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Investigation of Heat Transfer Through Fins Using Fem

Mr. H.N. Gandate* Dr. D.V. Bhope#
*Student, IV semester M.Tech. (CAD/CAM)
Mechanical Engineer Department, Rajiv Gandhi College of Engineering and Research &Technology, Chandrapur 442 403- (Maharashtra) (India)
Professor and Head
Mechanical Engineer Department, Rajiv Gandhi College of Engineering and Research & Technology, Chandrapur 442 403- (Maharashtra) (India)

ABSTRACT
Analysis of heat distribution, thermal stresses and strain for engine cylinder and fins are discussed in this paper. The cylinder and fins being analysed using finite (FE) software ANSYS AND by FE (simple model). When a cylinder is subjected to certain pressure and temperature thermal distribution and thermal stresses analysis of cylinder is necessary to avoid the failure during working condition. In this work the temperature distribution and thermal stresses are evaluated by considering only temperature effect, temperature and gas pressure effect and also evaluate the same by considering the effect of cylinder head.

I. INTRODUCTION

Temperature of burned gases in the cylinder of an internal combustion engine may reach up to ten times of its surface temperature and leads to great heat fluxes emitted to the chamber walls during combustion period. Maximum metal temperature for the inside of the combustion chamber space are limited to much lower values by a number of consideration and hence cooling for the engine must there for the provided. In region of high heat flux, thermal stresses must be kept below levels and that would cause fatigue cracking (less than about 400^{0}C for cast iron and 300^{0}C for aluminum alloy). The gas side surface of the cylinder wall must also be kept low to prevent deterioration of the lubricating oil film. Spark plug must be kept cool to avoid knock and pre-ignition problems which result from overheated spark plug electrode.

In contrasts to transferring the heat away, the heat transfer would also give effects on the engine performance, efficiency and emission. For a given mass of fuel within the cylinder, higher heat transfer to the combustion chamber wall will lower the average combustion gas temperature and pressure which in turn reduce the work per cycle transfer to the piston. Thus specific power and efficiency are reduced.

So it is very important to predict the magnitude of heat transfer in designing engine, hence it is the objective in this analysis to study the dissipation of heat as well as temp distribution on the cylinder for the engine model.

II. MODELING

For the above analysis following model shown in figure 1 of cylinder and fin is considered

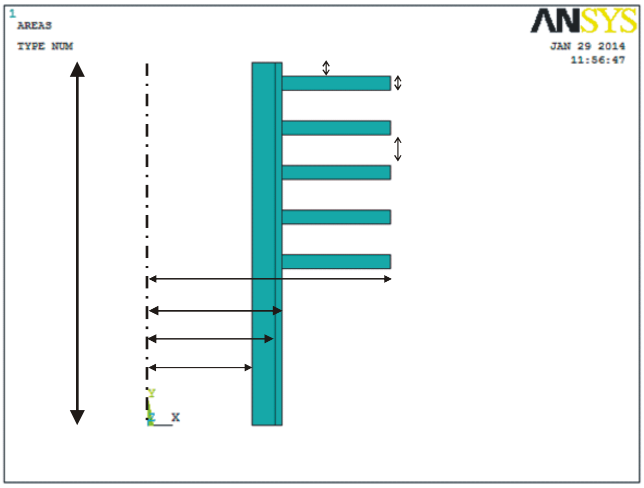


Fig No. 1 - Model of Cylinder and fin

L - Length of cylinder (81mm)
R_1 - Inside radius of liner (23.5mm)
R_2 - Outside radius of liner (28.5mm)
R_3 - Outside radius of cylinder (30mm)
R_4 - Outside radius of fin (54.5mm)

III. ANALYSIS

The present analysis uses to different approaches, finite element method (FEM) Coded software namely ANSYS and FE (simple model). For the analysis of cylinder and fins different section at each fin are considered.

Due to symmetry about axis Y-Y, it is convenient to consider one quadrant of model.

Two types of material used in the cylinder assembly are the Gray Cast Iron (ASTM A48) and Die Cast Aluminum Alloy (ASTM B390). Liner is to be from gray cast iron while the cooling fins to be from aluminum alloy. The required input material properties include the thermal conductivity, density and specific heat.

3.1 LOADS AND RESTRAINTS

Loads and restraints in another word, the boundary conditions define the working conditions of the model. The boundary conditions specified in thermal analysis are the thermal loads and convection boundary on outer surfaces. In the analysis, the thermal loads were specified as surface temperature and are defined on the inner wall of the cylinder. The surface temperature on the cylinder wall is defined from the top edge of the cylinder. Piston head is not modeled in the stimulation because temperature distribution on the piston is not the subject of interest. Spark plug is also neglected in this study. Temperature of 450 ^{0}K and 423^{0}K are specified on the cylinder wall. These temperatures are specified base on the typical temperature distribution for SI Engine during steady state operation.

Since the cooling system of engine uses air, convection boundary is defined on all the outer surface of the cylinder and fins. In the thermal analysis the cylinder assembly is configured as in natural convection where all the outer surface of the cylinder and fins are assumed to be exposed to the environment naturally with no significant air flowing surround it. For the convenience of the study, heat transfer by radiation is neglected where all the heat flows to the ambient only for convection. The convection boundaries are defined by specifying the value of the heat transfer coefficient. The convection heat transfer coefficient is merely a definition and depends on flow condition in which it cannot be tabulated and needs to determine for each flow condition. Hence in this study, the typical value of constant is specified as 9 W/m^{2}K for natural convection of gases.

In static analysis, the result from thermal analysis is brought directly into a static analysis as the restraints. Apart from that, displacement restraints are also defined. The bottom faces of the cylinder block and cylinder liner are restricted from moving in vertical direction and top face also restricted from moving downward.

3.2 ASSUMPTIONS

For the thermal analysis, it is assumed that,

- There is no significant change in the ambient air temperature at the engine assembly outer surfaces.
- The convection heat transfer coefficient is the same for all surfaces.
- Temperature increase from cylinder wall and friction is neglected.
- All loads are applied slowly and gradually until they reach their full magnitudes. After reaching their full magnitudes load remains constant.
- Boundary condition does not vary during application of loads. Loads are constant in magnitude, direction and distribution.
- The relationship between loads and induced response is linear.
- The induced displacements are small enough to ignore the change in stiffness caused by loading.

3.3 MESHING

From finite element analysis (FEA) provides a reliable numerical technique start with creation of a geometric model and then subdivides the model into small pieces in to simple shapes (elements) connected at the common points (nodes). This process are subdividing model into small pieces is called meshing. The accuracy of solution depends largely on the quality of the mesh. In general, the finer the mesh, the better the results. The sizes of generated mesh depends on the geometry and dimension of the model as well as the specified element order, element size, mesh tolerance, mesh control and contact specification.

3.4 RESULTS

Results from the thermal analysis are shown as temperature distribution contour as given in fig. 2. From fig. 2 it can be seen that maximum temperature is developed.

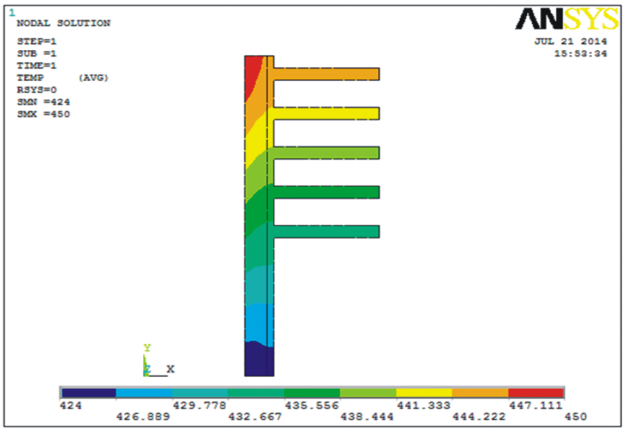
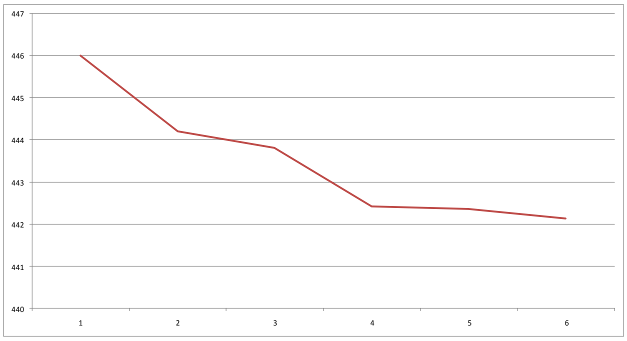
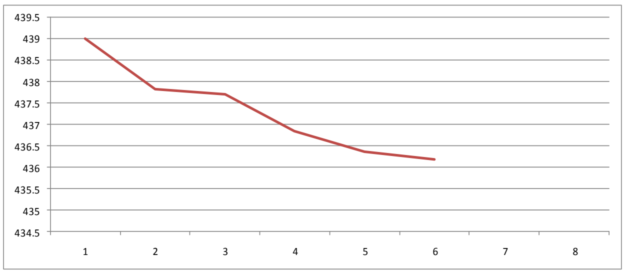


Fig. 2 Nodal temperature

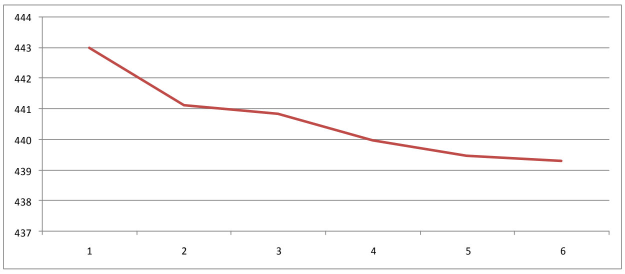
Figure 3 to fig. 7 shows the plot of local temperature across the fins. From fig 3 to fig.7 it is noticed that temperature dropped becomes constant at the point when the heat is passing through the contacting surfaces.



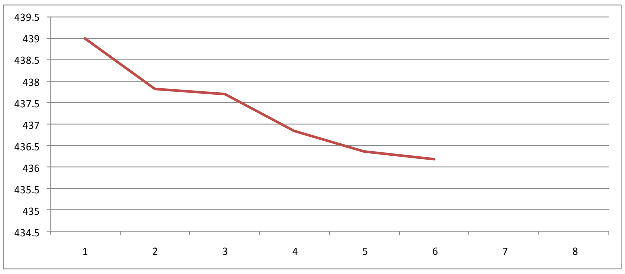
Distance from inner surface
Fig. 3: Temperature distribution of 1st fin.



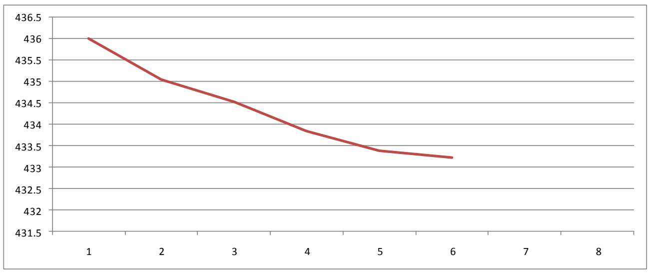
Distance from inner surface
Fig. 4: Temperature distribution of 2nd fin.



Distance from inner surface
Fig. 5: Temperature distribution of 3rd fin.



Distance from inner surface
Fig. 6: Temperature distribution of 4 th fins.



Distance from inner surface
Fig. 7: Temperature distribution of 5th fin.

Table 1 Temperature distribution

FINS	T_1 ^{0}K	T_2 ^{0}K	T_3 ^{0}K	T_4 ^{0}K	T_5 ^{0}K	T_6 ^{0}K
1	449	446.32	445.98	445.06	444.55	444.36
2	446	444.2	443.82	442.42	442.37	442.14
3	443	441.11	440.85	439.97	439.48	439.3
4	439	437.82	437.7	436.84	436.36	436.18
5	436	435.03	434.53	433.85	433.37	433.22

T1= TEMPRETURE AT INNER SURFACE OF LINER
T2= TEMPRETURE AT INNER SURFACE OF CYLINDER
T3= TEMPRETURE AT OUTER SURFACE OF CYLINDER
T4= TEMPRETURE AT THE END OF FIRST PART OF THE FIN
T5= TEMPRETURE AT THE END OF SECOND PART OF THE FIN
T6= TEMPRETURE AT THE END OF THE FIN

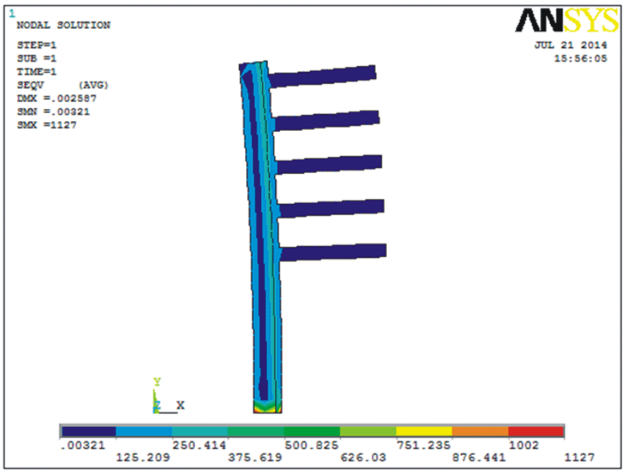


Fig. 8: Result of Von Misses Stress

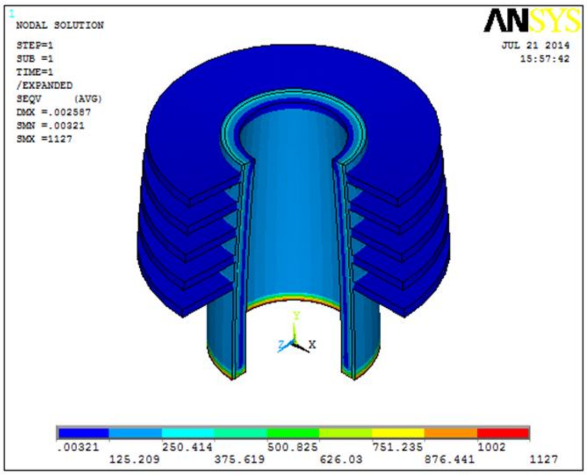


Fig. 9 Result of Von Misses Stress

Figure 10 and fig. 11 shows the deformation and displacement of cylinder liner and fins the maximum displacement observed at the top cooling fin where the temperature distribution is at the highest.

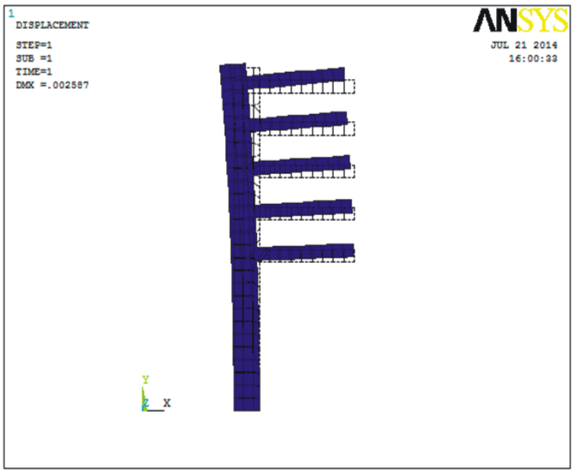


Fig 10: Result of deformation

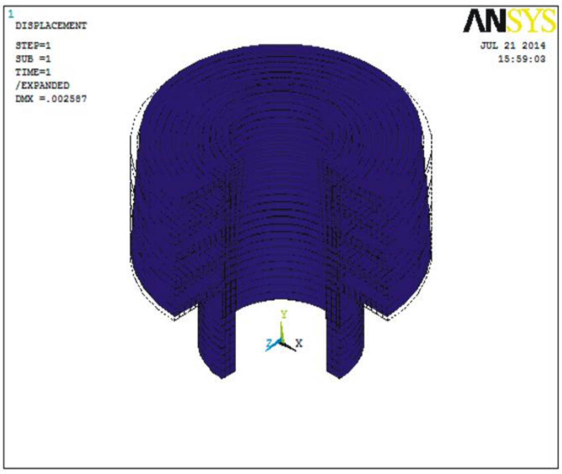


Fig 11: Result of deformation

Figure 12 & fig. 13 shows the total mechanical and thermal strain in cylinder liner and cooling fins. Maximum strain is developed at the top portion of cylinder liner and fins.

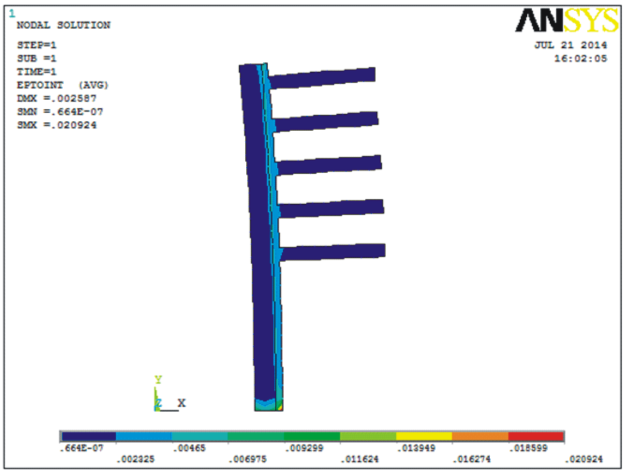


Fig 12: Result of Strain

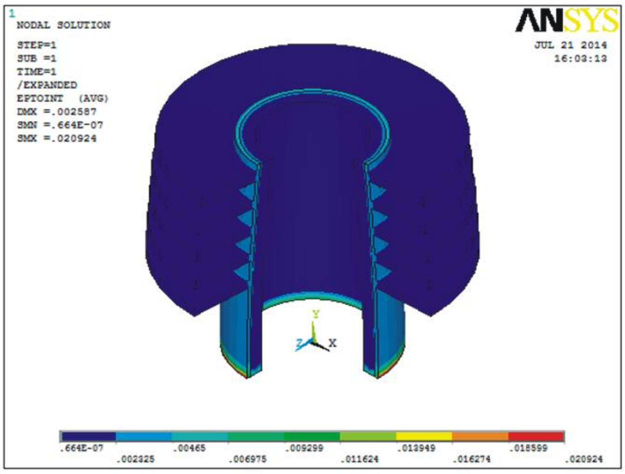


Fig 13: Result of Strain

Figure 14 & fig. 15 shows the Von Misses stresses developed in cylinder and fins with the effect of gas pressure and temperature. It is maximum at the top portion of the liner and fins.

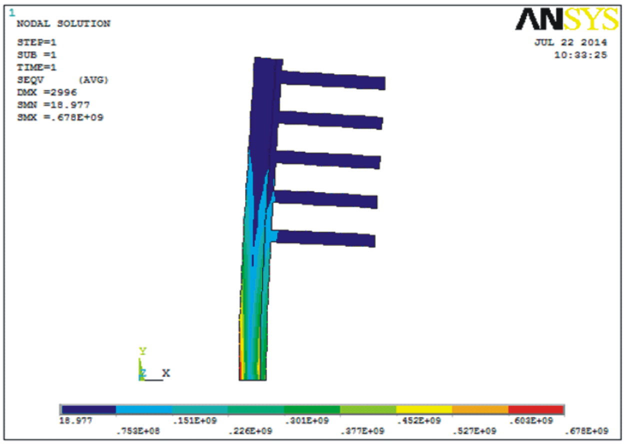


Fig No. 14 Result of von Misses Stress

[With pressure]

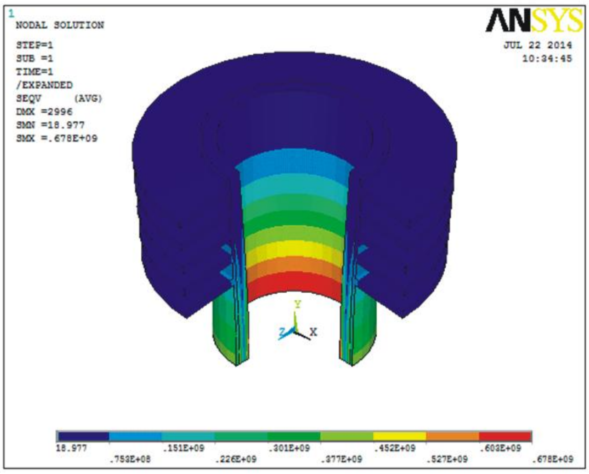


Fig No. 15 Result of von Misses Stress
[With pressure]

Figure 16 and fig. 17 shows the deformation and displacement of cylinder liner and fins under the effect of gas pressure.

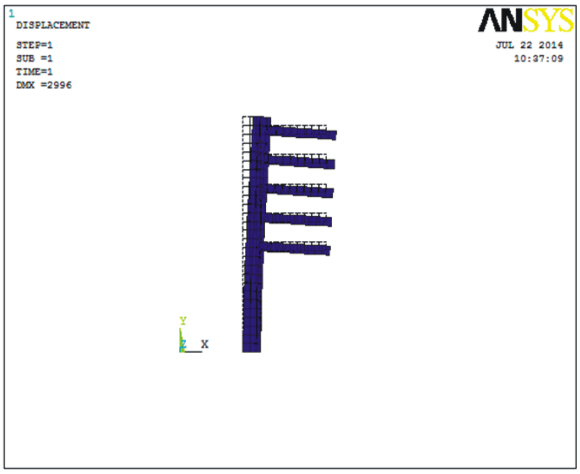


Fig 16: Result of deformation
[With gas pressure]

Fig 17: Result of deformation
[With gas pressure]

Figure 18 and fig 19 shows the total mechanical and thermal strain developed in cylinder liner and fins with the effect of gas pressure inside the engine cylinder.

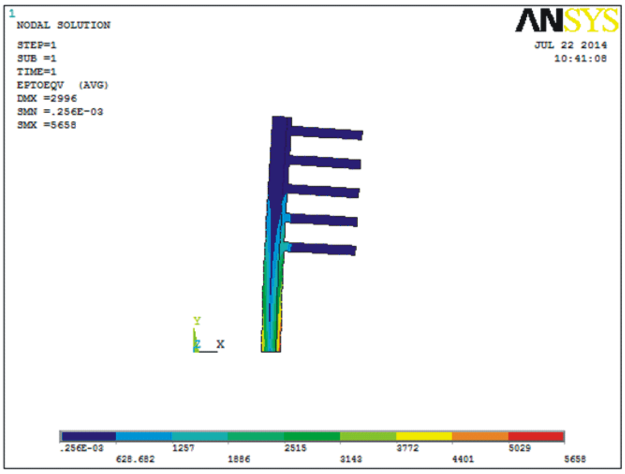


Fig No 18: Result of strain [with gas pressure]

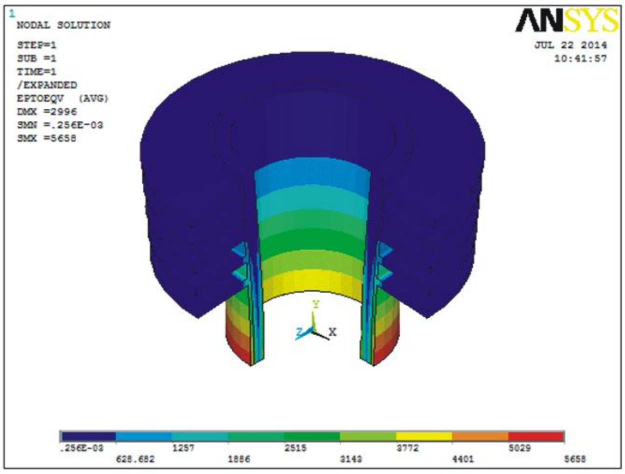


Fig No 19 Result of strain [with gas pressure]

Table 2: Stresses developed along the cylinder and fins

No.	Cylinder [N/mm^2]	Fin [N/mm^2]
1	35.74	1.64
2	37.24	3.03
3	24.38	1.63
4	28.86	2.17
5	39.85	2.87

Figure 20 and fig. 21 shows the effect of cylinder head on stresses in cylinder and fins.

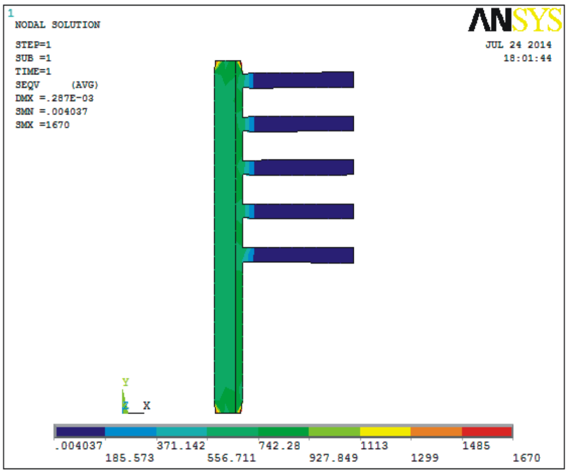


Fig 20 Result of Von Misses Stresses

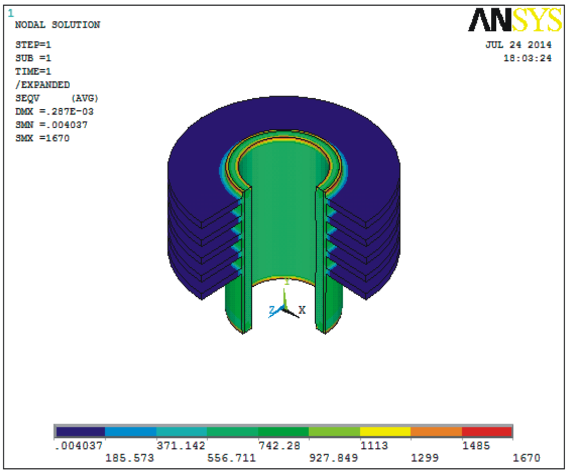


Fig 21 Result of Von Misses Stresses

Figure 22 and fig. 23 shows the deformation of cylinder liner and fins under the effect of cylinder head.

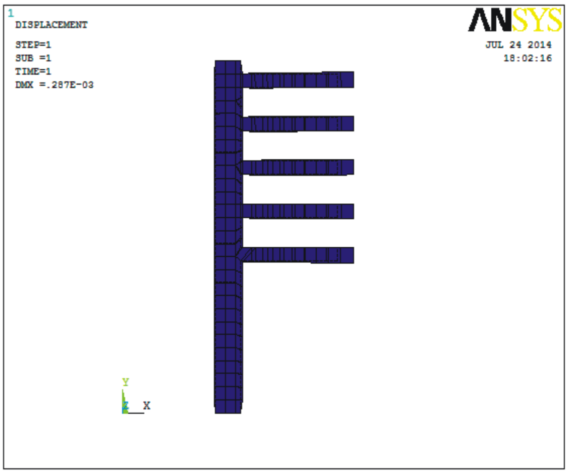


Fig No. 22 Result of Deformation

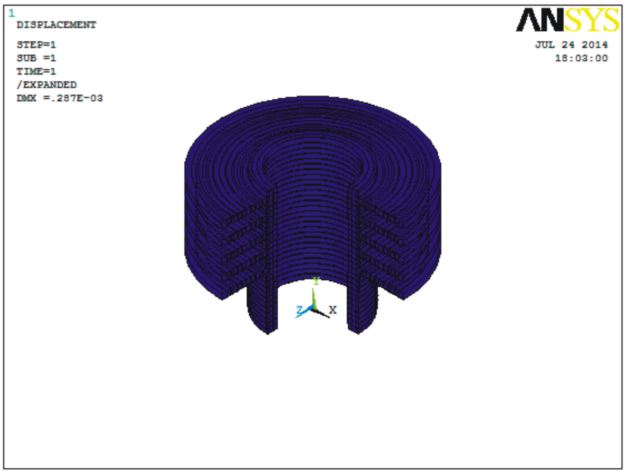


Fig No. 23 Result of Deformation

Figure 24 and 25 shows the thermal stress distribution in cylinder liner and fin under the effect of gas pressure inside the cylinder.

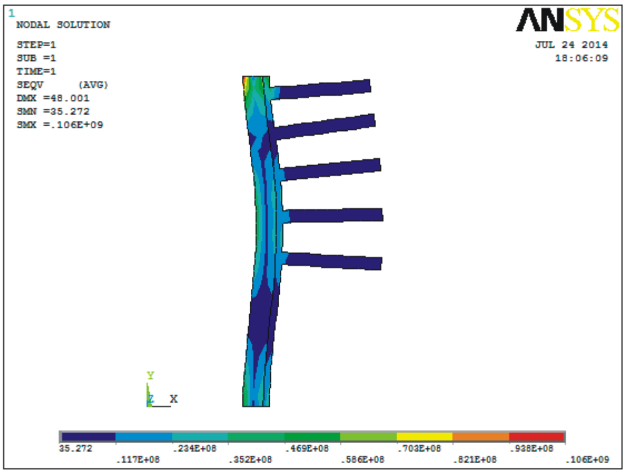


Fig 24 Result of Von Misses Stresses (with gas pressure)

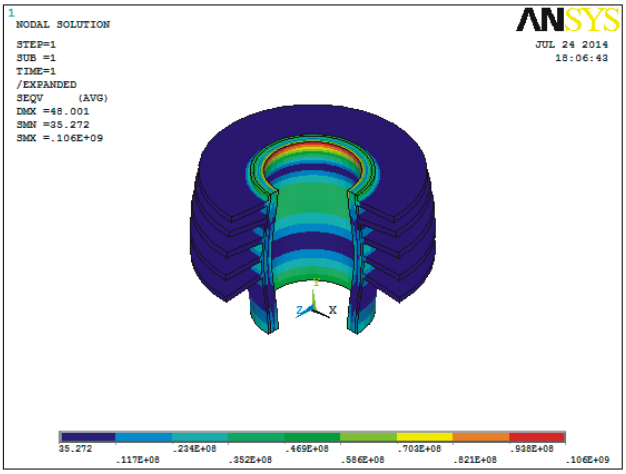


Fig 25 Result of Von Misses Stresses (with gas pressure)

Figure 26 & fig. 27 shows the deformation of cylinder liner and fins under the effect of cylinder head with gas pressure.

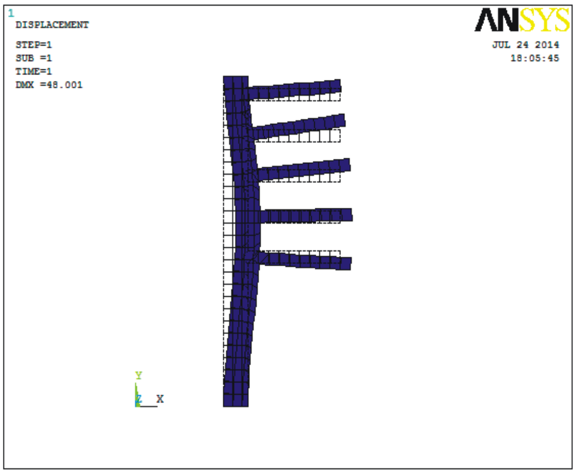


Fig 26 Result of deformation
(With gas pressure)

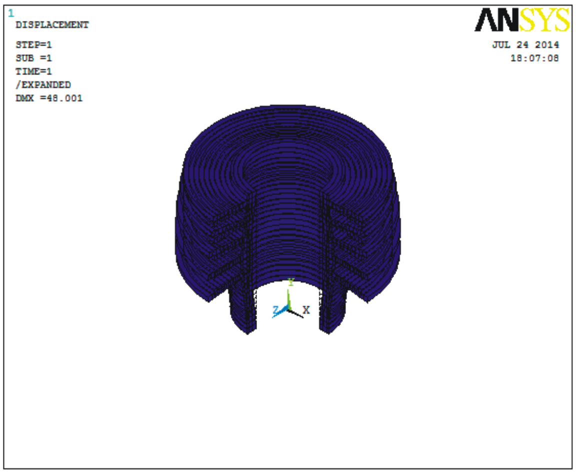


Fig 27 Result of deformation
(With gas pressure)

Figure 28 shows the Von misses stresses developed by considering actual cylinder head.

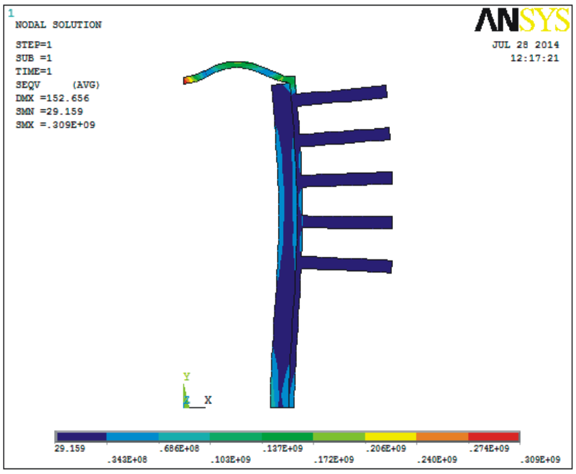


Fig 28 Von Misses stresses developed in cylinder liner,
Fins and cylinder head

Figure 29 shows the Deformation of cylinder head and fins by considering actual cylinder head.

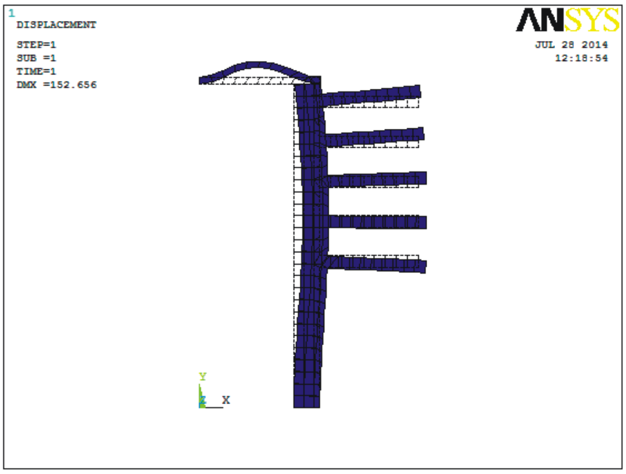


Fig 29 Deformation in cylinder liner, fins and cylinder head

Table 3 Stresses developed along the cylinder
And fins with gas pressure
When cylinder restrained at top and bottom

No.	Cylinder [N/mm^2]	Fin [N/mm^2]
1	84.37	24.97
2	76.42	22.32
3	70.35	20.16
4	76.32	21.17
5	84.37	24.34

4 ANALYSIS OF TEMPERAUTE DISTRIBUTION AND THERMAL STRESSES BY FE APPROACH (SIMPLE MODEL)

Equations are used for the analysis the temperature distribution and thermal analysis by FE approach

$$K_T = \frac{k_e}{\ell_e}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$r_q = \frac{Q_e \ell_e}{2}\begin{Bmatrix} 1 \\ 1 \end{Bmatrix}$$

$$\begin{bmatrix} (K_{11}+C) & K_{12}\ldots & K_{1L} \\ K_{21} & K_{12}\ldots & K_{2L} \\ \vdots & & \vdots \\ K_{L1} & K_{L2}\ldots & (K_u+h) \end{bmatrix} \begin{Bmatrix} T_1 \\ T_2 \\ \vdots \\ T_L \end{Bmatrix} = \begin{Bmatrix} (R_1 + CT_0) \\ R_2 \\ \vdots \\ (R_l + hT_\infty) \end{Bmatrix}$$

Equations are considered for the analysis the temperature distribution and thermal analysis are....

$$K_T = \frac{k_e}{\ell_e}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

$$r_q = \frac{Q_e \ell_e}{2}\begin{Bmatrix} 1 \\ 1 \end{Bmatrix}$$

$$\begin{bmatrix} (K_{11}+C) & K_{12}\ldots & K_{1L} \\ K_{21} & K_{12}\ldots & K_{2L} \\ K_{L1} & K_{L2}\ldots & (K_u+h) \end{bmatrix}\begin{Bmatrix} T_1 \\ T_2 \\ T_L \end{Bmatrix} = \begin{Bmatrix} (R_1+CT_0) \\ R_2 \\ (R_1+hT_\infty) \end{Bmatrix}$$

$$\theta^e = \frac{E_e A_e \ell_e \alpha \Delta T}{x_2 - x_1}\begin{Bmatrix} -1 \\ 1 \end{Bmatrix} \ldots(1)$$

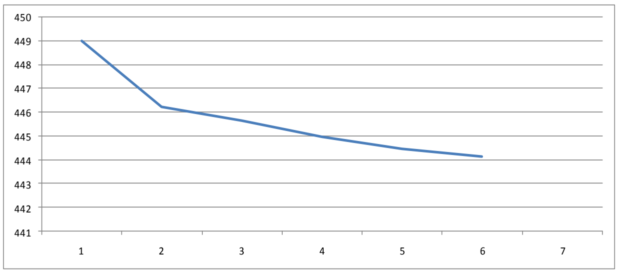
$$\sigma = \frac{E}{x_2 - x_1}[-1 \;\; 1]q - E\alpha\Delta T \ldots..(2)$$

Table 4 shows the result of temperature at various cross sections of the cylinder liner and fins by using FE approach (simple model).

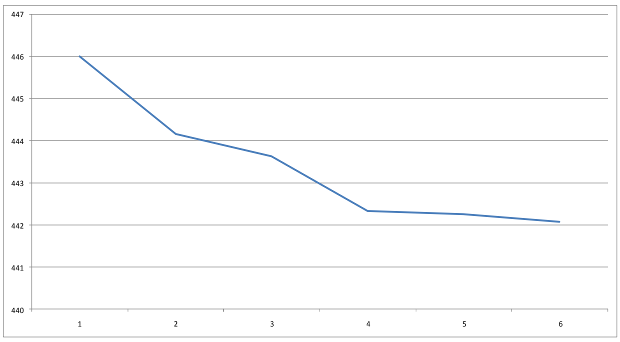
Table 4 FE (Simple model) temperature distribution along the rectangular fin

FINS	T1 ^{0}K	T2 ^{0}K	T3 ^{0}K	T4 ^{0}K	T5 ^{0}K	T6 ^{0}K
1	449	446.23	445.64	444.96	444.48	444.14
2	446	444.16	443.64	442.34	442.26	442.08
3	443	441.01	440.65	439.87	439.36	439.03
4	439	437.68	437.5	436.74	436.21	436.08
5	436	435.01	434.33	433.65	433.13	433.09

Figures 30 to fig. 34 show the temperature distribution along the cylinder liner and fins.

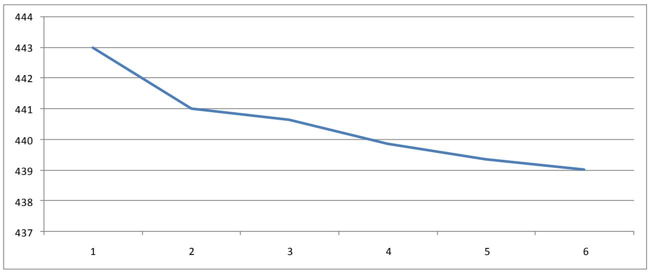


Distance from inner surface Fig. 30 Temp. Distribution of 1st fin



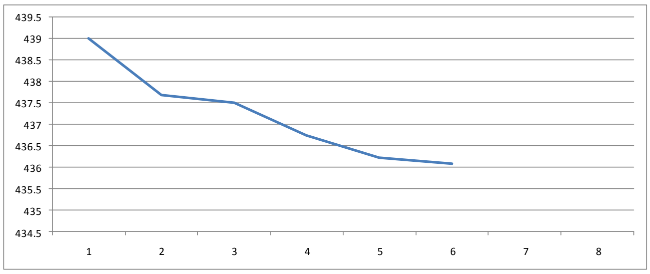
Distance from inner surface

Fig. 31 Temp. Distribution of 2nd fin



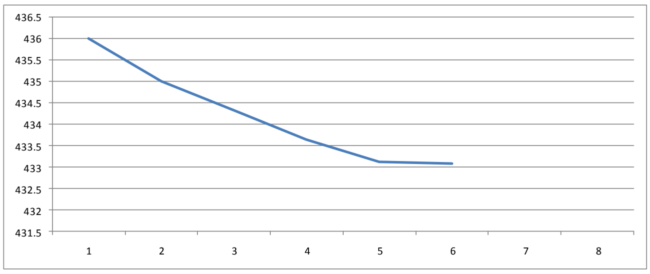
Distance from inner surface

Fig. 32 Temp. Distribution of 3rd fin



Distance from inner surface

Fig. 33 Temp. Distribution of 4 th fin



Distance from inner surface

Fig. 34 Temp. Distribution of 5 th fin

Table 5 shows the result of stresses at cylinder liner and fins by FE approach (simple model).

Table 5: Stresses developed along the Cylinder and fins

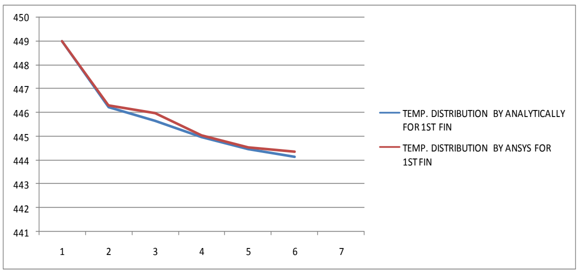
No.	Cylinder [N/mm^2]	Fin [N/mm^2]
1	35.74	1.64
2	37.24	3.03
3	24.38	1.63
4	28.86	2.17
5	39.85	2.87

IV. COMPARISON

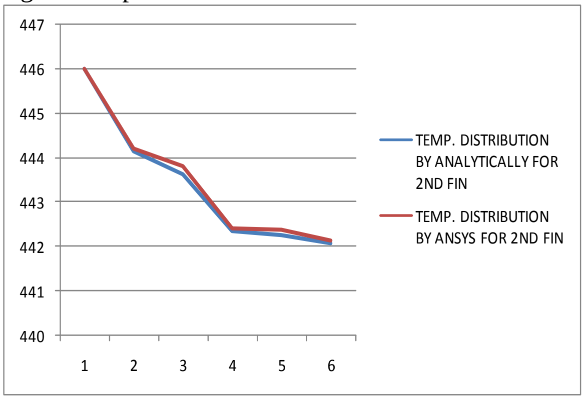
Table 6 shows the temperature distribution in cylinder liner and fins using FE model and FE approach using simple model.

Table 6: Comparison of temperature distribution between FE model and simple model

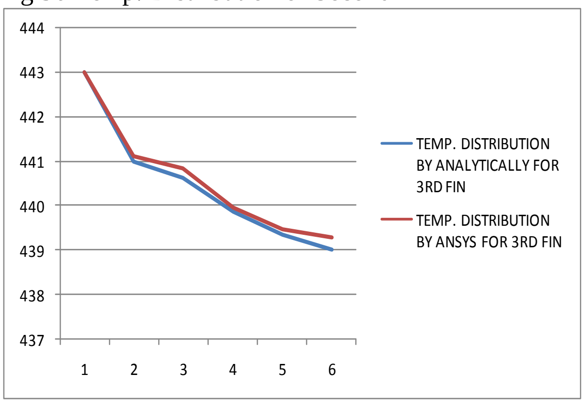
FINS	TEMP	T1 °K	T2 °K	T3 °K	T4 °K	T1 °K	T6 °K
1	FE	449	446.32	445.98	445.06	444.55	444.36
	FE(Simple Model)	449	446.23	445.64	444.96	444.48	444.14
2	FE	446	444.2	443.82	442.42	442.37	442.14
	FE(Simple Model)	446	444.16	443.64	442.34	442.26	442.08
3	FE	443	441.11	440.85	439.97	439.48	439.3
	FE(Simple Model)	443	441.01	440.65	439.87	439.36	439.03
4	FE	439	437.82	437.7	436.84	436.36	436.18
	FE(Simple Model)	439	437.68	437.5	436.74	436.21	436.08
5	FE	436	435.03	434.53	433.85	433.37	433.22
	FE(Simple Model)	436	435.01	434.33	433.65	433.13	433.09



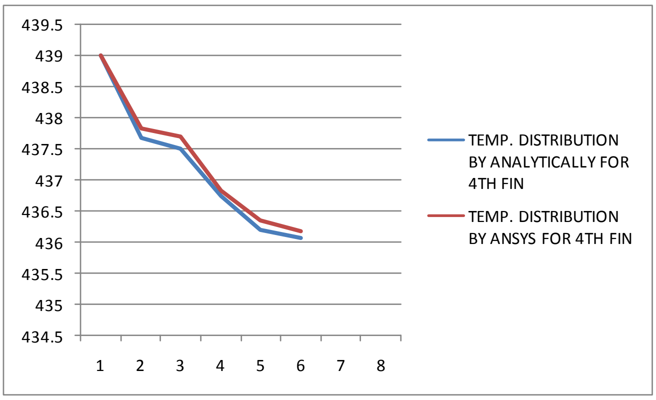
Distance from inner surface
Fig 35 Temp. Distribution of first fin



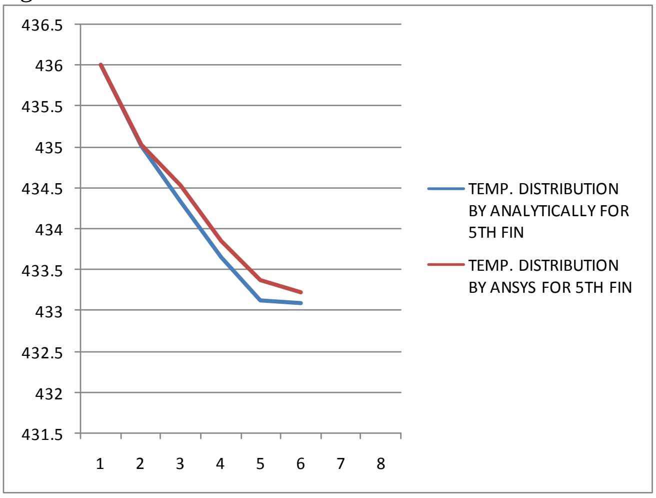
Distance from inner surface
Fig 36 Temp. Distribution of Second fin



Distance from inner surface
Fig. 37 Temp. Distribution of Third fin



Distance from inner surface
Fig. 38 Distribution of fourth fin



Distance from inner surface
Fig. 39 Distribution of Fifth fin

Table 7 shows the comparison of stresses developed along cylinder and fins by FE and FE (simple model).

Table 7: Comparison of stresses developed at cylinder liner and fins between FE and FE (simple Model)

FINS	TEMP	Cylinder(N/mm^2)	Fins (N/mm^2)
1	FE	32.184	11.876
	FE(Simple Model)	35.74	1.64
2	FE	35.564	16.011
	FE(Simple Model)	37.24	3.03
3	FE	35.154	15.104
	FE(Simple Model)	24.38	1.63
4	FE	35.024	15.478
	FE(Simple Model)	28.86	2.17
5	FE	36.556	17.299
	FE(Simple Model)	39.85	2.87

V. CONCLUSION

With reference to result obtained for the cylinder with rectangular fins following discussion is done and conclusions are drawn.

In these analysis different sections of IC engines cylinder liner and fins are considered and temperature distributions at various sections of above are calculated. Also by considering various sections of IC engines cylinder liner and fins maximum Von Misses stresses are determined. On the basis of the result presented earlier, the discussion and conclusion are as follows.

It is seen that due to combustion of fuel In combustion chamber maximum temperature is developed in top portion of the liner and in first fin of the cylinder and temperature decreases from top to bottom of the cylinder. From results plotted in table 1 to 7 and fig .No. 3 to 7, Fig No. 30 to 34 and Fig. 35 to 39, it is seen that the temperature distribution obtained by FE and analytically is same.

Table 2 to 7 shows result from static analysis of thermal stress distribution. As can be seen in table, the Von Misses stresses are concentrating at the mounting location i.e. stud holes also on the cylinder liner. Stresses are concentrated on the stud holes due to restraining effect of the stud to fasten the cylinder blocks to the crankcase of the engine assembly.

Table 7 shows the result of effect of cylinder head on stresses distribution. As can be seen in table maximum Von Misses stresses developed at the top and bottom portion of the cylinder and liner.

From the above analysis it is seen that maximum stresses are developed at the restraining portion of the cylinder.

The maximum Von Misses stresses developed are 36.556 N/mm^2 at cylinder liner and 17.299 N/mm^{2at} fins without gas pressure when the cylinder is constrained at bottom face. When the gas pressure is applied, maximum Von Misses stresses at cylinder liner is 67.65 N/mm^2 And 26.36 N/mm^2 at the fin.

The maximum Von Misses stresses developed are 80N/mm^2 at cylinder liner and 18.57 N/mm^2 at the fins, when cylinder is constrained at both ends without pressure and by the application of pressure stresses developed are 84.37 N/mm^2 and 24.34 N/mm^2 at cylinder liner and fins respectively. When the actual cylinder head is considered Von misses stresses developed are 88.38N/mm^2 and 22.32 N/mm^2 at cylinder liner and fins respectively without application of gas pressure and 87.36 N/mm^2 and 29.82 N/mm^2 by the application of gas pressure at cylinder liner and fins respectively.

From above discussion it is seen that maximum Von Misses stresses are developed at cylinder liner and fin when the gas pressure applied and actual cylinder head is considered.

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