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Double Surface Cracks Interaction on Cylindrical Rod Under Tensile and Torsional Loading

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Abstract: The existence of cracks under loadings such as tensile and torsional loads is one of the factor that cause structures to experience failures. Further study regarding the effect of cracks have to be performed to analyse more about the severity of the defect on structures especially when it involves multiple cracks. Each crack configuration will emit different type of severity to the structures. This study aims to find the interaction between two identical surface cracks on a cylindrical rod under combination of tensile and torsional loadings. The dimension for length and diameter of the cylinder has been set as 200 mm and 50 mm respectively. The analysis is simulated into 3-D model using ANSYS Workbench Software where the meshing model and crack geometry is done by finite element analysis. There is no angular crack distance set for this study as both cracks are located parallel to each other. The distance between the interacting cracks is kept constant at 100 mm. The crack depth ratio used are 0.1 to 0.4 with the increment of 0.1 while for crack aspect ratio are 0.2 to 1.2 with the increment of 0.2. Stress intensity factor would be determined from the result of simulation process. The value of stress intensity factor for single cracks and double cracks are applied in the formula of normalised stress intensity factor. The relation between stress intensity factor and interaction factor would be analysed in this study.

Keywords: Crack interaction, Stress intensity factor, Parametric analysis

1. Introduction

Crack can be defined as surface or subsurface fissures that have been developed in a material. The propagation of energy derived from mechanical, thermal and chemical or a combination of these may influence the crack ignition and growth. Different types of crack occur in metals and can be characterized as cooling, solidification, centreline, crater, grinding, pickling, heat treatment, machining tears, plating, fatigue, creep, stress corrosion and hydrogen cracks. When the crack are growing, it leads

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to complete fracture of the component by posing significant threats to component life. The crack must be discovered immediately before they propagate to the point of fracture [5].

The crack might induced because of the production flaws or cyclic loading where the cylindrical components experience long period of operating time. The behaviour of the crack front which grow in semi elliptical shape symbolise different root cause. It might be started to grow either from inside or outside of the material. Plus, the depth of the crack will be not the same compared to the others since it has different way of propagation which depends on the load acting on it. As mentioned, there will be different behaviour for each crack as it contains different key characteristics such as the depth and the length of crack. Moreover, the location of the stress state at the crack tip or crack front will be represented by stress intensity factor (SIF) and it is related to the rate of cracks growth [6].In addition, it is used to establish the failure criteria due to the fracture occur in the object.

The crack initiation will lead to formation of cracks on the surface of a material. The main cause for the formation of cracks on some surfaces is fatigue which lead to the progressive structural damage and fracture. It occurs when the material experiences cyclic loading for long period of time. The growth of crack can be defined as the extension of the surfaces of the crack as it shown by increases in length of the crack. Plus, it will form the crack front which is the forward part of the crack. The stress intensity factor for the crack front is different depends on specific characteristic such as the location and depth of the cracks. The cracks propagation factor aids in determining the value of stress intensity factor. Furthermore, it will specify the first point or location which started to be induced. Other than that, the cracks formed at the material might be more than one. Stress intensity factor will be used in identifying if there is any relation between the cracks.

2. Methodology

For the purpose of achieving the main objectives, the analytical method used in determining the stress intensity factor (SIF) of double cracks on solid rod and the influence of interaction towards stress intensity factor (SIF). The simulation will be used to perform the analysis. Moreover, the analysis is focused on mixed mode fractures which are Mode 1 and Mode 2.

2.1 Finite Element Analysis processes

1. Pre-processing phase
   Within this phase, the model is set up which includes a number of steps.

   a) Define the geometry.
   b) Create lines, areas or volumes.
   c) Define the element type and material.
   d) Generate element mesh.

2. Solving phase

   a) Apply boundary conditions.
   b) Obtain solution.

3. Post processing phase

   a) Results will be displayed out.
   b) Analyse the results.

2.2 Crack configuration

Figure 1 show the cracks position on a cylindrical rod. The symbol L refers to the length while D refers to the diameter of the rod. For F and T, it refers to tensile force and torsion force respectively. The length and diameter applied to the cylinder are 200 mm and 50 mm respectively.

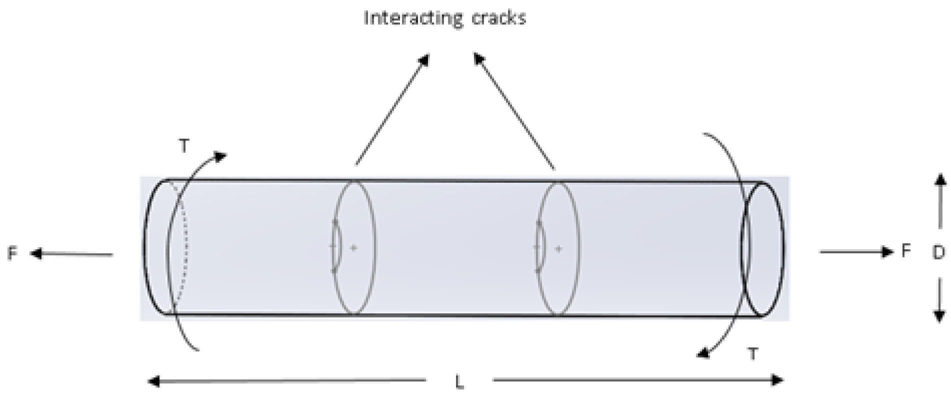

Figure 1: Diagram of two interacting cracks on a cylindrical rod

2.3 Equations

Firstly, the stress intensity factor for a single crack and double crack could be obtained from the ANSYS workbench simulation method. The stress SIF for single crack and double cracks defined as $K_{single\ crack}$ and $K_{double\ crack}$ respectively. By referring to the formula defined by [7], the interaction factor could be determined by applying formula of γ.

$$\gamma = \frac{Kinteracting\ cracks}{Knon\ interacting\ cracks} \qquad \text{Eq. 1}$$

Since cracks only interact when more than one crack presence near to each other, it could be rephrased γ as ratio of the cylinder with two cracks to the cylinder with single crack. The formula is

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$$\gamma = \frac{Kdouble\ cracks}{Ksingle\ crack} \qquad \text{Eq. 2}$$

Moreover, the normalised stress intensity factor could be determined from the formula

$$\boldsymbol{F} = \frac{K}{\sigma\sqrt{\pi\alpha}} \qquad \text{Eq. 3}$$

The variables and constants in this study which involve crack depth ratio and crack aspect ratio are shown in Table 1.

Table1: The variables and constants used in this study

Crack depth ratio, *a/D*	Crack aspect ratio, *a/b*	Crack depth, *a* (mm)	Crack length, *b* (mm)
0.1	0.2	5.0	25.00
	0.4	5.0	12.50
	0.6	5.0	8.33
	0.8	5.0	6.25
	1.0	5.0	5.00
	1.2	5.0	4.17
0.2	0.2	10.0	50.00
	0.4	10.0	25.00
	0.6	10.0	16.67
	0.8	10.0	12.50
	1.0	10.0	10.00
	1.2	10.0	8.33
0.3	0.2	15.0	75.00
	0.4	15.0	37.50
	0.6	15.0	25.00
	0.8	15.0	18.75
	1.0	15.0	15.00
	1.2	15.0	12.50
0.4	0.2	20.0	100.00
	0.4	20.0	50.00
	0.6	20.0	33.33
	0.8	20.0	25.00
	1.0	20.0	20.00
	1.2	20.0	16.67

3. Results and Discussion

This section would focus on analysing and discussing the final results and data collected from the simulation process. The significance of the results and data would be discussed in order to meet the objectives requirement. Stress intensity factor has been set as the main factor that has to be focused in the discussion.

3.1 Stress intensity factor of cracks

The stress intensity factor values for each crack realistically should be difference as every crack has dissimilar physical characteristics but in the research methodology the double cracks on the cylindrical rod for each set of simulation process have been set to have same physical characteristic which are the crack length and the crack depth. By defining the same characteristic for both cracks, the stress intensity factor values will remain constant or might be just slight differences. Other than that, the external factors which should be considered have also been set as constant variables which are the tension force, torsional force and distance between cracks. These parameters are kept constant to prevent it from influencing the changes of SIF values.

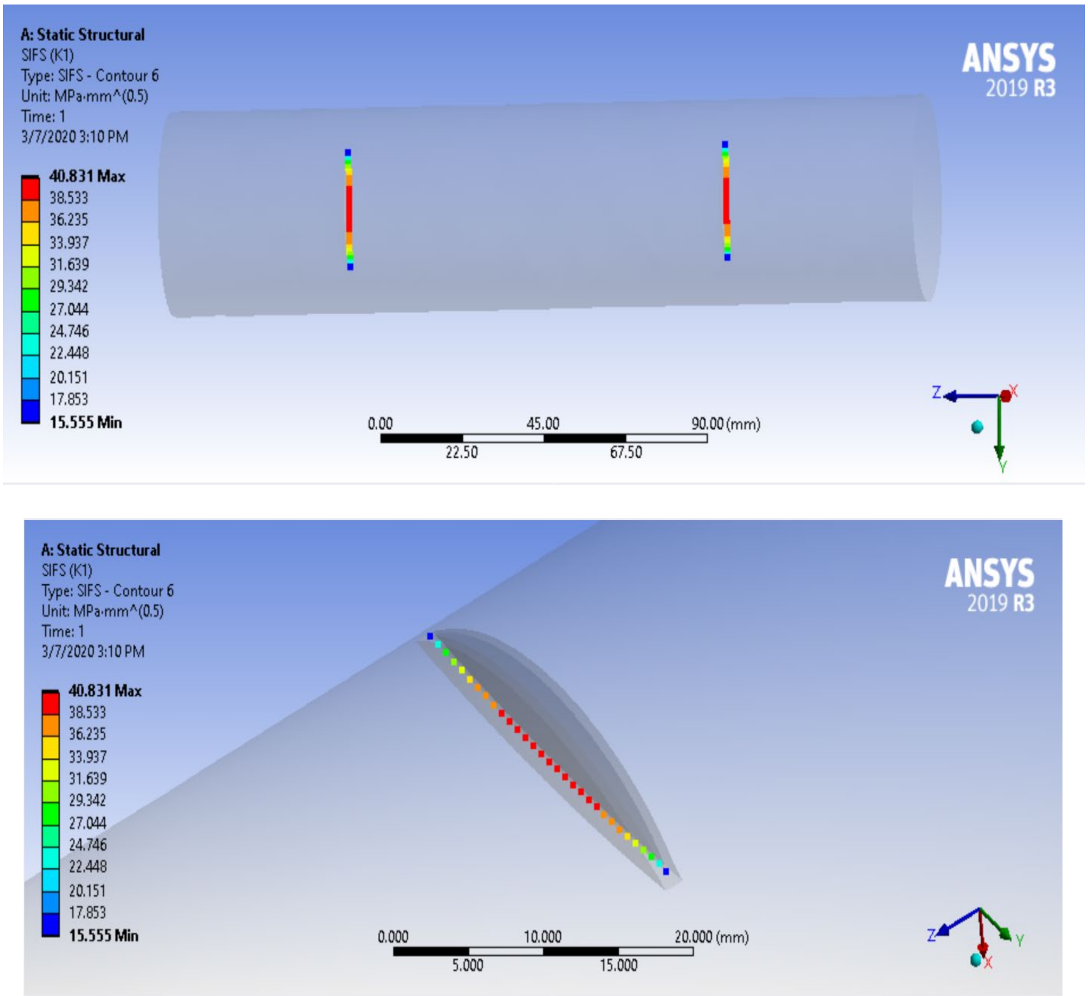

Figure 2: Example of simulation results (a/D = 0.1; a/b = 0.2)

Figure 2 has shown the points lie on the crack front which represents different SIF values at different location. As stated, the stress intensity factor for the crack front is different depends on its specific characteristic which are the depth and length of the crack. Based on the results, the highest SIF value is positioned at the deepest point of the crack which is the crack tip. It could be seen that, the SIF values decrease towards the outer side of crack front. It shows that the stress is highly concentrated at crack tip compared to the outer side of the crack front. The stress concentration is the position in the object where tensional force is reduced. Crack is developed from its base where the concentration is the maximum. It could be seen that the crack is propagated from the crack tip and distributed around its environment which is the crack front.

Figure 3.1.2 shown the highest SIF value located at the outer side of crack front while the lowest is found at the crack tip. The variations of external factors have affected the concentration of stress on the crack front. Thus, it is recognised that crack could not spread from low concentration location.

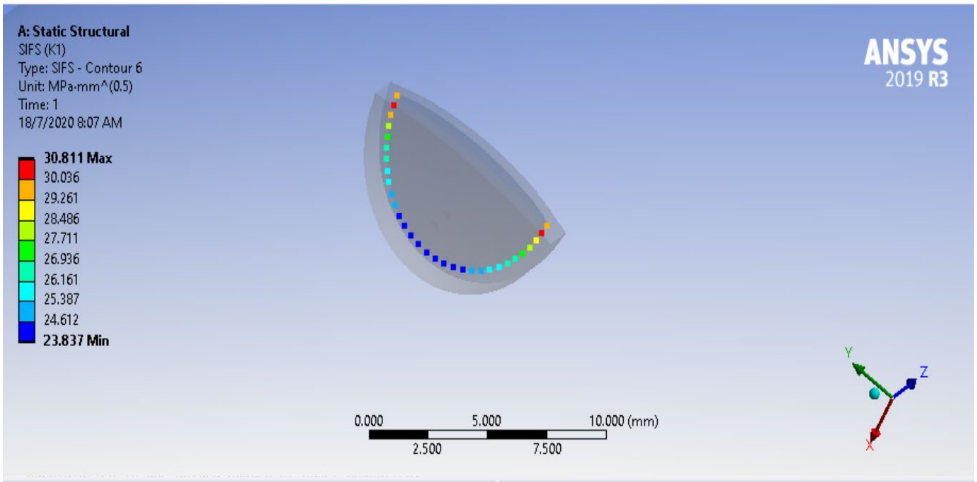

Figure 3: Example of simulation results (a/D = 0.1; a/b = 1.2)

3.2 Influence of crack depth ratio towards normalized stress intensity factor

Stress intensity factor value has been proven which it is influenced by changes of crack depth ratio value. When the depth of crack is increased, it shows that the distribution of the energy along the crack front required is higher. Figure 4.3.2 has shown the positive gradient to indicate that the relationship between stress intensity factor and crack depth ratio which it is increase linearly to each other.

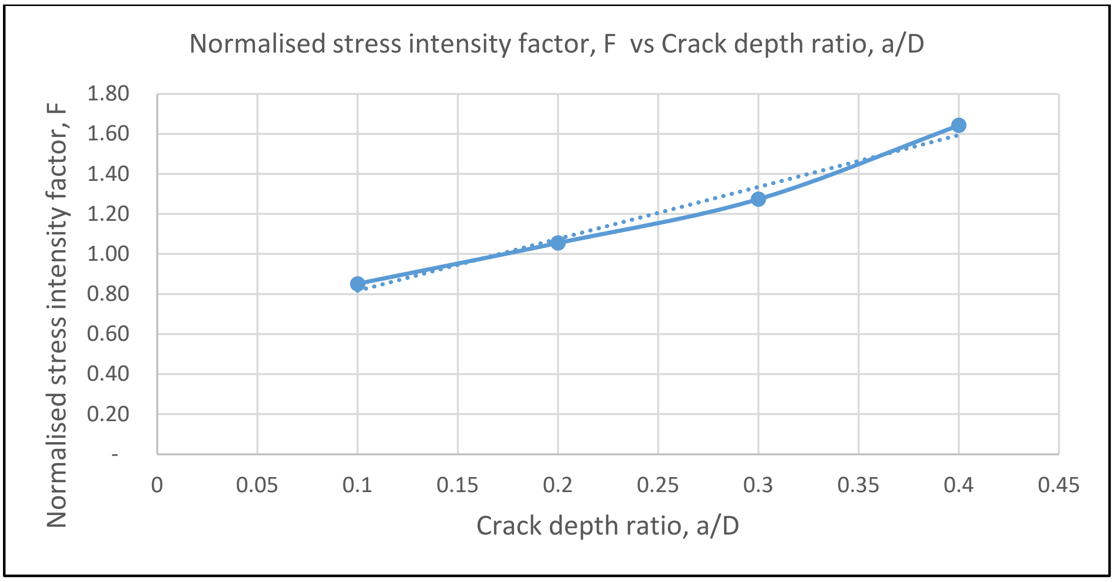

Figure 4: Graph of normalized stress intensity factor against crack depth ratio

3.3 Influence of crack depth ratio towards normalized stress intensity factor

It is justified that stress intensity factor is decreased when crack aspect ratio is increased. As set in the beginning, the crack depth is kept constant while the crack lengths are varied for each set of simulation. So, the decrement of the crack length has varied the crack aspect value. By that, it could be understood that when the crack length is decreased, the distance between crack tip and outer side of crack front is shorter. Thus, lower stress intensity factor required to be distributed along the crack front for the shorter crack length.

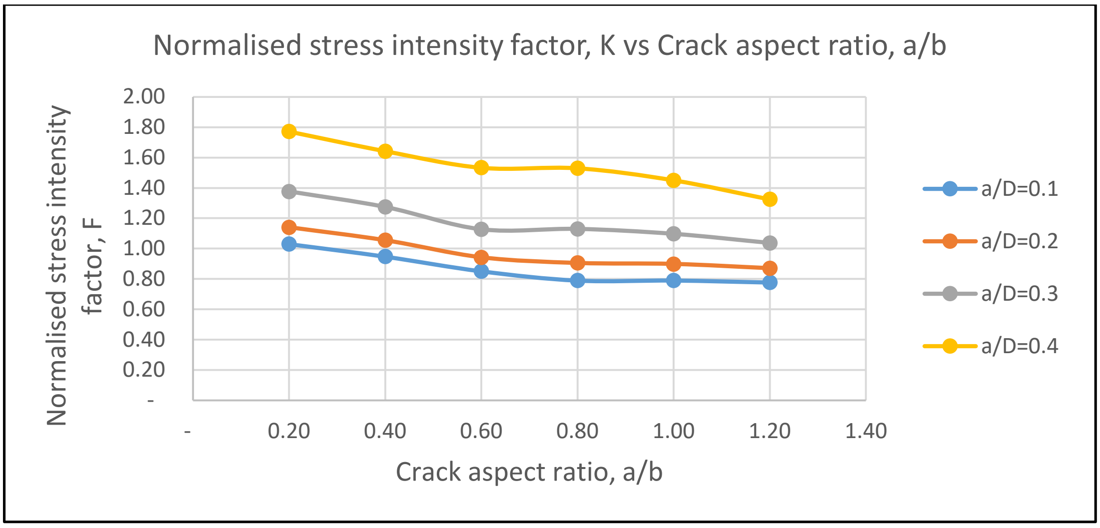

Figure 5: Graph of normalised stress intensity factor, F against crack aspect ratio, a/b

3.4 Influence of crack depth ratio and crack aspect ratio towards interaction factor values

The graph from Figure 6 obviously has described the impact on how interaction factor values response to a change in crack depth ratio. The graph has shown a positive slope function which resolved that interaction factor increase linearly with crack depth ratio.

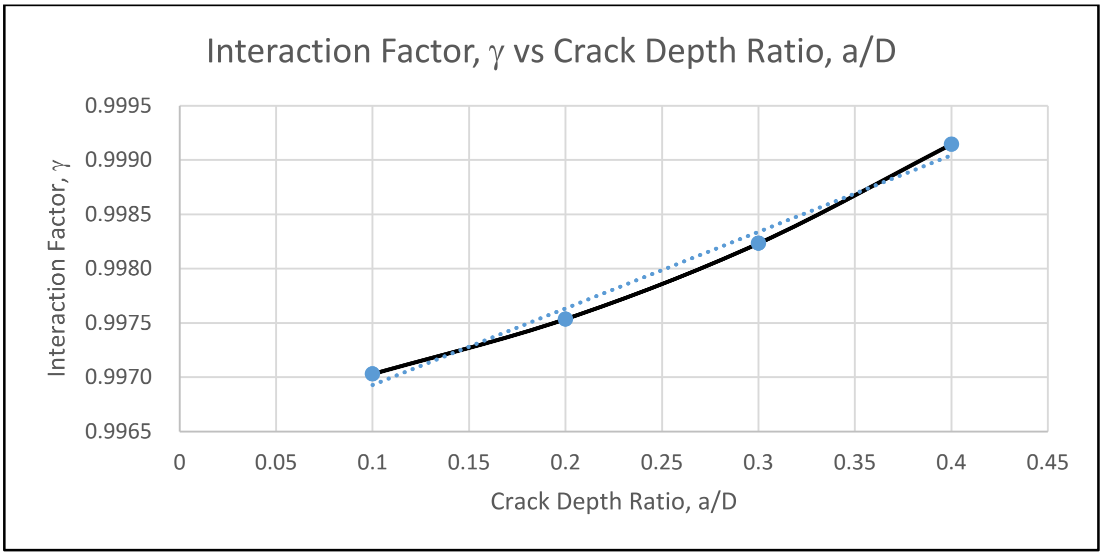

Figure 6: Graph of interaction factor, γ against crack depth ratio, a / D

3.5 Relation between normalised stress intensity factor and interaction factor

As studied, interaction factor value depends on the presence of SIF value. It is expressed that interaction factor is ratio of SIF for single crack to SIF for double crack. From the calculated data, it is shown that the SIF value for both elements are almost the same. By applying the calculation, the normalised stress intensity factor could be obtained and it shows that the higher stress intensity factor, the higher the value of normalised stress intensity factor. So that, the relation presented in Figure 7 by normalised stress intensity factor and interaction factor is the value of interaction factor would increase when the value of normalised stress intensity factor is increased too.

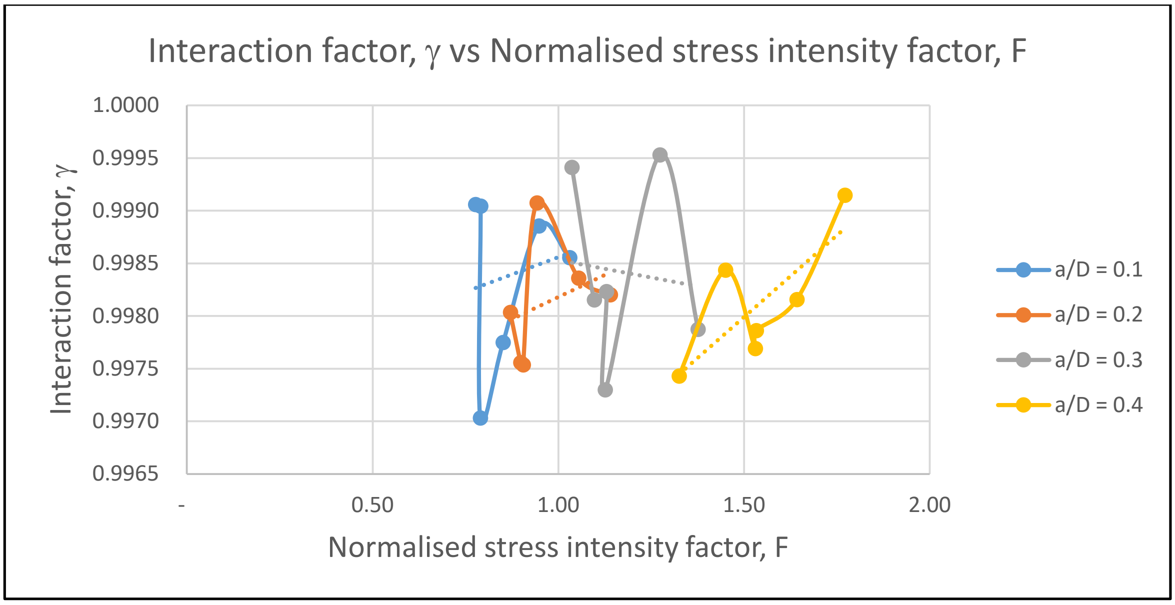

Figure 7: Graph of interaction factor, γ against normalised stress intensity factor, F

4. Conclusion

The cracks generated for each set of simulation process have different physical characteristics which are different crack depth ratio and crack aspect ratio which. The presence of these two factors has impacted the changes of stress intensity factor value for the double cracks formed on the cylindrical rod. Stress intensity factor will increase as crack depth ratio increase and crack aspect ratio decrease. It shows that the concentrated stress required to be distributed along the crack front is higher when the distance between crack tip and outer side of crack front is further. The interaction of cracks is identified to be influenced by stress intensity factor. The calculation in order to determine the interaction factor involve stress intensity factor. Thus, they show the relation that higher interaction factor represent higher stress intensity factor of cracks.

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