# INVESTIGATE THE EFECTIVENESS OF STOP DRILL HOLE IN DELAYING CRACK FROM CRACK INITIATION

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## ABSTRACT

Many failures in engineering applications or machine components have been caused by a crack initiated from points at which stress was concentrated. As the stress concentration level is higher than a critical value, continuous crack-growth results in failure in the machine components. Crack initiation behavior has been evaluated to prevent an early failure of machine equipment. Delaying the crack initiation is important for the maintenance of machine elements as well as for the detection of crack initiation. Hence, the main objective of this study is to investigate the delay of crack using stop drilled holes. The investigation was based on the diameter of the stop drilled holes, the location of stop drilled hole and the ancillary stop hole drilled. The experiment and selected experiment on finite element analysis were done in order to validate the result. The experiment was carried out by using tensile test to obtain maximum applied load to the specimen while the finite element analysis was analyzed by using ALGOR software to obtain the stress of the specimen.The experimental results and the finite element analysis results show that the crack initiation life of the specimen was longer when the diameter of the stop drilled holes increased. The further the location of the stop drilled holes with the slits location, the longer crack initiation life of the specimen. The influence of extra stop-hole drill increase more time for delaying the crack on the specimen. From the experiment the longest time on delaying crack propagation is 92.32% increase compare before install stop-hole drill gained from Experiment 3. Thus, the influence of the stop drilled holes on the crack initiation life has been proved.

## ABSTRAK

Kebanyakan kegagalan dalam bidang kejuruteraan dan komponen mesin adalah disebabkan permulaan retak yang bermula dari titik pada tekanan yang tertentu. Apabila paras penumpuan tegasan adalah lebih tinggi daripada nilai kritikal bahan, kesinambungan keretakan akan menyebabkan kegagalan dalam komponen mesin. Permulaan retak telah dinilai bagi mencegah kegagalan awal dalam komponen mesin. Melambatkan permulaan retak adalah penting bagi tujuaan penyeliaan elemen-elemen dalam mesin. Maka, objektif utama kajian ini adalah untuk mengkaji kelambatan permulaan retak dengan menggunakan penahan lubang yang ditebuk ke atas besi lembut. Kajian adalah berdasarkan diameter, susunan penahan lubang dan penambahan penahn lubang. Eksperimen dan juga analisis *finite element* yang telah dipilih dijalankan untuk mengesahkan keputusan ujikaji. Eksperimen telah dijalankan dengan munggunakan mesin tegangan untuk mendapatkan daya maksimum yang dikenakan ke atas spesimen manakala analisis *finite element* dianalisis menggunakan perisian ALGOR bagi mendapatkan nilai tekanan yang dikenakan ke atas spesimen. Keputusan eksperimen dan analisis *finite element* menunjukkan hayat permulaan retak lebih adalah lebih lama apabila saiz diameter penahan lubang dititngkatkan. Semakin jauh lokasi penahan lubang dari lokasi belahan, semakin lama hayat permulaan retak. Pengaruh daripada kehadiran ekstra penahan lubang juga meningkatkan lagi masa untuk menahan retak pada spesimen. Daripada eksperimen , masa terpanjang untuk melambatkan perambatan retak adalah 92.32% peningkatan berbanding sebelum menebuk penahan lubang yang diperolehi daripada eksperimen 3. Oleh itu, pengaruh penahan lubang pada permulaan retak telah dibuktikan.

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# LIST OF SYMBOLS

| | |
|---|---|
| $a$ | Crack length, m |
| $\sqrt{a}$ | Material constant |
| $\varepsilon$ | Distance of plastic zone, m |
| $K$ | factor, MPa$\sqrt{m}$ |
| $p$ | Radius of curvature, m |
| $q$ | Notch sensitivities |
| $r$ | Radius of plastic zone, m |
| $\sigma$ | Stress, MPa |

## Subscript

| | |
|---|---|
| $a$ | Stress at the tip of A axis |
| $c$ | Critical stress intensity factor |
| $ij$ | Stress Tensor |
| $f$ | Fatigue notch factor |
| $t$ | Stress Concentration factor |
| $y$ | Yield strength |
| $yy$ | Stress gradient |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AISI | American Iron and Steel Institute |
| ASTM | American Society for Testing Materials |
| FE | Finite Element |
| FEA | Finite Element Analysis |
| FEM | Finite Element Model |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project Background

Many failures in engineering applications or machine components have been caused by a fatigue crack. Any plates that undergoing vibration or the defect on manufacturing of the plates can cause an initiation crack. The fatigue crack initiated from points at which the stress concentrated. Where the stress concentration level is higher than a critical value the crack-growth will grow larger and longer until the plate failed. Thus, introducing repairing method could be useful to arrest the crack-growth before the failure.

A number of investigations have been performed to prolong the fatigue life of the cracked components. The crack repair lies in retarding or arresting the crack propagation, which can be achieved by reducing crack-tip intensity, introducing residual compressive stresses, and reducing crack-tip stress concentrations (Broek, 1986). The reduction of crack-tip stress intensity occurred by crack filling (Song, 1998; Shin, 2000), composite patches (Schubbe, 1999; Baker, 1993) and welding repair (Linnert, 1967). The introduction of residual compressive stresses was through overloading (Novotny, 1986; Vardar, 1988), indentation (Miyagawa, 1985; Song, 2002) cold expansion (Buxbaum, 1987; Ball, 1998) and defence hole drilling (Miyagawa, 1985, Goto, 1996). The reduction of crack-tip stress concentrations was by stop-hole drilling (Ghfiri, 2000).

One of the most popular techniques of arresting fatigue crack propagation was stop-hole method. The stop-hole method is an emergency repair technique that has been employed for a long time to extend the fatigue life of cracked structural components that cannot be replaced as soon as the crack discovered (Broek, 1986; Shubbe, 1999). This classical resource is used in many maintenance crews all over the world since it is relatively inexpensive, simple and fast to apply. In its simplest form, this method consists of boring a hole in the vicinity of, or centred at the crack tip, to transform the crack into notch, increasing in this way the residual fatigue life of the cracked structure in comparison to the life it would have if not repaired.

However, the appropriate modelling of stop-holes drill is not simple. Several parameters can influence the fatigue life increment caused by stop-hole. Among them, at least the radius, the position and the surface finish of hole; the type and the size of the crack; the geometry and the mechanical properties of component; the magnitude of the load; and the residual stresses around the stop-hole border can all influence the effectiveness of the repair.

## 1.2 Problem Statement

Stop-hole drill needs an appropriate way to be model so that can delay propagation of the crack. But there are several parameters that need to be followed to make sure stop-drilled hole effectively delay the crack plate.

## 1.3 Scope Of Study

In this research, the fatigue crack initiation lives prediction of specimen aluminium alloy improving with stop-hole method will be investigate. The initiation cracks will be delayed by diverting the cracks to detour to less important section. This investigations concern to the stop-hole drill method with various techniques applied. The techniques that will be studies are the improvement of fatigue life of mild steel with different type of diameters of stop-hole. Besides that, the location of stop-hole drill will also determined as one of the factor influence in improvement of fatigue crack of specimen. Also the study focuses on the effectiveness of providing additional holes or ancillary holes following the drilling at the crack tips. The effectiveness of thus techniques will be developed by doing an experiments using tensile machine.

## 1.4 Objectives Of the Project

The objectives of the research are to investigate the effectiveness with appropriate techniques of stop-hole to delay the crack line from crack initiation by;

1. Suitable diameter of the stop-hole drill.
2. Suitable location for the stop-hole drill.
3. Application of additional hole following the stop-hole drill at the crack tip.

## 1.5 Summary

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project on the effectiveness of the stop-hole drill in enhancing the fatigue crack life of material. This chapter is as a fundamental for the project and act as a guidelines for project research completion.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

The purpose of this chapter is to provide a review of past research efforts related to crack behaviour, factor influencing crack initiation, stop-hole drilled and also finite element analysis. A review of other relevant research studies is also provided. Substantial literature has been studied on stress history computation, techniques of arresting crack using stop-hole drill, and fatigue life prediction after introducing stop-hole drill. However, little information can be found on integrated durability evaluation methods. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort. The review is detailed so that the present research effort can be properly tailored to add to the present body of literature as well as to justly the scope and direction of present research.

## 2.2 Crack

A fracture happen when an object is separate into two or more pieces under applied of stress. A crack say to accompany fracture which the crack propagates through the material that end up separate the material into two pieces. Crack properties are different for ductile material and brittle material. In ductile material, cracks slowly propagate through material and it is accompanied with large plastic deformation. The crack will stop unless extra stress is applied. For brittle material, crack is spreading fast with no plastic deformation. The crack that propagates in brittle material will continue to grow once they are initiated (Anderson, 2005).

### 2.2.1 Concept of Fracture Mechanic

#### 2.2.1.1 Crack modes and stress intensity factor

There are three types of loading that a crack can experience, as shown in Figure 2.1.

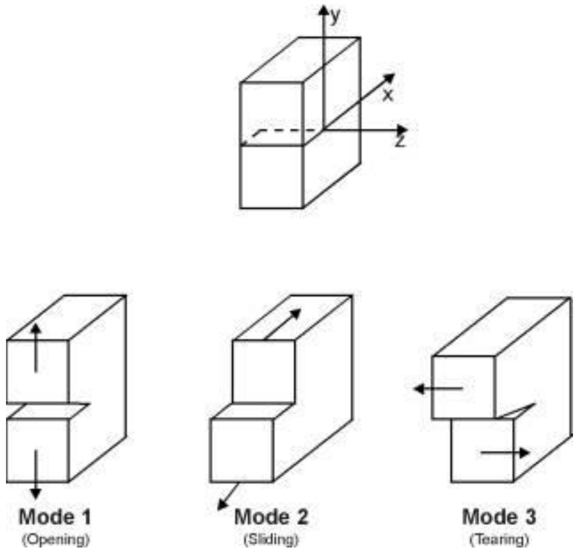


**Figure 2.1**: Three modes of loading that can be applied to a crack

Source: Anderson T.L 2005

A tensile stress field gives rise to mode 1, the opening crack propagation mode. Mode 2 is the sliding mode, which due to in-plane shear and mode 3 is tearing mode, which arises from out-of-plane shear. In this experiment we will only consider the mode 1, since it is common in practice and crack behaviour almost related to mode 1.

In study of crack, stress intensity factor plays a big role that take account the stresses in the vicinity of crack tip. If the quantity reaches its critical values, crack will initiates (Khoshravan, 2007).Irwin (1957) (Irwin, 1957) research found a method of calculating the stress field in any linear elastic cracked body if polar coordinate axis with the origin at the crack tip was define. The equation is given by

$$\sigma_{ij} = \frac{K_I}{\sqrt{2\pi r}} f_{ij}^{\alpha}(\theta) \tag{2.1}$$

where $\sigma_{ij}$ is stress tensor, $r$ is the distance from the crack tip, $\theta$ is the angle with respect to the plane of the crack, and $f_{ij}$ are functions that are independent of the crack geometry and loading conditions. Irwin called constant $K$ as stress intensity factor. Since $f_{ij}$ is dimensionless units , stress intensity factor, $K_I$ has units of stress.$\sqrt{\text{length}}$ .( MPa-$\sqrt{\text{m}}$.). Since experiment is conducted only stress on tensile field, calculation taken only on mode 1 crack, the opening crack propagation mode is taken. The equation is given as

$$K_I = \lim_{r\to 0} \sqrt{2\pi r}\,\sigma_{yy}(r,0) \tag{2.2}$$

Equation 2.2 can written as

$$K_I = \sigma\sqrt{\pi a} \tag{2.3}$$

Broek (Broek, 1972) then derive relationship between stress intensity factor and crack length:

$$K_I = F\sigma\sqrt{\pi a} \tag{2.4}$$

$F$ is the correction factor of $K_I$, which is given in the different forms by researchers. Since our specimen is initially crack at the edge of the plate, the correction factor of specimen must be considered. The edge of the crack can be obtained by slicing the plate in Figure 2.2 through the middle of the plate.

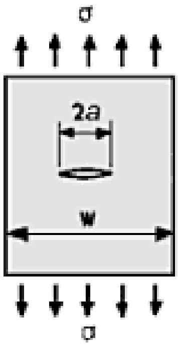


**Figure 2.2**: Centre cracked plate

Source: Michael Janssen

The stress intensity factor for the edge of the crack is given by

$$K_I = 1.12\sigma\sqrt{\pi a} \tag{2.5}$$

which increase by 12% increase in $K_I$ for the edge of the crack that cause from different boundary conditions at the free edge. Further study by Tada (Michael) is related to our test specimen shown the calculation of double edge notched plate given as

$$K_I = \left[1.12 - 0.43\left(\frac{a}{W}\right) - 4.79\left(\frac{a}{W}\right)^2 + 15.46\left(\frac{a}{W}\right)^3\right]\sigma\sqrt{\pi a} \tag{2.6}$$

which a and W can be measure as shown from Figure 2.3

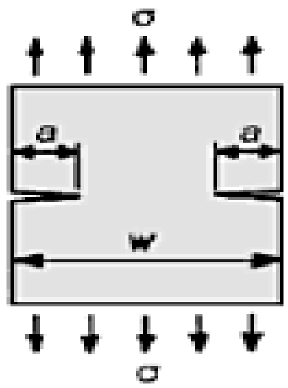


**Figure 2.3**: Double edge notched plate

Source: Michael Janssen

### 2.2.1.2 Plastic zone at the crack tip

Plastic zone exist in the vicinity of crack tip for an elastic plastic material with yielding stress ($\sigma_y$) which follows the maximum yield stress criteria. M.R Kshorsravan (Khoshravan, 2007) state that inside the plastic zone, there is a bearing zone which appear at the time the crack initiation. There is also an elastic zone outside the plastic zone which has greater area than the plastic zone. The plastic zones are depending on the thickness of the specimen, the crack length and strain rate. Figure 2.4 shows the location of the bearing, electro-plastic and elastic zones at the crack tip.

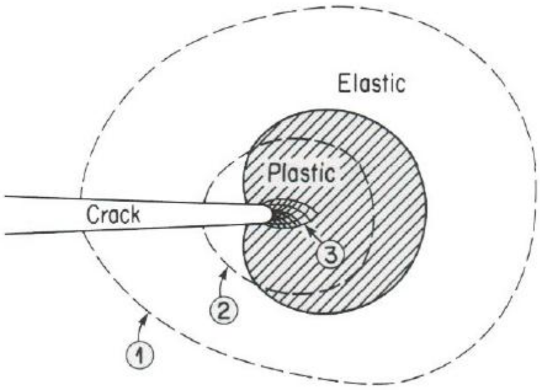


**Figure 2.4**: Three bearing, elasto-plastic and elastic zone in the crack tip

Source: Li.H, 2003

The size of the crack-tip-yielding zone can be estimated using Irwin approach. To estimate the extent of the plastic deformation, Irwin equated yield strength to the y-direction stress along the x-axis and solved the radius. For the plane stress state, the radius of the plastic zone is:

$$r = \frac{1}{\pi}\left(\frac{K}{\sigma_y}\right)^2 \tag{2.7}$$

In the plastic zone strain state, yielding is suppresses by the tri-axial stress state, and the Irwin plastic zone correction is smaller by factor of 3:

$$r = \frac{1}{3\pi}\left(\frac{K}{\sigma_y}\right)^2 \tag{2.8}$$

### 2.2.2 Factors influencing crack initiation behaviour

Crack initiate when the material come to its limit of yield stress. When the applied stress is more than material yield stress, crack will initiate. There are two main factors that influence the crack initiation behaviour that are stress concentration factor, $K_t$ and fatigue notch factor.

#### 2.2.2.1 Stress Concentration factor $K_t$

Stress concentration is a location in an object where stress concentrated. An object is strongest when force is evenly distributed over its area, so a reduction in area for example caused by a crack, results in a localized in stress. Material will fail when the crack propagated cause from exceeding stress concentration of the materials theoretical cohesive strength. Fatigue cracks always start at stress concentration, so removing such defects increases the fatigue strength. Inglis (Inglis, 1913) have provided a quantitative evidence for the stress concentration effect of flaws, analyzed elliptical holes in flat plates. His analyses included an elliptical hole 2a long by 2b wide with an applied stress perpendicular to the major axis of the ellipse (Figure 2.5).

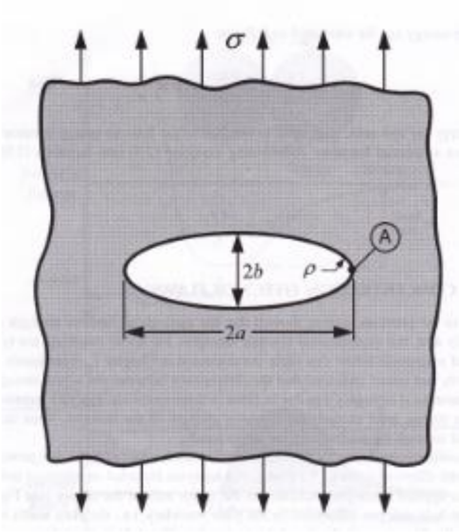


**Figure 2.5**: Elliptical hole in a plate

Source: Michael Janssen

The stress at the tip of the major axis (which is point A) is given by

$$\sigma_a = \sigma\left(1 + \frac{2a}{b}\right) \quad (2.9)$$

The ratio $\sigma_a/\sigma$ is defined as the stress concentration factor, $K_t$ . Then Inglis found more convenient to express equation 2.9 in terms of radius of curvature $\rho$:

$$\sigma_a = \sigma\left(1 + 2\sqrt{\frac{a}{\rho}}\right) \quad (2.10)$$

Where

$$\rho = \frac{b^2}{a} \quad (2.11)$$

For delaying crack, we must design the geometry to minimize stress concentrations. The geometry can be achieve by drill hole with relatively large diameter causes a smaller stress concentration then a sharp end of crack.

**2.2.2.2 Fatigue notch factor**

The effect of notches on the fatigue life is accounted for by the fatigue notch factor, $K_f$ , which depends on not only notch geometry and loading modes but also on material types, and its follows the Peterson expression (Peterson, 1959).

$$K_f = 1 + \frac{K_t - 1}{1 + \sqrt{a/r}} \quad (2.12)$$