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STUDY OF HIGH PRESSURE TURBOJET TURBINE CASE USING FINITE ELEMENT METHOD

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ABSTRACT

Influence of boss size on the stress distribution in the material is always taken into account for the failure analysis of metallic structures. In this investigation, the effect of round shaped through holes in the turbojet turbine case on the stress distribution under uniform pressure is carried out using Ansys Workbench software. Two types of steel, namely mild steel and high carbon steel with thickness of cylinder 0.8, 1.0, 1.25 and 1.5 mm were considered independently. Also considered are, cylinder with and without bosses under 5 and 7.5 bar pressure separately. Von Mises stress values so obtained are tabulated for comparision. Presence of bosses introduce more stress in the cylinder than that for cylinder without bosses. Effect of thickness of cylinder on the Von mises stress distribution is observed in both the materials. FEM result is matching with the calculated classical mechanics result with 2 to 4% error approximately.

KEYWORDS: *Boss size, turbine case, stress gradient, FEM, Classical mechanics.*

INTRODUCTION

With the increasing use of pipes, high pressure-cylinders,[5] boilers and many types of equipment of curved surfaces, there is huge requirement of correct assessing methods and sufficient structural integrity in these components for longer periods of usage. A turbo shaft engine for example, is basically, a gas turbine engine[2] which is designed to produce shaft power rather than jet thrust. In concept these engines are similar to turbo jets with additional turbine expansion to extract heat energy from the exhaust and convert it into the output shaft power. Turbine engine has many important parts, in that the turbine casing is the most critical one, as it is been subjected to different pressure and temperature gradients during its working cycle. Hence there is a need of thorough analysis of turbine casing, in the presence of various parameters to synthesize and to get an optimum design of structural member. Numerous investigations performed by many authors shows that, the slow crack propagation mechanism that causes the majority of pipe failures can be simulated in the laboratory using different commercial software. These studies included the failure of components either under structural load during the service or with creep at elevated temperatures. Thus FEM is emerged as one of the numerical tool[1] to asses the failure of material under different environmental conditions. Hence, study on the effect of round shaped through holes in the turbojet turbine case on the stress distribution under uniform pressure is carried out using Ansys Workbench software. Parameters, such as thickness of the case, material and pressure are varied independently and von mises stress around the boss is registered. Effect of thickness of cylinder on the Von mises stress distribution is observed in both the materials. In fact, reciprocal relationship between wall thickness and stress gradient across of the material is observed. Finally the FEM results are validated with analytical results with minimum errors.

MATERIAL AND METHODS

As steel is a dominating as per as the material for the turbine case[3] is concern, two types of generally recommended steel is considered. Namely mild steel and high carbon steel. Fig 1 (a & b) shows the typical turbojet turbine case with other details. Figure shows that, turbine case consists of three bosses, two of which carries 60 mm diameter and other one is 17.5 mm diameter, respectively on the circumference of the turbine. Finite element analysis is carried out, by using SHELL element and Hex mesh, constrianing the front and rear flange faces to zero. Later, turbine is subjected to internal pressure in radial direction and induced stresses around the bosses were studied. Similarly, FEA is carried out considering the turbine without bosses under the identical pressure and body constraints. The ratio of stress (SR) obtained for cylinder with bosses to that of without bosses under identical working condition is calcualted. Also, the relationship between SR and the thickness of the cylinder is established. Graph of von Mises stress vs cylinder thickness is constructed for all the materials under different pressure.

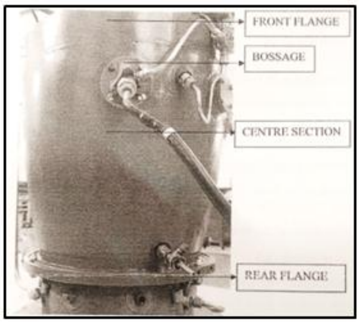


Fig 1a: Typical Turbojet turbine case.

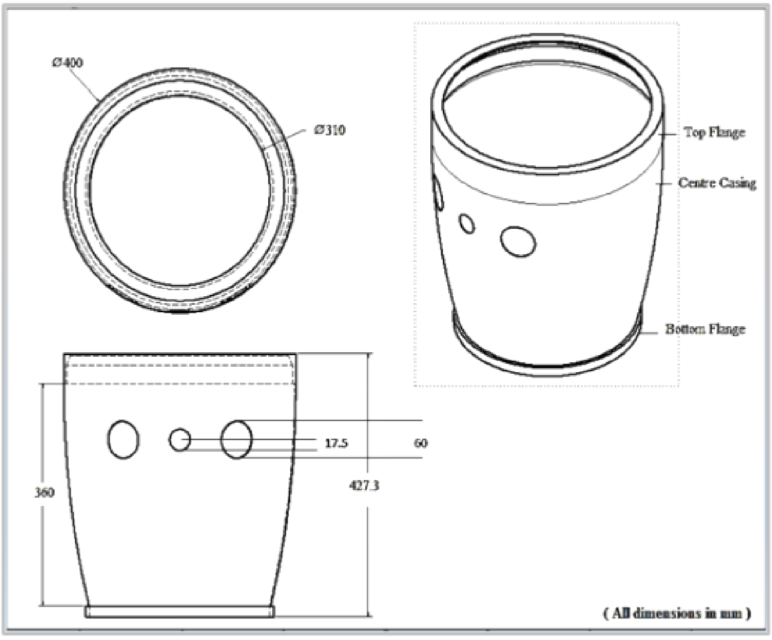


Fig 1b: Turbine Casing part drawing.

Validation of distributed stress in the cylinder is done with the induced hoop stress using the equation, $\sigma_C = \frac{PD}{2t}$ --------(1) obtained by classical mechanics approach. Where P is applied pressure, D and t are diameter and the thickness of the turbine respectively. FEA results with specimen details are made available in the results and discussion section that to be followed.

RESULTS AND DISCUSSION

Determination of equivalent stress induced in the cylindrical surface, due to absence and presence of bosses were analysed independently under identical pressure condition. Variables considered for the analysis are as below;

Applied pressure : 5 bar and 7.5 bar

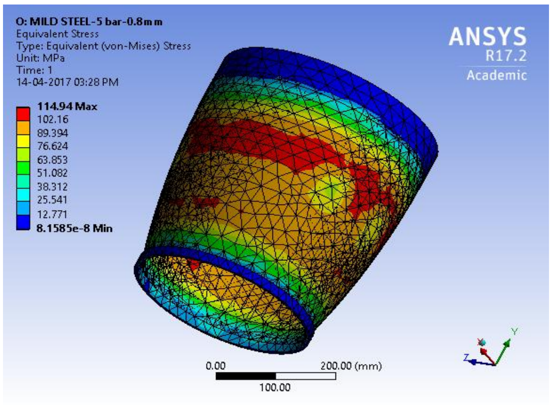
Materials : Mild steel and high carbon steel.

Cylinder thickness : 0.8 mm, 1.0 mm, 1.25 mm and 1.5 mm

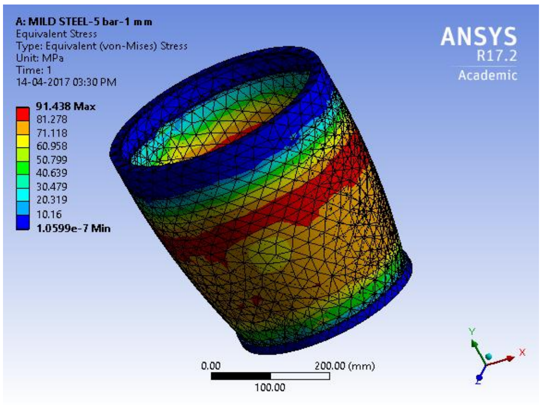
Further discussion begins with cylinder without and with bosses under 5 bar pressure, followed by 7 bar pressure one after the another. Finally, validation of FEA results with analytical solution is discussed. Ansys Workbench results and further discussion are made as below;

Von mises Stress for Cylinder without Bosses under 5 bar pressure

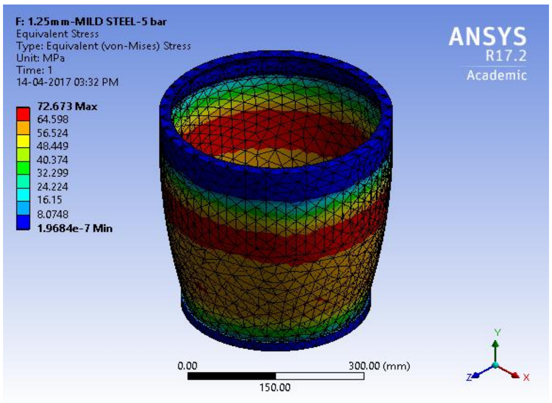
On introducing the 5 bar pressure around the cylindrical surface the FE results so obtained is as shown in Fig. 2(a-d). Note that, mild steel is considered for the cylinder analysis.



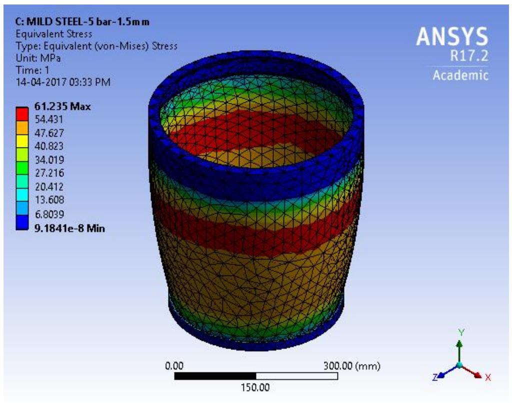
(a).



(b).



(c).



(d).

Fig. 2: FE solution for Cylinder without bosses with thickness a) 0.8 mm b) 1.0 mm c) 1.25 mm d) 1.5 mm.

Von Mises stress values so obtained are tabulated as shown in Table 1, for 5 bar pressure and Table 2, for 7.5 bar pressure respectively.

Table 1: FEA results for 5 bar pressure.

	von Mises stress (MPa)	
Cylinder thickness(t) , mm	**Mild steel**	**High carbon steel**
0.8	114.94	116.47
1	91.43	92.41
1.25	72.67	73.83
1.5	**61.23**	61.9

Table 2: FEA results for 7.5 bar pressure without without Bosses Bosses.

	von Mises stress (MPa)	
Cylinder thickness(t), mm	Mild steel	High carbon steel
0.8	172.4	174.7
1	137.16	138.62
1.25	109.01	110.74
1.5	91.85	92.86

It shows that high carbon steel marginaly experience more stress than that by the mild steel material and this is because of by virtue of its comparitively more yield strength.

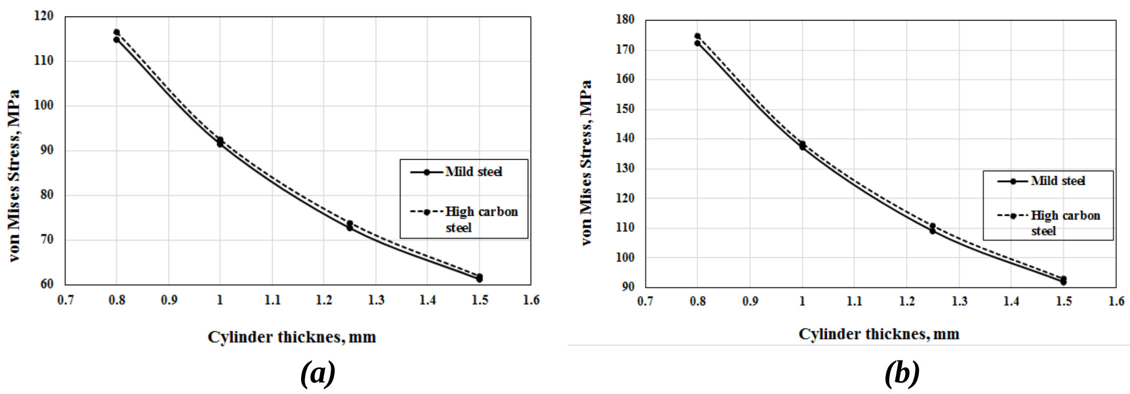


Fig. 3: Variation of stress across the thickness under a) 5 bar pressure b) 7.5 bar pressure.

Fig. 3 a and b shows that, as thickness of material increases, von Mises stress accumulation decreases substantially across the cross section. This is because there exist a reciprocal relationship between wall thickness and stress gradient across of the material. To be specific, we have relation for plate thickness as,[4]

$$B \geq 2.5\left(\frac{K_{IC}^2}{{\sigma_{ys}}^2}\right)$$

Equivalently, we can rewrite the above expression for cylinder without any defect, as the above expression holds good for plate with crack in it.

$$B \propto constant\left(\frac{1}{Stress\ gradient^2}\right)$$

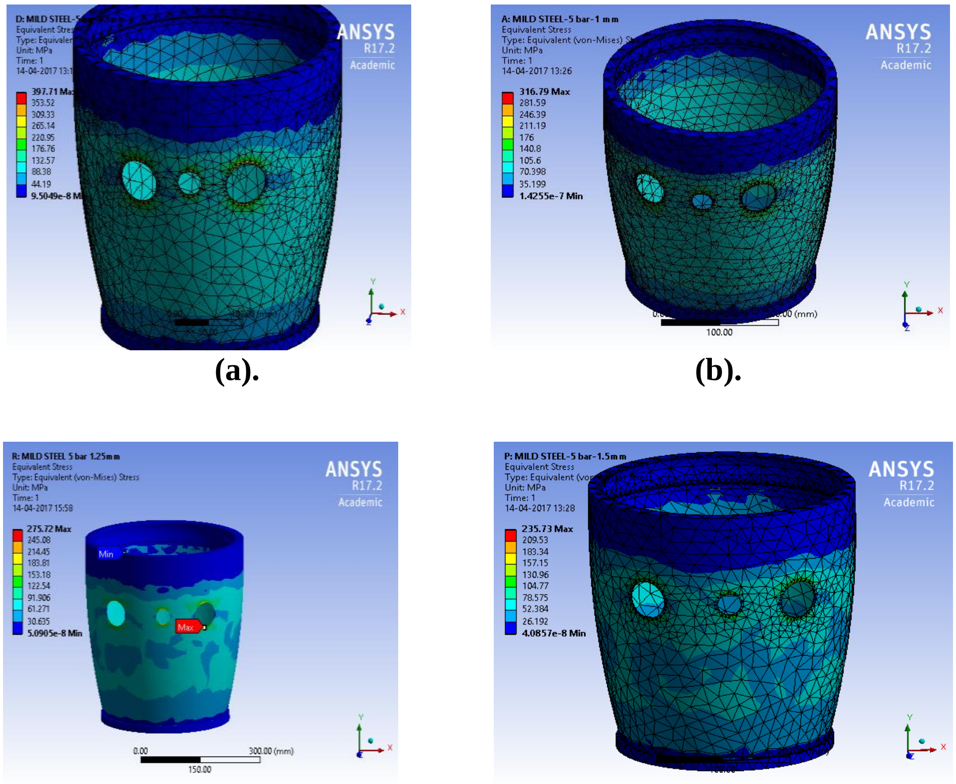
or

$$Stress\ gradient^2 \propto constant\left(\frac{1}{B}\right)$$

This relationship shows that, thicker plate has smaller stress gradient, thus are less tougher against the pressure than that of the thin plates under identical working conditions. Similarly, von Mises Stress for cylinder without bosses under 7.5 bar pressure is obtained and tabulated further. Increase in pressure has increased the stress distribution[1] and the Table 2, gives those results.

Von Mises Stress for cylinder with bosses under 5 bar pressure

Similarly, on introducing 5 bar pressure into the cylindrical with bosses, the FE results so obtained is as shown in Fig. 4 (a-d).



(a). **(b).**

(c). **(d).**

Fig. 4: FE solution for Cylinder with bosses with thickness a) 0.8 mm b) 1.0 mm c) 1.25 mm d) 1.5 mm.

Table 3, gives the equivalent stress distribution in the two materials, under identical 5 bar pressure.

Table 3: FEA results for 5 bar pressure with bosses.

Cylinder thickness (t), mm	Mild steel	High carbon steel
0.8	397.71	407.05
1	316.79	323.41
1.25	275.72	276.38
1.5	235.73	240.55

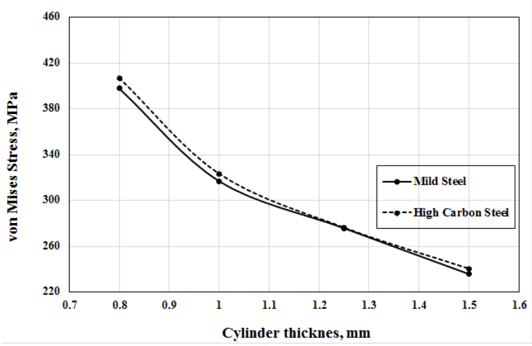


Fig. 5: Variation of stress across the thickness of the two materials under 5 bar pressure.

For 1.5 mm thickness, FE solution so obtained is also shown. It shows that, high carbon steel dominates again over the mild steel in resisting the stress. Fig. 5 shows that, as thickness increases, stress resistance decreases. And marginal difference in the stress between the two materials is observed. Comparison between the stress ratio for the cylinder with and without bosses under same 5 bar pressure and for mild steel has been made and Table 4 shows these results.

Table 4: Stress Ratio for mild steel.

Cylinder	von Mises stress in mild steel- cylinder under 5 bar pressure Cylinder thickness (t) in mm			
	0.8	**1**	**1.25**	**1.5**
Without bosses	114.94	91.43	72.67	61.23
With bosses	397.71	316.79	275.72	235.73
Stress Ratio	3.46	3.47	3.79	**3.85**

Table 5: Stress Ratio for high carbon steel.

Cylinder	von Mises stress in high carbon steel- cylinder under 5 bar pressure Cylinder thickness (t) in mm			
	0.8	**1**	**1.25**	**1.5**
Without bosses	116.47	92.41	73.83	61.9
With bosses	407.05	323.41	276.38	240.55
Stress Ratio	3.49	3.50	3.74	**3.89**

It shows that, presence of bosses on the circuference of the cylider does changes the stress pattern significantly. This significance is measured using the parameter called *Stress ratio (SR),* i.e. the ratio of stress obtained for cylinder with bosses to that of without bosses under identical working condition. In this case, SR is more than 1, hence illustrates that presence of bosses introduce more stress in the material than that for cylinder without bosses. Also the SR increases as the thickness of the cylinder increases under the identical working condition.

That is, SR of **3.46** is obtained for 0.8 mm thick cylinder where as that for 1.5 mm thick cylinder is **3.85**. In case of high carbon steel also, the same trend of SR is obsrved and it is as shown in Table 5. Where as Fig. 6 a and b gives the effect of bosses on the stress distribution for the two materials under 5 bar pressure. Similarly, comparison of von Mises Stress in mild steel- and high carbon steel cylinder under 7.5 bar pressure was carried out and same consequence is observed.

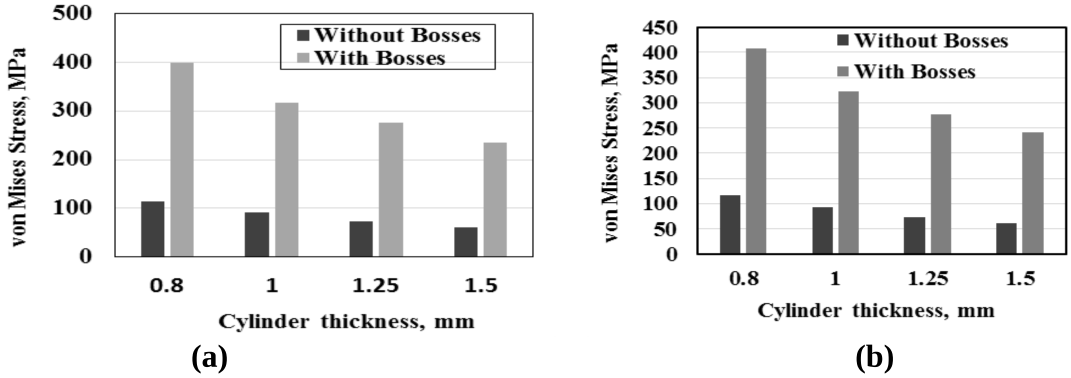


Fig. 6: Effect of bosses on the stress distribution for a) mild steel b) high carbon steel.

10.1.5.3 Validation of results

Validation 1

In order to check the correctness of FE results, Classical mechanics approach was used to calculate the induced stress in the cylindrical section of the Turbine Casing of a turboshaft Engine. For the comparison, mild steel cylinder with 0.8 mm thickness under 5 bar pressure is considered and the same is as below;

Inner diameter of the cylinder around the bosses, D= 380 mm

Internal pressure, P_i = 0.5 MPa

Ratio, R / t = 237.5 > 10. Thus it is ***thin cylinder case.***

Induced hoop stress, as per equation (1) $= \sigma_C = \frac{PD}{2t} = \mathbf{118.75}\frac{N}{mm^2}$

Von Mises stress in the cylinder as per FEA (Table 1) = $\mathbf{114.94}\frac{N}{mm^2}$

Hence FEA result is matching with the calculated classical mechanics result with 3.33 % error.

Validation 2

In order to check the correctness of FE results, Classical mechanics approach was used to calculate the induced stress in the cylindrical section of the Turbine Casing of a turboshaft

Engine. For the comparison, high carbon steel cylinder with 1.5 mm thickness under 7.5 bar pressure is considered and the same is as below;

Inner diameter of the cylinder around the bosses, D= 380 mm

Internal Pressure, P = 0.75 MPa

Ratio, R /t = 126.7 > 10. Thus it is ***thin cylinder case.***

Induced hoop stress, as per equation (1) $= \sigma_C = \frac{PD}{2t} = 95 \frac{N}{mm^2}$

Von Mises stress in the cylinder as per FEA (Table 2) = 92.86 $\frac{N}{mm^2}$

Hence FEA result is matching with the calculated classical mechanics result with 2.3 % error.

CONCLUSION

Pressurized cylinder made up of two materials is studied independently, using the numerical method. High carbon steel can marginaly experience more stress than that by the mild steel due to more yield strength . Presence of bosses introduce more stress in the cylinder than that for cylinder without bosses. Effect of thickness of cylinder on the Von mises stress distribution is observed in both the materials. In fact, reciprocal relationship between wall thickness and stress gradient across of the material is observed. Thicker plate have smaller stress gradient, thus are less tougher against the pressure than that of the thin plates under identical working conditions.

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