Simulation and Modelling Of Edge Crack Propagation of 2D-Plate Using Casca and Franc-2D

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Abstract — In present endeavour, a methodology has been proposed to predict the edge crack growth of a steel 2D plate by using CASCA (Mesh Creator) and FRANC-2D simulation tools. Stainless steel 316 was considered for this investigation. The edge crack model of 316 stainless steel 2D plate was concerned to locate the path of crack propagation thus assisting to find out the stress intensity factor at mode I and mode II simultaneously. FRANC-2D and CASCA have been programmed by fracture research group of Cornell University. FRANC-2D is finite element based two-dimensional crack propagation simulator and is specifically employed for predicting the crack propagation assuming material having isotropic nature. All the steps to model the 2D plate and to simulate a crack in the plate till its propagation have been covered in a sequential manner in the present paper. Application of FRANC-2D proved useful and time saving for predicting the edge crack propagation behaviour of stainless steel 316. The availability and applicability of such innovative simulation tools encourage research and development of applied fracture mechanics to address crack growth problems in a variety of engineering alloys.

Keywords — **Crack simulator; FRANC-2D; CASCA; Stainless steel 316, Edge crack propagation.**

I. INTRODUCTION

The idea of crack simulation tool came into picture from NASA Airframe Structural Integrity Program (NASIP), which has been formed to generate understanding in structural integrity problems in aircraft design and commercial transport applications. This led to birth of FRANC-2D software which was developed by Cornell University. The program code for FRANC2D has been created to fulfill requirement in modeling actual behaviour of crack propagation using finite element approach. Therefore, FRANC-2D is based on two-dimensional linear elastic fracture mechanics (LEFM) Model which is an established approach for understanding crack propagation in Fracture Mechanics. This approach can model the quasi-static crack propagation problems. In FRANC-2D three propagation theories are considered according to which crack propagation behaviour is examined. The three theories are (a) Sigma theta max theory (b) G theta max theory and (c) S theta min theory given by Erdogan and sih in 1963, Hussain et al in 1974 and Sih in 1974 respectively [1].

These days several experimental approaches are employed to investigate the crack propagation behaviour in steel plates. But most of these experimental methods are destructive in nature, costly and take a lot of time to reach to a significant solution. To overcome these difficulties, many analytical and finite element approaches have been proposed by various researchers to reach final solutions rapidly [2-6]. Stress intensity factor and stress concentration factor are two essential entities which are required to predict stress in the locality and at sharp crack etc. The stress concentration factor gives stress at a point in the material under consideration [7] whereas stress intensity factor (K) is a parameter which indicates stress field of a crack. To establish relationships for stress analysis of cracks in elastic solids, it is convenient to define three types of relative displacements among two crack surfaces. These displacement modes represent the local deformation ahead of a crack.

The mode I is referred as opening mode under the effect of tensile forces where the crack edges are separated in the y-direction. The deformations are assumed symmetric with respect to the planes perpendicular to the y-axis and the z-axis. In the mode II, which is refereed as sliding mode displacement occurs under shear forces corresponding to the crack surfaces sliding over each other in the x-direction. Thus, deformations are symmetric with respect to the plane perpendicular to the z-axis and skew-symmetric with respect to the plane perpendicular to the y-axis. Whereas, in mode III, the tearing mode, displacement takes place under the effect of shear forces parallel to the crack front and the crack surfaces. The sliding of crack surfaces over each other occurs in the z direction. The deformations are then skew-symmetric with respect to the plane perpendicular to the z and the y-axis [8-9].

II. LITERATURE ON MATHEMATICAL CRACK GROWTH MODELS

Nicolas et al. used a finite element method for predicting crack growth without re-meshing. This method allowed the complete crack to be studied individually in the mesh, and therefore the re-meshing was not required to model crack growth [10]. Carter et al. has described automated 3D crack growth simulation where a model environment for representing the evolving 3D crack geometry and for testing various crack growth mechanics is presented. Reference is made to a specific implementation of the model, called FRANC-3D. Computational geometry and topology are used to represent the evolution of crack growth in the investigated structure [11]. Belytschko et al. proposed an approach on fracture and crack growth by using element-free Galerkin methods and these methods need only nodal data and a description of the geometry for solving partial differential equations. The results obtained by element-free Galerkin methods are principally effective in progressive for fracture problems because it can precisely calculate stress intensity factors with very irregular arrangements of nodes [12]. Rafii et al. has successfully employed a model to mode I crack propagation in plates containing nano-scale bands of impurities situated in the locality of the crack tip [13].

III. METHODOLOGY

A. Material

As a primary requirement in any material simulation software, mechanical properties are needed to be inserted before setting up simulation parameters. For the present simulation, a low carbon alloy stainless steel (SS) 316 was considered whose chemical composition and mechanical properties are shown in Table 1 and Table 2 respectively.

Table 1 Chemical composition of SS316

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Chromium	Nickel	Molybdenum	Nitrogen	Iron
0.08	2.00	0.045	0.030	0.75	16.0–18.0	10.0-14.0	2.00–3.00	0.10	Balance

Table 2 Mechanical properties of SS316

Young's modulus (E)	Poisson's ratio (μ)	Ultimate tensile strength	Yield strength
220 GPa	0.3	611 MPa	366 MPa

B. Flow chart for setting up simulation in FRANC-2D

Following are the steps which are employed for prediction of edge crack propagation in a 2D-plate specimen using CASCA and FRANC-2D.

I. Create Geometry
II. Subdivide the geometry
III. Mesh the model
IV. Open in FRANC- 2D
V. Apply material properties
VI. Select Problem type (Plane stress or Plane strain)
VII. Fix-it
VIII. Apply Load
IX. Analysis > Linear > Direct stiff
X. Post-Process
XI. Deformed mesh
XII. Modify > New Crack > Traction Free > Edge Crack
XIII. Post-process > Deformed mesh
XIV. Fracture mechanics tool > Compute stress intensity factor
XV. Modify > Move crack > Standard Mathematics > Key Increment > Accept
XVI. Analysis > Linear > Direct stiff

Fundamentally, all problems in FRANC-2D and CASCA are solved with the help of above mentioned sequnce. Figure 1 shows a flow chart which summarizes these steps for easy reference K_1 is stress intensity factor in Mode 1 and K_{1c} is critical value of stress intensity.

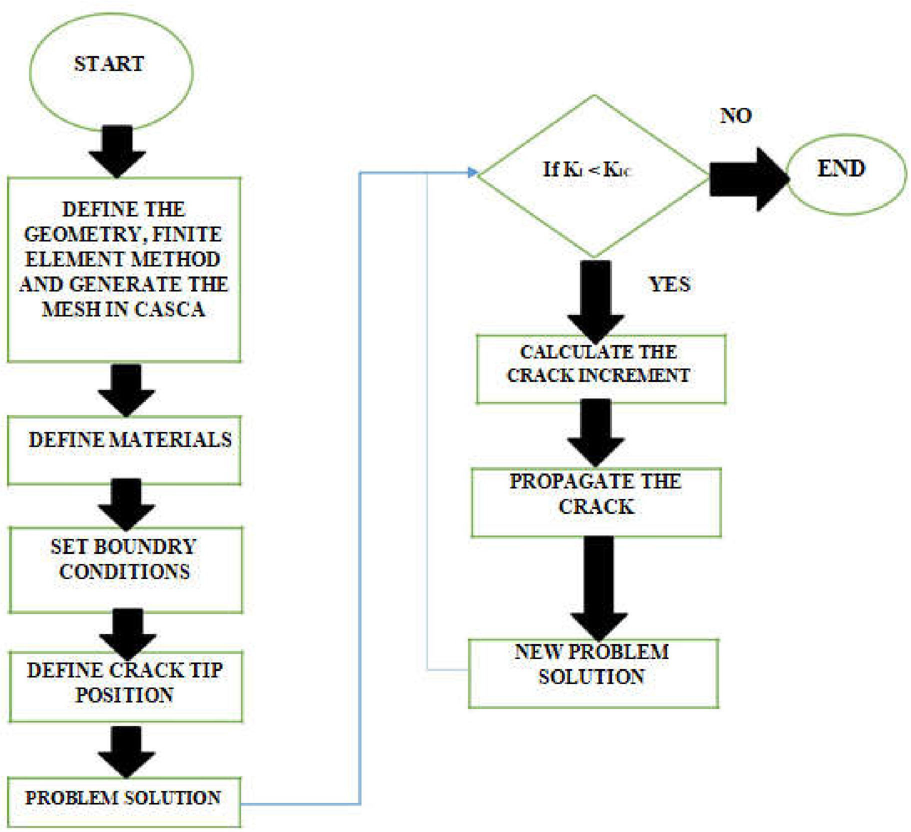


Figure 1 Flow chart of crack propagation approach in FRANC-2D

IV. MODEL DESIGN BY CASCA

CASCA tool was used to design the model first. All the dimensions were assigned with the support of CASCA as shown in Figure 2. The hexahedral type of meshing was selected in CASCA design since it gives maximum number of nodal points and therefore increases accuracy of the model.

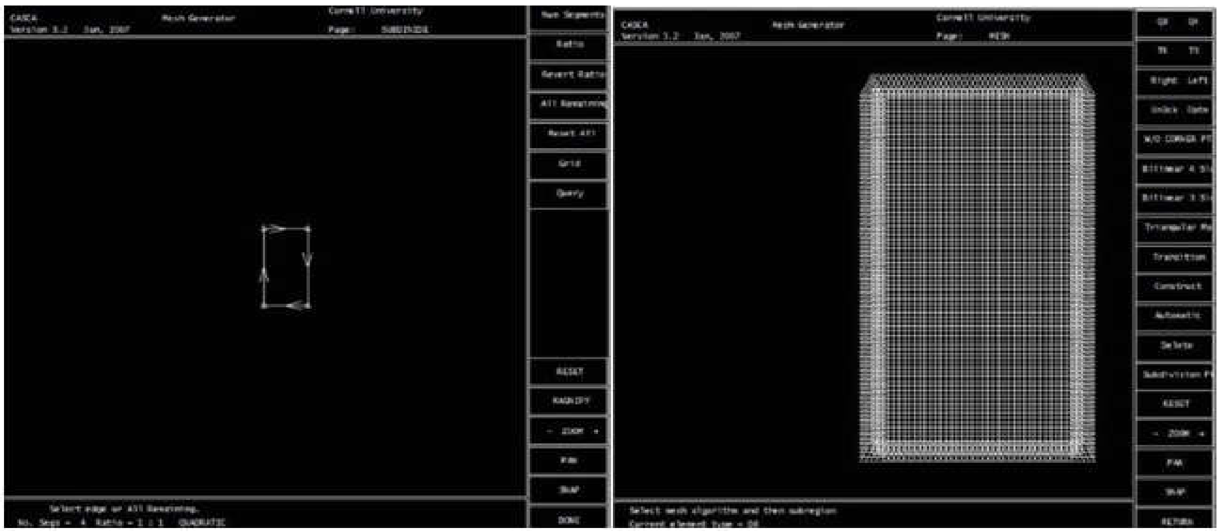


Figure 2 Model design and meshing by using CASCA

V. EDGE CRACK PROPAGATION SIMULATION USING FRANC-2D

After meshing, the model is loaded into FRANC-2D simulation tool. The definition of load distribution and material properties as given in FRANC-2D is shown in Figure 3.

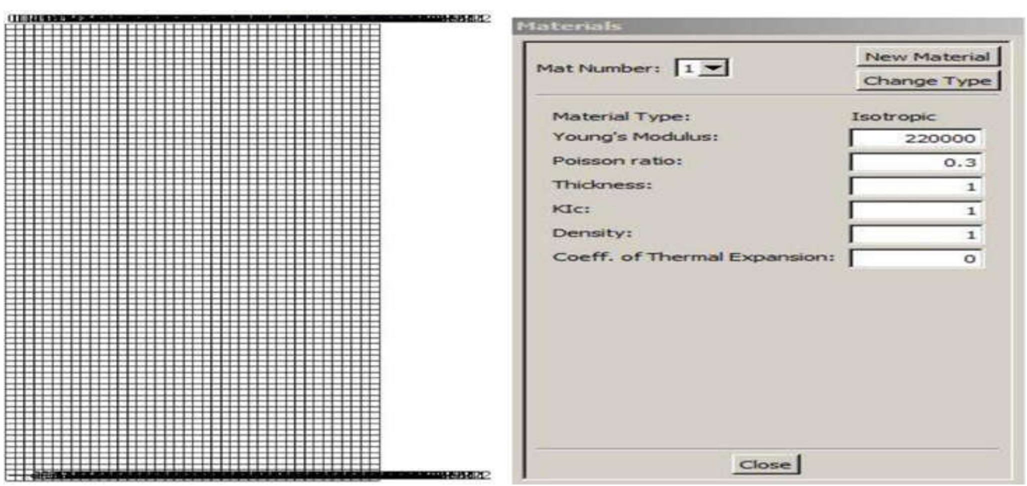


Figure 3 Definition of load distribution and material properties in FRANC-2D

The load is inclined in x and y direction. The direction of fix-it is on Y direction only. Crack propagation prediction is a step by step process, where a string of steps is repeated for a subsequent evolution of models.

Each incremental step of the simulation count is obtained by previously calculated results during whole simulation process and signifies one increment in crack formation. Precisely, four prime groups of databases are required for each incremental step. The first is the figurative database, means Ri, where the subscript classifies the increment step number. The figurative database gives an explanation of the model geometry, material properties, cracks and boundary conditions. The figurative database is converted by a discretization process D to a stress analysis database Ai. The discretization process generates a meshing function M which should satisfy equation (1).

D [Ri, M (Ri)] = Ai……………..(1)

Figure 4 shows the crack initiation at the meshing of crack locality and the flaw opened at cracked surface. Edge crack propagation theory based on LEFM approach which corresponds to simulation of crack growth criteria with strings of repeated steps can be easily observed as deformation in crack area meshing.

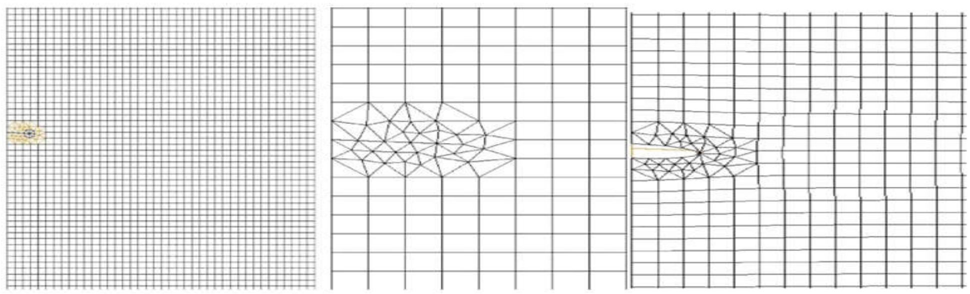
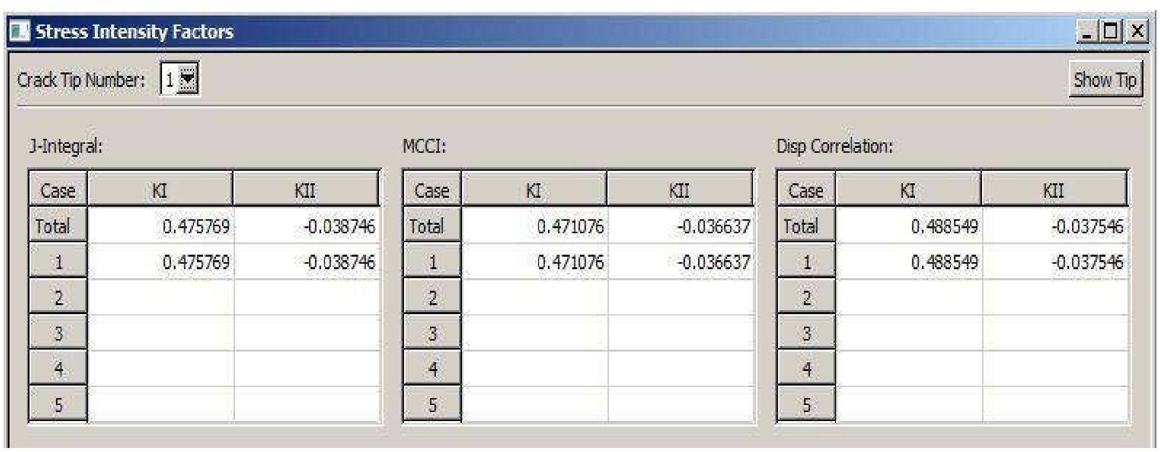


Figure 4 Crack initiation at crack flaw and deformation crack area meshing

The stress intensity factor as shown in Figure 5 has been evaluated successfully by FRANC-2D which calculated the stress intensity factor on the basis of standard mathematical equations of fracture mechanics, defining J-Integral, modified crack closure integral (MCCI) and displacement correlation [14]. Program code of FRANC-2D is inbuilt with basic fracture mechanics equations which assist to determine the stress intensity factor at crack tip before and after propagation.



Stress Intensity Factors

Crack Tip Number: 1 Show Tip

J-Integral:

Case	KI	KII
Total	0.475769	-0.038746
1	0.475769	-0.038746
2		
3		
4		
5		

MCCI:

Case	KI	KII
Total	0.471076	-0.036637
1	0.471076	-0.036637
2		
3		
4		
5		

Disp Correlation:

Case	KI	KII
Total	0.488549	-0.037546
1	0.488549	-0.037546
2		
3		
4		
5		

Figure 5 Stress intensity factor at crack initiation site

It can be observed that in J-Integral column, values of stress intensity factor are K_I = 0.475769 and K_{II} = - 0.038746 respectively. Whereas in MCCI, the calculated values of stress intensity factors are K_I = 0.471076 and K_{II} = - 0.036637. Simultaneously in displacement correlation method the resulting stress intensity factor values are K_I = 0.488549 and K_{II} = - 0.037546. These close values validate the designed CASCA model and shows reliability of result as obtained by FRANC-2D.

As given in the steps in the flowchart, the next is now crack propagation. Figure 6 gives the steps as captured from FRANC-2D interface involved in simulation process for edge crack propagation. Figure 7 shows the mesh in the edge crack propagation region.

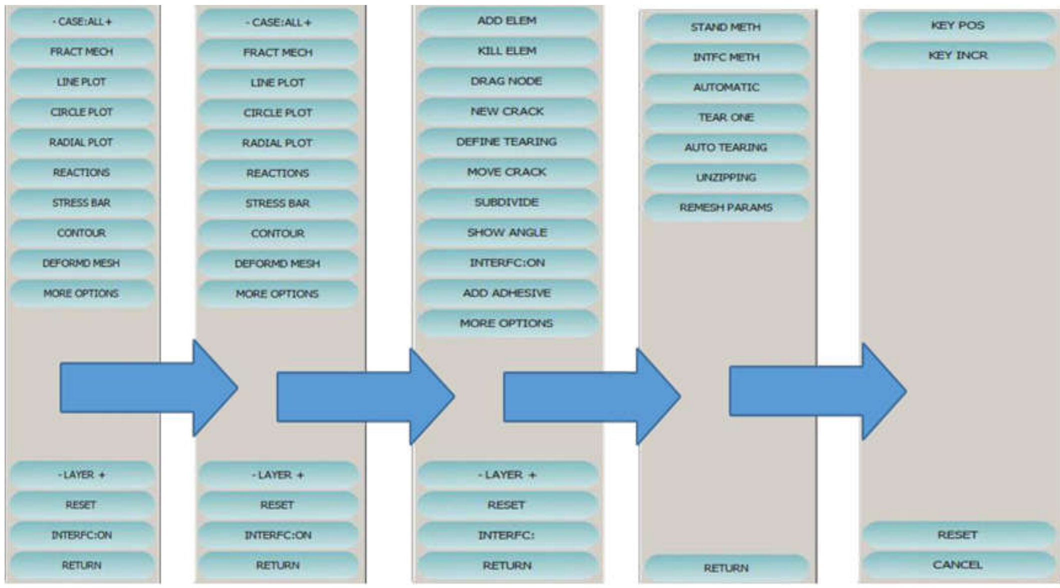


Figure 6 FRACN-2D simulation steps involved for crack propagation

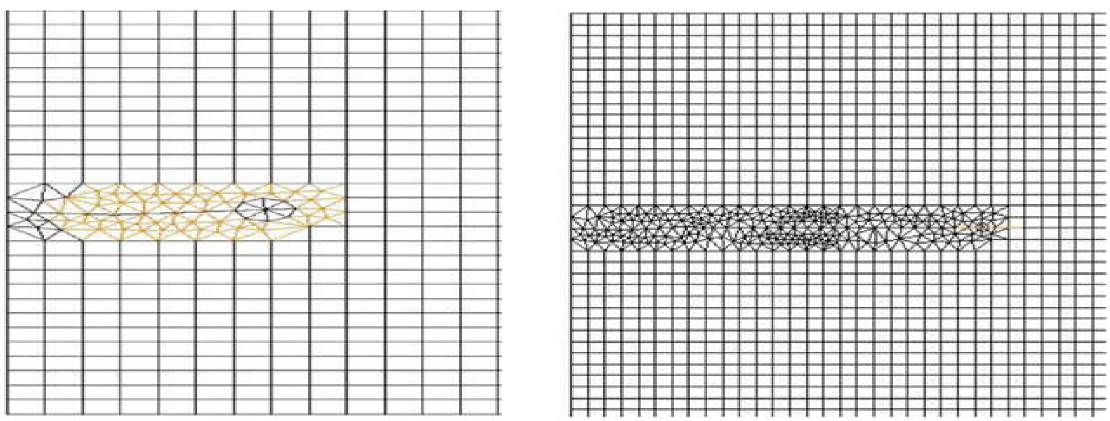
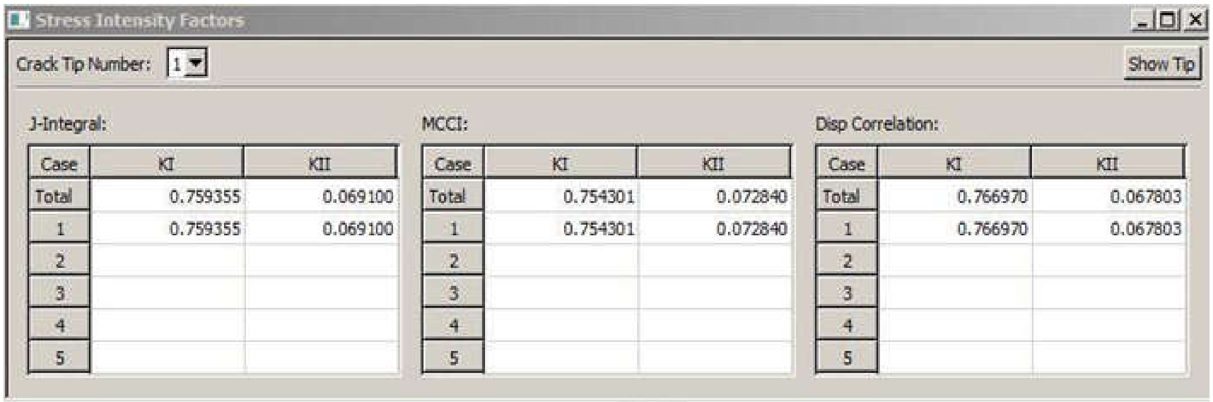


Figure 7 Meshing of the crack propagation region

The values of stress intensity factors increase after crack propagation as observed in Figure 8. As per the calculation of J-Integral method the stress intensity factors are, KI = 0.759355 and KII = 0.069100. For MCCI, the calculated stress intensity factors are KI = 0.754301 and KII = 0.072840 whereas for displacement correlation method calculations, the resulting stress intensity factors values are KI = 0.766970 and KII = 0.067803. Figure 9 shows simulated deformed mesh after edge crack propagation.


Stress Intensity Factors

Crack Tip Number: 1

Show Tip

J-Integral:

Case	KI	KII
Total	0.759355	0.069100
1	0.759355	0.069100
2		
3		
4		
5		

MCCI:

Case	KI	KII
Total	0.754301	0.072840
1	0.754301	0.072840
2		
3		
4		
5		

Disp Correlation:

Case	KI	KII
Total	0.766970	0.067803
1	0.766970	0.067803
2		
3		
4		
5		

Figure 8 Stress intensity factors after crack propagation as given by FRANC-2D

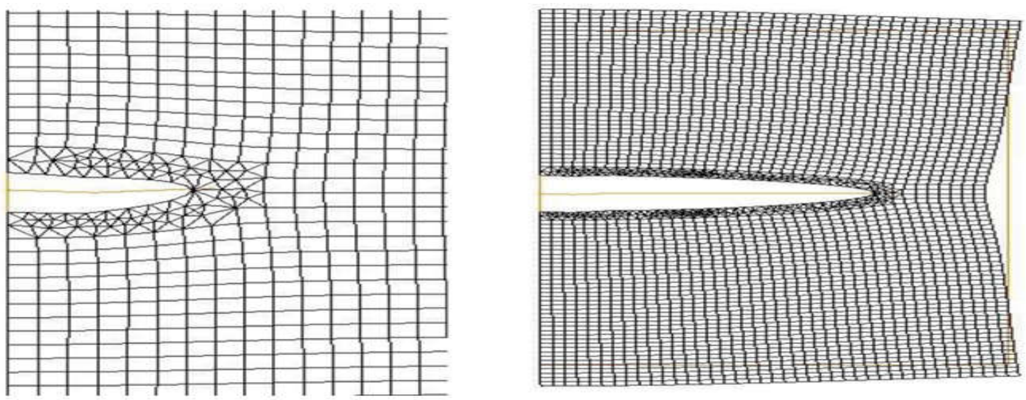


Figure 9 Deformed Mesh with crack Propagation region

VI. DISTRIBUTION OF STRESS INTENSITY FACTOR

The context of FRANC-2D is planned for modelling the subjective crack growth in 3D structures. With the representation of boundary conditions as well as constraints in the model it is possible to simplify the discretization which serves to make the theoretical model of crack propagation simulation a versatile tool for execution of crack growth simulations as shown in Figure 10. The calculated values of stress intensity factors along the crack length in the form of plots are shown in Figure 11. The correlation of crack length and K_{II} is well explained and the variation between them shows that as the primary region of K_I increases, the crack length simultaneously increases.

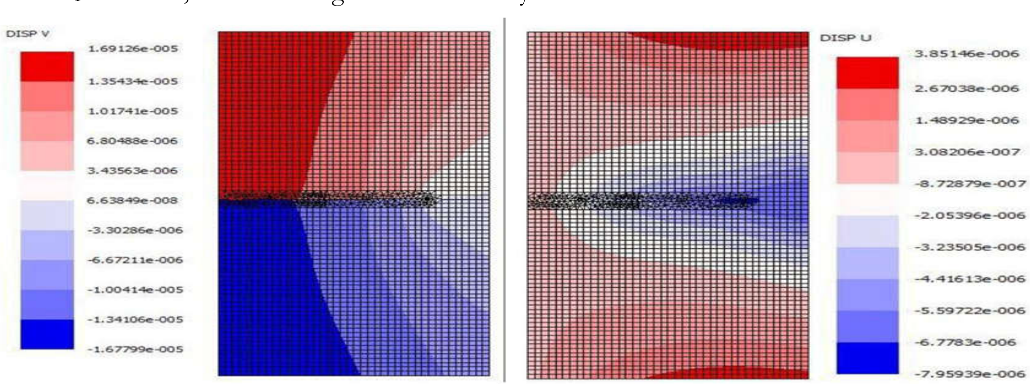


Figure 10 Distributions of Displacement ‘u’ and ‘v’ along ‘x’ and ‘y’

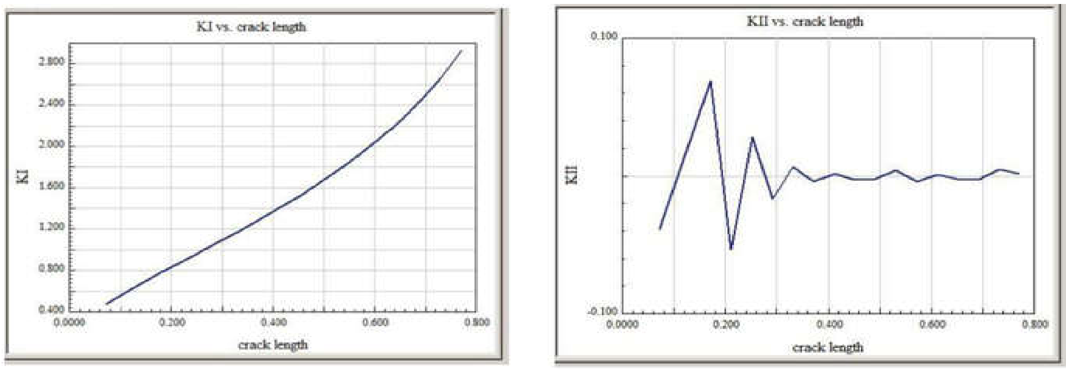


Figure 11 FRANC – 2D crack length versus stress intensity factor plots

VII. CONCLUSIONS

CASCA and FRANC-2D modeling tools were employed to analyze the edge crack propagation behaviour in Stainless steel 316. The solutions are solved with standard mathematical equations of linear elastic fracture mechanics which give stress intensity factors. Formation of meshing with crack propagation changes step by step, which further depend upon model geometry configuration and crack shape. The framework of FRANC-2D allows 2D models to validate experimental studies by forming the virtual crack geometry and deformed meshed structure.

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