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The Reduction of Stress Concentration at a Crack Tip Using Multi Stop-Drilled Hole (MSDH)

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ABSTRACT

A new shape of stop-drilled hole is proposed in which triple stop-drilled holes called Multi Stop Drilled Hole (MSDH) are drilling at the crack tip. The main objective of the proposing method is to reduce stress concentration at the edge of the stop holes. Reducing the stress concentration factor at the crack tip is the main issue to arrest the crack growth. In this study, a numerical methodology using finite element analysis with linear elastic behaviour assumption is considered to study the effect of the stop-drilled hole on the reduction of stress concentration at crack tip. The variation number of stop-drilled hole and hole diameter at the crack tip corresponding to the stress concentration will be investigated. It reveals that the number of stop-drilled holes significantly influenced to reduce the stress concentration factor. Increasing the number of the stop-drilled holes will reduce the stress concentration factor. Furthermore, the diameter of stop hole significantly affects the decreasing stress concentration. The increasing value diameter of the stop-drilled hole will reduce the stress concentration. In the meantime, the triple-drilled hole has the highest percentages of decreasing stress concentration and the lowest stress concentration comparing to single and double stop-drilled hole.

KEY WORDS: *crack growth arrest, stop hole, stress concentration*

1.0 INTRODUCTION

In structure or component machine, fatigue crack propagation is one of the important issues for failure mechanism. The cracked structure or component machine requires temporary to repair in order to extend the service life before its catastrophic failure occurs. The crack usually initiates in structure or component machine at an area having high stress concentration. Once the crack initiates, the potential crack growth is considered. Therefore a method is needed to develop to arrest crack growth so that the service life of structure or component machine increase. Some methods of retarding crack growth have been studied by some researches such as using composite or metal patches on area having crack [1], overloading [2,3], indentation [4,5], laser shock peening [6], spot heating [7] and stop-drilled hole [8-11]. However, the most common method using to arrest the crack growth is a stop-drilled hole (SDH) at the crack tip. The aim of SDH is to reduce the stress concentration at the crack tip by making a hole at the crack tip. Song at al [8] introduced that the stop drilling hole improved the crack initiation life and fatigue life and also the diameter of stop drilling hole has significantly affected to retard the fatigue crack propagation. Murdani at al [9] investigated the additional hole around stop hole at crack tips can effectively be retarded fatigue crack propagation. In this study, the stress concentration factor for stop hole and the additional hole would be evaluated. The results showed that the additional holes had a positive or negative effect on lowering stress concentration at the stop drilled holes which depend on the combination of the arrangement and size of the two kinds of holes.

While Makabe at al [10] introduced the arresting crack growth by drilling holes in the vicinity of crack tip and then inserting a pin into the hole. It reveals that the drilling holes and inserting pin could change the crack growth direction. It also found that compressive residual stress, which occurred by inserting pin, was more effective method to retards the crack growth than reducing the stress concentration around crack tip by

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making drilling hole. More recently, Razavi at al [11] proposed double stop-hole drilling method to retard the fatigue crack propagation. The effects of the double stop-hole method on fatigue life extension were studied both experimentally and numerically. This study reveals that the stress concentration around the double stop hole is lower than single stop-hole. Therefore, this method is effectively used to generate the high fatigue crack initiation life of structure.

In this paper, a new shape of stop drilled hole is proposed in which triple stop holes called multi stop-drilled Hole (MSDH) are drilling at the crack tip. The main objective of the proposing method is to reduce stress concentration at the edge of the stop holes. In this present study, the effect of variation number of stop-drilled hole and diameter of stop hole corresponding to stress concentration factor would be evaluated numerically. Reducing the stress concentration, it leads to arrest the crack growth.

2.0 THE ANALYSIS MODEL

The analysis model for this present study is shown in Fig. 1(a). An edge cracked specimen is presented by a model with a height of H and width of W. The specimen subjected to stress (σ_0) lead to the high stress at the crack tip. The stress distribution from the crack tip at specimen is highlighted in Fig. 1(b). The stress concentration factor (K_t) is commonly expressed by

$$K_t = \sigma_{max}/\sigma_0 \quad (1)$$

where σ_{max} is the local maximum stress at crack tip and σ_0 is the applied stress subjected to the specimen. In general, the stop-drilled hole is applied to reduce the stress concentration.

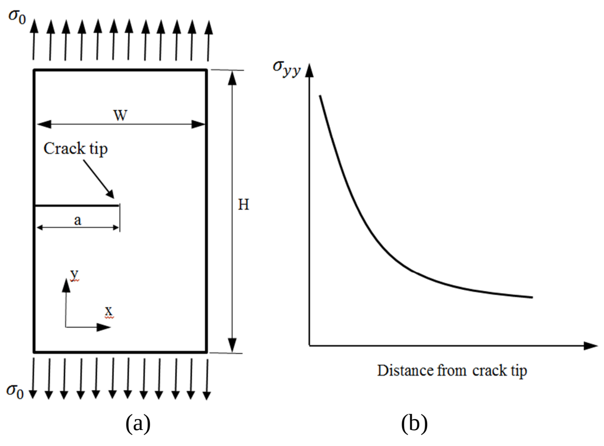

Figure 1: The analysis model (a) An edge cracked specimen and (b) Stress distribution at distance from crack tip

The crack growth is depended on the shape of the crack tip. In this present study, the shape of the crack tip is shown in Fig.2. Moreover, the variation number of the stop-drilled hole is investigated and compared with a model without a/the stop-drilled hole (H-0) as shown in Fig. 2(a), The position of the crack tip is fixed while the stop-drilled hole is used to reduce the stress concentration. It means that the initial crack length does not change when the stop-drilled hole is applied. Fig. 2(b) illustrates the single stop-drilled hole (H-1) with a radius of R. Thus the double stop-drilled hole (H-2) with a radius of R is shown in Fig. 2(c). The distance of ℓ between the center of the hole and the crack is 0.5R. Furthermore, Fig. 2(d) highlights the triple stop-drilled hole (H-3) with the radius of R. The distance of ℓ between the center of the hole and the crack is R.

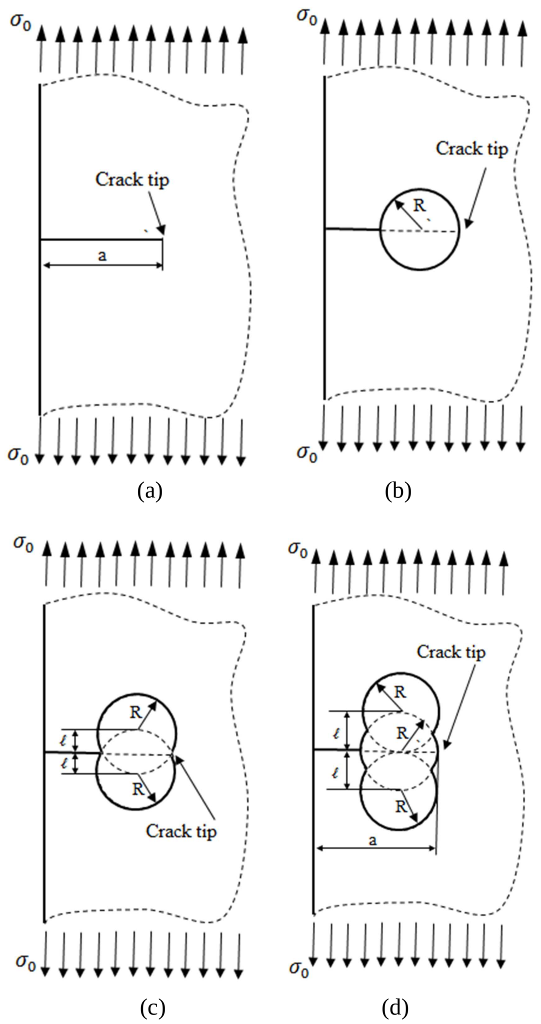

Figure 2: Shape of crack tip (a) without stop-drilled hole (H-0), (b) single stop-drilled hole (H-1), (c) double stop-drilled hole (H-2) and (d) triple stop-drilled hole (H-3)

3.0 NUMERICAL MODEL

A numerical methodology using finite element analysis with linear elastic behaviour assumption is considered to study the effect of the stop-drilled hole on the reduction of stress concentration factor (K_t) at crack tip. The model of thickness (B) = 5 mm, width (W) = 50 mm and height (H) = 100 mm with the initial crack length (a) of 25 mm is subjected to the axial stress of

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10 MPa on top of model surface and the fixed support on bottom of model surface. The crack is modeled as a slit with a distance of 1 mm. The crack tip is assumed to be blunt with radius of 0.5 mm to simulate the finite element modeling without stop drilling hole (H-0). The stop-drilled hole is considered for various hole diameter (D) of 2.5, 5.0 and 7.5 mm. The mechanical properties of the finite element modeling are elastics modulus (E) = 210 GPa and the poisson's ratio = 0.3. The size and the distribution of mesh in the finite element modeling are shown in Fig. 3 for three different stop drilled hole model.

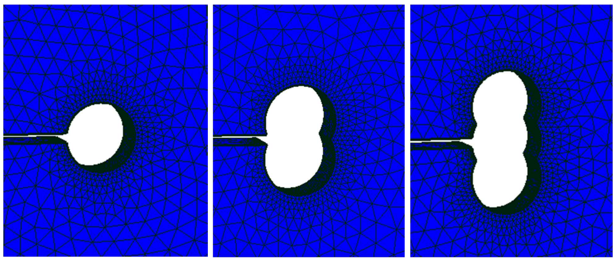

Figure 3: Finite Element Modelling (a) single stop-drilled hole (H-1), (b) double stop-drilled hole (H-2) and (c) triple stop-drilled hole (H-3)

4.0 RESULTS AND DISCUSSION

The stress distributions around the single, double and triple stop-drilled hole are illustrated in Figure 4. As seen in Figure 4(a), the stress distribution is concentrated in one position for single stop-drilled hole model (H-1). While for the double stop-hole model (H-2) the stress distributions are divided into two areas with two stress concentrations as shown in Fig. 4(b). Furthermore, for triple stop-drilled hole model (H-3) the stress distributions are divided into three regimes with three stress concentrations. However, stress concentration at the edge of the middle hole is lower than other two holes as shown in Fig. 4(c). It can be seen that the triple stop-drilled hole model (H-3) has the stress distribution more spreading than two kinds of stop-hole model. It causes to reduce significantly stress concentration at edge of hole.

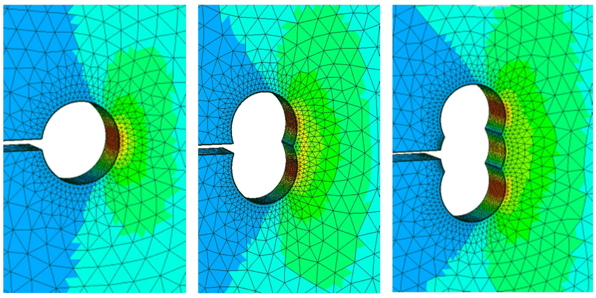

Figure 4: Stress distribution (a) Single stop drilling hole (H-1), (a) Double stop drilling hole (H-2) and (a) Triple stop drilling hole (H-3)

4.1 The effect of stop-drilled hole number

The effect of variation number of the stop-drilled hole (H) on the stress concentration factor (K_t) for 2.5 mm of hole diameter (D-2.5) illustrates in Fig. 5. According to Fig. 5, the stress concentration factor (K_t) will decrease significantly along with increasing number of the stop-drilled hole (H). It can be seen that the highest stress concentration factor (K_t) of 46.28 for no stop-drilled hole (H-0) decreases sharply to 29.88 for the single stop-drilled hole (H-1) and continue to experience a downward trend to 24.52 and 23.27 for double hole (H-2) and triple hole (H-3), respectively.

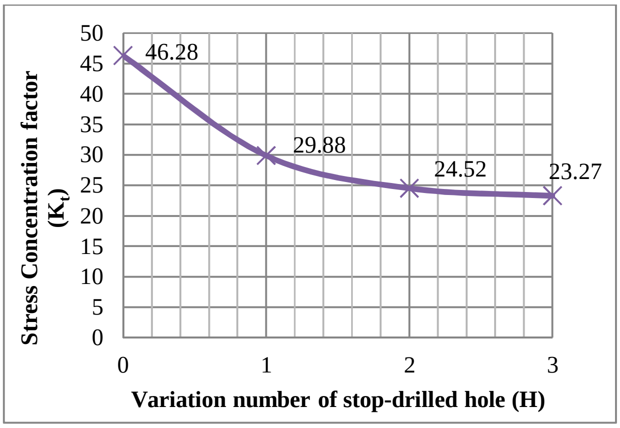

Figure 5: The stress concentration factor (K_t) in variation number of stop-drilled hole (H) for diameter of hole (D) = 2.5 mm

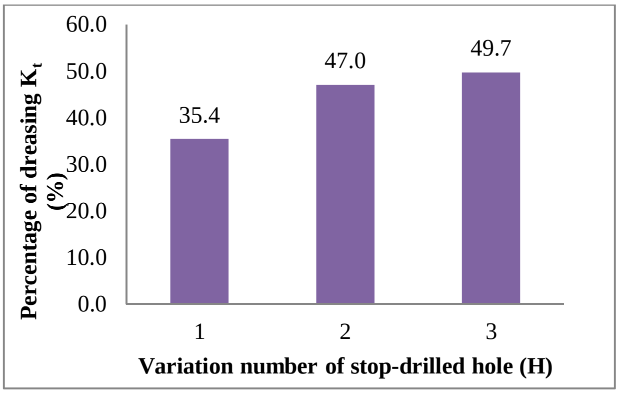

Figure 6: The percentages of decreasing stress concentration factor (K_t) in variation number strop-drilled hole with diameter of hole (D) = 2.5 mm

The decreasing stress concentration factor (K_t) can be seen clear in a value of percentages. If stress concentration factor (K_t) for no stop-drilled hole (H-0) at the crack tip are considered as references, the percentages of decreasing stress concentration factor (Kt) will be evaluated in variation number of the stop-drilled hole as shown in Fig. 6. According to Fig. 6, the percentages of decreasing stress concentration factor (Kt) will increase gradually along with increasing number of the stop-

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drilled hole. It can be seen that the percentages of decreasing stress concentration factor (Kt) increasing significantly to 35.4%, 47.0% and 49.7 % for single stop hole (H-1), double stop hole (H-2) and triple stop hole (H-3), respectively. There is significant growth of 11.6 % in decreasing stress concentration factor (Kt) from single stop hole (H-1) to double stop hole (H-2) and continued increase of 2.7% for triple stop hole (H-3).

4.2 The effect of the stop-drilled hole diameter

The effect of the stop-drilled hole diameter on the stress concentration factor (K_t) for triple stop-drilled hole (H-3) illustrates in Fig. 7. According to Fig. 7, the stress concentration factor (K_t) will decrease significantly along with increasing variation diameter of the stop-drilled hole. It can be seen that the stress concentration factor (K_t) would be sharply reduced from 23.27 to 17.68 for stop-drilled hole diameter (D) of 2.5, and 5.0, respectively. Moreover, the stress concentration factor (K_t) experiences a downward trend to 15.51 for stop-drilled hole diameter (D) of 7.5 mm.

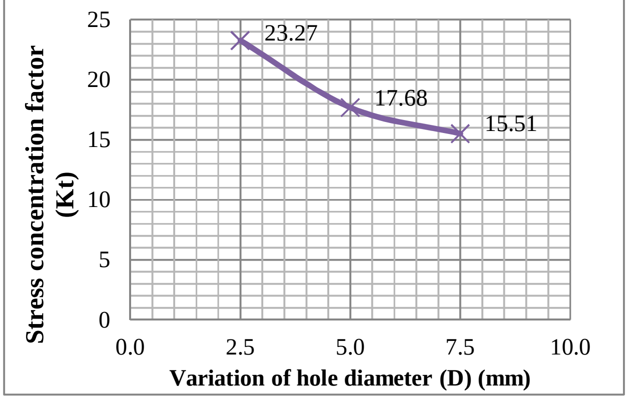

Figure 7: The stress concentration factor (K_t) in variation strop-drilled hole diameter (D) for triple stop-drilled hole (H-3)

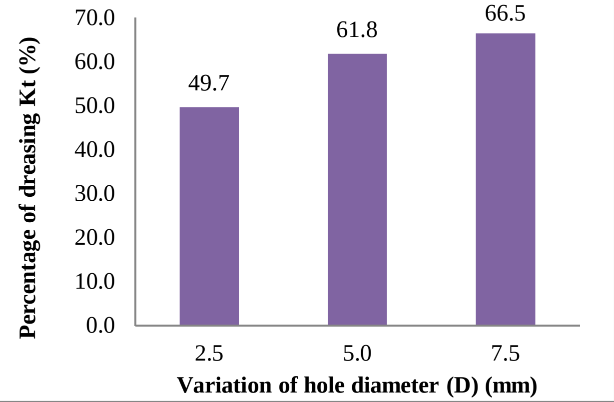

Figure 8: The percentages of decreasing stress concentration factor (K_t) relating to the strop-drilled hole diameter (D) for triple stop-drilled hole (H-3)

As discussed earlier, the stress concentration factor (K_t) for no stop-drilled hole (H-0) at the crack tip is considered as references, the percentages of decreasing stress concentration factor (Kt) will be evaluated in variation diameter of stop-drilled hole as shown in Fig. 8. As seen in Fig. 8, the percentages of decreasing stress concentration factor (K_t) will tend to increase along with increasing diameter of stop-drilled hole. It can be seen that the percentages of decreasing stress concentration factor (K_t) rise significantly to 49.7%, 61.8% and 66.5 % for stop-drilled hole diameter (D) of 2.5, 5.0 and 7.5 mm, respectively. There is significant growth of 12.1 % in decreasing stress concentration factor (Kt) from hole diameter of 2.5 to 5.0 mm and continued growth of 4.7% for hole diameter of 7.5 mm.

5.0 CONCLUSION

It is clear that the stress concentration is significantly influenced by the number of the stop-drilled hole. The stress concentration factor (K_t) will decrease significantly along with increasing number of the stop-drilled hole (H). Furthermore, the diameter of the stop-drilled hole significantly affects the decreasing stress concentration. The increasing value of diameter of stop-drilled hole will reduce the stress concentration. In the meantime, the proposed triple-drilled hole has the highest percentages of decreasing stress concentration and the lowest stress concentration comparing to single and double stop-drilled hole. It can be concluded that triple stop-drilled hole became an alternative method to reduce stress concentration.

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