



Fatigue crack growth of a double fillet weld

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ABSTRACT

The welded structures have a broad applicability, steel constructions, car industry, aeronautical, marine, pipelines, etc. These structures are generally subjected to cyclic requests. A simple existing defect after welding can generate a catastrophic fracture. This work studies the fatigue crack growth of a double fillet weld with the existence of a semi-elliptical crack. Two types of aluminum alloys are studied with knowing the alloy 2024 T351 and the 7075 T6. Crack growth analysis uses linear elastic fracture mechanics and related crack growth material properties to determine how fast a crack or crack-like defect will grow. Fracture mechanics is based on the concept of stress intensity (K) that describes the magnitude of both the stress and strain fields around a crack. It is computed from the stress range ($\Delta\sigma$), and crack size (a) and crack shape (β). The effect on the fatigue life of the geometrical parameters of the crack (a/c ratio), the angle of inclination of the weld bead and the level of loading are studied. In order to predict the fatigue behavior of the welded structure, a constant amplitude loading is applied where the influence of the load ratio over the fatigue life is presented. A comparative study of fatigue crack growth of the cited aluminum alloys are detailed in order to show the effect of several parameters.

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1. Introduction

In all cases, welding is the primary jointing method and fatigue is a major design criterion. Welding may be replaced by some alternative jointing method with higher fatigue strength, e.g. adhesive bonding is largely useful [1]. There is growing interest in the structural use of aluminum alloy, for such applications as aerospace, aeronautic, automotive, marine applications, etc [2,3]. The welding of aluminum and its alloys provides a basic understanding of the metallurgical principles involved in the way that alloy achieve their strength and how welding can affect their properties [4].

Two types of cracking will normally cause failure of a fillet welded joint. They are root cracking and toe cracking [5]. The failure analysis of weldment suggests that fatigue alone is considered to account for most of the disruptive failures [6].

Fatigue assessment procedures for welded aluminum structures presented in reviewed work [7] shown that the cumulative damage under realistic stress affect the fatigue limit. In discussed work of Swellam et al. [8], the weld fatigue failure process can be divided into three stages such as crack initiation and growth as kinked cracks emanating from the main crack, crack propagation through

the sheet thickness and crack propagation through the width of specimens.

Fatigue crack growth behaviour of welded joints depends on the material, loading and in particular, the geometric configurations of the weld and plate thickness [9,10]. The effect of butt weld geometry parameters (weld toe, flank angle, plate thickness, initial crack geometry) on the fatigue crack propagation life have been studied [11] by using Linear Elastic Fracture Mechanics (LEFM), Finite Element Analysis (FEA) and superposition approaches. A criterion has been established to forecast the possible crack initiation region (toe or root) in the double fillet welded load carrying cruciform joint [12].

The fatigue behavior of 2024-T3 friction stir welded overlap joints is characterized by Fersini and Pironi [13] where in the welded joint two crack-like unwelded zones are present at overlap ends. In the Fersini and Pironi study, the stress intensity factor at the crack tip and the fatigue crack path have been studied using the FE code Franc2d and the lifetime has been estimated by integrating the material propagation law with the software AFGROW. The fatigue crack growth of welded aluminium alloy 2024 T351 was studied under effect of several parameters [14] (residual stress, weld orientation, etc.).

The aim of this work is the study of fatigue crack growth of a double fillet weld with the existence of a semi-elliptical default where two aluminum alloys are considered.

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2. Fatigue crack growth of double fillet weld

The evaluation of the fatigue life of welded structures is complicated by large variations in weld geometry, welding defects, residual stress, etc. The crack propagation is the dominant part of the fatigue life. Different regions of fatigue crack growth are shown in Fig. 1.

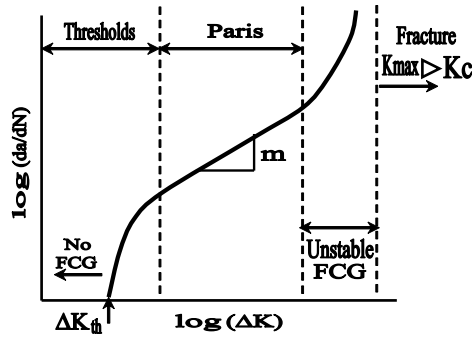


Fig. 1. Schematisation of fatigue crack growth.

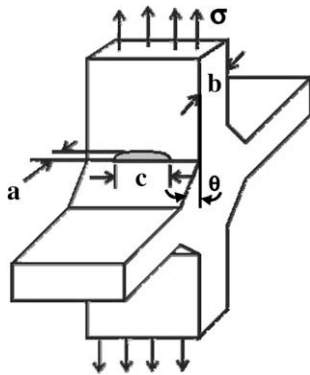


Fig. 2. Semi-elliptical crack in double fillet weld.

Table 1
Characteristic of materials

Materials	<i>E</i> (GPa)	ΔK_{th} (MPa $\sqrt{m}$)	<i>C</i>	<i>m</i>
2024 T351	71.02	2.0	4.34×10^{-11}	3.45
7075 T6	70.90	2.3	1.10×10^{-10}	3.45

Semi-elliptical surface cracks occur frequently at the weld toes of welded joints [15]. Fatigue crack growth rate is usually analyzed in terms of fracture mechanics by using relations involving stress intensity factor.

The fatigue process under constant amplitude loading can be described by the following equation:

$$\frac{da}{dN} = f(\Delta K, R) \quad (1)$$

where ΔK is stress intensity factor and R is stress ratio.

The most frequently used model to describe the fatigue crack propagation is Paris' Law [16]

$$\frac{da}{dN} = C \Delta K^m \quad (2)$$

where C and m are material constants.

Others models are proposed to describe the total curve of fatigue crack growth and effects of different parameters [17–19].

In order to analyze the fatigue behaviour in welded joints using fracture mechanics techniques, it is necessary to calculate the value of the stress intensity factor of the fatigue crack.

It is known that the stress intensity factor (K) for crack opening mode (I) can be expressed in the following form:

$$K = \beta \cdot \sigma \cdot \sqrt{\pi \cdot a} \quad (3)$$

A correctional factor M_k was introduced for considering the effect of welding geometry for the cracks which propagate in the region of stress concentrations produced by the geometry of welded joints, i.e. cracks at weld toes, a further correction factor (M_k) is introduced and known as geometry magnification factor [20]. Then Eq. (3) can be written as follows:

$$K = \beta_0 \cdot M_k \cdot \sigma \cdot \sqrt{\pi \cdot a} \quad (4)$$

The geometry of a double fillet weld is shown in Fig. 2.

To predict the effect of several parameters on fatigue crack growth, a fatigue calculator code is used. Crack growth analysis requires a crack growth curve for the material. The linear portion of the curve represents stable crack growth and is characterized by an intercept (C) and slope (m).

For the considered materials [21,22], 2024 T351 and 7075 T6 the characteristic materials and coefficient C and m are presented in Table 1.

The number of cycles required to propagate a crack from an initial crack size $a_0 = 0.1$ mm, to a final crack $a_f = 10$ mm can be calculated by using the following equation when numerical integration is applied:

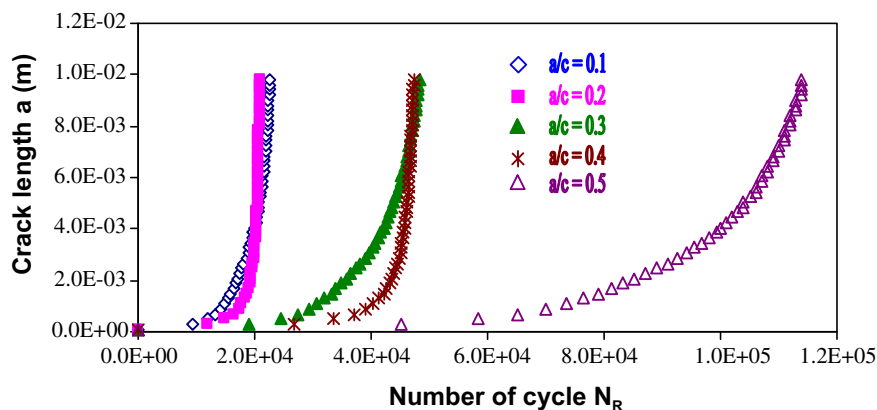


Fig. 3. Fatigue crack growth for $\theta = 30^\circ$.

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