Evaluation of Kerf as a Crack Arrestor in a Plate under Tension Loading using FEA

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Abstract. Crack arrestor means to prolong the life cycle of the crack. There are many methods has been studied to arrest crack but the use of a kerf as a crack arrestor has not been widely studied. Initial study has stated that the value of SIF at the crack tip can be reduced with the presence of the kerf in the same body, but detail dimension of the kerf that will produce best arresting effect is unknown. The finite element analysis was used to model the finite plate which contains different kerf geometries and a crack to obtain crack’s tip stress intensity factor. Four types of kerf’s configuration have been considered which are: single central kerf, double central kerf, single edge kerf and double edge kerf. Each type used different kerf’s geometries selection that is predicted will produce higher kerf-crack interaction. The results of SIF were calculated as a percentage reduction when compared to SIF of a single edge crack without any kerf. Results show double edge kerf type is the most suitable for crack arrestor. Maximum percentage SIF reduction of 34.27% can be achieved when the crack is the shortest and separation to width ratio equal to 0.1. If the longer crack is detected on a structure, highest percentage SIF reduction can be achieved by fabricating maximum kerf length with separation to width ratio in the range of 0.15 and 0.25.

1. Introduction
One of the crack arresting methods in fracture mechanics is by using kerf fabrication parallel to an edge crack. The introduction of the kerf reduces the fatigue crack growth rate at the early stage and increase its fatigue life cycles. This is based on fatigue test study [1] that has been conducted using specimens with an edge crack and a kerf under tension loading. The presence of the kerf reduces the stress intensity factor (SIF) of the crack tip and thus retards the crack growth rate. This is due to the kerf-crack interaction which produces similar shielding effect near the crack tip as the crack-crack interaction [2]. The advantage of using kerf is it can be easily machined near the crack region such as by using wire electrical discharge machine (WEDM) [3]. The early experimental study of crack arrestor using kerf [1] has been completed but detail dimension of the kerf that will produce best arresting effect is not clear. It is important to study the sizes and configuration of kerf that will produce best solution for crack arresting method. Therefore, the main objective of this study is to find the best dimension and configuration of a kerf as a crack arrestor using finite element analysis.

Kerf is a slit or a gap that produced when the amount of material is removed by machining tool including its tool cutting tolerance [1]. Figure 1 shows how the kerf fabricated by using Wire cut Electrical Discharge Machine (WEDM). Crack arrestor is a mechanism that used to prolong the life...
cycle of crack and total fatigue in the crack body [4]. There are many methods to arrest the crack growth in metal, such as drilling (stop-hole), welding, routing and sealing, and stitching [5].

Most of the analysis which relate to the cracks in a body will apply the theories of Linear Elastic Fracture Mechanics (LEFM) [6]. LEFM assumes that linear elastic theory can be applied to bodies containing cracks even though a plastic zone exists at the crack tip. Crack grows in the body due to the increase of the stress at the crack tip called Stress Intensity Factor (SIF) and the energy release at the crack tip [7]. The higher the value of SIF means the higher chances of crack will grow depending on its life cycle.

The study of kerf-crack interaction [8] demonstrated that the value of SIF is decreased when kerf is added to the crack body. This study shows that the kerf is also can be considered as one of the crack arresting method. Meanwhile, this finding is also supported by the study of crack-crack interaction [9]. The study demonstrated the crack interaction produces shielding effect which reduces the stress normal to the crack surface.

It is predicted that the crack interaction disturbs the stress flow when passes near the crack tip. The presence of another crack or kerf parallel to the crack will divert this stress flow away from the crack tip. Two types of kerf’s configurations were considered in order to divert this stress flow which is edge kerf and central kerf as shown in Figure 2. Figure 2 (a) shows the stress flow around the edge crack. The stress contour near the crack tip is closely distributed. Figures 2 (b) & (c) show the stress flow near the crack tip is slightly diverted. This phenomenon will reduce the SIF value as it depends on the
stress value at the crack tip. Therefore, the work focuses on these two major types of kerf geometries as a basis for its configuration. Another modification for each type is by introducing another parallel kerf so that it will have two similar kerfs. The purpose is to ensure smooth and stable stress flow diversion.

2. Methodology

This research is mainly used finite element analysis software to model different types of specimens to obtain their SIF values. The package software used in this study is Abaqus [10]. Mild steel with yield strength of 210 MPa was selected as a material. An experiment was conducted to obtain actual size of the kerf such as its gap and diameter at the kerf tip. Ten samples of thickness 4 mm were cut using WEDM using wire diameter of 0.25 mm and measured with microscope.

Every FE model has an edge crack followed by different types of kerfs. There are four types of kerfs that were used in the FE model: single edge, double edge, single central, and double central. Figure 3 shows the FE model for double edge kerf and double central kerf. Single edge kerf and single central kerf have only one kerf as highlighted in Figure 2. The design of the specimen for FE model follows the ASTM standard [11]. Initially the FE models without any kerf were run using FEA to obtain their SIF values. SIF values for the 5 FE models with different crack to width ratio a/W, are shown in Table 1. The SIF values were used as a reference for comparison with FE models that contain kerf. The parameter of the FE models used for the edge and central kerfs are shown in Table 2.

Figure 4 shows the flowchart to complete all types of FE models for FEA. To get the accurate result in package software, the domain integral method [12] was used to get the value of SIF at the crack tip. This is because domain integral using area instead of line as for contour integral method [13]. The pressure value of 150 MPa was applied as a tensile stress. The model was partitioned and meshed using quad normal type but at the crack tip region sweep mesh was used to ensure accuracy of the FEA results. Each model was submitted and run using the FEA software. The FE model will be modified if an error occurs during the process. The SIF values of the successful model were recorded for analysis.

| Crack length, a/W | Stress intensity Factor, MN/m²²/2 |
|-------------------|----------------------------------|
| 0.1               | 15.75                            |
| 0.2               | 23.57                            |
| 0.3               | 37.92                            |
| 0.4               | 55.59                            |
| 0.5               | 83.14                            |

| Crack length, a/W | Kerf length, b/a | Distance between crack and kerf, d/W |
|-------------------|------------------|-------------------------------------|
| Central           | Edge             |                                     |
| 0.1               | 0.20             | 0.5                                 |
| 0.2               | 0.25             | 0.6                                 |
| 0.3               | 0.30             | 0.7                                 |
| 0.4               | 0.35             | 0.8                                 |
| 0.5               | 0.40             | 0.9                                 |

Table 1. SIF value for single edge crack.

Table 2. Parameter for FE models for all types of kerfs.
**Figure 3.** Finite element model for (a) double edge kerf, and (b) double central kerf.

**Figure 4.** Summary for FEA flow using different FE models.
3. Results and Discussion

The main result in this study is the value of SIF at the crack tip with the presence of the kerf. The results of SIF were calculated as a percentage reduction when compared to SIF of a single edge crack without any kerfs. Table 3 summarizes maximum percentage SIF reduction obtained from each type of kerf from all parameters in Table 2. Obviously, the use of double edge kerf produces the highest SIF reduction. Figure 5 shows deformed and underformed of the FE model for the double edge kerf model. Figure 6 shows results of percentage SIF reduction versus kerf to crack ratio, b/a for various separation to width ratio, d/W and crack to width ratio, a/W values. All figures show similar trend where the percentage SIF reduction increases as the kerf length increased. All results shows highest SIF reduction can only be achieved at maximum kerf to crack length ratio (b/a = 0.9). This is the maximum possible b/a value that can be modelled as beyond 0.9, the new crack will initiate and propagate from the kerf’s tip instead of at crack’s tip [1].

The most significant result is for the case of shorter crack length (a/W = 0.1) as shown in Figure 6(a). The maximum result is when d/W equal to 0.1 with 34.27% reduction. SIF reduction becomes less significant when the crack length is the longest (a/W = 0.5) as shown in Figure 6(e). This is because at longer crack the SIF will increase rapidly as it is closer to fracture phase. Figures 6(b)-(d) show that highest SIF reduction for other a/W values can be achieved using d/W values in the range of 0.15 and 0.25.

Table 3. Maximum SIF reduction values for all types of kerf.

| Type of Kerf     | Maximum SIF reduction, % |
|------------------|---------------------------|
| Single central   | 22.07                     |
| Double central   | 29.9                      |
| Single edge      | 16.94                     |
| Double edge      | 34.27                     |

Figure 5. Double edge kerf model.
4. Conclusions
A presence of kerf in the crack body would be reducing the value of SIF value at the crack tip. The best method of using kerf as a crack arrestor is by fabricating double edge kerf parallel to the edge crack. Maximum kerf length (b/a =0.9) needs to be used as it will produces good kerf-crack interaction. Maximum percentage SIF reduction of 34.27% can be achieved when the crack is the shortest and separation to width ratio, d/W equal to 0.1. If the longer crack is detected (a/W = 0.2, 0.3 & 0.4) on a structure, highest SIF reduction can be achieved by fabricating maximum kerf length with d/W in the range of 0.15 and 0.25.

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