Evaluation of Kerf as a Crack Arresting Method

by

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LIST OF ABBREVIATIONS

2D	Two dimensional
3D	Three dimensional
ASTM	American Society for Testing and Material
CAD	Computer Aided Design
CAE	Computer Aided Engineering
COD	Crack Opening Displacement
CT	Compact Tension
ESDU	Engineering Science Data Unit
FE	Finite Element
FEA	Finite Element Analysis
LEFM	Linear Elastic Fracture Mechanic
SCF	Stress Concentration Factor
SEC	Single Edge Crack
SIF	Stress Intensity Factor
WEDM	Wire Electric Discharge Machine

LIST OF SYMBOLS

A	Area
a	Crack length
a1	Secondary crack
a2	Primary crack
2a	Half crack length
2b	Half crack length for secondary crack
d	Distance between kerf and crack
d1	Diameter of stop-hole
d2	Diameter of ancillary holes
h	Vertical distance
da/dN	Fatigue crack growth rate
E	Young Modulus
J	J-integral
K	Stress Intensity Factor
ΔK	Stress Intensity Factor range
s22	Stress in horizontal direction
Y	Dimensionless parameter geometry function
W	Width
σ	Stress
σ_{yy}	Stress normal to the crack
σ^{∞}	Normalised stress
σ_{max}	Stress at crack tip
σ_{reff}	Stress applied
v	Poisson ratio
θ	Degree of crack growth
r	Plastic zone size
T	Width
Q	Global displacement vector
F	Global load vector
X	Direction
T_i	Traction vector compound
Γ_0	Inner integral
Γ_1	Outer integral
Γ_{+-}	Upper or lower integral
ρ	Minimum effective notch tip radius
τ_{xy}	Shear stress
F_0	Correction factor
m_i	Weight function in mode 1
P	Pressure applied
R^2	Accuracy of equation
S	Standard error

Penilaian Kerf Sebagai Kaedah Penangkapan Retak

ABSTRAK

Kajian ini membentangkan kerka penyelidikan menggunakan kerf sebagai kaedah menahan retak dalam analisis mekanik patah. Kerf adalah pemotongan celahan dengan proses pemesinan dan ia boleh mencontohi interaksi retak dan menurunkan Faktor Keamatan Tegasan (SIF) dengan mengganggu aliran tekanan berhampiran hujung retak. Objektif utama kajian ini adalah untuk menilai kerf sebagai penahan retak dengan menggunakan perisian Analisis Unsur Terhingga (FEA). Ujian makmal menggunakan mesin ujian lesu telah dijalankan untuk mengesahkan penemuan. Kerja ini menggunakan kajian berparameter untuk membangunkan model Unsur Terhingga (FE) dengan pelbagai geometri iaitu nisbah kerf terhadap nisbah retak (*b/a*), nisbah retak terhadap lebar (*a/W*) dan nisbah jarak antara Kerf-retak dan lebar (*d/W*). Model FE terlibat dengan spesimen yang mengandungi retakan tepi tanpa sebarang kerf dan spesimen yang mengandungi retakan tepi bersama dengan empat konfigurasi kerf yang berlainan. Konfigurasi yang ditetapkan ialah kerf pinggir tunggal, kerf pinggir dua, kerf pusat tunggal dan kerf pusat dua. Konfigurasi dipilih berdasarkan anggaran kedudukan kerf terbaik untuk mengganggu pengedaran tegasan berhampiran ujung retak. Hasil FEA berdasarkan pengurangan peratusan SIF dibandingkan dengan model FE tanpa kerf. Keputusan menunjukkan konfigurasi terbaik kerf adalah kerf pinggir dua dua kerf yang menghasilkan pengurangan maksimum SIF sebanyak 34.3%. Model FE tambahan yang memberi tumpuan kepada dua kerf pinggir terus dilakukan untuk mendapatkan hasil yang lebih tepat. Ia dapat disimpulkan bahawa pengurangan maksimum SIF didapati apabila *d/W* = 0.15, *b/a* =0.9 dan *a/W* = 0.15. Persamaan matematik untuk mewakili graf tidak lurus untuk peratus pengurangan SIF maksimum dengan nisbah retakan panjang dan lebar, kemudian dibangunkan menggunakan kaedah lengkung padan. Persamaan matematik berdasarkan model regresi Hoerl paling sesuai untuk model tidak lurus ini. Hasil eksperimen berdasarkan geometri terbaik menunjukkan peningkatan dibandingkan dengan spesimen tanpa kerf (10800 kitaran). Hasil daripada kajian makmal menunjukkan kerf terpanjang (*b/a*= 0.9) menunjukkan keputusan terbaik (34900 kitaran). Sedikit pengubahsuaian terhadap spesimen dilakukan dengan memperkenalkan lubang berhenti di hujung kerf kerana permulaan keretakan baru berlaku di hujung kerf. Keputusan untuk spesimen yang diubah rekabentuk adalah lebih baik daripada rekabentuk asal dengan 88000 kitaran dengan *b/a*= 0.9.

Evaluation of Kerf as a Crack Arresting Method

ABSTRACT

The study presents research work using kerf as a crack arresting method in Fracture Mechanics analysis. Kerf is a slit notch cut by machining process and it can emulate the crack interaction and able to lower the Stress Intensity Factor (SIF) by disturbing the stress flow near the crack tip. The main objective of this thesis is to evaluate the kerf as a crack arresting method using Finite Element Analysis (FEA) software. An experiment using fatigue test machine was conducted to verify the finding. Parametric studies were performed using FE model with various geometries consist of kerf to crack ratio (*b/a*), crack to width ratio (*a/W*) and distance between kerf-crack to width ratio (*d/W*). The FE model involves a specimen that contains an edge crack without any kerf and a specimen which contains an edge crack together with four different configurations of kerf. Four types of configuration were used which are single edge kerf, double edge kerf, single central kerf and double central kerf. The configuration was chosen based on the estimation of best kerf's position to disturb the stress distribution near the crack tip. The results of FEA are based on percentage reduction of the SIF compared to the FE model without kerf. Results show that the best configuration of kerf is double edge kerf which produces maximum SIF reduction of 34.3%. Additional FE models which focused on double edge kerfs were further performed to obtain accurate results. It can be concluded that maximum SIF reduction occurs when the *d/W*=0.15, *b/a*=0.9 and *a/W*=0.15. Mathematical equation to represent non-linear graph of maximum SIF reduction with respect to crack length to width ratio is then developed using curve fit method. Mathematical equation based on Hoerl regression model is best fit for this non-linear model. Experimental results based on the best geometries showed an improvement compared to specimen without kerfs (10800 cycles). The results show that the double edge kerf specimen with the longest kerf (*b/a*= 0.9) yield the best result (34900 cycles). Slight modification to the specimen was performed by introducing a stop hole at the kerf tip due to new crack initiation occurring at the kerf tip. The best result for stop-hole is better than the no stop-hole design with 88000 cycles when *b/a*= 0.9.

CHAPTER 1 : INTRODUCTION

1.1 Research background

The theory for the understanding of crack is based on theories of fracture mechanics. Fracture mechanics is a failure theory of study which gives special care for the growth of the crack by using the displacement and material parameter (Roylance, 2001). Then, Linear Elastic Fracture Mechanics (LEFM) is a theory that provides understanding of fracture mechanics in the aspect of material, stress, and deformation fields at the crack tip (Zehnder, 2012). Fracture or fatigue of structural failures happen because of the behaviour of the stress and strain subjected to the cracked bodies but depend on the strength of material to pass the plastic deformation.

Each design and structure contains flaws or defects because of the negligence during the design process or continuous loading (Annigeri, 1990). Cracks are one of the flaws or defects of a design and structure that can be harmful to human and nature. Other than that, cracks are natural phenomenon defects because of cyclic fatigue loading towards to the structures that can be continuously growing because of the stresses at the crack tip. Figure 1.1 shows that the cracked region at the crack tip where the highest Stress Intensity Factor (SIF) occurs and will grow depending on the load on it. The symbol r, a, and θ in Figure 1.1 represent plastic zone size, crack length and degree of crack growth, respectively.

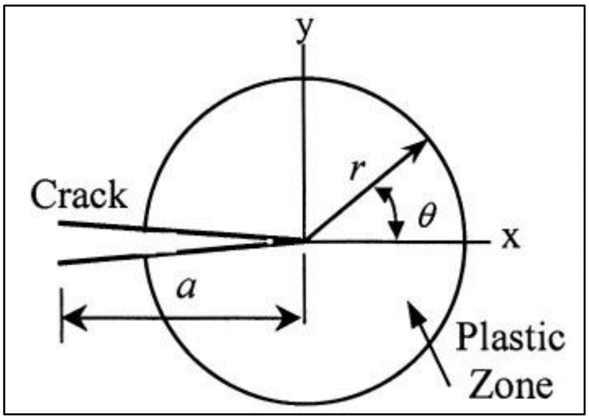

Figure 1.1: Crack tip region (Perez, 2004)

Meanwhile, kerf can also be considered as a crack because kerf is a slit notch on a body and the kerf is easily fabricated by using cutting precise machining (Tosun, Cogun, & Tosun, 2004) such as Wire Electrical Discharged Machining (WEDM), laser machining and water jet. The differences between crack and kerf are crack is a natural phenomenon and kerf is produced by the machining process, and the gap or seam which is cracked has very close discontinuity, while kerf has bigger discontinuity. Figure 1.2 shows the fabrication of the kerf, the width of cut part is the kerf width produced using WEDM.

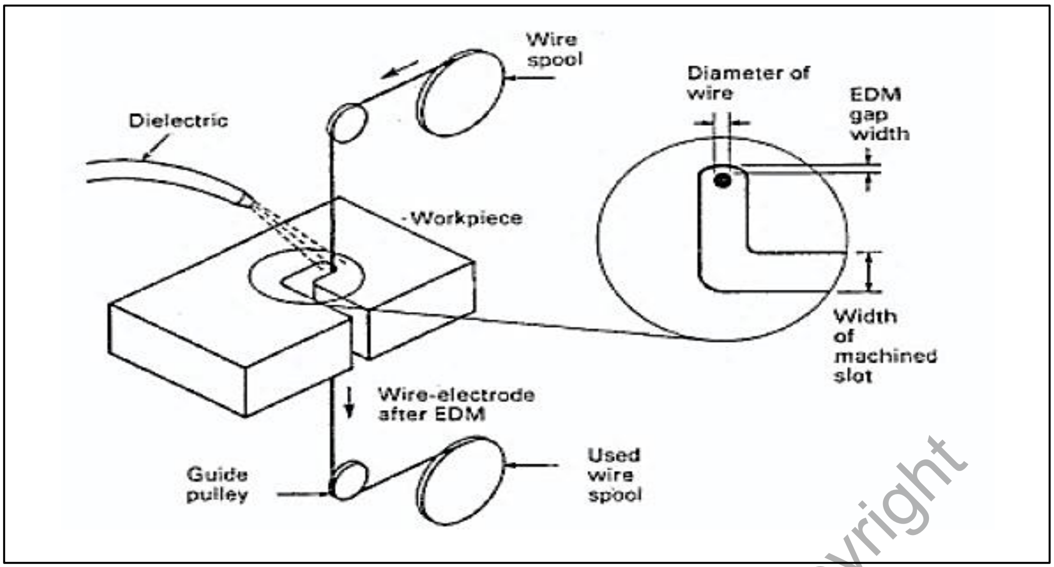

Figure 1.2: Fabrication of kerf by using Wire Electrical Discharged Machining (WEDM) (Selvam & Kumar, 2017)

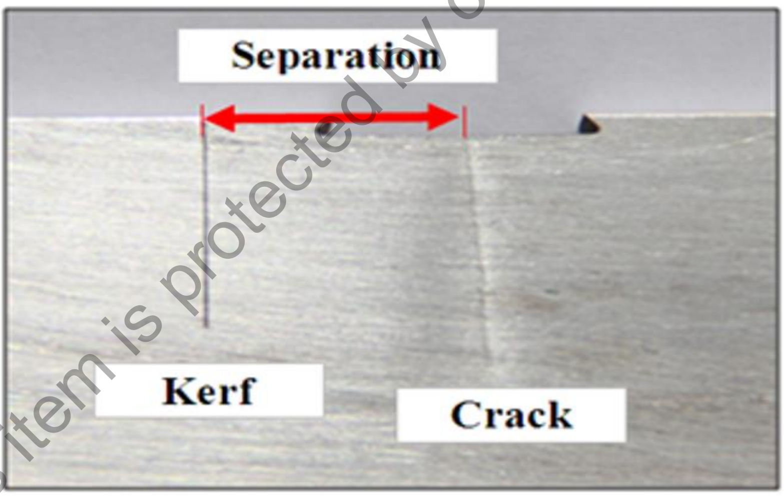

Figure 1.3: Fabrication of kerf on plate (Annuar, 2015)

Figure 1.3 shows the fabrication of kerf on the plate on the Fracture Mechanic analysis in a study by (Annuar, 2015). The author had conducted a study on Fracture Mechanics analysis of multiple edge cracks in a finite plate by using kerf to emulate crack interaction. The main objective is to replace the edge crack with kerf by comparing them using non-uniform stress distribution in Finite Element Analysis (FEA) and weight function. The result of study shows the decrease of SIF at the crack tip with the presence of the kerf leads to slower crack growth.

1.2 Problem statement

Crack growth due to cyclic load being applied on the crack body results in large stress at the crack tips. Reducing the stress at the crack tips can slow down the crack growth by adding another crack, but there will be some complicated laboratory procedures (Manan, 2008). Annuar, (2015) has replaced the secondary crack with kerf in his study to emulate crack interaction. Later research work (Azamudin, Manan, Annuar, Firdaus, & Leong, 2018) showed that the kerf can prolong the crack cycle. Then, the kerf can be recognised as one of crack arrestor mechanisms. However, there is limited information on how well the kerf reacted on other lengths and types of cracks. Configuration of kerf should be studied well to provide the best effect on the crack body. Mathematical equation should be applied to kerf as a crack arrestor mechanism to examine how kerf reacts on the crack body. Furthermore, the data collected from FEA should be validated through experimental processes to verify the correlation between theoretical and experimental results.

1.3 Objective

The main objective of this research is to evaluate kerf as a crack arrestor for fracture mechanics analysis by using FEA tools. The specific objectives of this research are outlined as below:

a) To determine the optimum geometry of kerf as a crack arrestor using FEA in software (Abaqus).
b) To express mathematical equation that represents the configuration of kerf as a crack arrestor.
c) To validate the FEA results using experimental fatigue testing and to further improve to acquire better findings.

1.4 Research question

The main objective of this study is to evaluate the kerf as a crack arrestor but the specific factor that impact the crack life cycle still unknown. The research question is detailed as below:

a) To what extend can kerf reduce the SIF value at the crack tip?
b) What are the parameters of kerf that must be considered?
c) What is the best configuration of kerf geometries that is able to produce highest crack interaction (arresting a crack)?
d) What are the most accurate types of mathematical equation that can represent kerf as a crack arrestor?

1.5 Research scope

The scopes of the research are as follow:

a) Using two-dimensional model in finite element as specimen and modelled in CAE package software.
b) The analysis is only cover mode 1 (crack opening) and under tension loading condition.
c) Only single edge crack be considered with additional of either edge kerf or central kerf.
d) The load applied for specimens are only under tension and only focus on the best configuration of kerf as crack arrestor.
e) Two types of validations be used. (1) Validation of equation based on the accuracy of the plotted line in the graph. (2) Experiment of fatigue testing using best configuration of kerf be conducted and compared with FEA and specimen without kerf.

1.6 Significance of study

The main objective of this study is to introduce the kerf as a crack arresting mechanism in edge crack body. Kerf is widely used in woodworking but there is still limited study on kerf interactions with other materials. Furthermore, the contribution of this study is to improve the knowledge about kerf as an alternative to edge crack interaction and to add the kerf as a crack arresting mechanism in LEFM. This is due to the fact there is no specific mathematical equation to counter the problem of the kerf as a crack arrestor and this research extends the specific geometries details of kerf.

In addition, there are a few existing crack arresting methods and this study will contribute by introducing an alternative method for crack arresting mechanism. Most of crack arresting study before consist of stop-hole method and welding method, but these methods are not suitable for all situations.

1.7 Thesis outline

There are five chapters to cover the research arrangement in the research. The arrangements are:

a) Chapter 1, contains research background, problem statement, objective, research questions, scopes and significant study of kerf as a crack arrestor.
b) Chapter 2, discusses the literature review based on the previous study to support the research work.
c) Chapter 3, shows the methodology of the research that is employed in order to complete the research work.
d) Chapter 4, discusses and analyses the results of the FEA, mathematical equation, and fatigue test.
e) Chapter 5, summarize the overall research findings and some recommendations for future works related to the kerf as a crack arresting method.