Available online at www.elixirpublishers.com (Elixir International Journal)

Applied Chemistry

ISSN: 2229-712X

Elixir Appl. Chem. 49 (2012) 10102-10104

The effects of stress ratio on the fatigue crack propagation of the 6061 T6 alloy aluminium of 0.1: $\Delta\sigma$=80 MPa

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ARTICLE INFO

Article history:

Received: 27 June 2012;

Received in revised form:

16 August 2012;

Accepted: 21 August 2012;

Keywords

Centre crack tensile,

Fatigue crack propagation,

Pre-cracking,

Stress ratio of 0.1,

Scanning Electron Microscope (SEM).

ABSTRACT

The effects of stress ratio on the fatigue crack propagation of the 6061 T6 alloy aluminum with a thickness of 5 mm were investigated at room temperature. The fatigue crack growth rates were studied at stress ratios of 0.1with stress range, $\Delta\sigma$=80 MPa using centre cracked-tension specimen M (T). The results are expressed in term of crack tip stress intensity factor range that was derived from linear elastic theory. From the collected data, the fatigue crack growth versus stress intensity factor range was plotted. It was obtained that the overall stress intensity factor range is within 6 to 19.5 MPa√ m, and the value of fatigue crack growth rate is within 10^{-7} to 10^{-3} mm/cycle. For R=0.1 the stress intensity factor range is within 8 to 19.5 MPa√ m, and the value of fatigue crack growth rate is within 10^{-6} to 10^{-4} mm/cycle. Finally, the value of (m) and (C) were determined from the graph using the Paris Law equation. The results showed that the increase in continuous crack length and load cycle will result to the acceleration of fatigue crack growth. Scanning Electron Microscope (SEM) was used to check the microscopic of fractured surface. From the fractography analysis, the material fails in ductile fracture. Hopefully this collection data's will used as reference to the next researcher.

Introduction

In engineering design, safety factor is a very crucial element to ensure an optimum design to function. Fatigue failure pointing with micro-cracks and usually occurs at places of stress concentration of a component as the key hole and bolt holes. After the crack is formed, increased stress concentration at the crack tip due to the reduction in surface area and the crack may propagate to higher rates. Fatigue failure can be classified into three stages of fatigue crack growth rates of the initial crack, the crack propagation constant and immediate failure in the unstable crack propagation.

Problem Statement

There are several factors that influence the rate and propagation effects such as fatigue and environmental effects of temperature, thickness and type of specimen, the wave form and frequency, the effect of welded, stress amplitude and R-ratio effect. Studies on the different R-ratios in a material need to be done. This is because the actual stress range acting on the components and the engineering structure constant, but varies widely. Aluminum alloy sheets have been widely used in engineering structures where high strength and low density is a basic requirement in many engineering design.

Research Objective

The objective of this study was to determine the behavior of the fatigue crack propagation in 6061 T6 aluminum alloy sheet as a result of the R-ratio is varied.

Significant of Study

The results of this study are to predict the period of life for an engineering component designated and to ensure the consumers safety. The experimental results shall be determine the crack propagation rate. It's almost as critical in the loading cycle before the pace of the critical size occurs and can lead to fracture failure at the end of 6061 T6 aluminum.

Literature Review

The failure of engineering components and structures often found failing under the load-changing action. The phenomenon of failure by the applicable burden is called fatigue failure and occurs below the yield limit of material (Norton, Robert L, 1996). Material fatigue failure can be classified into three levels as illustrated in Figure 2.1. Studies on fatigue properties of materials are particularly important when predicting the service life of new engineering structures in addition to avoid of fatigue failure occurs. When the crack extends, the direction of propagation does not depend on the orientation of the grain, otherwise the normal applied stress (Flinn, Richard A, Paul K, 1981).

Research Methodology

The methods of pilot research is using aloi alumimium 6061 T6 It was obtained that the overall stress intensity factor range is within 6 to 19.5 MPa√ m, and the value of fatigue crack growth rate is within 10^{-7} to 10^{-3} mm/cycle. For R=0.1 the stress intensity factor range is within 8 to 19.5 MPa√ m, and the value of fatigue crack growth rate is within 10^{-6} to 10^{-4} mm/cycle. Finally, the value of (m) and (C) were determined from the graph using the Paris Law equation. The results showed that the increase in continuous crack length and load cycle will result to the acceleration of fatigue crack growth. Scanning electron microscope (SEM) was used to check the microscopic of fractured surface. From the fractography analysis, the material

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fails in ductile fracture. The stress variable is Δσ at 80 MPa of room temperature.

Limitation of Study

In this study, the material used is 6061 T6 alloy aluminum which are determined their properties first. Mechanical properties of materials obtained by performing tensile tests at low strain rates. This test is performed to obtain the yield stress, ultimate stress, and modulus of elasticity. The pilot test of fatigue crack propagation will determine the behavior of fatigue crack propagation rate. This test is performed on the R-ratio of 0.1, in the stress range, Δσ of 80 MPa at room temperature.

Data's Analysis (R=0.1)

Stress Test

To obtain the mechanical properties of materials, tensile tests were performed on specimens with the length, width and thickness of each specimen is 200 mm, 20 mm and 5 mm. While the gauge of length was 50 mm according to ASTM E 8M-91. Mechanical properties of 6061 T6 aluminum alloy material is recorded and the average value taken. Table 4.1 shows the mechanical properties of the material.

Table 4.1: Mechanical properties of aluminum alloy 6061 T6

Modulus Young ,E-(Gpa)	Ultimate Strength	Yield strength
68.35GPa	330 MPa	316 MPa

Fatigue crack propagation

Table 4.2 shows the data of crack length and load cycle on the pre-crack and the critical material parameters of the experiment with R = 0.1. The values of the pre-crack distance is about 5.19 mm in magnitude $2a_0$ and currently reading for the number of cycles set to zero. For the specimen that is critical to achieve the long-crack fatigue failure and the number of cycles has changed. The difference between the two readings is dependent on the ratio of R-charged during the experiments

Table 4.2: Data crack length and load cycle on the pre-crack and the critical.

R-Ratio	Pre-Crack		Critical	
	$2a_0$ (mm)	No (Cycle)	$2a_f$ (mm)	N_f (Cycle)
R=0.1	5.19	0	21.38	393480

Fatigue crack propagation rates Versus Stress intensity factor range graph fatigue crack propagation rate, da / dN against tensile ΔK plotted intensity factor range at the crack length, 2a, and load cycles, N. Scale graph plotting the log. Log means is intended to facilitate discussion on the rate of fatigue crack growth rates at the specimen tested at R-ratio is varied. Graph log scale - the impact of log-ratio R varying graph shown in figure 4.1.

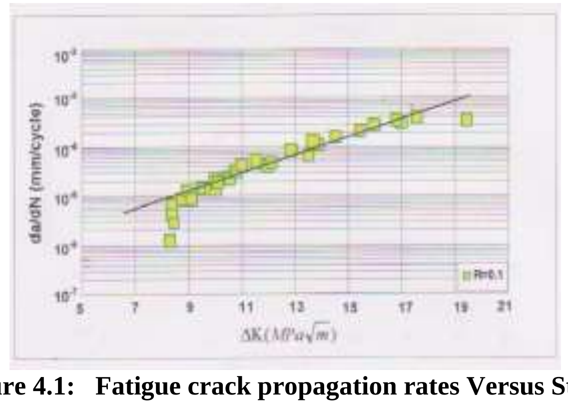

Figure 4.1: Fatigue crack propagation rates Versus Stress Intensity Factor Range R = 0.1, at frequency 10 Hz

From the graph was plotted, it can be observed that the fatigue crack propagation is divided into three main stages of the threshold level, the fatigue crack propagation and failure levels. In the second stage of the fatigue crack propagation by the Paris power law equation, $da/dN = C(\Delta K)^m$ (Refer to table 4.3). For the ratio R = 0.1-intensity factor range is between 8 to 19.5MPa √ m, found the rate of fatigue crack growth in 10^{-7} to 10^{-4} mm/cycle.

At first stage, it was found that the ratio of-R is inversely proportional to the stress intensity factor range. This stage is known as the threshold level, ΔK th which, when high-value-ratio R lower ΔK th. It can be seen in the ratio R = 0.1 the threshold value is between 8 MPa √ m. Cracks will not propagate the crack propagation threshold and otherwise will occur after the crack length exceeded 8 MPa √ m for the ratio R = 0.1(C.C. Wigant and R.I Stephens,1983).

Table 4.3: Paris equation constants

R-Ratio	C	m
0.1	7.827×10^{-11}	5.24

The second stage is the fatigue crack propagation in which the main focus of this experiment. At this stage of fatigue crack propagation process of forming a straight line and follow the law of Paris on the log scales. Significant changes in the value ΔK can be seen in this second stage. Increasing the value of ΔK will also give rise to da/dN, it's shown that both elements are relative to each other. By increasing the ratio R, the rate of fatigue crack growth at this level also increased. Fatigue crack propagation rate is clearly shown by the increase in R-ratio (Nirbhay Singh, Ram Khelawan and G N Mathur, 2001). In addition this material by the relationship da / dN = C (ΔK) m which has been highlighted by Forman et al (1967). Thus the effect of R-ratio fatigue crack growth in aluminum alloys is proving support by other researchers.

In the third stage is the last process in the crack. At this stage, the crack propagates at a rate so fast that the acceleration of crack propagation and finally the specimen fracture under conditions that are unstable. In this case the critical intensity factor range for the experimental specimen at R = 0.1 ratio was 19.5 MPa √ m.

Fractography Analysis

Figure 4.2 (a, b, and c) shown the fractography (photo of specimens) for mid-level of (3) stages for fatigue specimens tested at the ratio of R = 0.1. All photomicrography, the crack propagation direction is from left to right. From the results of this fractography analysis, it's clearly shown the differences levels of fatigue failure. Below figure (4.2a) show the beginning of the pre-crack, the crack propagation rate was found at the threshold stress intensity factor range for the ratio-R produces a smooth surface texture compared to the immediate fracture of a failure regarding to the crack propagation rate is faster and less stable, producing a rough texture areas (C.C Wigant and R.I. Stephens, 1983). By this stage, there had been no bands are rather weak, shallow valley and the border. While the fatigue crack propagation constant, the texture is a transition between the first and third stage.

The texture is smooth to start cracking is believed to be caused by indentations on the specimen where the initial crack existed at the time the test was conducted. In this area, found the texture of brightly colored, this indicates that the surface is smooth. When the initial crack diagram investigated, found the extrusion. The extrusion processes in the material due to the sliding track. Figure 4.2a, show the extrusion of the material which is cantilevered out from the surface while the extrusion is formed in the shallow channel. This section fractography. figure 4.2 (a, b and c) covers with the photomicrography of fatigue crack growth rate in the ratio R = 0.1 and Δσ = 80 Mpa.

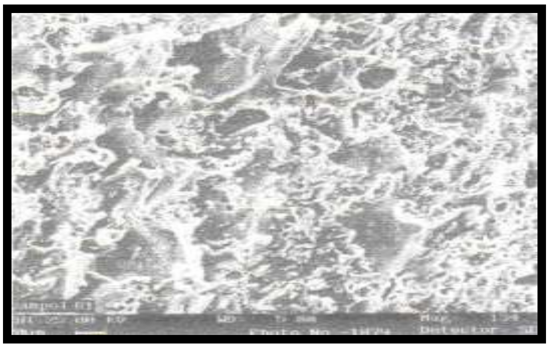

Figure 4.2a: Photomicrography fracture surfaces for the pre-crack

Figure 4.2b: Photomicrography fracture surfaces for crack propagation

Figure 4.2c: Photomicrography fracture surface for catastrophic failure

The next stage is the stage of fatigue crack propagation constant, the second stage of crack propagation process. At this stage the crack propagates stably and complies with the Law of Paris, da / dN. Fractography ratio R = 0.1 showed the formation of a narrow border at the beginning of the crack. The nature of this structure can be easily found at a low rate of crack propagation (CC Wigant and RI Stephens, 1983). Figure 4.2 (b) shows the second stage process of fatigue crack growth that occurred in specimens tested at the ratio of R = 0.1.

Figure 4.2 (c) shows fractography referring to the third stage of the sudden failure. This stage is part of a range of critical stress intensity factor, ΔK_c and rapid crack propagation rate is the ratio of R = 0.1, ΔK_c is 19.5 Mpa$\sqrt{m}$. It was found that the grain boundary is clearly seen that the crack propagates through it causes decreased resistance to fatigue fracture. At this stage also can be seen cracks propagate between the boundaries of dendrites. Eventually cause catastrophic failure occurs rapidly without control. Fractography showed a fracture surface of a shell and a slope due to the shear that occurs in the material.

Conclusions

In this study found that the stress intensity factor range, ΔK increase with increasing da / dN. ΔK low values have a major impact on the da / dN against high ΔK where da / dN increasingly converging. At the threshold ΔK_{th} is inversely proportional to the ratio of-R. Fractography of the second stage showed that there was fatigue striation in which the size and the distance between the lines are dependent on the ratio of fatigue-R. In general, changes in the ratio of R causes a range of stress intensity factor, ΔK changes and fatigue crack growth rate according to the Paris power law was also changed. With this proves that the R-ratio effect is an important factor in determining the fatigue crack propagation rate of a material.

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