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Finite Element Method Analysis of Stress Intensity Factor in Different Edge Crack Positions, and Predicting their Correlation using Neural Network method

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Abstract

According to the fracture mechanics, crack propagation in the body of structures may lead to a failure. In this field, Stress Intensity Factor is utilized to determine the stress intensity near the tip of a crack, and to predict if a crack starts to grow. The crack propagation can be determined by comparing Stress Intensity Factor to the Critical Stress Intensity Factor. This study attempts to analyze the Stress Intensity Factor in various edge cracks along the length of a finite plate which is under a uniform tension. Finite Element Method is utilized for the analysis. In addition, Neural Network Method is used to predict the correlation of Stress Intensity Factor and the position of edge crack along the length of a finite plate.

Keyword: Crack, stress intensity factor, finite element method, neural network.

Introduction

Recent development in engineering structures shows that small cracks in the body of structures can be cause of failure despite the authenticity of elasticity theory and strength of materials. As a result, fracture mechanics filed which is concerned with the propagation of cracks in materials has developed to study more about this subject. According to this, in fracture mechanics, there are three modes of fracture. In the first mode which is named as mode I or opening mode, tensile load is applied in perpendicular direction to the crack surface. In mode II which is known as sliding mode, shear force parallel to the crack surface is applied. Finally, mode III, sliding mode or tearing mode is when shear force is parallel to the crack front while the crack surface slides over each other in direction of Z axis. In all the modes, the original orientation of crack can be the main orientation of the crack propagation[1].

In many situations, a mixed mode of crack extension which is called a superposition of modes could happen. In the case of superposition mode, $\sigma_{ij}{}^{I}$, $\sigma_{ij}{}^{II}$, $\sigma_{ij}{}^{III}$ which are referred as stress in mode I, mode II and mode III respectively, can be integrated as components of σ_{ij} according to the formula (1)[1]:

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

By considering the previous three modes, and according to semi-inverse method of Irwin [2, 3], the relation between distance to the tip of crack, a; and stress component , σ, can be formulated as below in formula (2)[1, 4]:

$$\sigma \approx \frac{k}{\sqrt{\pi a}} \tag{2}$$

Meanwhile, parameter k, Stress Intensity Factor (SIF), has an important role in the fracture mechanics since it characterizes the stress field in the crack tip region, and helps to predict the fracture condition and remaining life. SIF depends on the size and location of the crack, geometry, and the magnitude of load[5]. SIF is needed to be determined to predict the crack propagation[6].

It is important to know the maximum allowable stress to determine when a crack starts to grow. One factor that can help engineer to determine this limitation is the critical stress intensity factor which is named as fracture toughness, K_c. According to this, crack stability can be determined by comparing K and K_c[7].

In order to determine the stress intensity factor, various numerical methods were utilized. The methods were the boundary element method[8,9], the meshless method[10,11], the finite element method[5, 12-20], and virtual crack extension[21,22].

The stress intensity factor for edge crack in finite plate can be achieved by the formula (3) when $\left(\frac{h}{b}\right) \geq 1$ and $\left(\frac{a}{b}\right) \leq 0.6$, according to the figure-1[4].

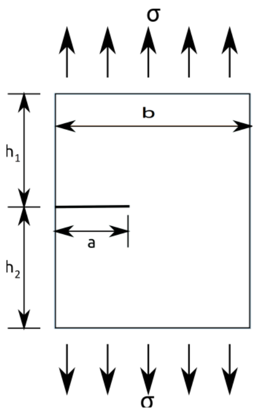

Figure-1
Edge crack in a finite plate under uniaxial stress

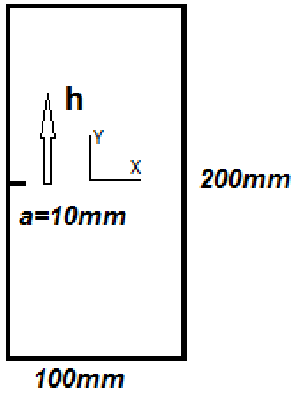

Figure-2
Steel plate with the thickness of 1 mm

$$K_I = \sigma\sqrt{\pi a}\left[1.12 - 0.23\left(\frac{a}{b}\right) + 10.6\left(\frac{a}{b}\right)^2 - 21.7\left(\frac{a}{b}\right)^3 + 30.4\left(\frac{a}{b}\right)^4\right] \quad (3)$$

By this formula, SIF can be calculated when the edge crack is in the middle of the plate's length, $h_1=h_2$.

As the formula of stress intensity factor considers the edge crack position in the middle of the plate, this study attempts to determine the SIF in different edge crack position along the length of the rectangular finite plate, in Y axis, and find the correlation of SIF and edge crack position under uniform tension.

Material and Methods

Material and Geometry: In this study, an edge crack in the steel plate with the Poisson ratio of 0.3 and elasticity modulus of 300Gpa, is studied. The 200 kPa of uniaxial stress is applied on the top and bottom edge of the plate. The plate size is 100mm*200mmwith the thickness of 1 mm. In this study, h is the distance from the middle of the plate length in Y axis. In addition, the length of the crack is 10mm.

Finite Element Method: Finite element analysis (FEM) has become commonplace in recent years, and is now the basis of a multibillion dollar per year industry[23]. The finite element methods (FEM) are techniques utilized for approximating differential equations to continuous algebraic equations by a finite number of variables[24]. This method is one of the most practical ways for analyzing structures with a large number of degrees of freedom[25]. To get a more accurate result from FEM, it is recommended to use some software in order to carry out the numerical computation part. In addition, saving time is another factor which motivates specialists to use software instead of solving problems manually[26]. Various FEM based software such as ABAQU are utilized to solve engineering problems. The general process of FEA is divided into three main phases, preprocessor, solution, and postprocessor[27]. In this study, ABAQUS software is used to calculate the stress intensity factor of the edge crack in finite plate.

Mesh Convergence Study: A mesh convergence study was done to choose the optimum mesh number from the computational accuracy point of view. Meanwhile, SIF was computed for different types of meshing. In order to get better result in different analysis with ABAQUS software, mesh convergence study was done in the sample simulations.

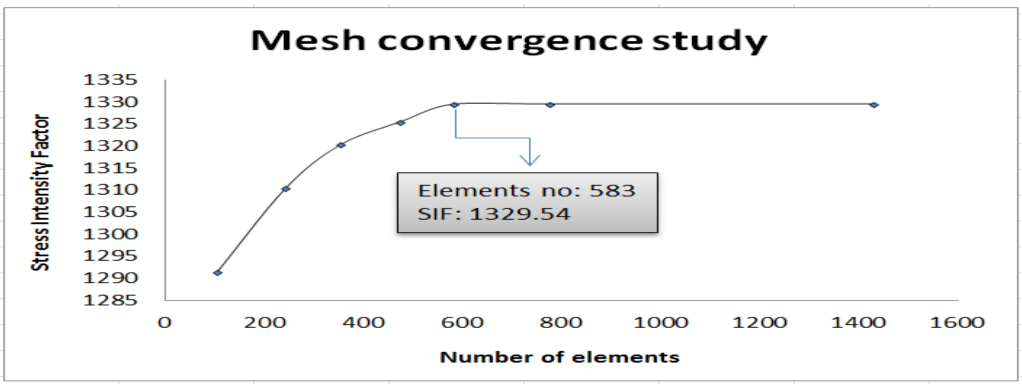

Figure-3
Trend line of mesh convergence study

As it is shown in figure-3, by increasing the number of elements, SIF goes up sharply and then approximately remains steady. The mesh convergence study was started with 104 elements that increase until 1430 elements. In the first test, SIF is1291.4, which goes up until 1329.58 in the last test at1430 elements. As it is shown, with 583 elements, SIF stops its sharp increase at1329.54 and keeps its very slight rise until the last point. As it is shown in the figure 3, the point with 583 elements is a proper point to be utilized in all simulations. Figure-4, demonstrates a meshed blade with 583 elements.

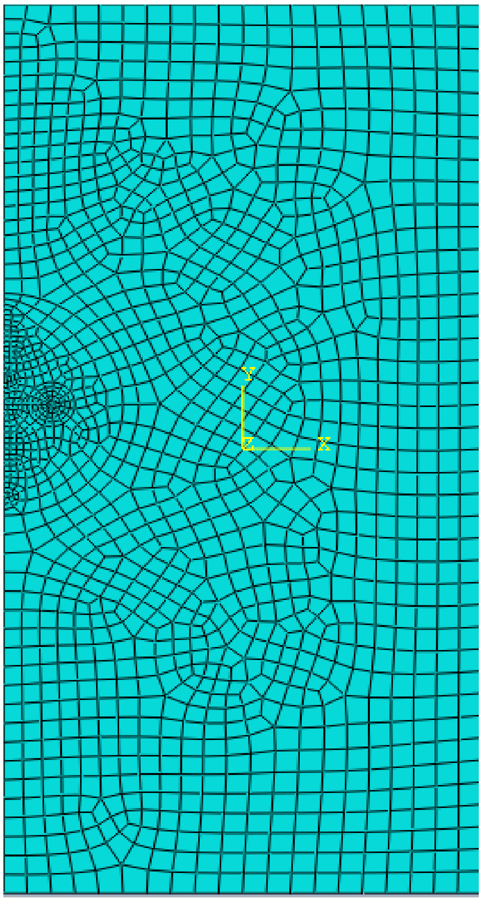

Figure-4
Meshed plate with 583 elements, h=10

Validation of Software's Result with the Formula: By comparing the two amounts of K_I which are calculatedfrom software and formula, the method of using ABAQUS software will be validated.

In the case of h=0, the edge crack is in the middle of the length, $K_I$which is calculated by softwareis 1333.22, and according to the formula (3), K_I is 1326.9 which has just 0.4% error that is negligible.

According to this validation, method of calculating K_I in ABAQUS can be used in calculation of K_I in various h.

Neural Network Method: Neural network algorithm functions on the base of real biological neuron. The modern application of this algorithm which is referred to ANN (Artificial Neuron Network) is used to model complex nonlinear systems that are not easily modeled with the closed-form equations[28]. MATLAB software has the ability to use this algorithm to find the most appropriate solution that fits data as well[29].

This study usesneural FF network and Back Propagation Training Algorithm to predict the trend of changing SIF in various positions along Y axis. In addition, two-layer function, Logsig and Purel in transfer functions, and adaptive training are used to solve this problem in MATLAB.

Results and Discussion

In this section, stress intensity factor in the first mode, K_I, is calculated in various edge crack position along Y axis. Figure 5 illustrates the deformed plate under 200 kPa uniaxial stress. In this sample simulation, K_I is 1333.37.

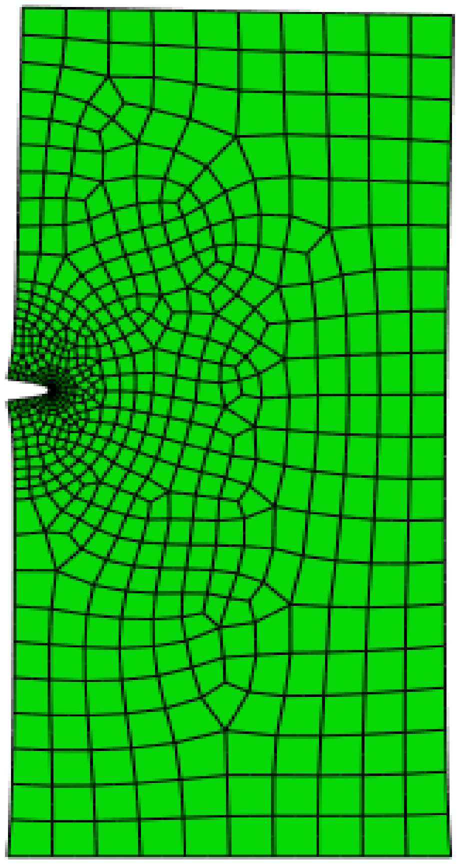

Figure-5
Deformed finite plate under 200 kPa stress loading. Plate thickness is 1mm, and h is 10mm

Figure-6 shows the deformed plate under 200 kPa uniaxial stress. In this simulation h=80mm. The stress intensity factor is 1629.48.

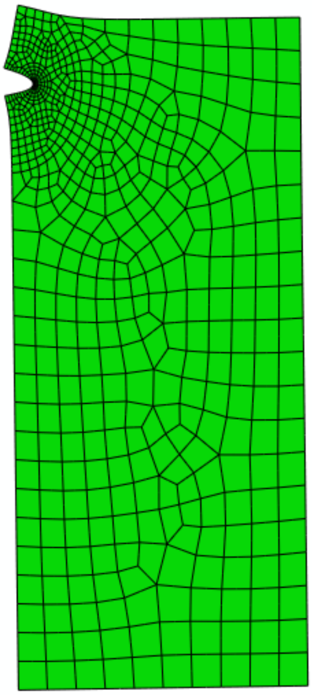

Figure-6
Deformed finite plate under 200 kPa stress loading. Plate thickness is 1mm, and h is 80mm

SIF is calculated in various h, -90 to +90. Figure-7 illustrated the trend of changing SIS in various positions along Y axis.

As it is shown above, by changing the h from -90 to +90, SIF increases. As the plate and loading is symmetric, SIF is the same for +h and –h in all position.

The graph increases slightly from h=0 to h=70, after that, the graph rises sharply to the maximum amounts.

In the middle of the plate, h=0, SIF is 1333.22.Furthermore, the maximum of SIF is 2269.17 at h=±90.

Conclusion

The objective of this paper was finding the correlation of the stress intensity factor and position of edge crack along Y axis in finite plate. The plate size was 100mm * 200mm (rectangular), and it was made from steel with the Poisson ratio of 0.3 and elasticity modulus of 300Gpa. The edge crack length was 10 mm.

It examined the mentioned variables by the use of finite element method and predicted the stress intensity factor trend in various position along the length of the plate by the use of Neural Network method.

In order to complete this study, the basic concepts related to the fracture mechanics were elaborated. Furthermore, an investigation of the previous study was done. Then, ABAQUS software was adopted to utilize finite element method to calculate the stress intensity factor in the finite plate with an edge crack under uniaxial stress loading. Different edge crack positions were analyzed. In order to predict the stress intensity factor trend in all the positions of edge crack, Neural Network method was utilized.

The results showed that stress intensity factor for the cracks, which are near the middle of the plate, is higher than the cracks that are near to the top and bottom of the plate.

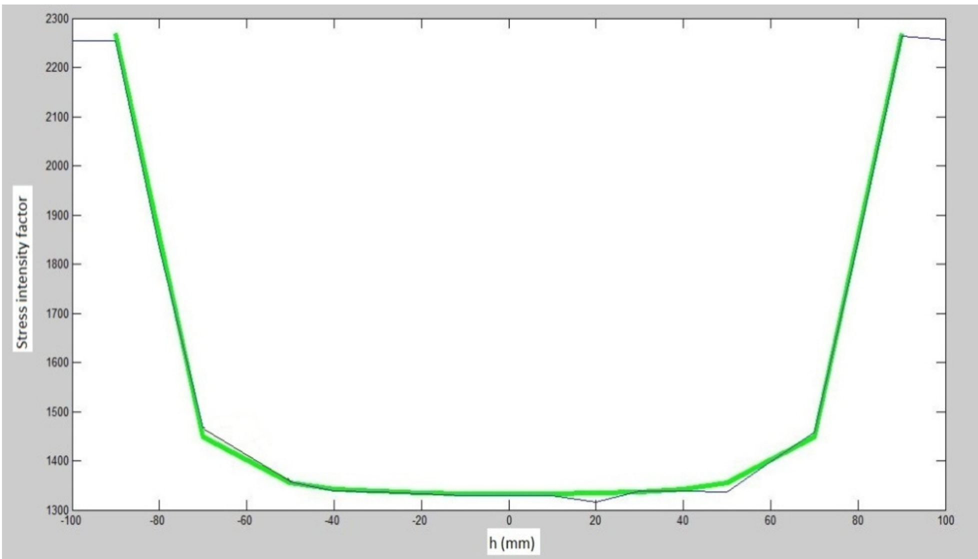

Figure-7
Stress intensity factor vs. edge crack position along Y axis, h

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