



## **FINITE ELEMENT METHOD ANALYSIS OF RECTANGULAR PLATE WITH CIRCULAR HOLE USING ANSYS**

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### **ABSTRACT**

The geometrical irregularities provided with elements, which are used in machining. These irregularities disturb the stress distribution. In this study, the stress distribution of rectangular plate having a circular hole is analyzed. The two different materials are used for this analysis and results compared with one another to get an idea about stress distribution and deformation for the designing of the machine. From the present investigation, it can be concluded that the maximum stress occurs at corners of holes in both materials. Also, for both materials, it is observed that, as T/D ratio increases, it also increases stress concentration factor. The stress concentration factor values obtained from finite element analysis shows the maximum error of 0.33% for magnesium alloy and 0.30% for polyethylene, which is very minor. Thus, from the present study, it can be said that finite element analysis is a very effective tool to determine stresses induced in various materials.

**Key words:** Finite element method, ANSYS, Magnesium alloy, Polyethylene, Rectangular plate with hole.

### **INTRODUCTION**

The elements, which are used for machining purposes offered with geometrical irregularities, which disturb the stress distribution and therefore, the state of stress in stress concentrated regions cannot be described in machine elements. Thus, the finite element method (FEM) is an important tool used to analyze the stress<sup>1</sup>. The finite element method (FEM) is a numerical method of analysis for stresses and deformations in structures of any given geometry. The structure is discretized into the so-called 'finite elements' connected through nodes. The type, arrangement and a total number of elements affect the accuracy of the results<sup>2</sup>. It is frequently used to solve the difficult engineering problems, mostly in the fields of mechanical, civil, and aeronautical engineering<sup>3</sup>. Also, it is a solution of several other types of engineering problems like heat conduction, fluid dynamics, electric and

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magnetic fields, structure analysis, solid mechanics, dynamics, thermal analysis, electrical analysis, biomaterials.<sup>4,5</sup>

Magnesium alloys are mixtures of magnesium with other metals (called an alloy), often silicon, copper, aluminum, zinc, manganese, rare earth, and zirconium. While, a polymer of ethylene is a partially crystalline thermoplastics, which is resistant to chemicals and moisture, have good insulating properties, and are used especially in packaging and insulation. The magnesium alloy and polyethylene both are lightweight and have excellent properties due to which they have a wide range of applications. The magnesium alloy finds so many uses in the field of automobiles and aircraft. Whereas, polyethylene applied in equipment, home appliances, cutlery, fuel tanks, containers, agricultural tanks, highway barriers and water and waste water tanks. In general, the rectangular plate having a central hole is a common structure, but stress concentration around the hole makes the material liable to failure across the hole region. There are many solutions to reduce the stress concentration includes providing relief notches, holes etc.<sup>6,7</sup>

Many research activities are carried out in this field by different researchers. Dhanjal and Arora<sup>1</sup> analyzed a rectangular plate with a circular hole at the center is by using finite element analysis. They observed that the SCF increases with increase in T/D ratio whereas, von Mises stress decreases with increase in T/D ratio. Shivlinges et al.<sup>2</sup> studied SCF's depend on the dimension ratio defined as the hole diameter of the beam to the width of the beam. Mekalke et al. (2012)<sup>3</sup> investigated a plate with a circular hole applied to a uniform stress and examined the deviation in the results obtained through different meshes. Also, Brahmhatt et al.<sup>4</sup> analyzed rectangular plate with a central elliptical hole using ANSYS. They concluded that lower values of aspect ratio, stress intensity factor gives less error.

Jain<sup>5</sup> calculated stresses and deflection in rectangular isotropic and orthotropic plates having a central circular hole under transverse static loading. Shaik and Mirzana<sup>6</sup> calculated stress analysis around the circular hole made up of different materials using ANSYS. They found that stress concentration is always taking place on hole boundary in a finite width plate with a central hole under in static loading. Endigeri and Mannur<sup>7</sup> concluded that introduction of auxiliary holes on either side by with composite plate decreased stress concentration factor. Mallikarjun et al.<sup>8</sup> observed that maximum stress ratio increases with the increase of the angle of obliquity.

Thus, nowadays, there is a requirement of information about the stress concentration in designing the structure component. Although, the majorities of service cracks occurred in the area of stress concentration at the edge of a hole. In this investigation, the stress distribution of circular holes plate with different materials is carried out and results compared

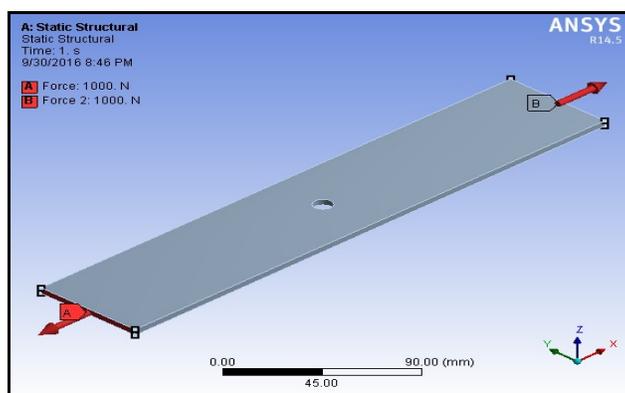
with one another to get an idea about stress distribution and deformation for the designing of the machine.

### Problem definition

For present work, a rectangular plate of material magnesium alloy and polyethylene has to be taken for calculating stresses induced and deformations produced due to the applied load. Also, the effect of T/D ratio i.e. ratio of the thickness of the plate has been analyzed by using four T/D ratios which are 0.4, 0.6, 0.8 and 1.0. The stress concentration factor has to be calculated for both methods i.e. analytical method and finite element method using ANSYS and the results were compared with one another. The material properties are shown in Table 1. Fig. 1 shows the boundary condition of given rectangular plate with a circular hole.

**Table 1: Materials properties**

Material	Density	Young's modulus MPa	Yield strength MPa	Poisson's ratio	Bulk modulus MPa	Shear modulus MPa
Magnesium alloy	$1.8e^{-6} \text{ kg mm}^{-3}$	45000	193	0.35	50000	16667
Polyethylene	$9.5e^{-7} \text{ kg mm}^{-3}$	1100	33	0.42	2291.7	387.32



**Fig. 1: Boundary conditions of rectangular plate with circular hole**

### Analytical method

The present investigation deals with the study of the rectangular plate having a circular hole subjected to a uniform stress. The plate length of 300 mm, thickness is varied from  $T = 4, 6, 8, 10$  mm, width  $W = 60$  mm, with a hole of diameter  $d = 10$  mm. and an

applied uniform stress of  $\sigma_0 = 1000 \text{ N}$  to the both sides. The stress concentration factor is evaluated using following theoretical formula<sup>3</sup> –

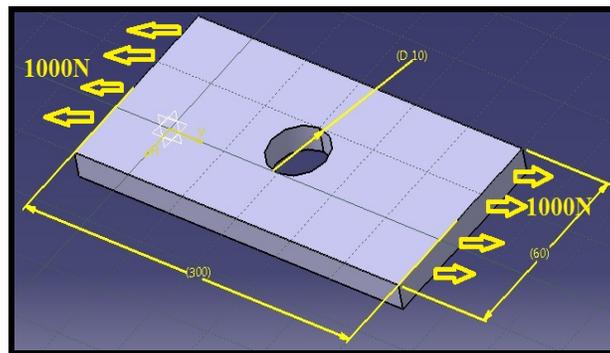
$$\text{Stress concentration factor (Kt)} = 3.0 - 3.13(d/W) + 3.66(d/W)^2 - 1.53(d/W)^3 \quad \dots(1)$$

$$\text{Stress concentration factor (Kt)} = 3 - 3.13(10/60) + 3.66(10/60)^2 - 1.53(10/60)^3$$

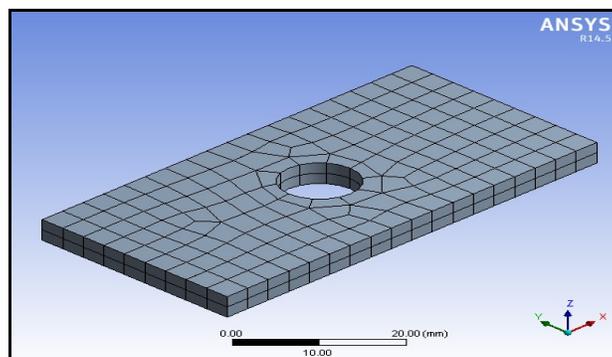
$$K_t = 1.6067$$

### Finite element method

The finite element method analysis is executed in popular FEA package ANSYS 13. The model of the geometry is produced and analyzed in ANSYS. The force is applied on both sides of the plate. The model is meshed with solid 84 elements and having 728 total nodes. This element has the capabilities like plasticity, creep, stress stiffening, large deflections etc.<sup>1</sup> The Fig. 2 shows that CAD model of rectangular plate with hole and Fig. 3 shows that meshed body of rectangular plate with hole.



**Fig. 2: CAD model of rectangular plate with hole**



**Fig. 3: Meshed body of rectangular plate with hole**

The stress concentration factor for a rectangular plate of finite width and centered circular hole is given by the following equation<sup>1,3</sup>.

$$\text{Stress concentration factor (Kt)} = \frac{\sigma \text{ Maximum stress}}{\sigma \text{ Normal stress}}$$

Whereas  $\sigma_{\text{max}}$  is the maximum stress, which is likely to occur near the irregularity whereas  $\sigma_{\text{nom}}$  is the nominal stress in the member.

However,  $\sigma_{\text{normal}}$  is calculated by following equation<sup>1,3</sup>.

$$\sigma \text{ Normal} = \frac{\text{Applied force}}{\text{Area}} = \frac{F}{A}$$

$$\begin{aligned} \text{Area of plate (A)} &= (W \times T) - (\pi/4 \times d^2) \\ &= (60 \times 4) - (\pi/4 \times 10^2) \\ &= 161.5 \text{ mm}^2 \end{aligned}$$

$$\sigma \text{ Normal} = \frac{1000 \text{ N}}{161.5 \text{ mm}^2}$$

$$\sigma \text{ Normal } 4 \text{ mm} = 6.1919 \text{ MPa}$$

$$\sigma \text{ Normal } 6 \text{ mm} = 3.552 \text{ MPa}$$

$$\sigma \text{ Normal } 8 \text{ mm} = 2.490 \text{ MPa}$$

$$\sigma \text{ Normal } 10 \text{ mm} = 1.9175 \text{ MPa}$$

$$\text{Stress concentration factor (Kt)} = \frac{\sigma \text{ Maximum stress Ansys value}}{\sigma \text{ Normal stress value}} \quad \dots(2)$$

$$\text{Kt for magnesium alloy} = \frac{11.035}{6.1919}$$

$$\text{Kt for magnesium alloy } 4 \text{ mm} = 1.7821$$

$$\text{Kt for magnesium alloy } 6 \text{ mm} = 2.0644$$

$$\text{Kt for magnesium alloy } 8 \text{ mm} = 2.2017$$

$$\text{Kt for magnesium alloy } 10 \text{ mm} = 2.280$$

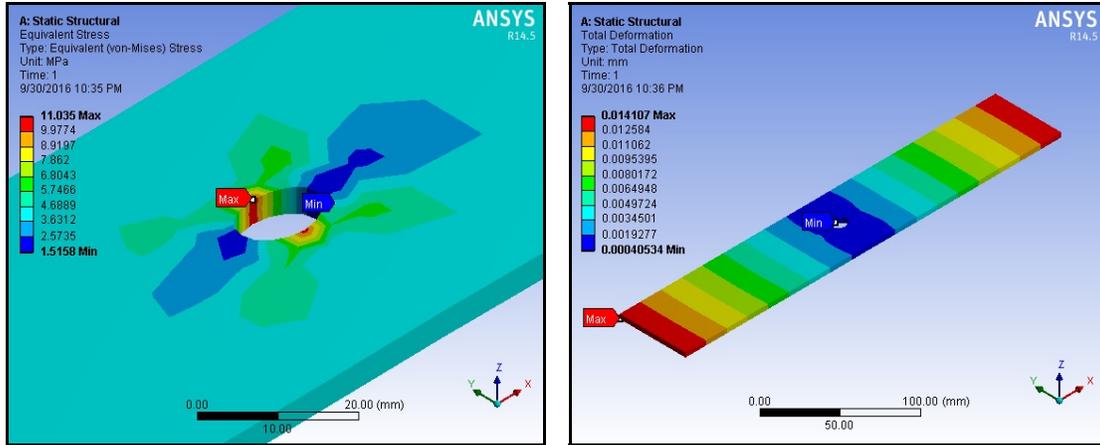
Similarly,

$K_t$  for polyethylene 4 mm = 1.7792

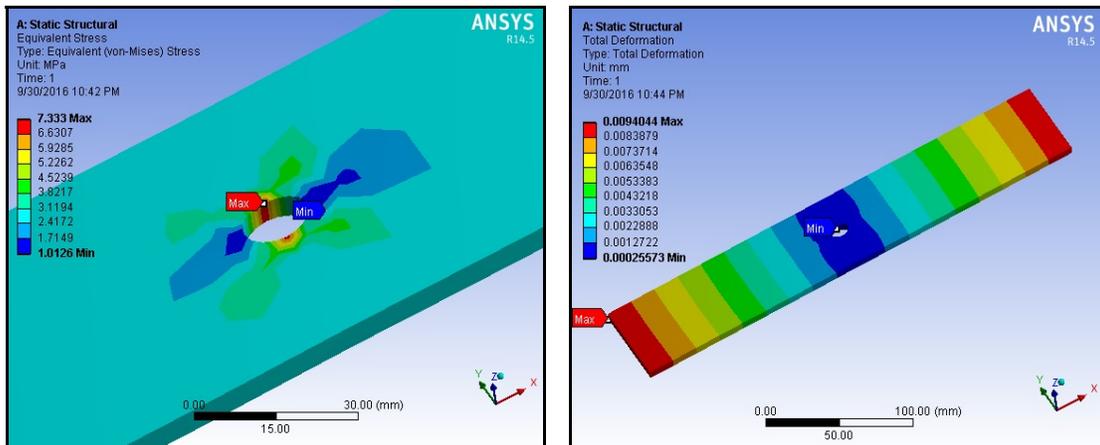
$K_t$  for polyethylene 6 mm = 2.0598

$K_t$  for polyethylene 8 mm = 2.1956

$K_t$  for polyethylene 10 mm = 2.2730



**Fig. 4: Equivalent (Von-mises) stress and deformations of magnesium alloy 4 mm thickness rectangular plate**



**Fig. 5: Equivalent (Von-mises) stress and deformations of magnesium alloy 6 mm thickness rectangular plate**

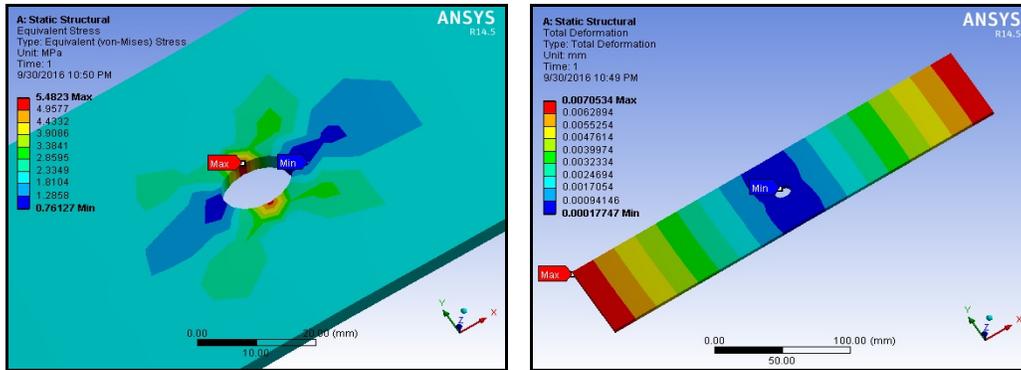


Fig. 6: Equivalent (Von-mises) stress and deformations of magnesium alloy 8 mm thickness rectangular plate

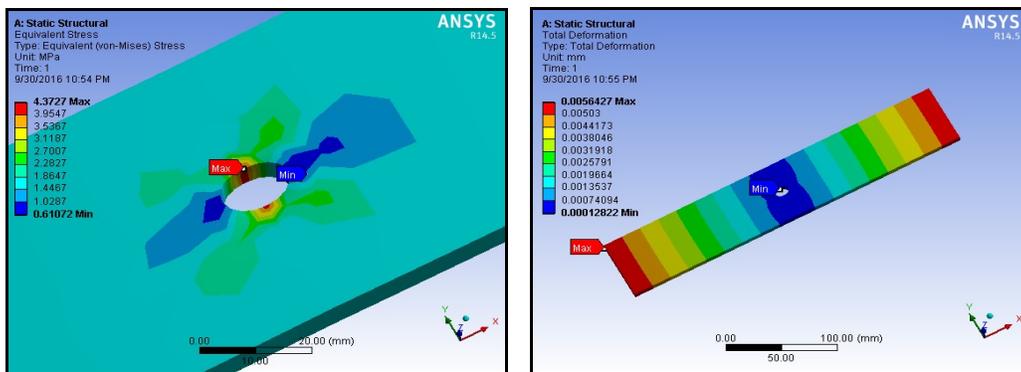


Fig. 7: Equivalent (Von-mises) stress and deformations of magnesium alloy 10 mm thickness rectangular plate

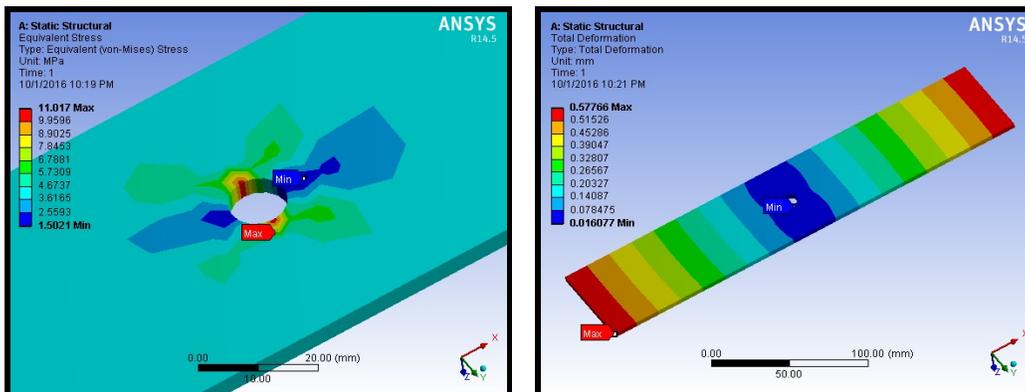
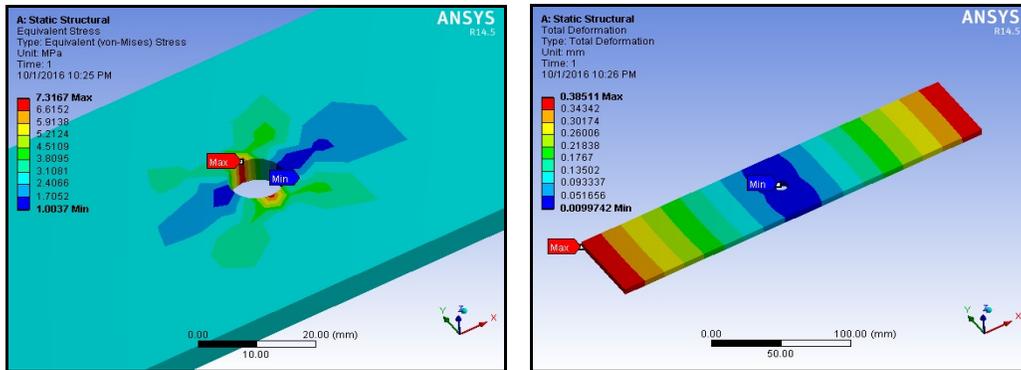
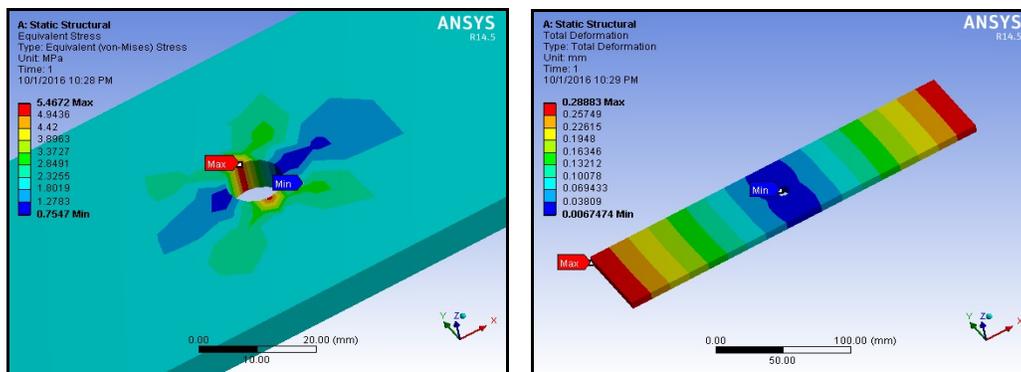


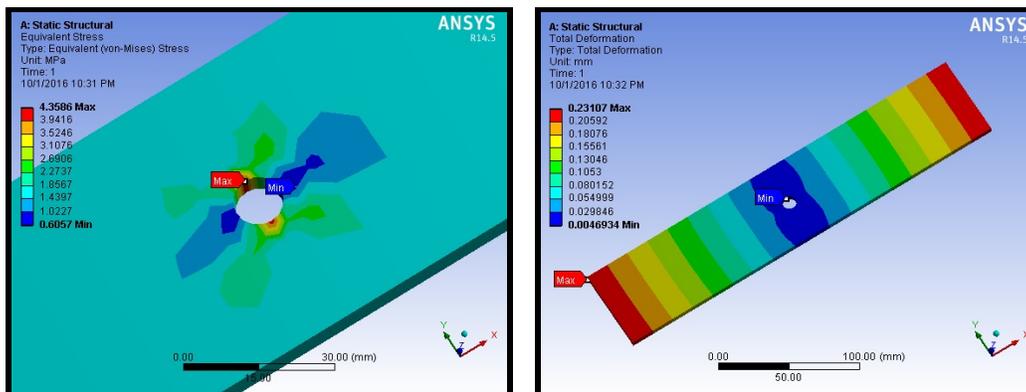
Fig. 8: Equivalent (Von-mises) stress and deformations of polyethylene 4 mm thickness rectangular plate



**Fig. 9: Equivalent (Von-mises) stress and deformations of polyethylene 6 mm thickness rectangular plate**



**Fig. 10: Equivalent (Von-mises) stress and deformations of polyethylene 8 mm thickness rectangular plate**



**Fig. 11: Equivalent (Von-mises) stress and deformations of polyethylene 10 mm thickness rectangular plate**

$$\text{Percentage error in theoretical and practical values} = \frac{\text{Theoretical value} - \text{FEM values}}{\text{Theoretical values}}$$

## RESULTS AND DISCUSSION

The values of T/D ratio, maximum Von mises stress, maximum deformation and stress concentration factor are depicted in Table 2 for both the materials. The values of stress concentration factor is based on eq. (1) and eq. (2) are compared and error % is calculated, which is also depicted in Table 2. From the table, it is observed that in both materials, when the T/D ratio and stress concentration factor shows lower values at that time the von Mises stress and deformation values showed higher values. As compared to theoretical values of stress concentration factor, the factor values obtained by FEM shows good accordance in both materials. The magnesium alloy shows 0.33% and polyethylene shows 0.30% error between FEM and theoretical values for T/D ratio of 0.4.

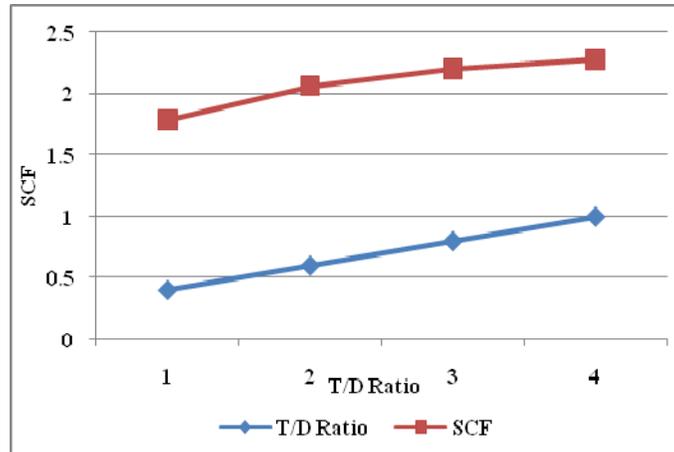
**Table 2: Parameters obtained from finite element analysis and theoretical values**

T/D Ratio	Material	Maximum (Von) mises Stress (MPa)	Max Deformation (mm)	Stress concentration factor		Error %
				FEM values	Theoretical values	
0.4	Magnesium alloy	11.035	0.01401	1.7821	2.5729	0.33
0.6		7.333	0.00940	2.0644	2.5729	0.19
0.8		5.4823	0.00705	2.2017	2.5729	0.14
1.0		4.3727	0.00564	2.280	2.5729	0.11
0.4	Polyethylene	11.017	0.57766	1.7792	2.5729	0.30
0.6		7.3167	0.38511	2.0598	2.5729	0.19
0.8		5.4672	0.28883	2.1956	2.5729	0.14
1.0		4.3586	0.23107	2.2730	2.5729	0.11

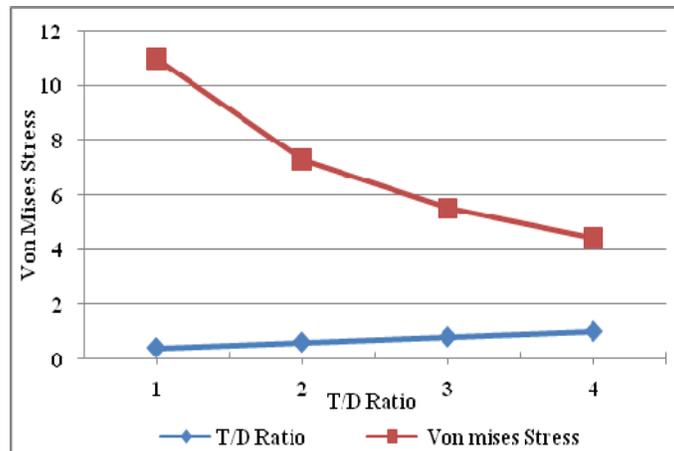
The graphical presentation of variations in T/D ratio, Von mises stress and stress concentration factor of both the materials is represented in Figs. 12 and 13.

Also, for the detailed study of the relations between T/D ratio, Max Von mises stress, deformation and stress concentration factor, the statistical analysis i.e. Correlation coefficient, is carried out, which is shown in Table 3. According to it, the values showing >

+ 0.70 indicates strong positive correlation i.e. as one parameter increases with it other parameter also increases. Whereas, values showing  $>-0.70$  indicates strong negative correlation i.e one parameter increases with it other parameter decreases.



**Fig. 12: Max. SCF v/s T/D ratio**



**Fig. 13: Von Mises stress v/s T/D ratio**

From, Table 3, it is observed that T/D Ratio shows strong negative correlation with Von mises stress and deformation (-0.965, -0.967). Whereas, it shows strong positive correlation with stress concentration factor (0.962). The Von mises stress shows strong positive correlation with deformation (1.000), while shows strong negative correlation with stress concentration factor (-1.000). Deformation shows strong negative correlation with stress concentration factor (-1.000).

**Table 3: Correlation coefficient between different parameters obtained from finite element analysis**

	<b>T/D Ratio</b>	<b>Max von mises stress (MPa)</b>	<b>Max Deformation (mm)</b>	<b>Stress concentration factor</b>
T/D Ratio	1			
Max Von mises stress (MPa)	-0.965	1		
Max deformation (mm)	-0.967	1.000	1	
Stress concentration factor	0.962	-1.000	-1.000	1

### CONCLUSION

From the present investigation, it can be concluded that the maximum stress occurs at corners of holes in both materials. Also, for both materials, it is observed that The deformation decreases with increase in T/D ratio, while an increase in T/D ratio resulted into a decrease in von Mises stress and as T/D ratio increases with increase in stress concentration factor. The stress concentration factor values obtained from finite element analysis shows a maximum error of 0.33% for magnesium alloy and 0.30% for polyethylene, which is very minor. Thus, from the present study, it can be said that finite element analysis is a very effective tool to determine stresses induced in various materials.

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*Revised : 31.10.2016*

*Accepted : 03.11.2016*