Examination of Stress Intensity Factors for Composite Materials by FEM (II)

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Abstract

Background/Objectives: In this paper, an automated stress intensity factor (SIF) analysis for three-dimensional surface cracks in composite materials is described. Three-dimensional (3D) finite element method (FEM) is used to calculate the stress intensity factor for surface cracks in composite materials.

Methods/Statistical analysis: To check the accuracy of the system, the stress intensity factor for the semi-elliptical surface cracks in the plate under uniform loading was calculated and compared with Raju-Newman's solution. The developed system was then used to analyze the cladding effects of cracks in the composite. The analysis results of the cracks in the composite material were compared with those of the cracks in the homogeneous material and applied to analyze the cladding effect of the surface cracks in the composite material.

Findings:As a result, the SIFvalue at the maximum depth point tends to decrease as the depth ofthe crack increases, and the SIF value increases at the two surface points.As the distance d between cracks increases, that is, the distance between the two cracks decreases, the SIF value tends to decrease little by little.In particular, it can be seen that as the distance d between the cracks increases, the mutual interference effect between the cracks is smaller.These analyzes clearly demonstrate that the SIF of subsurface cracks is less than the SIF of surface cracks. In addition, the SIF values for the internal defects of the cladding material were significantly lower than those of the surface cracks without cladding. The smaller the crack depth ratio, i.e. the thinner the crack, the greater the effect by the cladding. Also, as the thickness of the cladding increases, the SIF value decreases as a whole.

Improvements/Applications: In the case of homogeneous materials with two surface cracks, the closer the distance between the two cracks, the greater the stress intensity factor. However, the mutual interference effect on the twin subsurface cracks had little effect.

Keywords: *Automatic Mesh Generation, Clad Material, Composite Materials, Finite Element Method, Singular Element, Stress Intensity Factor*

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I.Introduction

Cracks are found in structures have three-dimensional characteristics such as surface crack or internal crack. Therefore, three-dimensional crack analysis became an indispensable requirement for fracture mechanics evaluation of real structures. For this purpose, various analysis methods have been developed such as the FEM[1-5], the body force technique[6,7] and the iterative alternating technique[8]. Among these methods, the finite element method is the most widely used in terms of efficiency and versatility.

In reality, however, there are some difficulties in using the FEM. In other words, in the FE analysis of 3D cracks, large-scale analysis is easy and special element division is required near the crack tip, which is a stress-specific field. In particular, in the case of three-dimensional cracks present in non-homogeneous materials, automation of them is urgently required due to the difficulty of elemental division. In actual reactor vessels, the inner wall is clad with a material resistant to corrosion, such as stainless steel, in order to prevent the base material made of ferrite material from being corroded by the operating environment[9].

Therefore, in this paper, we developed a system that can perform stress intensity factor analysis for cracks existing on cladding-coated nonhomogeneous materials, that is, metals coated with other coated metals as a representative example of non-homogeneous materials.

II. Analysis System

It takes much time and effort to construct a 3D FE network with surface cracks. Therefore, in this paper, we developed a system that generates all the necessary procedures for automatic element generation and analysis for finite element analysis in three-dimensional cracks, thus constructing an overall analysis system for three-dimensional cracks.

This system consists of user input for crack shape, material property, boundary condition, node and element construction, an analysis part using ANSYS[10], a general analysis code, and an output part for calculating SIF values. The construction of such a crack analysis system is as shown in Figure 1. Here, the analysis file generated by the input unit is composed of ANSYS Parametric Design Language (APDL), which is an operation command of ANSYS. When the analysis file is executed in ANSYS, finite element modeling and crack analysis are automatically performed. As a result of analysis, the system was constructed so that the stress intensity factor K value was obtained directly at an arbitrary point (2Φ/π) along the crack tip.

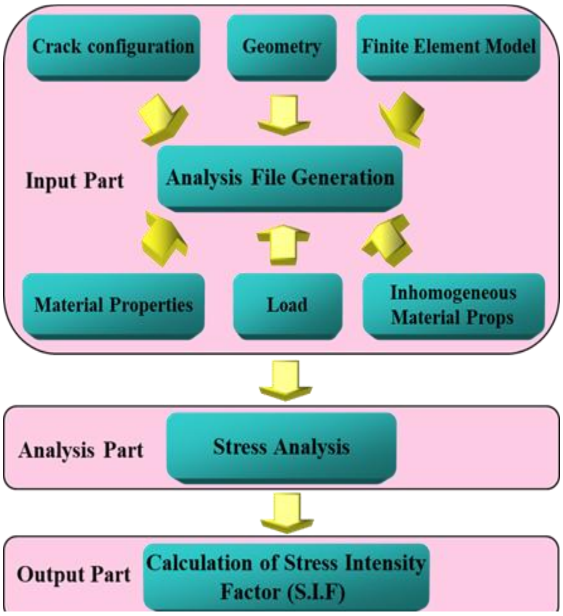
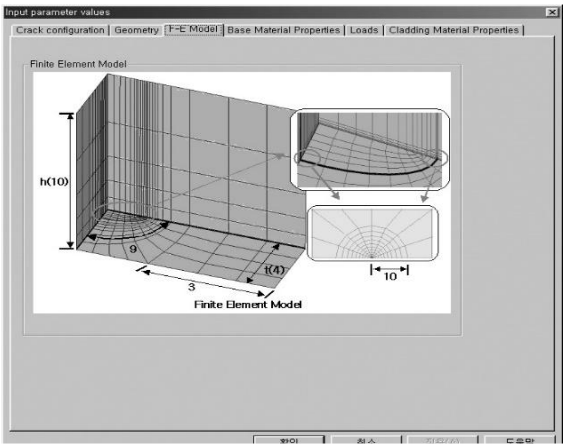


Figure 1. Flow chart of crack analysis system

Figure 2 shows the shape of the FE modeling according to the selected crack shape in the FEM window. In the crack configuration window, one surface crack can be selected for a single surface crack and for a single subsurface crack, respectively, and two surface cracks can be selected as homogeneous. It is configured so that it can be selected for the case of being present in the material and the case of being present in the inhomogeneous material, respectively.


Input parameter values

Crack configuration | Geometry | F-E Model | Base Material Properties | Loads | Cladding Material Properties

Finite Element Model

Figure 2. Input window of finite element model

III. Verification of Finite Element Analysis Model

Single crack in the plate

In order to verify the effectiveness of the developed module and system, we performed FE analysis on the presence of one semi-elliptical surface crack on the plate under tensile stress and compared it with the results of Raju-Newman[11] .

Analysis model

Figure 3 shows FE modeling of semi-elliptical surface cracks in homogeneous materials using the module developed in this study. Only one quarter of the model is modeled using symmetry planes. All parts except the crack tip were modeled as hexahedrons elements, and the crack tip was modeled as pentahedrons elements with 8 wedge-shaped wedges representing the most efficient element split design in FE analysis.

The analysis for verification was performed for the case where the crack shape ratio, a/c was 0.2, 0.4, 0.6 and the crack depth ratio a/t= 0.2, 0.4.

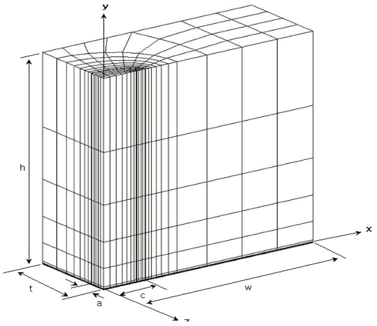


Figure 3. FE modeling for semi-elliptical surface crack

Analysis result

Figure 3 shows finite element modeling of semi-elliptic surface cracks in homogeneous materials using the module developed in this study. Only one quarter of the model is modeled using symmetry planes. All parts except the crack tip were modeled as hexahedrons elements, and the crack tip was modeled as pentahedrons elements with 8 wedge-shaped wedges representing the most efficient element split design in FEA.

The analysis for verification was performed for the case where the crack shape ratio (a/c) was 0.2 to 0.6 and the crack depth ratio a/t= 0.2, 0.4.Figure 4 shows the analysis results when the crack shape ratio is 0.4 and the crack depth ratio is 0.2. The horizontal axis represents the position along the crack tip, and the vertical axis represents the correction factor F, which is dimensionlessly expressed as the stress intensity factor K, as shown in Equation (1).

$$F = \frac{K}{\sigma\sqrt{\pi a / Q}} (1)$$

Figure 5 shows the analysis results for the case where the crack shape ratio is 0.2 and the crack depth ratio is 0.4.

The maximum SIF K tends to occur at the deepest point of the crack and gradually decreases as it approaches the surface, showing a difference of less than 5% compared to Raju-Newman's solution.

Figure 6 shows the SIF values with the change of material thickness at the deepest point of the semi-elliptical surface crack. The analysis was carried out in theshape ratio a/c = 0.2to1.0 of the cracks. These results show that, like Raju-Newman's solution, as the thickness increases, the SIF value at the deepest point increases at all the deepest points of the aspect ratio of the crack. It can also be seen that the SIF values at a/c = 0.2 are most affected by the thickness.

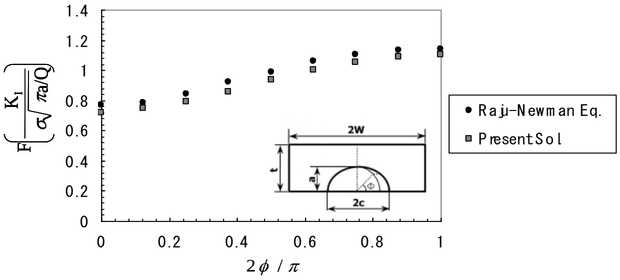


Figure 4. Stress intensity factor according to crack tip position (a/c=0.4)

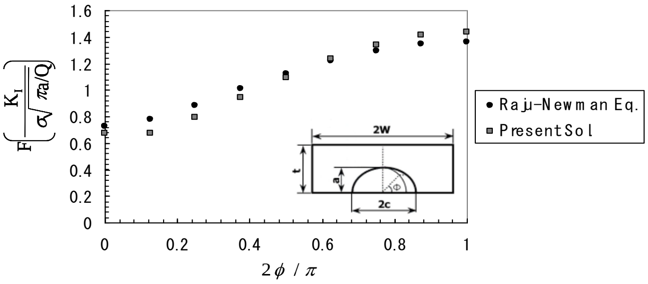


Figure 5. Stress intensity factor according to crack tip position (a/c=0.2)

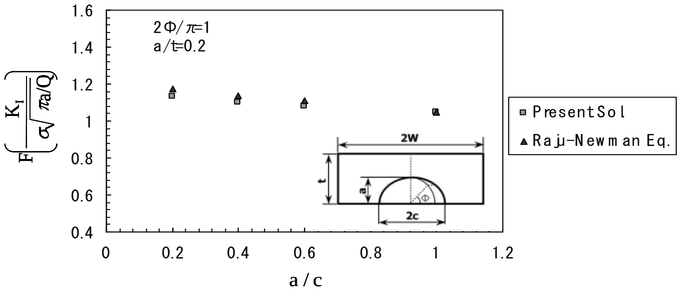


Figure 6. SIF at the deepest point of crack compared with Raju-Newman's solution

Twin surface crack in the plate

In this section, SIF is analyzed for the case oftwin semi-elliptic surface cracks in the same shape in finite plate and the effects of mutual interference between the two surface cracks are examined.

Analysis model

Figure 7 shows the mesh of FE modeling for the analysis of twin surface cracks. As with one surface crack, all parts except the crack tip were modeled as hexahedrons elements, and the crack tip was modeled as pentagonal elements.

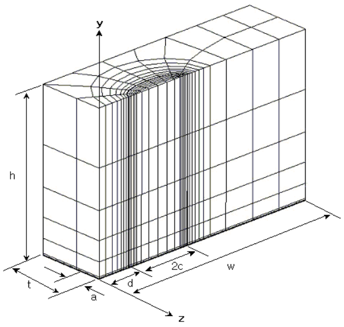


Figure 7.FE modeling for twin surface crack

Analysis result

Figure 8 shows the SIF values when the crack depth ratio is 0.2, increasing the distance d between cracks at the deepest point (2ø/π = 1). Regardless of the change in a/c, all SIF values at the deepest point become smaller as the distance d between cracks increases.

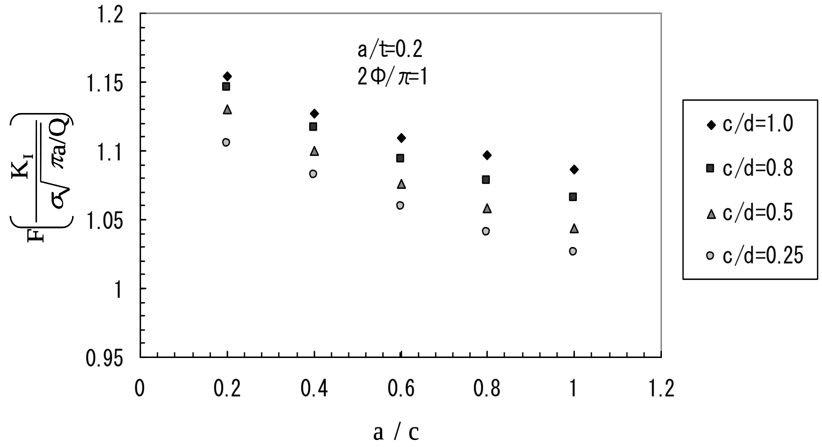


Figure 8.SIF at the deepest point according to the crack spacing

IV. Results and Discussion

In this chapter, SIF K analysis of internal cracks in cladding plate is performed and the effect of clad thickness is analyzed.Figure 9 shows FE modeling for internal crack, and Figure 10 shows the FE modeling for twin cracks. Figure 11 shows the effect of the SIF on the cladding thickness by varying the cladding thickness. Here, a/c = 0.2, a/t = 0.2, the thickness of the base material (SA 533 Grade B) was 100 mm, and the thickness of the cladding material (Stainless-steel) was changed to 2 mm to 10 mm. As shown in the figure, the SIF for the internal defects of the cladding material are significantly lower than the SIF values of the surface cracks without cladding. The smaller the crack shape ratio (a/c), that is, the thinner the crack, the greater the effect by the cladding. In addition, it can be seen that as the thickness of the cladding portion increases, the SIF generally decreases little by little.

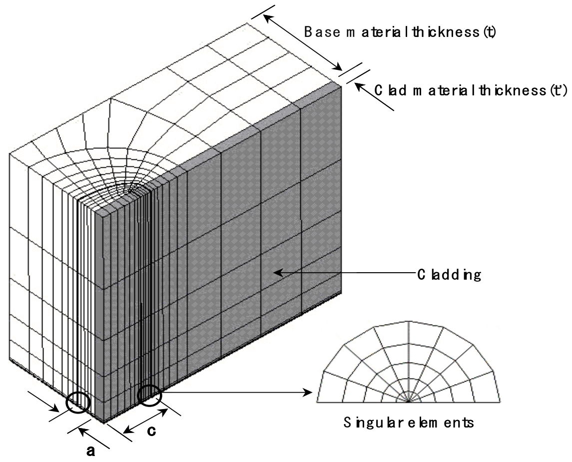


Figure 9. Element generation for single internal crack present in inhomogeneous material

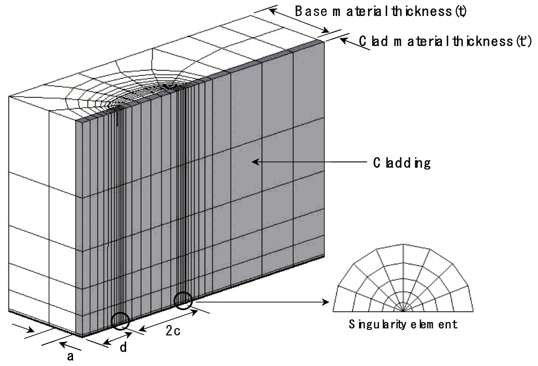


Figure 10. Element generation for twin

cracks present in inhomogeneous material

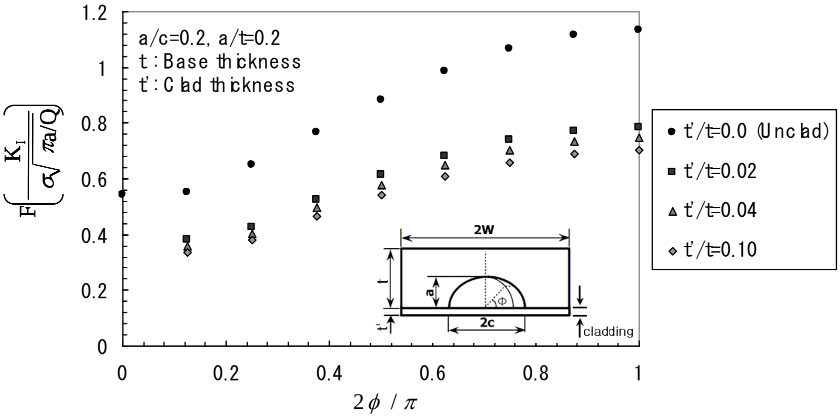


Figure 11. Effect of cladding effect on stress intensity factor

Figure 12 shows a/c = 0.4, a/t = 0.2, the thickness of the base material (SA 533 Grade B) is 200mm, and the thickness of the clad material (Stainless-steel) is changed to 4mm, 8mm, 12mm, 20mm. As with one internal defect of cladding material, the analysis of stress intensity factor for two internal defects is significantly lower than the stress intensity factor value of surface defects without cladding. Also, the thinner the crack, the greater the effect by the cladding.

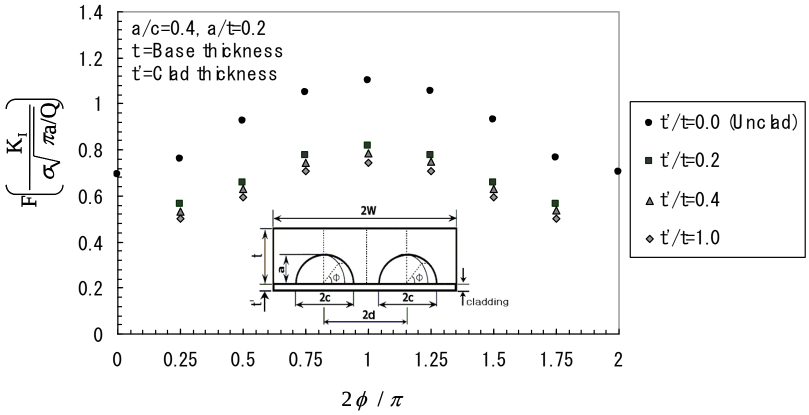


Figure 12. Effect of cladding effect on stress intensity factor

V. Conclusion

In this paper, an automatic element generation module was developed for the analysis of SIF for 3D cracks in composite materials. Using this developed system, the analysis of the surface cracks and internal cracks in the composite plate subjected to the tensile force was carried out.

Under the same conditions, the SIF for internal cracking of the inhomogeneous material was significantly reduced due to the restraint effect of the cladding material. Also, as the cladding thickness increased, it decreased constantly.The SIFs for the internal crackof the composite material were larger than the surface cracks of the homogeneous material.

In the case of surface cracks in composite materials, the SIF value at the crack surface point increases as the cladding thicknessincreases, which is greater than the value for surface cracks of the homogeneous material. The SIF of the crack deepest pointalso increased in proportion to the cladding thickness.

VI. Acknowledgment

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