CORROSION FATIGUE AT NOTCHES IN HIGH STRENGTH ALUMINIUM ALLOY

E. M. Kostyk, O. P. Ostash, I. R. Makoviychuk, R. V. Chepil*

The corrosion fatigue small cracks growth behaviour at sharp and blunt notches in Al-Cu-Zn-Mg aluminium alloy have been established. The damaging effect of salt water on the early stage of small crack growth is ascribed to microcrack nucleation at pits in the vicinity of a notch root and successive accelerated growth of small cracks, which exhibit a factor of two to three increase in fatigue crack growth rates when compared to laboratory air. Small crack transition length a_i to a macrocrack does not depend on the value of the notch radius and environment, and is equal to the characteristic distance $d^* \approx 100$ μm of the prefracture (process) zone, which is a material constant.

INTRODUCTION

The damaging effect of salt water in high strength aluminium alloys is characterised by the increased crack growth rate. In particular, in the presence of aqueous 3,5 % NaCl a macro (long) fatigue crack exhibits a factor of two to three increase in crack growth rates compared to laboratory air (Panasyuk, et al.(1)). Salt water accelerates up as well the growth rate of microstructurally short and physically small cracks (Piascik and Willard (2), Lu and Evans (3)). However, environmentally assisted initial stage of fracture has been studied insufficiently. For the time being criteria for its description have not been developed yet, in particular: a) its duration; b) the initial macrocrack length, or a criterion of micro to macrocrack transition event. It was suggested (Ostash and Panasyuk (4), Ostash at al (5)) that the macrocrack initiation process is considered to be accomplished when the dominant crack at the notch root overcomes the prefracture macrozone boundary (which value d^* is a material constant at the given test conditions) and becomes a macrocrack. This zone is formed at the notch root due to cyclic loading. Its depth is conditioned by the decrease of the yield strength in the presurface layer, microstructure and cyclic deformation hardening.

* Karpenko Phisico-Mechanical Institute, National Academy of Sciences of Ukraine, 5, Naukova Str., 290601, Lviv, Ukraine

The boundary of the prefracture macrozone is a major barrier for a growth of physically small cracks, that stipulates their significant retardation and specific propagation behaviour during continuous deformation. Therefore, a size of initial macrocrack a_i is regarded due to the criterion as $a_i = d^*$.

The proposed study considers environmentally assisted small crack growth and its transition to a macrocrack.

EXPERIMENTAL PROCEDURE

Tests were carried out on the compact tension (CT) specimens of Al-Cu-Zn-Mg aluminium alloy (analogous to 7075-T6 alloy), prepared from the rolled sheets (thickness t = 4mm), quenched and aged. Mechanical properties were determined to be 0.2 % yield strength = 456 MPa, ultimate strength = 510 MPa, elongation to failure = 12 %, Young's modulus = 71 GPa. Due to recommendation (4), (5) the value of characteristic distance d^* was estimated as d^* = 100 μm both in air and aqueous NaCl. Specimen width was W = 64mm, the value of the notch radius ρ = 0.1 and 4.0 mm. A crack propagated in L-T direction. Specimens were tested at the constant loading amplitude with load ratio R = 0.1 and frequency 1 Hz in laboratory air and in aqueous 3,5 % NaCl. Initiation and growth of microcracks was monitored on both side surfaces of a specimen in the vicinity of the notch root using optical microscope (x 100). As a result, the relationships between the crack length (a) and a number of loading cycles N as well as the corresponding crack growth rate (*da/dN*) and the crack length (a) were established. Since the slip bands significantly complicated the visual observation of the initial stage of crack growth, the side surfaces were polished every time before the measurement, which was carried out at 70 % of maximum load.

RESULTS AND DISCUSSION

Investigation of the initial stage of damage accumulation in air revealed (see schemes in Fig.1 a, c) that microcrack initiation was observed from the notch root surface in the slip bands due to the shear mechanism. The length of these initial microcracks independently of the notch radius is a = 30 to 50 μm, that coincides with the structure parameter of this alloy (grain size in transverse direction is 20 to 50 μm). The successive crack propagation is going in the planes where the maximum tensile stress acts (mode I fracture).

Environmentally assisted crack initiation starts from pits. The depth of a pit is about 30 to 50 μm independently of the notch radius ρ. The following crack growth is also of mode I fracture and is only different by the increase crack growth rate, when compare with air (Fig.1 b, d). A number of through thickness cracks around the notch root contour and their increments were fixed in photographs with certain intervals. This allowed to establish the dominant macrocrack and in reverse order to plot the relationships a vs. N (Fig.1 a, c) and *da/dN* vs. N (Fig.1 b, d) within the crack length a = 30 to 2000 μm. The growth of corner cracks does not significantly affected the established relationship unless one of them became a dominant crack. Therefore, a special attention was given to through thickness dominant cracks, which are denoted as 1 in Fig.1. All cracks that became non-propagating are denoted as 2,3,4 and marked by different symbols. The specimens with notch radius ρ = 0.1 and 4.0 mm were tested at the same value of local stress range $\Delta\sigma^*_y$ (4), (5) both in air and aqueous 3.5 % NaCl. This provided an equal number N_i of cycles to initiation of a macrocrack of length a = 100 μm independently of notch radius ρ. In air it turned out to be $(N_i)_{air}$ = 8.7 to 11.0 thousands of cycles and in aqueous 3.5 % NaCl to be $(N_i)_{env}$ = 5.4 to 6.2 thousands of cycles (Fig.1 a, c), that is, duration of the microcracks growth period to the length of $a \approx 100$ μm in corrosion environment is approximately by two times as less that in air (Fig.1 a, c). When the crack length exceeds $a > 100$ μm, it is the only dominant crack propagation that was observed. Its growth rate is significantly accelerated - curves 1 in Fig.1. At the same time, when the crack length exceeds 100 μm, the onset of crack closure effect was monitored.

The increase of notch radius causes the increase in a number of initial microcracks around the notch root contour (Fig.1). However, the presence of aqueous 3.5 % NaCl stipulates the decrease in number of propagating microcracks, that is, the development of pits causes the higher localisation of fracture, contrary to the neutral environment. The length of non-propagating cracks did not exceed 100 μm both in air and aqueous 3.5 % NaCl.

It is evident that independently of the notch root radius value (0.1 or 4.0 mm), small crack growth behaviour in air and in aqueous 3.5 % NaCl is similar, i. e. their growth rate decreases by more than one order of magnitude within the length range $30 < a < 100$ μm and they become non-propagating, except the only one, which we denoted as a dominant crack (Fig.1). Therefore, on the basis of the proposed model (4), (5) it can be suggested that at $a \approx d^* = 100$ μm in Al-Cu-Zn-Mg alloy a microcrack transforms to a macrocrack. Near the tip of just formed macrocrack the conspicuous plastic zone is formed. Crack closure effect influences the fatigue crack growth rate for $a > 100$ μm. Time, required for the macrocrack formation, which includes the nucleation and growth of microcracks within the prefracture zone ($0 < a < 100$ μm), determines the period of macrocrack initiation N_i. Henceforth, for a crack of length $a > d^*$ the period of the macrocrack growth N_p begins, which is described by the standard da/dN vs. ΔK curve.

The observed crack growth rate acceleration in aqueous NaCl can be explained by the action of hydrogen enhanced local plasticity (HELP) mechanism at the crack tip (Bond (6)).

SYMBOLS USED

a = crack length
a_i = initial macrocrack length
d^* = characteristic distance of the prefracture (process) zone
da/dN = growth rate of fatigue cracks
t = specimen thickness
W = specimen width

ρ = notch root radius
$\Delta\sigma_y^*$ = local stress range
R = load ratio
N = number of cycles
N_i = number of cycles to macrocrack initiation of length a_i
ΔK = stress intensity factor range

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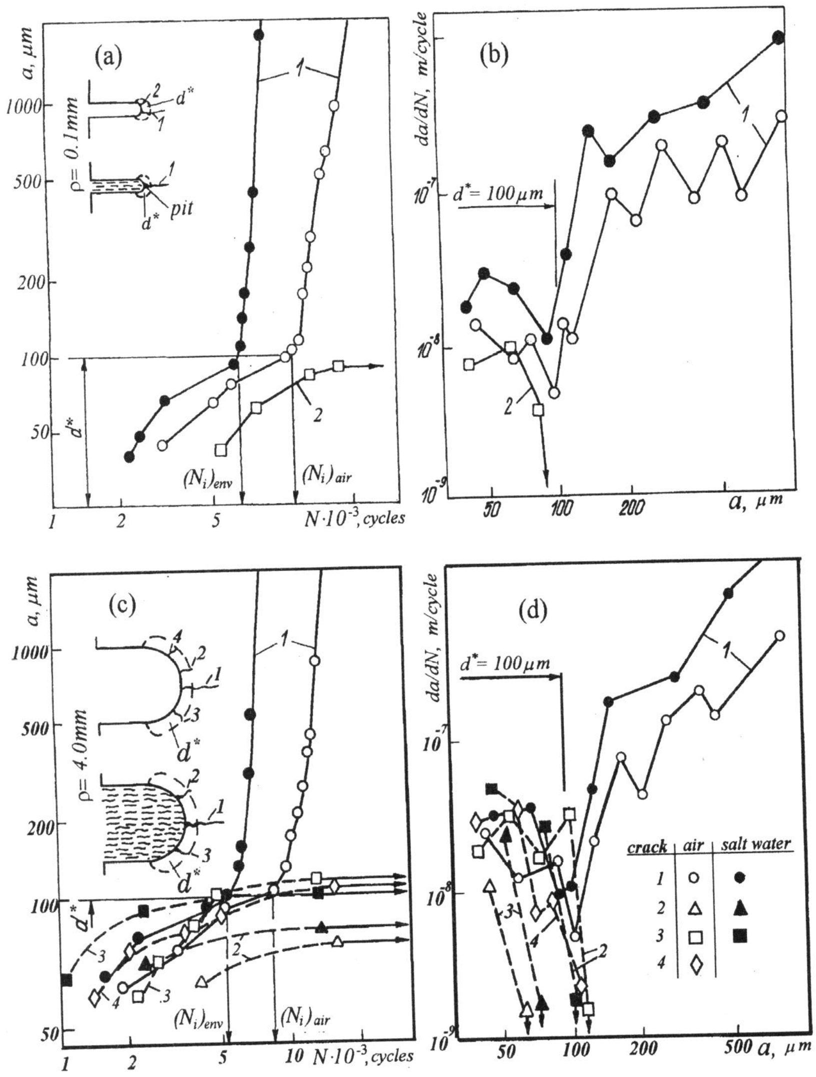

Fig. 1 A comparison of small crack growth from sharp (a, b) and blunt (c, d) notches in air and salt water: 1 - dominant crack; 2, 3 , 4 - non-propagating cracks.