

## Numerical Analysis Of An Arbitrary Crack In A Turbine Rotor Blade For Various Crack Lengths

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### **ABSTRACT**

In the present study, numerical simulation of an arbitrary semi-elliptical crack in a turbine rotor blade has been carried out using commercial 3D Finite element analysis code ANSYS with an intention of accurate estimation of stresses in the region of stress singularity which may lead to crack initiation. Initially, a 3D Finite element model specimen has been analysed for crack analysis. Further, finite element analysis has been carried out by introducing semi elliptical crack at the identified locality of stress singularity to determine the stress range at the crack tip. Stress intensity factor is the parameter in fracture mechanics to calculate the effect of crack on the component strength. In this research paper, the three-dimensional crack is modelled by using finite element analysis program ANSYS R19.1 and the blade profile is modelled by CATIA V5R20 software. The main objectives of this paper is to analyse the problems like crack location, stress intensity factors for the crack has been examined. In this paper stress intensity factor for single semi elliptical crack has been analysed in linear elastic fracture mechanics regime by FEM model.

**KEYWORDS:** *Semi Elliptical crack, Stress Intensity Factor (SIF), ANSYS and LEFM*

### **I. INTRODUCTION**

The turbine blades of the warmer stages are those parts which are subjected to the most damaging stresses due to numerous factors such as the very high temperature of the burnt gases, the strong thermal gradients present during the take-off and landing phases in the case of aircraft engines, creep of centrifugal force, hot corrosion, high stresses induced by complex geometry and vibration fatigue is shown in the Figure 1.

The literature reveals that, surface cracks are one of the most common flaws especially in aging aircrafts [1].

Assessment of structural integrity of components containing cracks can be made using different fracture mechanics parameters corresponding to different fracture mechanisms.

The known stress intensity factor (SIF) equations for Semi-elliptical cracks are obtained on the basis of previous numerical analysis. This paper presents a review of finite element solutions for the stress intensity factors along the front of Semi-elliptical cracks on a turbine rotor blade.

In this study, SIF calculations is analysed based on the location where maximum principal stress theory is considered and semi-elliptical cracks are obtained using Finite element method (FEM).

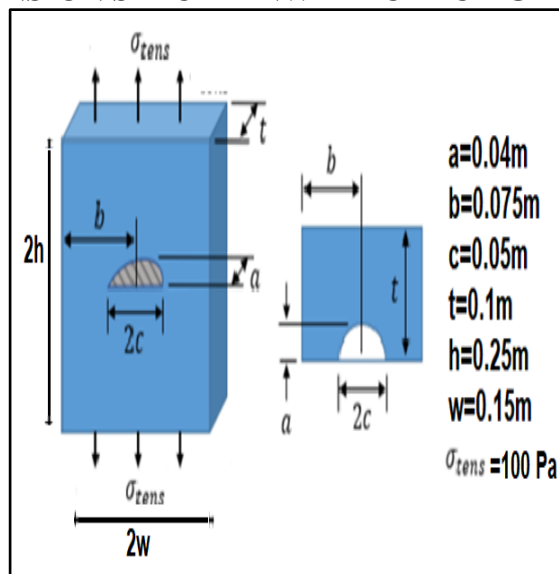


**Fig. 1 A Typical Combined Failure Mode showing both TipRub, Hot Corrosion, and a Fatigue Failure in turbine disc (3)**

**II. DESCRIPTION OF THE PROBLEM**

In this study, a semi-elliptical crack is modelled based on von Mises stress and the maximum principal stress regions on the blade profile are considered. Maximum Stress intensity factors of a semi-elliptical crack at various contours are calculated for different crack lengths. Titanium alloy blade material is considered for analysis which is a good corrosion resistant, high chemical stability and excellent mechanical properties. This project work aimed to find a critical region or crack zone, predict fatigue crack growth and crack propagation life.

**III. THREE DIMENSION SPECIMEN WITH CRACK GEOMETRY MODEL**



**Fig.2. 3D model with crack geometry(1)**

Stress Intensity factor for a semi-elliptical crack (2) can be determined using the following Eq.(1).

Stress Intensity factor,  $K = (Y_t \sigma_t) \sqrt{\pi a}$ .....(Eq.1)

By calculating the values for  $Y_t$ , stress Intensity factor,[4]

$K = 0.77 * 100 \sqrt{\pi * 0.04} = 27.29 \text{ Pa.mm}^{1/2}$

**A. Material properties**

Table.1.

Material	Density Kg/m <sup>3</sup>	Young's modulus(E)	Poisson's ratio(v)
Structural steel	7.85E-6	2 E5	0.3
Titanium alloy	4.62E-6	9.6 E4	0.36

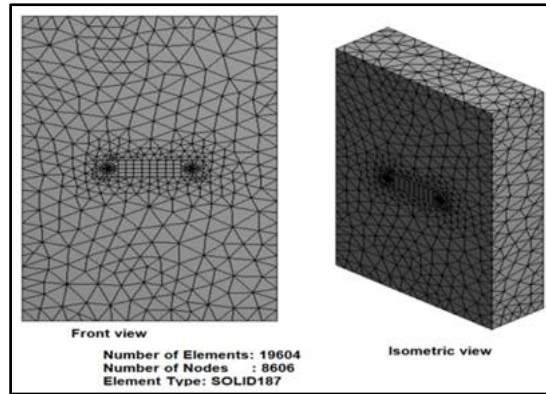
**IV. NUMERICAL SIMULATION OF 3D SPECIMEN**

**A. Geometric modelling**

The geometric modelling was carried out using CATIA V5. Structural steel material is used for 3D specimen analysis.

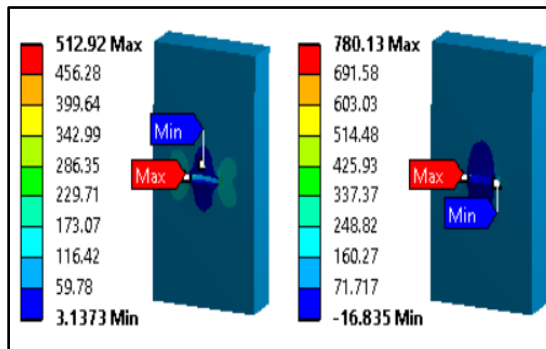
**B. Finite Element modelling**

The specimen is modelled with loads and boundary conditions according to the specimen shown in Fig.1 using ANSYS workbench software 19.1. For meshing, Tetrahedron elements were used for semi-elliptical cracks with hexa-dominant using SOLID 187.(9)

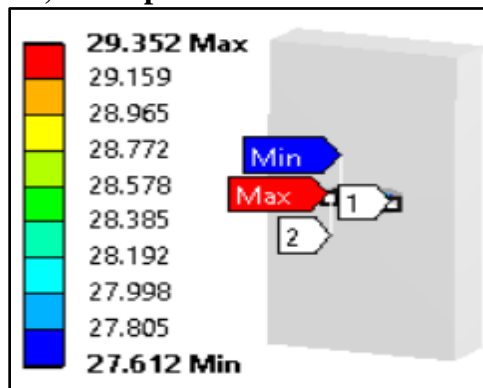


**Fig.3 Mesh generation at the crack tip(3D specimen)**

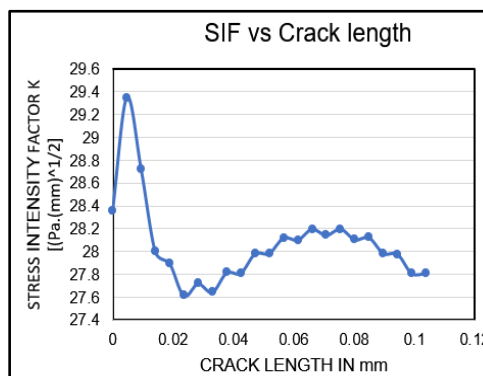
**C. Finite element results**



**Fig.4 Von Mises stress, Principal stresses at the crack region (3D specimen)**



**Fig.5 Stress Intensity factor (K1) at the crack region.(3D specimen)**



**Fig.6 Stress Intensity factor for different crack lengths (3D specimen)(0~0.1 mm)**

**V. NUMERICAL SIMULATION OF 3D ROTOR BLADE**

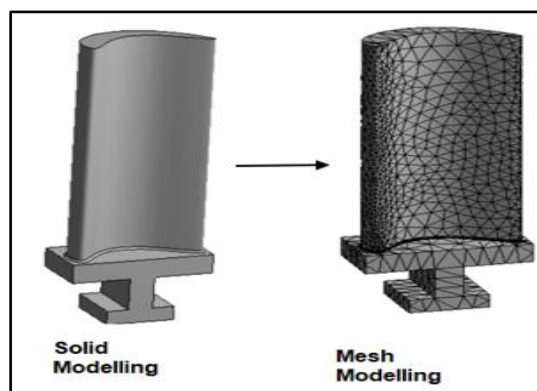
**A. Geometric modelling**

The geometric modelling was carried out using CATIA V5. Titanium alloy is used for blade analysis.

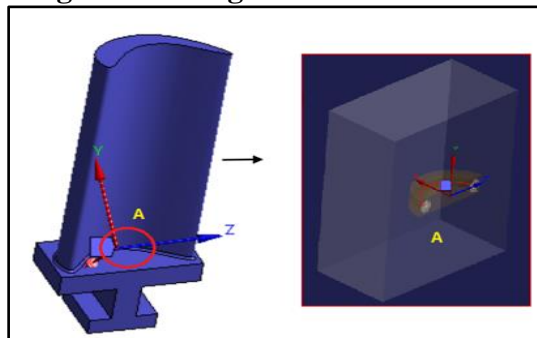
**B. Finite element modelling**

The rotor blade was modelled with loads and boundary conditions using ANSYS workbench software 19.1 (5) (7) and (8).

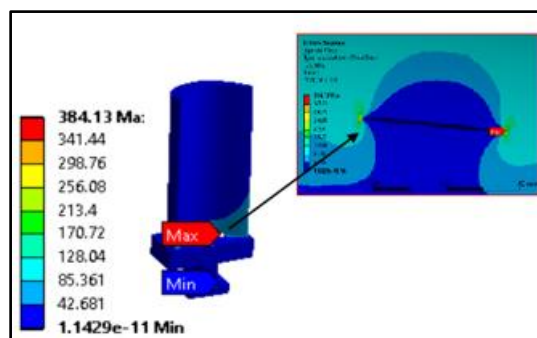
For meshing, Tetrahedron elements were used for semielliptical cracks with hexadominant using SOLID 187 and the procedure for crack modeling for rotor blade is used as same in 3d specimen with nodes of 28,976 and 14,602 elements. The number of contours for crack integration is set to 6. A semielliptical crack is inserted into an existing non-cracked mesh which eliminates need to manually embed semielliptical crack(s) in solid model and automatically connects cracked region to the entire model. Only major and minor radii of the crack is required.



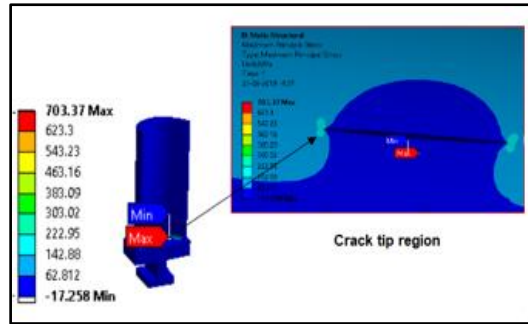
**Fig.7 Modelling of Gas turbine blade**



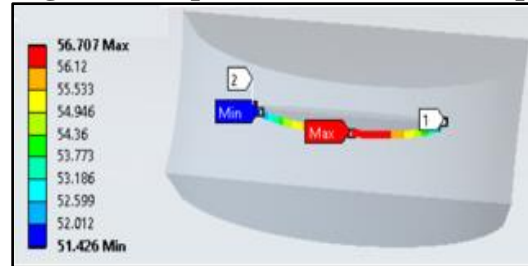
**Fig.8 Crack Modelling of Gas turbine blade**



**Fig.9. Von Mises stress at the crack tip**



**Fig.10 Principal stress at the crack tip**



**Fig.11 Stress Intensity factor(K1) at the crack tip.**

## VI. RESULTS AND DISCUSSIONS

### *Case 1.*

In static analysis of 3D specimen, Structural steel material was used for calculating the SIF  $K_1$ . It is observed that the analytical value of SIF ( $K_1$ ) for 3D specimen is  $27.29 \text{ Pa.m}^{1/2}$  and from Figure .5, the finite element value is  $29.3532 \text{ Pa.m}^{1/2}$  with an error of 4 to 6%. From Fig.6, the maximum stress Intensity factor is observed at  $29.4 \text{ Pa.(mm)}^{1/2}$ .

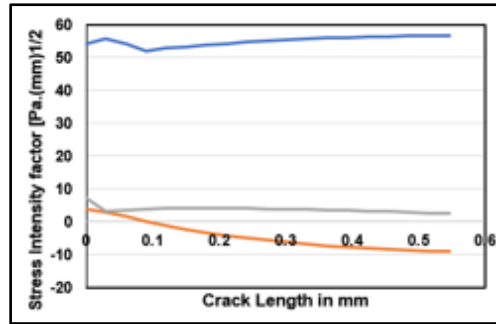
Crack Object provides automated tools for embedding crack(s) into existing meshes in ANSYSnew program.FractureToolenables postprocessing of fracture mechanics directly within the Mechanical interface that eliminates need to use Command Objects to access MAPDL /POST1 commands.

### *Case2*

From the Fig.9 and Fig.10,it was observed that von Mises stress 385 MPa and Principal stress 703.37 MPa are maximum at the crack tip because of singular elements and concentrated plastic zone at the crack tip. From fig.12, it was observed that SIF ( $K_1$ ) is maximum for the crack value of 0.6563mm crack length whereas the values of  $K_2$  and  $K_3$  show lower SIF values due to the fact that  $K_2$  and  $K_3$  follow mode 2 and mode 3 type of fractures whereas  $K_1$  follow mode 1 type of fracture.

## VII. CONCLUSION

The observation made in the finite element analysis of gas turbine rotor blade for semielliptical crack analysis that the maximum stress intensity factor (SIF) value occurs at  $K_1$  for various crack lengths because mode 1 is predominant whereas stress Intensity factor values occurs at lower values at  $K_2$  and  $K_3$  for the applied load.



**Fig.12 Graph of K1,K2 and K3 (SIF) for various crack lengths**

**Table 1. Values of K1, K2 and K3 for crack lengths**

Crack Length (mm)	SIF-K1	SIF-K2	SIF-K3
0	54.241	3.6422	7.2473
3.01E-02	55.668	2.7376	3.0486
6.02E-02	54.266	1.5105	3.4794
9.05E-02	51.974	-3.94E-02	3.70E+00
0.12082	52.968	-1.279	3.99E+00
0.15118	53.084	-2.3884	4.07E+00
0.18152	53.814	-3.4025	4.142
0.21187	54.137	-4.2762	4.0878
0.24223	54.681	-5.0653	4.0356
0.27258	54.99	-5.7554	3.9269
0.30294	55.398	-6.3714	3.817
0.3333	55.635	-6.9101	3.6736
0.36366	55.932	-7.3882	3.5309
0.39402	56.099	-7.8039	3.3662
0.42438	56.306	-8.1685	3.2041
0.45473	56.415	-8.4793	3.0253
0.48509	56.545	-8.7457	2.8485
0.51545	56.608	-8.9653	2.6611
0.54581	56.678	-9.1426	2.4739

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