INFLUENCE OF AMPLITUDE LOADING AND STRESS RATIO ON FATIGUE LIFE OF ALUMINUM 2024 T3 ALLOY

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Abstract— A systematic study of the effects of stress ratio on small fatigue crack growth in Al 2024 T3 was conducted under constant amplitude loading. Specimens were tested axially at room temperature under three amplitude loading and with three different stress ratios (R) of 0, 0.1, and -0.1at a frequency of 20 Hz. For a given material and environment, the fatigue crack growth behavior is essentially the same for different specimens or components because the stress intensity factor range is the principal controlling factor in fatigue crack growth. Variable loading effect was also analyzed in step down order to study the fatigue growth rate. Thus the fatigue crack growth rate (da/dN) versus K data obtained on simple specimen configurations, under constant amplitude conditions can be used for engineering design.

Keywords: Crack length (a), Fatigue Crack Growth Rate (da/dn), Number of cycles (N), Stress ratio (SR).

I. INTRODUCTION

Owing to their high strength and low density, the Al-Zn-Cu-Mg based 2000 series aluminium alloys, such as 2024 are widely used for constitutive parts of aircrafts and thus damage tolerance is critical issue in aeronautics [1,2,3]. New generation aluminium alloys are developed to improve their specific properties including damage tolerance through optimization of microstructures to replace conventional metals. The accurate estimation of fatigue lives of metals in service environment is still a challenge for the designer or fleet manager. In particular, military aircrafts are often required to achieve long lives under demanding operational conditions consisting of highly complex and variable spectra. Similar demands are made for the rail industry. In Australia, most of the coal exports are carried to port by rail. It is estimated that over the next five years there will be a 50% increase in demand [4].

To meet the challenges for the aerospace industry and rail industry, and other industries prone to metal fatigue, the primary goal of this work was to investigate one model that may: (i) Rapidly and accurately access the durability, and therefore the safety, of existing and new designs and structural modifications under both current and future operational environments; and (ii) Allow a reduction in weight of the vehicles without compromising safety or durability.

The science of fatigue crack growth has traditionally revolved around the relationship between the stress intensity factor range, ΔK and the crack growth rate da/dN with the maximum stress intensity factor Kmax. Liu [5] was the first to suggest the crack growth rate; da/dN was a function of the stress intensity factor range, ΔK. A similar relationship was subsequently proposed by Paris and Erdogan [6]. Here the results of a series of constant amplitude crack growth tests were used to express the crack growth rate da/dN where N is the Number of cycles, and a is the crack depth or length, at time N as a function of ΔK on a log scale. The fatigue life of a metallic material is divided into several stages: crack nucleation, micro-crack growth, macro-crack growth, and failure. The AGARD [7, 8, 9] and NASA/CAE [10,11] studies on small-crack behavior in a variety of materials showed that about 90% of the fatigue life is consumed in crack growth from about 10 µm to failure. This is the reason that there is so much interest in the growth behaviour of small cracks.

Fatigue-crack-growth tests have been conducted on specimens made of 2024-T3 thin-sheet (B = 2 mm) of aluminum alloy over a wide range of applied stress levels and for three stress ratios (R = 0, 0.1 and -0.1). Thus the fatigue crack growth rate (da/dN) versus K data obtained on simple specimen configurations, under constant amplitude conditions, can be used for engineering design.

II. EXPERIMENTAL WORK

A. Mechanical Testing

The materials investigated in this study are aluminium 2024 T3 widely used for aeronautical applications. The fatigue tests were performed in a load controlled servo hydraulic INSTRON (model 8801) machine with 100 KN of capacity.

Crack length verses number of cycles was recorded for each test. Specimens of 150x50x2 mm3 of aluminium 2024 T3 with a V notch (Figure 1) have been subjected to fatigue testing. The experimental readings of crack length a, and the corresponding number of cycles, N, were recorded periodically after suitable crack increments.

The alloy used was provided by the ALCAN Company of production of aluminium alloys. A hydraulic machine test was used to conduct unpatched fatigue tests. First the specimen was subjected to a sinusoidal pressure of an amplitude of 70 MPa for three different stress ratios (R= 0, 0.1 and

-0.1) at a frequency of 20 Hz, with a waveform and at room temperaturein laboratory air of which the humidity was maintained at about RH 15 pct and then it was repeated for 90 and 120 MPa amplitude loading. The following figure (2A and 2B) shows the specimen in the machine before and after the failure. MATLAB was used to draw these graphs. The three graphs in figure 3, 4, 5 are for the 70 MPa of loading.

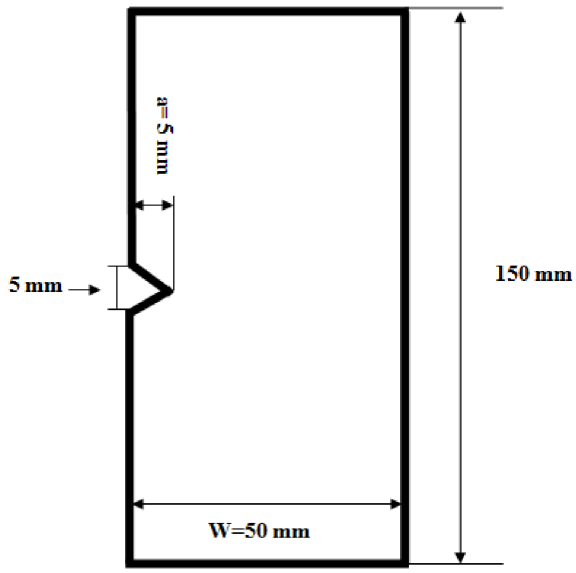

Fig. 1 Single Edge Notch Tension (SENT) Specimen dimensions

Fig. 2A specimen in INSTRON machine (data acquisition system)

Fig. 2B specimen in INSTRON machine (After failure)

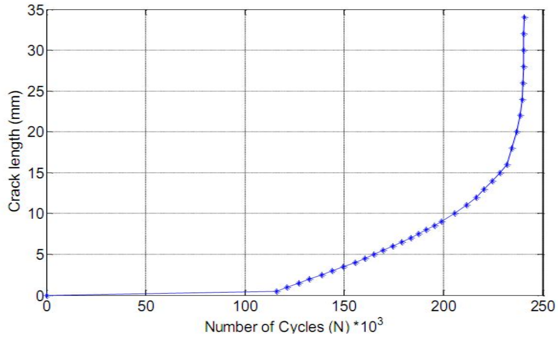

Fig.3 Crack length versus number of cycles for -0.1 stress ratio

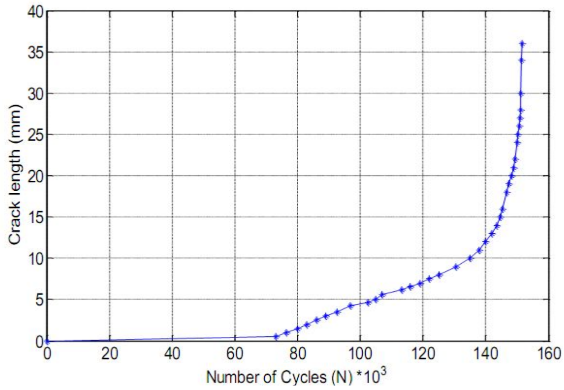

Fig. 4 Crack length versus number of cycles for (0) stress ratio

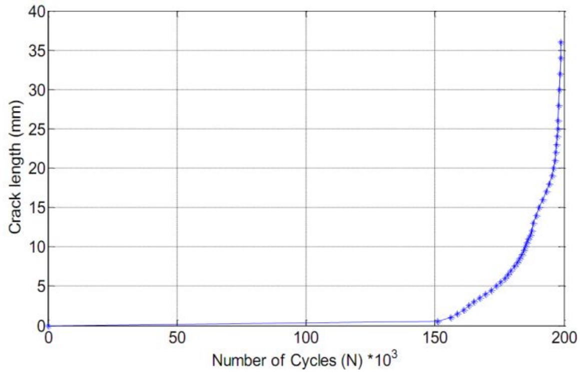

Fig. 5 Crack length versus number of cycles for (0.1) stress ratio

The following three graphs in figure 6, 7, 8 were drawn for 90 MPa for three stress ratios. For zero stress ratio the signal are equally distributed and remain stable under the mean.

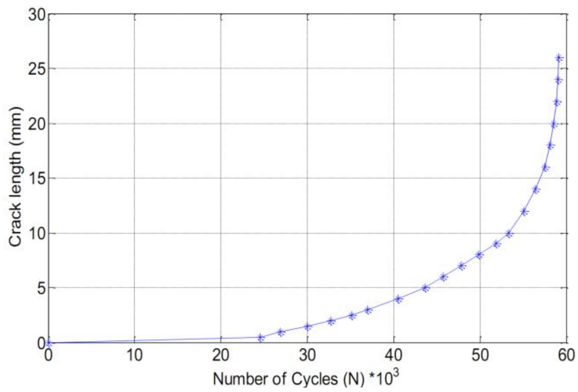

Fig. 6 Crack length versus number of cycles for (-0.1) stress ratio

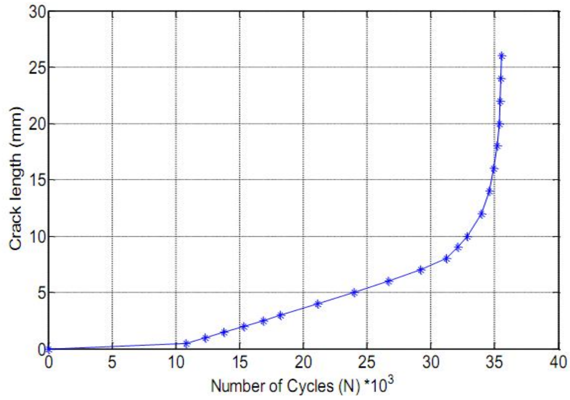

Fig. 7 Crack length versus number of cycles for (0) stress ratio

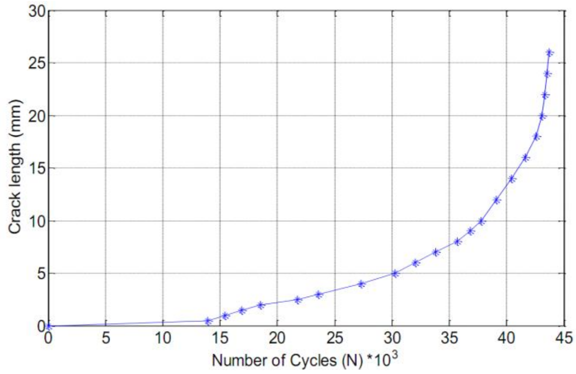

Fig. 8 Crack length versus number of cycles for (0.1) stress ratio

The following three graphs (figure 9, 10, 11) were drawn using MATLAB for 120 MPa for three stress ratios. From these graphs we can see the effect of loading and stress ratio. For negative stress ratio, the number of cycles to failure is high because of tension and compression.

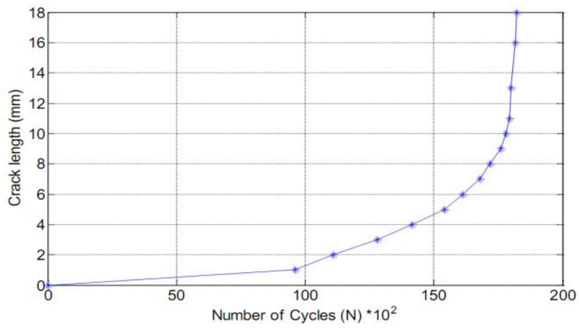

Fig. 9 Crack length versus number of cycles for (-0.1) stress ratio

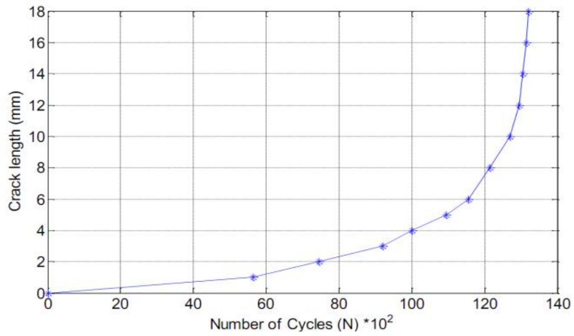

Fig.10 Crack length versus number of cycles for (0) stress ratio

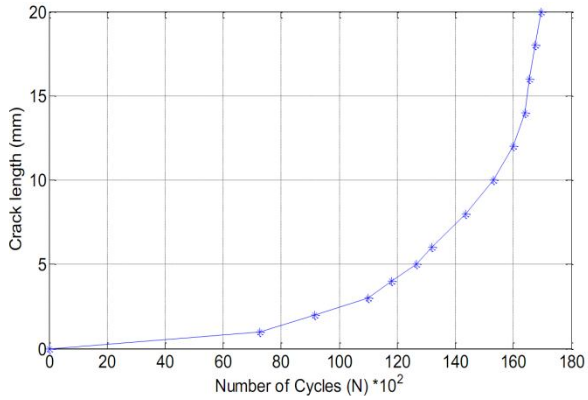

Fig. 11 Crack length versus number of cycles for (0.1) stress ratio

We also test the sample for variable loading in steps for two stress ratios, starting with 110MPa for a crack length of 3 mm and then continued with 70 MPa until failure. From this we concluded that for the second loading condition it took almost the same number of cycles as the new sample with no crack.

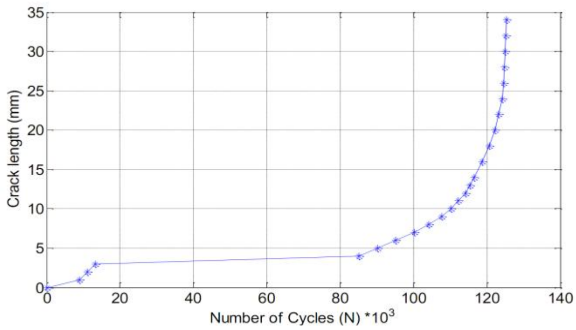

Fig. 12 Crack length versus number of cycles for variable loading (0.1 stress ratio)

III. ANALYSIS AND RESULTS

Fatigue crack growth is highly dependent on the stress ratio as well as the amplitude loading. Increasing the stress ratio in a positive sense accelerates the growth rate, but its decrease conversely reduces the rate, when only the positive stress intensity range is considered as a driving force. The above examples have shown that the growth of small to medium cracks in several different materials appears to be exponential, and that the relationship between the slopes of the exponential curves is governed by the applied stresses. A number of researchers have proposed crack growth laws whereby the crack growth rate was proportional to the crack length. It was concluded from these experiments that the stress ratio may substantially affect crack growth rates in both compressive-tensile and purely tensile fatigue cycling. However, these effects are not of a cumulative nature.

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