ISSN: 2278-0181
NCERAME - 2015 Conference Proceedings

Finite Element Analysis of Finite Plate with Normal and Oblique Tapered Holes Subjected to Tensile Load

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***Abstract* – The safe life of a component is the very essential factor a designer should consider while designing mechanical engineering component, hence the study of stress analysis plays a vital role in designing the component. The long twisted blades of gas turbine with normal & oblique tapered holes (cooling holes) constituting a geometrically complex, three- dimensional body that is subjected to the action of centrifugal force. In design, Stress Concentration Factor (SCF) can be used as multiplication factor, and using that maximum stress can be predicted, thus it shows the stress field around local region. This stress can be found by numerical methods like Finite Element Analysis. FEA descritize the structure into small, finite, well defined and compilation becomes easier. Hence, in this paper an attempt is made to study on the tapered hole by oversimplifying the complicated analysis of effect of cooling tapered holes on a gas turbine blade by generalizing the problem into a finite plate with normal and oblique tapered holes. The value of maximum equivalent von-Mises stress is determined with the help of analysis software ANSYS. Effect of the geometry of hole on the stress distribution around the hole is studied and the results of the analysis have been presented with the help of stress contours, tables & plots.**

Key terms- Finite plate, Normal and oblique tapered hole, Finite Element Method, ANSYS 14.0, Stress Concentration factor.

I. INTRODUCTION

The present study relates generally to a gas turbine engine, and more specifically to an air cooled airfoil in the engine. Air foils used in gas turbine engine, such as rotor blade and stator vanes (guide nozzles), require film cooling of the external surface where the hottest gas flow temperatures are found. The airfoil leading region is exposed to the highest gas flow temperature and therefore film cooling holes are used here [1]. A normal tapered hole is one which is normal to the plate which it penetrates and an oblique tapered hole is one whose axis is not normal to the plate which it penetrates. These holes can be found at non-radial openings in cylindrical and spherical shells, gas engine turbine blades [2].

Design is either to formulate a plan for the satisfaction of a specified need or to solve a problem. With the use of Computer Aided Design, the development of 3dimensional designs from which conventional 2 dimensional orthographic views with automatic dimensioning can be produced and computed [3].

The stress concentration factor is a ratio between the maximum stresses produced at the discontinuity divided by the nominal stress at the hole. For a tapered hole in a finite plate, the stress concentration will be different depending on the thickness, geometry of the model and material property [4].

1.1. Notations

Following symbols & notations were considered for finite plate with tapered hole.

D	Upper hole diameter (mm)
d	Lower hole diameter (mm)
t	Thickness of the finite plate (mm)
w	Width of the finite plate (mm)
L	Length of the finite plate (mm)
P	Applied uniform tensile load (N)
E	Young's modulus (MPa)
μ	Poison's Ratio
ρ	Density of material (Kg/mm^3)

II. METHODOLOGY

Finite Element Method (FEM) procedures and model convergence were used to analyze a finite plate component with tapered hole subjected to tensile load.

2.1. Geometry with Normal & Oblique Tapered Hole

The plate is considered as finite plate so that width and length of plate were such that the effects of the plate edges and boundary conditions on the hole stresses were considered. As a result, a finite plate condition is attained in the region of the hole. Here the component is considered to be finite plate with the following equation:

—

w = width of the plate, mm
d = mean diameter of the tapered hole, mm [2]

In the present study, the effect of central normal tapered hole and oblique tapered holes on the stress distribution and deflection in a rectangular 3D plate of dimensions 250mm x 30mm x 10mm under tensile load has been analyzed using finite element method. Length of the model is taken as per ASTM standards which include holding or gripping. ANSYS 14.0 has been employed to find out the localized induced stresses in the plate. The geometry of the model with normal & oblique tapered holes is as shown in the figure below.

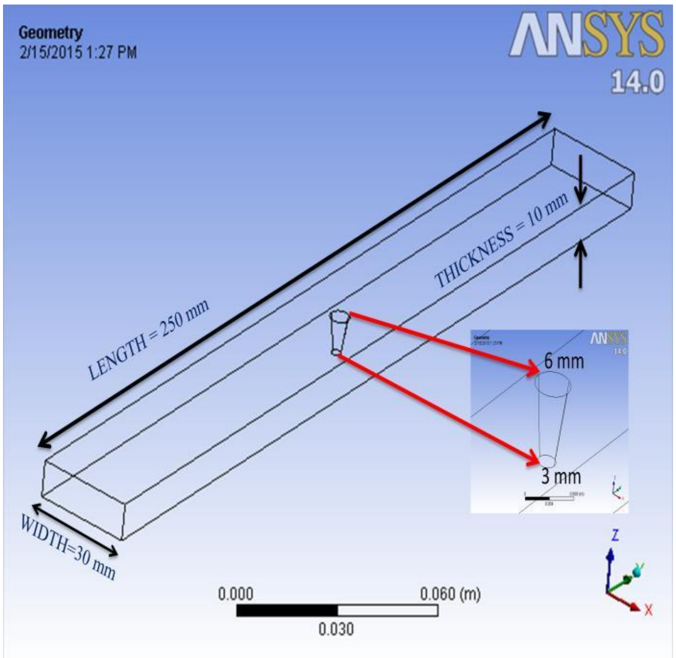

Figure 1(a): Geometrical Modeling of the Component with normal tapered hole

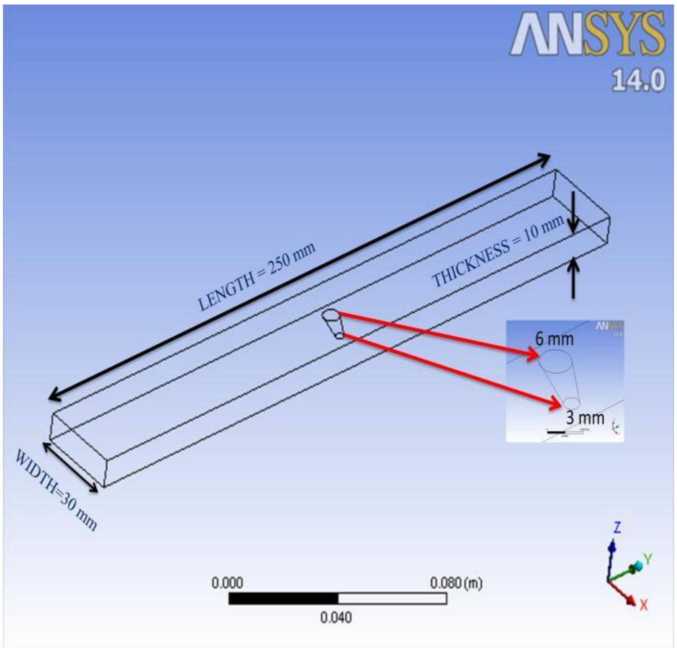

Figure 1(b): Geometrical Modeling of the Component with oblique tapered hole

2.2. FE Model

The CATIA V5 is a commercial package which is used for the geometrical modeling. For finite element model, discritization, applying boundary conditions and material properties have to be followed by pre- and post-processing of the Finite Element (FE) using ANSYS 14.0. For better accuracy, Triangular element is used in FE model here. ANSYS 14.0 is used as analysis tool to predict the stresses around holes. Finite Elements (FE), their mesh generators use an automatic technique that checks element failure and takes care of convergence values.

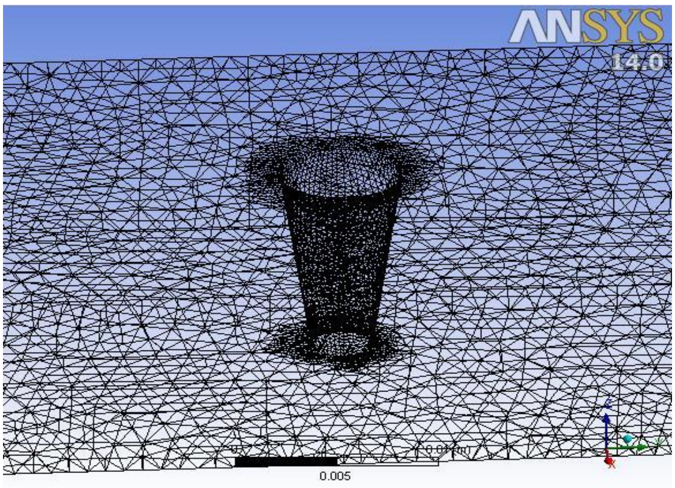

Figure 2(a): Typical Finite Element Mesh for finite Plate with Tapered Hole

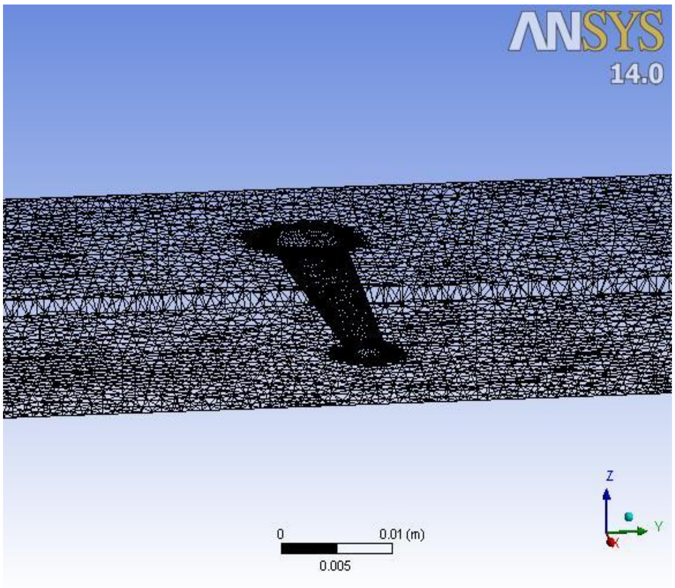

Figure 2(b): Typical Finite Element Mesh for finite Plate with Tapered Hole

The Finite element details for the converged models are tabulated in the following tables.

Table 1: Finite element details of the model.

Sl. No	Type of Tapered hole	Element Size (m)	Type of element	No of nodes	No of elements
1	Normal	0.0009	TRIA element	490476	112536
2	Oblique (30^0)	0.0009	TRIA element	210281	136106

2.3 Loading and boundary condition

The following figure 3(a) & figure 3(b) shows boundary condition & loading details for normal tapered hole and oblique tapered hole respectively. Where one end is fixed and other end is loaded with a tensile load as shown. For Low carbon alloy steel, yield strength is 305 Mpa and considering the factor of safety as 1.2, and applied load is computed as P= 72 kN.

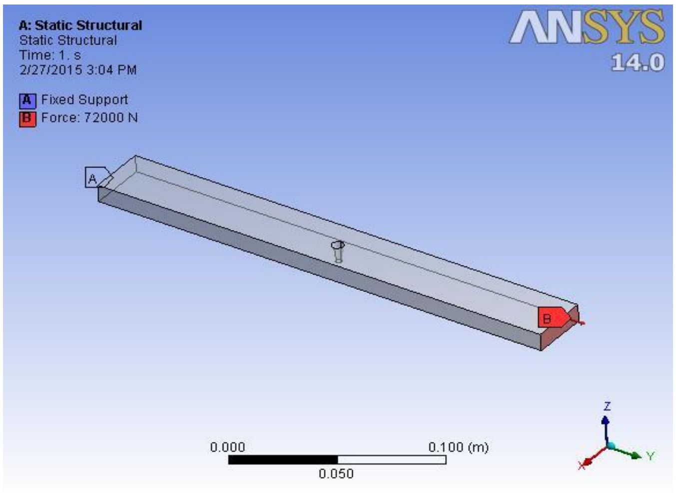

Figure 3(a): Boundary condition on the Component with normal tapered hole

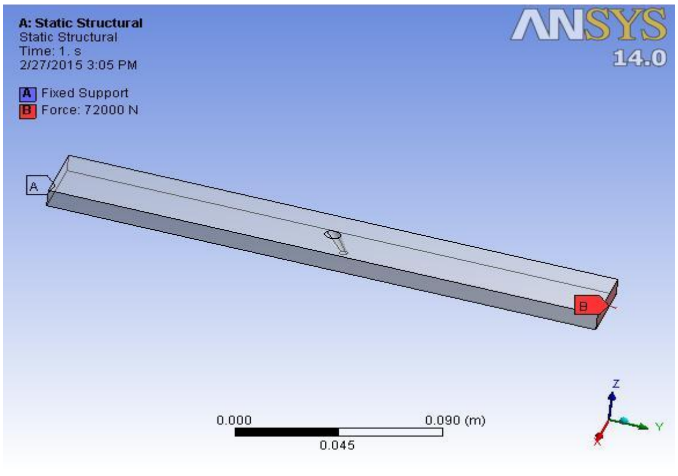

Figure 3(b): Boundary conditions on the Component with oblique tapered hole

2.4 Material property details

Stress analysis is carried out for stresses around hole for Alloy steel (low carbon steel) and their properties were considered for analysis around hole local region. The material property of alloy steel as shown in table 2.

Table 2: Material Properties of alloy steel (Low Carbon Steel)

Material Name	Modulus of Elasticity (E), MPa	Poisson's Ratio (μ)	Density (ρ) Kg/mm^3
Alloy steel	210×10^3	0.3	7.85×10^{-6}

ISSN: 2278-0181
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III. Results and Discussions

The distribution of stresses/stress contours around normal tapered hole subjected to applied tensile load for different refinements are shown in figures 4(a) to figure 4(c).

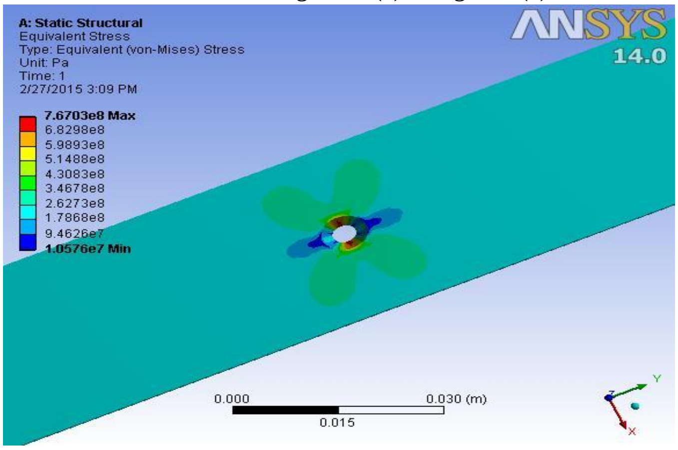

Figure 4(a): von-Mises stress contour band around normal tapered hole for 1st refinement

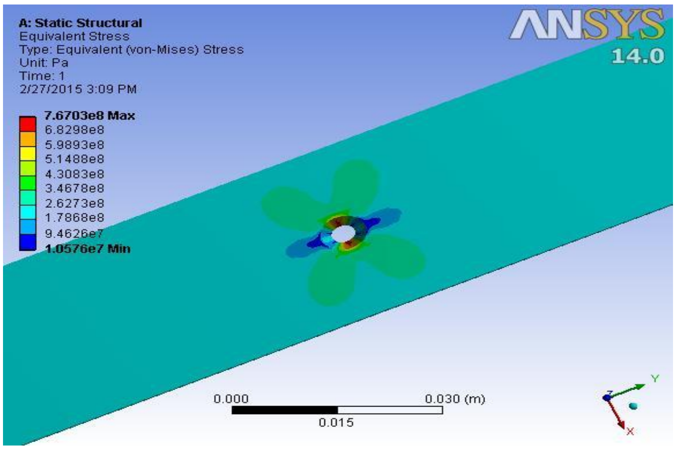

Figure 4(b): von-Mises stress contour band around normal tapered hole for 2nd refinement

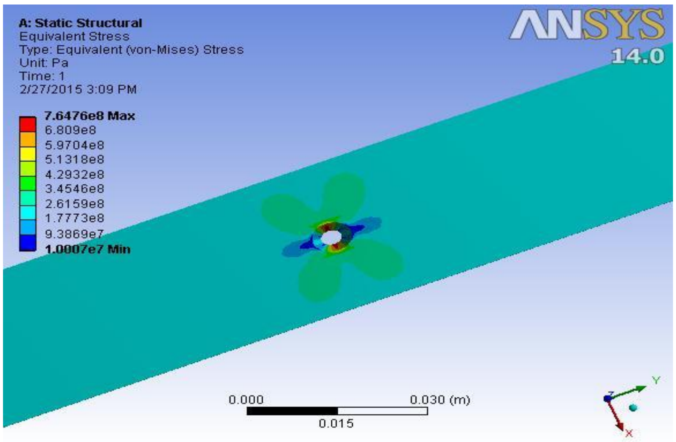

Figure 4(c): von-Mises stress contour band around normal tapered hole for 3rd refinement

The distribution of stresses/stress contours around oblique tapered holes subjected to applied tensile load for different refinements are shown in figures 5(a) to figure 5(c)

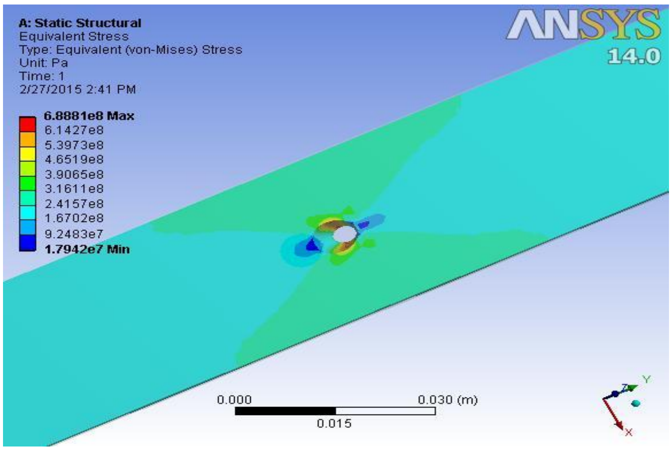

Figure 5(a): von-Mises stress contour band around oblique tapered hole for 1st refinement

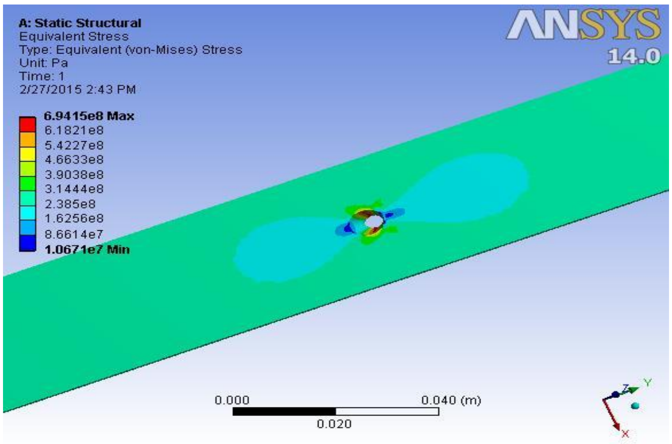

Figure 5(b): von-Mises stress contour band around oblique tapered hole for 2nd refinement

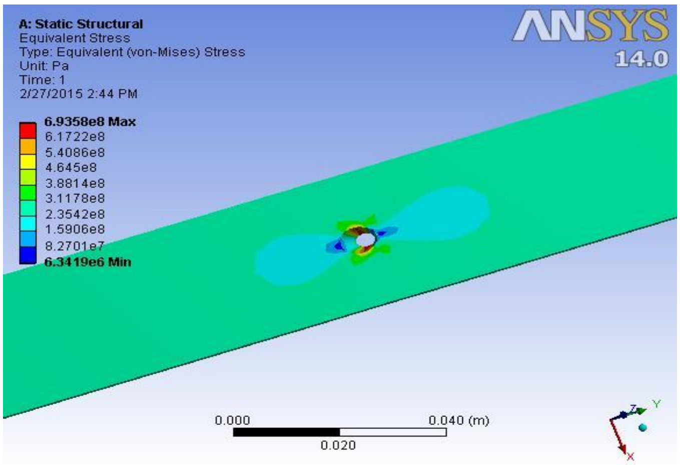

Figure 5(c): von-Mises stress contour band oblique normal tapered hole for 3rd refinement

The stress analysis around normal tapered hole and oblique tapered hole was obtained for different finite element refinements and results are shown in table 3(a) & table 3(b).

Table 3(a): Details of FEA Results for normal tapered hole

Sl No	No of Elements	Maximum von-Mises stress(MPa)	Stress Concentration Factor(SCF)
1	82768	$7.57*10^2$	2.9
2	95731	$7.67*10^2$	3.0
3	129381	$7.64*10^2$	3.0

Table 3(b): Details of FEA Results for oblique tapered hole

Sl No	No of Elements	Maximum von-Mises stress(MPa)	Stress Concentration Factor(SCF)
1	85670	$6.881*10^2$	2.71
2	99652	$6.941*10^2$	2.73
3	136106	$6.935*10^2$	2.73

The above finding results of alloy steel material when finite plate is subjected to uniform tension load will be considered as plane stress condition & stress analysis is carried out and it is observed that localized stresses around edges of tapered hole.

The above results are also presented in the form plots of induced maximum von-Mises stresses around edges of normal tapered hole Vs number of elements as shown in figure 6(a) and figure 7(a) for normal tapered hole and oblique tapered hole respectively. Figure 6(b) and figure 7(b) are plotted for induced maximum von-Mises stress around edges of the normal and oblique tapered holes Vs Stress concentration factor as tabulated in table 3(a) & 3(b).

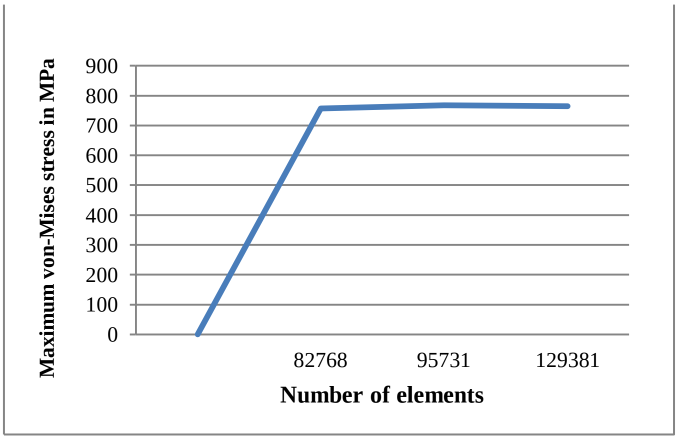

Figure 6(a): variation of Maximum von-Mises stress and number of elements

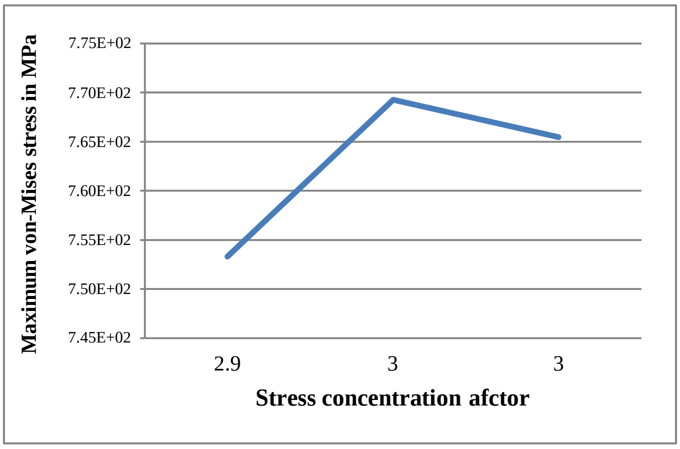

Figure 6(b): Variation of Maximum von-Mises stress and Stress concentration factor

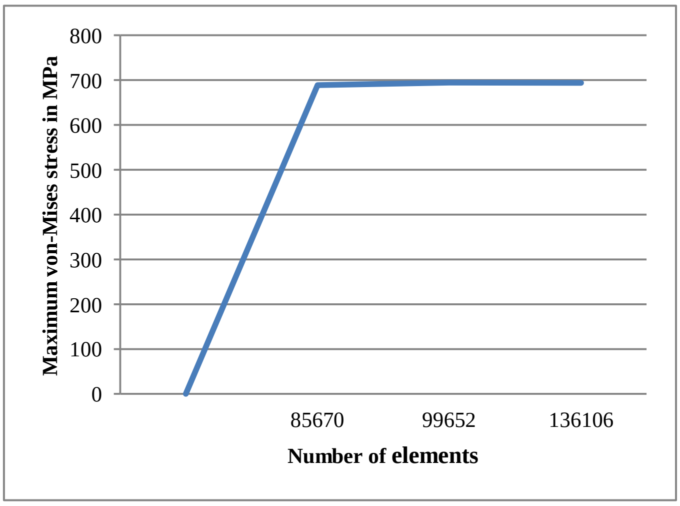

Figure 7(a): variation of Maximum von-Mises stress and number of elements

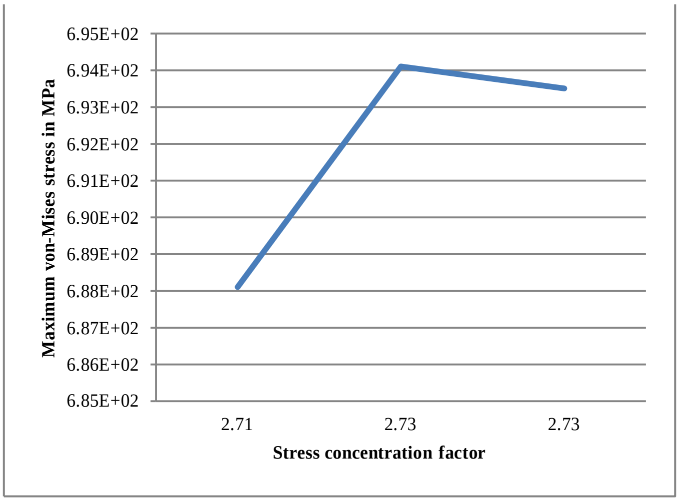

Figure 7(b): variation of Maximum von-Mises stress and stress concentration factor

IV. CONCLUSION

A stress analysis & stress concentration factor approach based on finite element analysis using analysis ansys tool, from the analysis conducted, several conclusions can be drawn as follows.

- Because of the unavailability of the theoretical formula to find out the stress concentration factor, numerical method is used and the compilation of the model is done.
- Figures 4(a), 4(b), 4(c) & figures 5(a), 5(b), 5(c) show the stress distribution contour around the normal tapered hole and oblique tapered hole for different refinement sizes.
- It is seen from above solution that maximum stress in the tapered hole is equally distributed along the perpendicular side to the load applied.
- The results have been tabulated in the tables 3(a) & 3(b) for normal tapered hole and oblique tapered hole as well.
- Graph is plotted for various maximum von-Mises stresses and number of elements for the convergence study of the model as shown in figures 6(a) & 7(a) and a comparison of maximum von-Mises stress and stress concentration factor is also done as shown in figures 6(b) & 7(b).
- Thus, a study of stress distribution around Tapered hole on Alloy steel (low carbon steel) for safe life of design is made.

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