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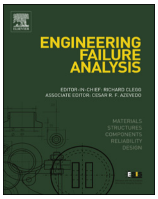

Mixed mode fatigue crack propagation behaviour of aluminium F357 alloy

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ABSTRACT

Manufacturing defects are often not in the plane perpendicular to the loading direction and will propagate under mixed mode fatigue loading condition. This paper presents a numerical study of mixed mode crack growth behaviour in H-shaped specimens made of aluminium F357 alloy. The size and orientations of the crack are based on the fractographic observation of defects in F357 specimens manufactured by foundry. Equivalent values of the stress intensity factor (SIF) and the maximum circumferential tensile stress criterion have been adopted to simulate growth of cracks at angles of 90°, 60° and 45° to the loading direction, respectively. Mixed mode fatigue crack growth behaviours are analysed in terms of the shape of crack front, SIF variation, and kink angle. The mixity of SIFs of three modes is complex at early stage of growth with the maximum mode III SIF value at the two ends and the maximum mode II SIF value at the middle of the crack front. The crack surface rotates during the mixed mode crack growth, becoming normal to the loading direction regardless of the initial orientation of the crack. The simulated crack front agrees well with the final elliptical shape of the crack front observed in the physical test specimens. The initial crack orientated at 45° to the loading direction has the longest fatigue life compared with other two crack orientations.

1. Introduction

A wide range of defects such as inclusions and porosities exist in foundry aluminium components which promote crack nucleation and significantly reduce the fatigue life of the component [1–4]. Inclusions are mainly due to the presence of slags [5], among which the most common ones are those due to the presence of the Al_2O_3 oxide [6,7], and other complex oxides (MgO and $MgAl_2O_4$) [8]. Porosities are caused by hydrogen dissolved in the liquid metal through reactions between water vapour and aluminium itself [8]. The fatigue life of a defect is dependent on its size and orientation to the loading direction. For a crack not perpendicular to the loading direction, the interaction of the three fracture modes affects not only the equivalent SIF range but also the crack path and the shape of the crack front.

The interaction among the three modes is material dependent and needs to be studied for each individual material to characterise its mechanical performance. Defects in aluminium F357 alloy manufactured by foundry have difference orientations and are often subject to mixed mode loading conditions. It is however found that no research has been reported in literature on mixed mode fatigue crack growth of the aluminium F357 alloy. This paper fills the gap by presenting numerical results of mixed mode fatigue crack

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Table 1
Chemical composition (wt%) of the F357 aluminium alloy.

Alloy	Al	Cu	Si	Zn	Mg	Fe	Mn	Ti	Be
F357	Bal	0.2	6.5–7.5	0.1	0.25–0.45	0.2	0.1	0.1	0.002

growth behaviour of the H-shaped specimens made of F357 aluminium alloy. The mixed mode condition was simulated based on the fractographic observations of the fracture surfaces of the F357 aluminium alloy.

2. Fractography

The fatigue behaviour is affected by their distribution, position, size and shape of the defects. L. Dietrich and J. Radziejewska [9] underlined that different types of defects distribution and shape affected the damage mechanisms and therefore the fatigue life of the component.

In order to identify the main source of crack in the specimens, SEM analysis have been carried out on the fracture surfaces of the F357 aluminium alloy specimens, for which the chemical composition is reported in Table 1.

As an example, two pictures showing the Subsurface defect (Fig. 1A) and the internal defect (Fig. 1B) in the tested specimens are shown.

The aim of the present work is to analyse the influence of the position and size of defects on crack growth behaviour in Aluminium F357 alloy specimens with an H-shaped geometry. The implementation of the numerical model was performed on the basis of experimental evidences collected through an experimental test campaign. The specimens were foundry manufactured by Augusta Westland. Axial fatigue tests were performed with a load ratio of $R = 0.1$ at a frequency of 10 Hz. During the fatigue test, each specimen was subject to an alternate tensile load with a maximum load value equal to $P_{max} = 84.4$ KN [10].

On the basis of the fractographic analysis carried out on the specimens tested under fatigue an initial defect having a dimension equal to 1 mm was chosen in order to consider the worst case scenario.

3. Numerical modelling

3.1. Remeshing technique

A finite element model of a cracked H-shaped specimen was implemented through the use of a commercial code FRANC3D®, which allowed to deal with the insertion of the cracks in the uncracked model by means of the remeshing technique [11]. The remeshing technique consists of discretizing the continuous propagation phenomenon in a finite number of crack growth steps. For each step a FE model with a crack made up of two free surfaces in contact is implemented. This approach makes possible to determine the SIF values along the front. On the basis of such information it is possible to propagate the crack and create a new mesh with the new crack.

The discretization of the continuous process in the remeshing technique introduces an error which depends on the chosen number of steps. In fact, by imposing a particular value of Δa the SIF value used to evaluate the progress is assumed to be a constant during each step of a certain number of cycles (Fig. 2). When the size of the Δa interval decreases, the constant value of the ΔK will be more representative. In order to determine the optimal Δa value considering both the accuracy and computational time, a convergence analysis is required.

The new position of the crack front after each step is calculated on the basis of the SIF values for each front node. The maximum increment is given to the nodes with the higher equivalent SIF value. The displacement is a function of the SIF value all over the crack front. The increment to be assigned to a certain node is the maximum value multiplied by the ratio defined above.

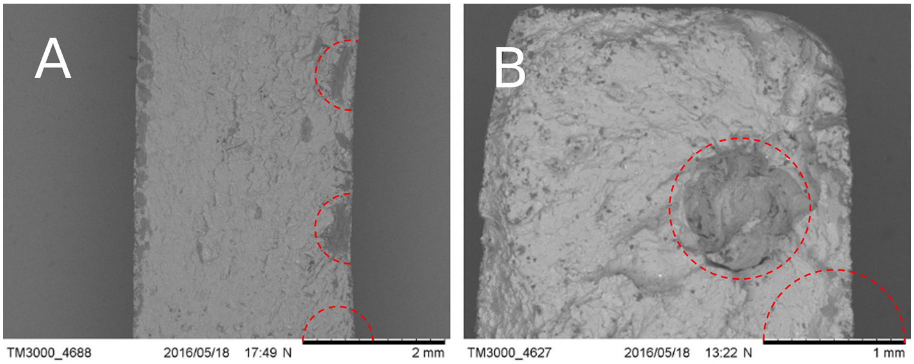

Fig. 1. SEM images taken from the specimens tested under fatigue. A) Subsurface defect B) internal defect.