition in weight %

	Al	Mg	Si	Fe	Cu	Cr	Zn	Zn
pure Al	99.87	0.1	0.005	0.005	0.02			
6061		0.79	0.61	0.06	0.3	0.11	0.01	0.01
7020	93.59	1.08	0.11	0.23	0.03	0.16	4.48	4.48
7075	87.57	2.72	0.14	0.27	1.73		7.26	7.26

Table 3: Determined $\Delta K_{eff\,th}$ and ΔK_{th} in MPa√m (specimen orientation LT)

Material	R	$\Delta K_{eff\,th}$	ΔK_{th}
pure Al cold rolled	0.7	0.75-0.85	
pure Al recryst.	0.1	0.75-0.81	2.5
	0.7	0.75-83	
7020	0.1	0.8-0.9	3.3
	0.7	0.8-0.9	1.4
7075	0.1	0.8-0.9	3
	0.7	0.8-0.88	1.5
6061	0.1	0.8-0.9	5
	0.7	0.8-0.9	2.2

Then the specimens where broken with a large ΔK and the extension of the crack was examined by fractographic technique. The behaviour was similar in all alloys (details see Pippan (12)). In the tests at ΔK smaller than 0.8 MPa√m no increase of the crack length was determined. At ΔK values between 0.9 and 1 MPa√m an extension between 5 and 20 µm was observed. Examples of such scanning electron micrographs (SEM) are shown in Figs. 2a and 2b.The increase of the crack length occurred along the whole crack front. At the tests with ΔK between 0.8 and 0.9 MPa√m in the pure Al-specimens the crack extension was between 1-5 µm along nearly the whole crack front, in the other alloys sometimes no or only a few parts along the crack front a small increase of crack length could be observed. The angle of crack deflection or twisting of the local crack plane, the orientation of the grain, and the distance to the next grain boundary vary along the crack front. Hence, the contribution of crack tip shielding due to crack deflection should "change" along the crack front and the intrinsic threshold may change along the crack front. But the necessary ΔK to cause the first extension of the "open" pre-crack along the crack front varies between 0.8 and 0.9 MPa√m independent of the alloy. Hence, the change of the sum of the intrinsic threshold and the contribution of crack deflection should not be larger than 0.1 MPa√m.

CONCLUSION

- The threshold of effective stress intensity range in the investigated aluminium alloys is 0.80 ± 0.05 MPa√m. Large differences in the yield stress and the significant difference in the chemical composition does not change $\Delta K_{eff\,th}$.

• The fractographic investigation indicates that the necessary ΔK_{eff} to cause a propagation of a crack is not significantly influenced by the grain orientation, the local shape of the crack, the distance to the next grain boundary or other micro-structural parameters which vary along the crack front.

• The change of threshold is caused by a change of the contribution of crack closure (contact shielding).

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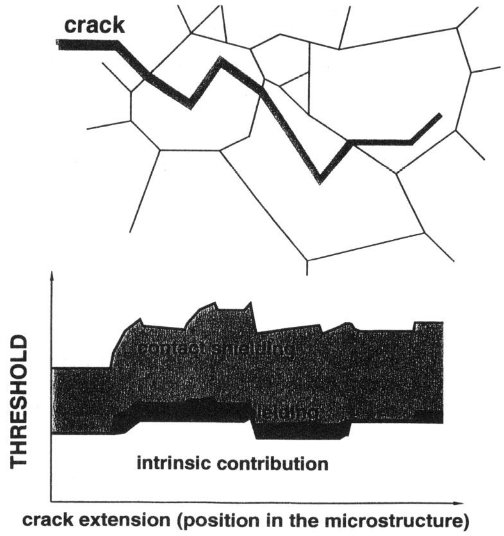

Fig. 1: Schematical variation of the different contributions to the threshold

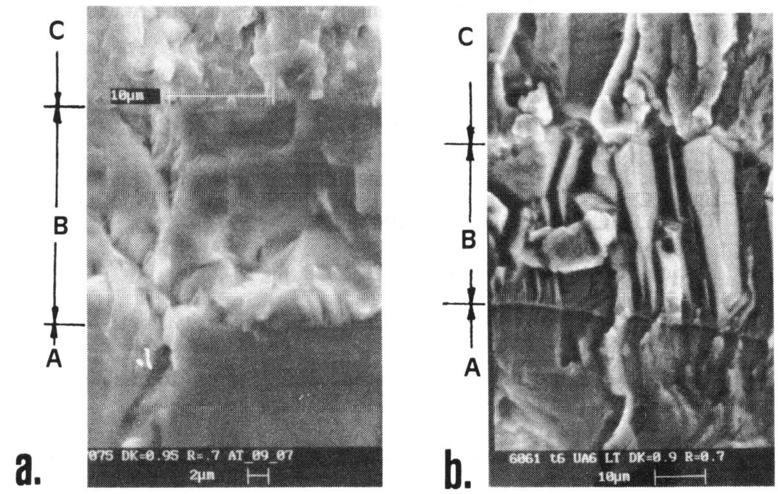

Fig. 2: SEM fractograph which indicates the crack extension in a 7075(a) and a 6061(b) alloy at (A pre-crack, B crack extension at ΔK about 0.9 MPa√m, C post fatigue fracture surface)