Effect of thickness on Fatigue Crack Growth of Aluminium alloys

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Abstract. The effect of thickness on fatigue crack growth has been investigated for aluminium alloys such as a high-strength aluminium alloy (A7075-T6), a medium strength alloy (A6063-T6), and A2024-T351. The fatigue tests were conducted using Instron 8801 fatigue testing machine on all those materials with thicknesses of 12.7, 15.8, and 20 mm. All specimens were undergoing finishing process on the surface. These tests were run under constant amplitude load for each different thickness and materials. Fatigue crack growth specimen made of A2024-T351 and A6063-T6 aluminium alloys with thickness of 12.7 mm were higher than specimen made of A7075-T6 aluminium alloy with thickness of 20 and 12.7 mm and A6063-T6 aluminum alloy with thickness of 15.88 mm. It is concluded that fatigue crack growth decreases significantly with increasing thickness, and the crack initiates very fast on surface material.

1. Introduction

In a previously paper, the fatigue crack initiation and growth of aluminium alloy A7075-T6, A6063-T6 and A2024-T351 with various stress ratios were investigated using the compact test specimens having thickness of 12.7 mm [1]. The result found that the gradients of crack growth rate increase while the stress ratio, R increase. Higher R ratio result in higher value range of minimum applied load. Using the sheet specimens having an edge notch 3 mm deep and 0.1 mm root radius at stress ratios R ranging from -0.5 to 0.5, the result shows that the fatigue crack propagation rate was dependent on the stress ratio that was the higher the stress ratio, the higher the rate of fatigue crack growth for a given ΔK value [2]. The present paper is concerned with an effect of thickness on fatigue crack growth of aluminium alloy. Effect of thickness in fracture of 2219-T851, 6061-T651,7075-T6, 7075-T651, and 7079-T651 aluminium alloy [3,4], the result show that value of KIC generally increase with increasing specimen thickness. Then, the amount of fatigue crack growth of 2024-T3 aluminum alloy delay increases with decreasing sheet thickness. This behavior is attributed to greater plastic strains associated with the larger plastic zone size formed under plane stress conditions [5]. With finite element analysis and experimental of critical crack-tip-opening angle (CTOA) in 2024-T351 aluminum alloy, the result shows both computationally and experimentally that the critical surface CTOA value continues to decrease for increasing specimen thickness [5,6]. The present thickness of specimens is used 20, 15.7, and 12.7 mm will investigate the fatigue crack growth of aluminum alloy.
2. Materials and Experimental Procedure

The fatigue tests were conducted using Instron 8801 fatigue testing machine on aluminium alloys such as a high-strength aluminium alloy (A7075-T6), a medium strength alloy (A6063-T6), and A2024-T351 with thickness of 12.7, 15.8, and 20 mm. All the specimen designs were referred to the ASTM E647-11 standard for compact test for fatigue crack growth rate testing. One of the specimens is shown in Figure 1. Recommended thickness and suggested minimum dimensions are provided to ensure the results or data obtained are valid and full in the range of predominantly elastic condition with the force applied. All specimens were undergoing finishing process on the surface. These tests were run under constant amplitude load for each different thickness and materials. The standard test method consists of determining the fatigue crack growth rate near threshold to maximum stress intensity controlled instability. The dimensions stated were provided with the tolerance. Design is done by AutoCAD software. Since the EDM wire cut machine is only support with the AutoCAD software drawing. Table 1 and Table 2 show the mechanical properties and chemical compositions of all types of aluminium alloy. Instron console software is the software that collaborates with the Instron 8800 to transfer the setting on the software successfully to the Instron 8801 Hydraulic Server Machine.

The fatigue crack growth experiment was conducted using Instron 8801 Hydraulic Server Machine. After the data acquisition system, the specimens were further analysing using the Scanning Electron Microscope (TM3000 Table top Microscope). SEM was used to analyze on specimen surface and the crack propagation area to identify the crack initiation and the fatigue behaviour on the particular locations. Paris law is used to describe the long crack behavior under constant amplitude loading with the small range of yielding. Further modification on Paris law are needed for describe the overall crack growth, the effect of stress ratio and the effect of high amplitude loading [12]. Paris-Erdogan equation can be shown as in Eq. (1) where \( \frac{da}{dN} \) = fatigue crack growth rate, \( \Delta K \) = Stress intensity factor range, \( C \) and \( m \) are the coefficients of material constants. \( \frac{da}{dN} = C (\Delta K)^m \)

\[ \text{Table 1. Mechanical Properties of Aluminum Alloy} \]

| Aluminum alloy | Yield Strength (MPa) | Tensile Strength (MPa) |
|----------------|----------------------|------------------------|
| A2024-T351     | 290                  | 444                    |
| A6063-T6       | 172                  | 207                    |
| A7075-T6       | 535                  | 585                    |

![Figure 1. Standard Compact Specimen for fatigue Crack Growth Rate Testing [11], dimension is in mm and degree.](image-url)
Table 2. Chemical Composition of Aluminum Alloy (%wt)

| Materials  | Si   | Fe  | Cu  | Mn  | Mg  | Cr  | Zn  | Ti  |
|------------|------|-----|-----|-----|-----|-----|-----|-----|
| A2024-T351 | 0.11 | 0.15| 4.58| 0.66| 1.54| 0.02| 0.04| 0.032|
| A6063-T6   | 0.42 | 0.22| 0.04| 0.05| 0.48| 0.02| 0.03| 0.03 |
| A7075-T6   | 0.10 | 0.38| 1.52| 0.10| 2.6 | 0.21| 5.55| 0.03 |

3. Results and Discussion

3.1. Fatigue crack growth of A2024-T351, A6063-T6, and A7075-T6 aluminum alloy.

Fatigue crack growth experiments under constant stress amplitude have been carried out in order to investigate the effect of thickness on fatigue crack growth aluminium alloys. The fatigue crack growth curves $da/dN$ vs $\Delta K$ is shown in Fig. 2 for all sizes of specimen. This figure shows as prediction of fatigue crack growth on A2024-T351, A6060-T6, and A7075-T6 aluminum alloys. Fatigue crack growth specimen made of A2024-T351 and A6063-T6 aluminum alloys with thickness of 12.7 mm were higher than specimen made of A7075-T6 aluminum alloy with thickness of 20 and 12.7 mm, and specimen made of A6063-T6 aluminum alloy with thickness of 15.88 mm. It can be seen that aluminum alloy with thicker size has lower fatigue crack growth rate in stress intensity, $\Delta K$ region (10-20 MPa m$^{1/2}$) significantly than that thinner size of specimen, which according to [8] are evidence of $\Delta K$ region the same as result for A2024-T351 aluminum alloy. Specimen with thickness of 20 mm for A7075-T6 aluminum alloy material, fatigue crack initiation and crack propagation were faster than others of aluminum alloy.

![Fatigue crack growth rate for all types of aluminum alloy with difference specimen size](image-url)
3.2. Effect of thickness on A2024-T351, A6063-T6, and A7075-T6 aluminum alloy

As mentioned earlier, fatigue crack growth of aluminium alloy specimen with thickness of 20 mm is higher than that of aluminum alloy specimen with thickness of 12.7 and 15.8 mm. However, fatigue crack growth based on crack length, the result show that specimen with thickness of 12.7 mm for A7075-T6 aluminum alloy is faster than of specimen with thickness of 20, and 15.8 mm for A7075-T6, A6063-T6, and A2024-T351 aluminum alloy. The effect of thickness on the fatigue crack growth for A7075-T6, A6063-T6, and A2024-T351 with thickness of 12.7, 15.8, and 20 mm is shown in Figure 3. Figure 3 shows that the crack length for A7075-T6 aluminum alloy materials specimen with thickness of 12.7 mm initiates at crack length of 20 mm and then crack propagate up to failure with crack length of 23.92mm. For A6063-T6 specimen with thickness of 15.88, and 12.7 mm and A2024-T351 specimen with thickness of 12.7 mm, crack initiates at crack length of 20 mm and propagate up to failure at similar crack length around 27.99 mm. Fatigue crack growth of A7075-T6 specimen with thickness of 20 mm initiates slower than that of other aluminum alloy. It can be seen that retardation occurrence of this crack due to the A7075-T6 specimen was thicker than that of other specimen.

Figure 4 shows crack length versus number of cycles curve. This figure indicates that at lower number of cycles, A7075-T6 specimen with thickness of 12.7 mm crack occurs faster than that of A6063-T6, A7075-T6, A2024-T351 and A7075-T6 specimen with thickness of 12.7, 15.8, 12.7, and 20 mm, respectively. Similarity the result from Figure 3 that fatigue crack growth based on crack length, A7075-T6 specimen with thickness of 12.7 mm initiates faster than that of other specimen.

**Figure 3.** Effect of thickness on fatigue crack growth for all types aluminum alloy with difference specimen size.
Figure 4: Crack length versus Number of cycles curve.

4. Conclusion
The effect of thickness on fatigue crack growth of aluminum alloys such as A2014-T351, A7075-T6, and A6063-T6 specimen with thickness of 12.7, 15.8, and 20 mm was investigated. Fatigue crack growths of A2024-T351 and A6063-T6 aluminum alloy specimen with thickness of 12.7 mm were higher than A7075-T aluminum alloy specimen with thickness of 20 and 12.7 mm, and A6063-T6 aluminum alloy specimen with thickness of 15.88 mm. It is concluded that fatigue crack growth of aluminum alloy decreases significantly with increasing thickness, and the crack initiates very fast on aluminum alloy material. Based on the number of cycles was found similar result that the crack size of 12.7 mm was faster than size of 20 and 15.8 mm. This conclusion should assist the designer in optimizing aluminum alloy selection for fracture resistant aluminum engineering structures.

5. References
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