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# Analysis of Surface Crack using Various Crack Growth Models

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# Analysis of Surface Crack using Various Crack Growth Models

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**Abstract.** This research focusing on fatigue crack growth experiment and assessments of fatigue crack growth model. Fatigue has been considered as the most important phenomena in the engineering problems. It has been found to occur in every engineering field. Many methods were introduced to overcome fatigue problem. One of it is fatigue crack growth prediction models. Fatigue crack growth model prediction can determine the residual life of the mechanical component. Fatigue crack growth is an important parameter in engineering. It may begin from undamaged area and propagate afterwards. In this case, a mechanical component condition before an unstable crack still can be used until fatigue. With the study of fatigue crack growth, it can predict the crack life of the component and can reduce cost to repair the component. In this thesis, primary objective is to develop, test and provide computational fracture mechanics model that emphasized an uncertainties quantification for surface crack. Fracture and failure study that has been promoted by S-version finite element method is focus on the analysis of the surface-crack problem. In this project, a few limitations of the study have been implemented as to present a specific scope of the investigation. Both fatigue crack growth model is considered; Paris law model and modified Forman model. The specimen in this analysis is aluminium al 2024 T3. The effect of load on the fatigue crack growth rate is investigated on aluminium 2024 T3. It is concluded that modified Forman has a low exponent compared to the Paris law. Further the crack growth prediction based on modified Forman is lower than Paris law. Paris law only can predict the crack in the region II while modified Forman can predict the crack in region II and III. After finish setup the project based on the instruction, the project is proceeded and the data is collected. The result is analysed based on the objective by using data collected from the project. After that, conclusion is made based on the result of the project.

## 1. Introduction

Surface crack which are mostly to be found in mechanical material or structures such as pipelines, aircraft body and building is a very serious matter in the engineering field. It has been recognized to be a potential failure for structures as it can be growth from normal to the worse. For a decade, a study of fatigue crack growth has been a most important subject as it brings a catastrophic failure to the engineering world. The surface cracks of finite thickness plate are subject to distant, bent bending or loading combined is a well-studied component for which the most effort for the surface crack problems so far has been devoted. It has been seen as a substance for the surface crack family.

Fracture mechanics is an analysis that cognate to the presence of the crack in an engineering material. It utilizes analytical solid mechanics methods to calculate the driving force act on the crack and to characterize the material's resistance to the fracture. During 1920, Griffith introduced the concept of fracture mechanics. He proposed that a brittle material contains a population of fine small cracks and flaws that have a variety of size, geometries and orientation [1]. Characterized the response of the material failure by using a quantifiable parameter within the concepts of engineering analysis was the main objective of fracture mechanic. The development of the fracture mechanics has elongated to the nonlinear quandaries with related to the material response and geometrical changes. In the latter case, numerical approaches and the application of software play an important role in predict the crack growth.

The service of the load histories may be completely in random pattern. This issue is either to be simple or repetitive or extreme at the other. In common, the prediction models were published in literature use basic material fatigue data as a reference. This data can be a fatigue limits, fatigue diagrams, crack growth data, stress-life data (S-N), and fracture toughness for the final failure. This prediction model has been utilized for crack growth studies under variable amplitude loading (VA) loading. This model varies from a simple modification that based on constant amplitude (CA) up to the complex models with a detailed description of an applicable fracture mechanism. For example, with an average over-load load spectrum, the crack growth of some prediction models can be calculated while many others tend to calculate by using a cycle-by-cycle analysis.

Although the development of the prediction models is more accurate in this phenomena description, it appears to be no general agreement about the most useful mathematical description. Even today, many engineers still use a simplest prediction models to solve the issue. An alternative to making predictions is to run an experiment for a particular fatigue question when it appears. But it appears that testing is not always possible due to geometry complication, time, costs etc [2]. This is even complicated by the fact that it is not easy to achieve an experimental fatigue conditions that will provide relevant answers to raised questions. Therefore, the whole fatigue life component is generally defined as follows; "Total life = Initiation life + Propagation life".

In a world nowadays, to display every one of the parameters influencing correctly is difficult. It is because of an unsystematic nature of a variable loading VA loading, the complexity of a mechanisms that involved in the FCG problems. Referring to the literature review, there is no universal model that has been indicated to have been developed to analyse the crack growth condition under a VA loading [3]. [3] states that it is difficult to predicting a fatigue crack propagation in metals under a random loading, mostly in particular due to the historical impact of the load, which has been known for a considerable length of time to stave off from plastic deformation in the surrounding area of the crack tip. A single overload could leads to a retardation of a material. While unloading could leads to the appearance of compressive residual stress. As well as, the subsequent of fatigue cycles leads to the complexity of the fatigue problem.

Also, the presence of crack can cause many hazards to the environments. The phenomenon of this cyclic fatigue crack growth is a structure that subject to a cyclic action involving a progressive localized damage, crack and crack propagation. Usually, crack begin to start originally at undamaged areas and then propagate afterwards. This process of crack propagation ultimately leading to the unstable crack growth where scientist would like to avoid.

Thereby, a method is required to complete the details of the crack growth deformation of the material in the surface plate as a model. The objective of this paper is to compare the fatigue crack growth and fatigue life of a specimen by using two different fatigue models.

## 2. Fatigue crack growth model

Fatigue crack growth (FCG) analysis is used to process a set of data for monitoring the crack propagation. It is based on FCG model. The FCG model can be integrated to obtain the crack length and the number of cycles. From initial crack to stable crack growth and initiate to the unstable crack growth region. As a result, there are many equations derived from the study of scientist in this field. Thereby, the FCG models can be used to conduct a FCG analysis if it is in accordance with the conditions of the data properly.

To date there is no universal acceptance for the FCG model. FCG model was developed based on specific factor that arise for every case study. The first model was introduced based on the calculations of the plastic zone size. Then, Willenborg (1971) and Wheeler (1972) came out with their own models. Elber (1972) introduced FCG model based on crack closure approach and has been used to model the crack growth rates under VA loading [4-5]. More example of recent proposals includes a combinations between Wheeler model and Newman crack closure model [6] and the other model which is based on the strain energy density factor [7].

Usually, it is difficult to examine each FCG demonstrate on account of the vast number in the writing. Thereby, the main factor of this section is to discuss which models are rather commonly used or promising. These models are divide into two groups which are fatigue crack growth model that use VA loading as a CA loading and the models which use a VA loading only. In this case, we only discuss about the FCG models for our scope only that is constant amplitude (CA) loading. The FCG models can represent the linear region in FCG graph.

The linear region in FCG graph was known as Paris law. The relation between crack growth rate and stress intensity factor on a log-log scales give a linear relationship. The equation is shown as:

$$\log\frac{da}{dN} = m\log(\Delta K) + \log C \tag{1}$$

When taking out log, it will become:

$$\frac{da}{dN} = C\Delta K^{m} \tag{2}$$

where $a$ is the crack displacement and $\frac{da}{dN}$ is the crack growth rate. The $C$ and $m$ are the fatigue materials constant that depend on the material, environments and stress ratios which acquired by laboratory experiments. $\Delta K$ is the stress intensity ratio of specimen during fatigue cycle.

$$\Delta K = K_{max} - K_{min} \tag{3}$$

Paris law can be used to quantify the remaining life of the specimen that given a particular crack size. Paris law remains an extremely valuable relationship because its cover every range of growth rate and it is most useful to engineering structures, and in light of the fact that an extrapolation into the limit administration gives a preservationist assess for the residual life.

Neither of the model could count for the unstable crack growth when the stress intensity factor approaching the fracture toughness although Walker improved the Paris model by adding the stress ratio. However, Walker model was improved by Forman by creating a new model. This model is able to depicting Region III in FCG graph. As well as the stress ratio effect, it is embedded in Forman model. The Forman model is given by:

$$\boldsymbol{\frac{da}{dN} = \frac{C_F(\Delta K)^{m_y}}{(1-R)K_c-\Delta K} = \frac{C_F(\Delta K)^{m_y}}{(1-R)(K_C-K_{max})}} \tag{4}$$

where $K_C$ is the fracture toughness of the material. In equation 4, it shows that $Kmax$ approaches $K_C$ and $da/dN$ is tends to be infinity. This shows that Forman equation is capable to represent the stable crack growth region (Region II) and the unstable growth rates (Region III). To represent the data for a various stress ratio, the Forman model can be used as follow:

$$Q = \frac{da}{dN}[(1-R)K_C - \Delta K] \tag{5}$$

Forman equation can be applicable and be used if $\Delta K$ and $R$ combinations fall on a stable crack growth (Region II) of log-log plot of $Q$ versus $\Delta K$. By comparing equation 4 and 5, Forman equation can be presented as:

$$Q = C_F(\Delta K)^{m_y} \tag{6}$$

If excluding the crack closure effects, the Forman model can represented as:

$$\frac{da}{dN} = \frac{C(\Delta K)^n}{(1 - \frac{\Delta K}{(1-R)K_c})^q} \tag{7}$$

Forman proposed its modified model for $0 \leq R < 1$ as:

$$\frac{da}{dN} = \frac{C(1-R)^m \Delta K^n (\Delta K - \Delta K_{th})^p}{((1-R)K_c - \Delta K)^q} \tag{8}$$

The Forman equation has an ability of representing the data of various stress ratios for the stable crack growth and unstable crack growth region. Further amendment of the Forman model by including the threshold stress intensity parameter, $\Delta K$ can be shown find in [8] as:

$$\frac{da}{dN} = \frac{C_{HS}(\Delta K - \Delta K_{th})^{m_{HS}}}{(1-R)K_C - \Delta K} \tag{9}$$

As well as another version of the Forman model is shown as follows:

$$\frac{da}{dN} = \frac{C_{MOD}(\Delta K)^{m_{MOD}}(\Delta K - \Delta K_{th})^{0.5}}{(1-R)K_C - \Delta K} \tag{10}$$

## 3. Results and discussion

In Paris prediction model, the value of the material properties which are $C$ and $m$ were taken from the other experimental work. After running the software, the data was collected.

Based on the Figure 1, the crack propagation shows a small propagation at the earlier but increase later. This is because of the Paris law's material constant that acquired by the other experimental work. The constant depends on the material, environments and stress ratios of the specimen. From the crack length of both prediction models, the difference value is too small because of the value of load applied is low. The difference value is in the scale of 0.001mm.

Based on the Figure 2, the graph shows the propagation of the crack growth length based on the modified Forman prediction model. Modified Forman is the one that has been improved from Walker model which taking account of stress ratio of the Paris model. By this result, modified Forman prediction model show a difference between Paris prediction model. In the Figure 2, the crack propagation also starts at 25 mm from width of the specimen and propagate afterwards.

After collected the data and analysed the crack growth length, the data from both fatigue crack growth model then is compared with the other experiment to see the trend of the graph. The comparison graph is from [9].

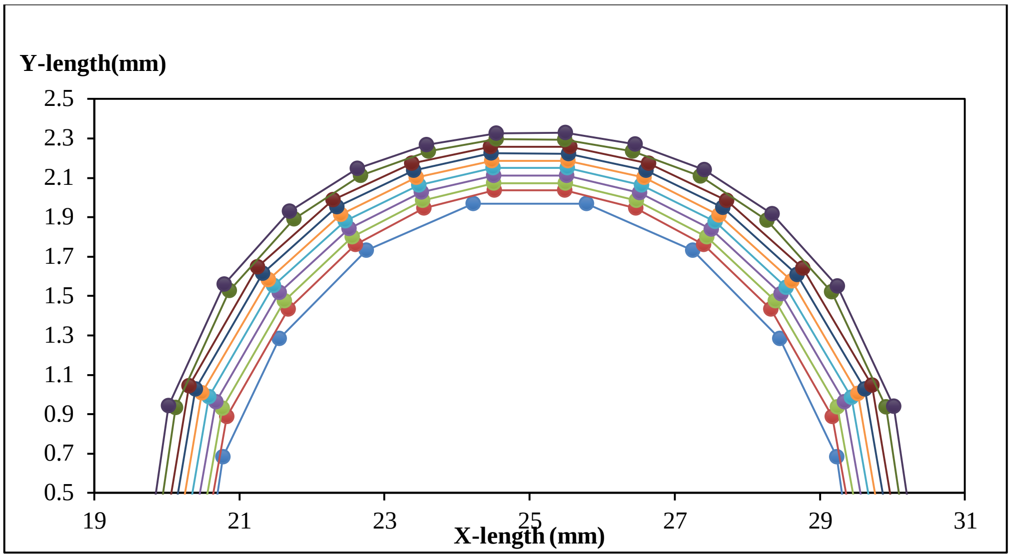


**Figure 1**. Crack growth length graph for Paris law

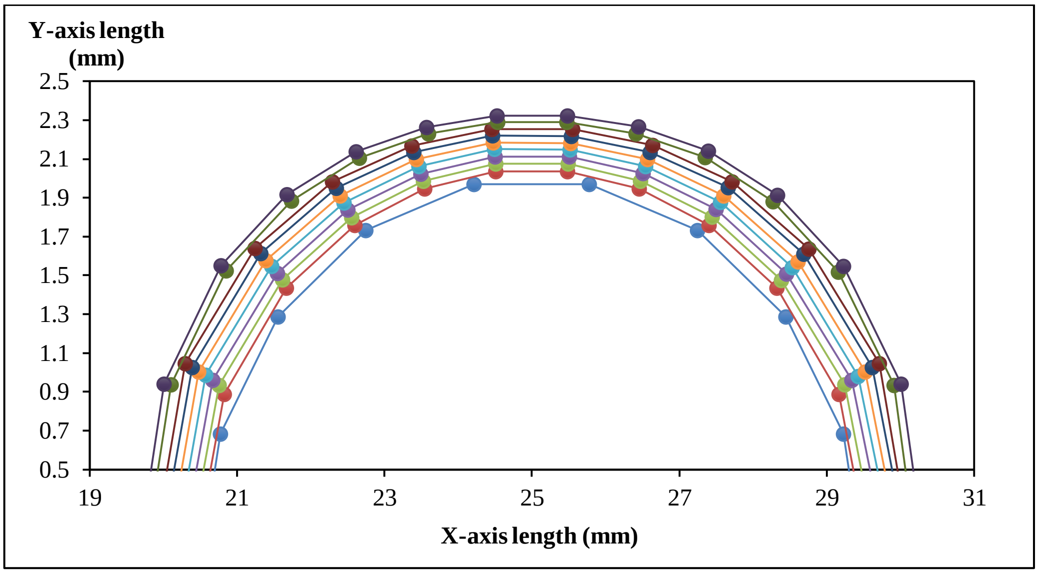


**Figure 2**. Crack growth length graph for modified Forman law

## 4. Conclusion

Two different models have been utilized to foresee the fatigue life on surface crack for the aluminium alloy specimen. The findings showed that the comparisons with the two different models concur with a few inconsistencies identifying with the test data. After comparing the result between reference experimental and simulation, it shows that the modified Forman prediction model can be used for proper fatigue crack growth prediction.

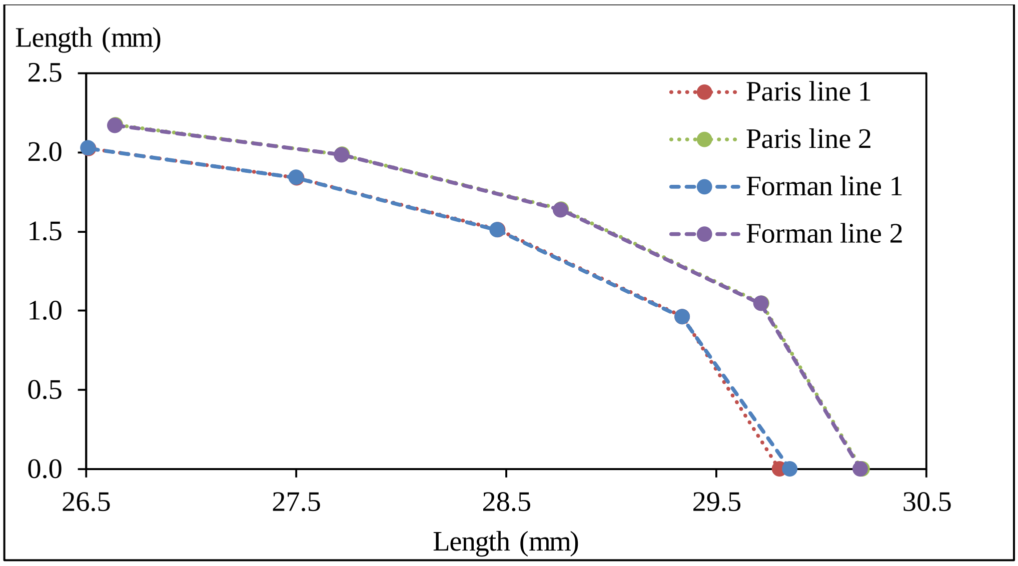


**Figure 3**. Comparison of crack growth length

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