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Variation of Stress Intensity Factor and Crack Distance Length for Double Edge Crack in Human Femur Bone

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Abstract – *The theory of linear elastic fracture mechanic (LEFM) has proven that we can evaluate the amount of stress located at the crack tip by determining the stress intensity factor (K). The stress at the tip of a sharp crack has the highest stress, which can lead to failure on the material. Thus, the cracks within human bones are quite complicated because of the bone microstructure. There are a few factors that can minimize the effect of the cracks so that patients can heal much faster. Hence, this paper focuses on how several crack distances, s between two parallel edge cracks can affect the value of stress intensity factor (K). Using the LEFM theory, the interaction between two neighbouring crack tips was investigated.*

Keywords: Linear elastic fracture mechanic, Stress intensity factor, Parallel cracks

1.0 INTRODUCTION

Bone is the main component in the skeletal system in our body. Bone plays important roles, especially to support our body. There are 206 bones inside an adult skeleton system [1]. The bone that is responsible to carry our body weight is located at the lower part of our body, which is called "femur" bone. The femur bone is located in the thigh region. It is the strongest bone in the body. The long and straight part of the femur is called the femoral shaft while at the end of the bone, which is in the proximal area (near to the midpoint of the body), we can find a ball-like head and a neck. The locations of the fracture are usually categorized into three forms, which are distal, middle and proximal. There are five types of common fracture in femoral shaft, which includes transverse fracture, oblique fracture, spiral fracture, comminuted fracture, and open fracture [2]. This research focuses more on the oblique fracture, which has an angled line across the shaft.

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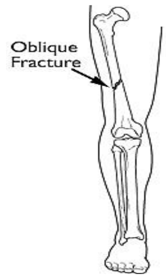

Figure 1: Oblique fracture in femur bone

Fig.1 clearly shows the fracture where the crack comes across the shaft. If a fracture occurs in the bone, it might take weeks to months or even years for a complete healing. This is why bone fracture is considered a critical problem in real life. Hence, this research focuses on investigating the geometrical effect of double co-planar edge cracks on the stress intensity factor (*K*) in the femur bone. A numerical model for amplified interaction between double co-planar edge cracks has been developed using computational method. The human femur bone is considered as an isotropic linear elastic material so that the amount of the stress intensity factor (*K*) at the crack tip can be calculated using stress singularity calculations. This calculation was done using numerical simulation available in ANSYS software. The value of K presents the idea of the stress level that acts upon the crack tip.

1.1 Numerical simulation

A numerical analysis was used to observe the crack propagation in human bone based on several forces and the effect of these parameters on the stress intensity factor (*K*) of the bone. Numerical analysis data were gathered using ANSYS software or more specifically, using the finite element mesh on the crack tip. The values of human bone's Poisson ratio and Young Modulus were inserted before the analysis was run. The most likely method to be used is the singular element method, where it is based on 8-node rectangular elements used in meshing by connecting the mid-side nodes to the nearest node. The next step is to move the two mid-side nodes to the quarter point close to the singular point [3]. The Jacobian method can help to capture singularities. The singularity was determined by the apex of the crack found. If there are two different materials found in the singularity problem, not only the elastic constant and local geometry of the material are considered, but the deformation mode also needs to be accounted for[4]. In this research, the crack failure is composed of mixed mode situations that combine both Mode I and Mode II crack deformation.

$$\sigma_{ij} = \sigma_{ij}^{I} + \sigma_{ij}^{II} \tag{1}$$

Eq. 1 indicates the amount of stress acted on the crack tip where *i* and *j* represent the direction of crack propagation (x and y directions), and I and II represent the mode of crack deformation. The derivation of the stress at the crack tip can be seen in Eq. 2.

$$\sigma_{ij}(r,\theta) = \frac{K_I}{\sqrt{2\pi r}} f^{I}{}_{ij}(\theta) + \frac{K_{II}}{\sqrt{2\pi r}} f^{II}{}_{ij}(\theta) + \sigma^{0}{}_{ij} + O(\sqrt{r}) \tag{2}$$

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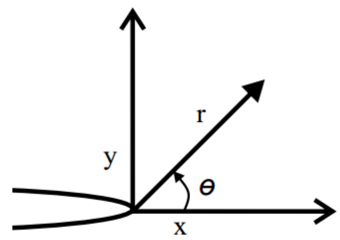

Figure 2: Crack tip coordinates [5]

In Eq. 2, θ is the angle of the opening crack located at the crack tip. Eq. 2 is used to determine the r value, which intends to propagate towards the 0 value where $\sigma^0{}_{ij}$ represents the finite stress at the crack tip. Hence, the corresponding value of the stress field (K_I and K_{II}) is indicated by both Eq. 3 and Eq. 4

$$K_I = \lim_{r\to 0} \sqrt{2\pi r}\sigma_{yy}(r,0) \tag{3}$$

$$K_{II} = \lim_{r\to 0} \sqrt{2\pi r}\sigma_{xy}(r,0) \tag{4}$$

2.0 RESULTS AND DISCUSSION

In this research, 8 node quad point elements were used, to find the value of K, which is determined using the computational method. It uses $\sqrt{r}$ behaviour for the strain and stress in the element of crack tip. For K_I and K_{II} modes, the stress intensity factor value was solved by using the Barsoum and linear displacement extrapolation methods (DEM) [6]. Two parallel edge cracks were identified and examined using numerical method to find the stress intensity factor (K). Both of the cracks were in an amplification effect, where the force acted on the crack was perpendicular to the crack direction. The results show the effect of varying the crack's distance, s on the K value. As the value of crack length increases, the crack propagates more until the two crack tips converge. Thus, the model is unstable at higher a/w values in the double edge crack. Fig. 3 shows the K_I values in double edge crack for several values of crack distance, s where the crack length, s is the crack distance and w , is the width of the developed model.

Based on Fig. 3, there is a pattern for the increasing value of K using several crack distances, s. At $s=0$, the value of K is at the highest rate compared to the others. Hence, if the value of s increases, the K values decrease. It can be concluded that K values are contrastingly proportional to s values.

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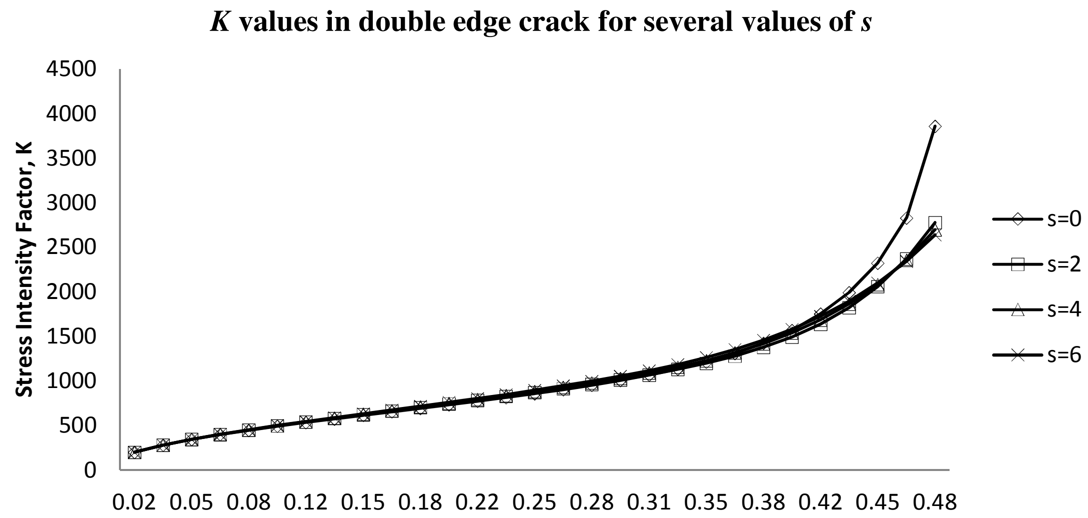

Figure 3: Graph of K values in double edge crack for several values of crack distance, s

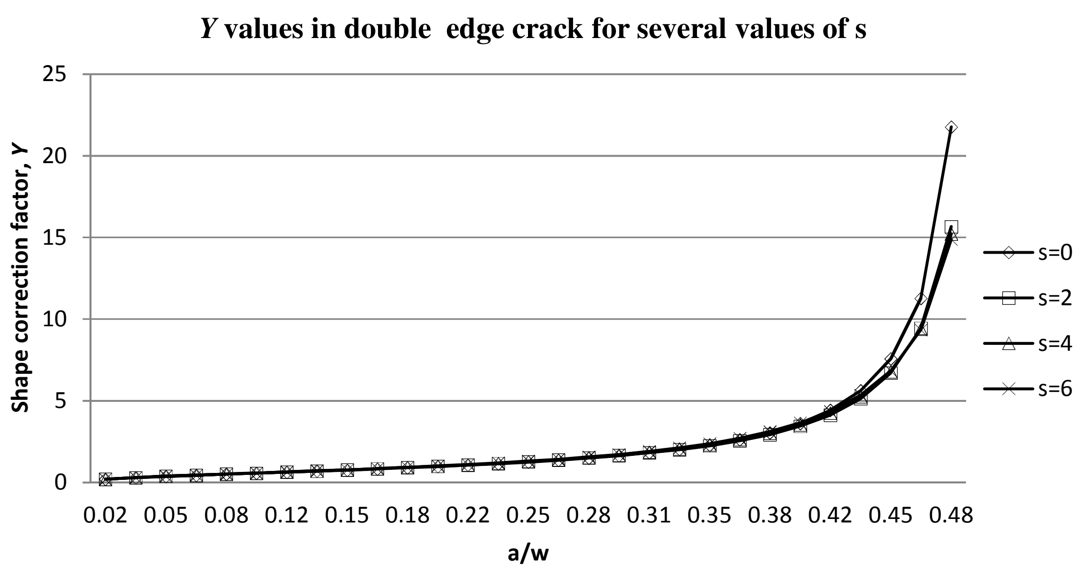

Figure 4: Graph of Y values in double edge crack for several values of crack distance, s

Based on Fig.4, the x-axis represents the ratio of, a/w while the y-axis represents the shape correction factor, $Y = K_I / K_0$ or $Y = K_{II} / K_0$ where $K_0 = \sigma\sqrt{\pi a}$ and σ is the load acted on the specimen. [7].

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3.0 CONCLUSION

Based on the result, from the analysis of the data, for different values of crack distance, s produces K values that are oppositely proportional to the s values. The higher the value of s, the lower the value of K. Based on this result, a critical condition of a certain fracture can be determined by locating the distance between two cracks. Hence, an appropriate implant can be introduced so that the interaction between the double edge cracks, which is the stress intensity factor, can be reduced.

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