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Failure Investigation and Thermo-Mechanical Analysis of Cylinder Liner

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ABSTRACT

Internal combustion engine are frequently operated in many mechanical sector applications. It is used in automotive, ships, power aircrafts, power generation units. In Internal combustion Engine, the cylinder liners are the important and the most load carrying part. This liner is subjected to various stresses during the engine working status. The stresses which act on cylinder liner are Stress due to action of gas pressure, heat and pressure of piston acting on liner. Result of that stresses Wear patters developed, Internal or external cracking and Corrosion of cylinder liner takes place. All above results are adversely effects on the performance of cylinder liner, and reduces the working efficiency of internal combustion engine. So, there is need to investigate the various reasons of failure of liner and methods to overcome and increase the efficiency of liner. The most important requirements for the satisfactory service life of the cylinder component in an engine are higher life, higher temperature resistance and higher mechanical properties. In this paper, complete thermo-mechanical analysis of cylinder liner is carried out at different temperature and different pressure.

Keywords: Cylinder Liner, Internal Combustion Engine, Piston

I. INTRODUCTION

A Cylinder liner is the part which is press fitted inside the cylinder block to improve wear resistance and rate of heat transfer. In general, there are two types of cylinder liner are as follows:

1) Wet type cylinder liner.
2) Dry type cylinder liner.

In wet type cylinder liner the outside is in direct contact with water which is not in dry type cylinder liner. Dry liner is simpler to replace and there is no danger of water leakage in to either combustion chamber or the crankcase. Its disadvantage is a decrease of the heat conduction through composite wall. In internal combustion engine there is continuous reciprocating movement of piston. Due to friction between piston and liner wall of the cylinder, the inner wall get wear and there is difficulty in compression stroke (leakage of charge). To overcome this problem cylinder liner are used. Cylinder components contribute to around 30% of total friction in an engine about 5% of the combustion heat or 10% of the potentially useful power is lost to mechanical friction. Even though improvements in friction performance have been made via design optimizations and lubricant improvement. No significant engine redesign has been attempted in order to re-capture friction energy. The most important requirements for the satisfactory service life of the cylinder component in an engine are higher life, higher temperature resistance and higher mechanical properties.

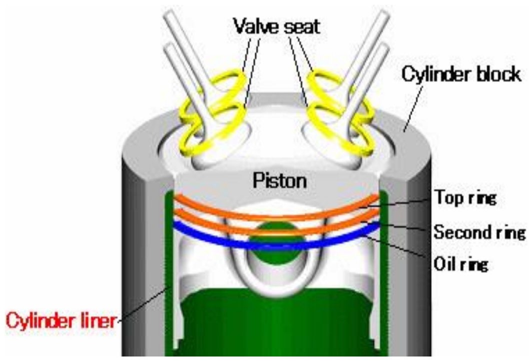

Figure 1 : dry cylinder liner

II. METHODS AND MATERIAL

Problem Statement

Physical phenomenon:

Figure 2(a) : Actual failure component

Figure 2(b): Actual failure component

The phenomenon which largely affects the wear in cylinder liner can be grouped into two categories.

Chemical Phenomenon:

Which carry the effects of adhesion, abrasion and scuffing of the overall cylinder liner?

Piston and liner surface are in continuous matting when the internal combustion engine is continuously running condition. Result of this formation of the confecting passage through local plastic deformation. These spot will exactly affects at their weakest points and it will result in transfer of the metal along with these two matting parts. In that case the hardness of both the material affected on the rate of wear. Adhesive wear is also the reason of failure of cylinder liner. The phenomenon of adhesive wear occurs in cylinder liner at the initial start of the cylinder liner and these affected by clearances of piston ring, surface finish, surface texture, nature of the component material.

Chemical reaction on cylinder liners:

Because of low or high i.e. changing or fluctuating temperature corrosive type of wear occurs in cylinder liner. In Many case study, it is observed that the working fuel contain excessive sulfur.

combustion

Sulfur → sulfur dioxide

Presence of H_2O vapor from combustion process+ air

↑

Sulfur dioixide → sulfur trioxide.

Sulfur trioxide + Moisture → Dilute Acid

Result of all above reaction formation of dilute acid and its precipitation. This affects the surface of liner undergoes to a rapid corrosive attack. And the results effects on performance of cylinder liner in internal combustion engine.

Analytical Analysis

In this project we are using Nickel-Chromium Iron alloy material for liner so we required some parameter while calculating the stresses and also for Analysis such as

TABLE I

MATERIAL PARAMETERS

Properties	**Values**
Modulus of Elasticity	1.3 e^5 N/mm^2
Density	7.8 e^{-9} Tonns/mm^2
Coefficient of thermal expansion	11.69 e^{-6} /^{o}K
Thermal Conductivity	70 W/M^{o}K
Poisson's ratio	0.28

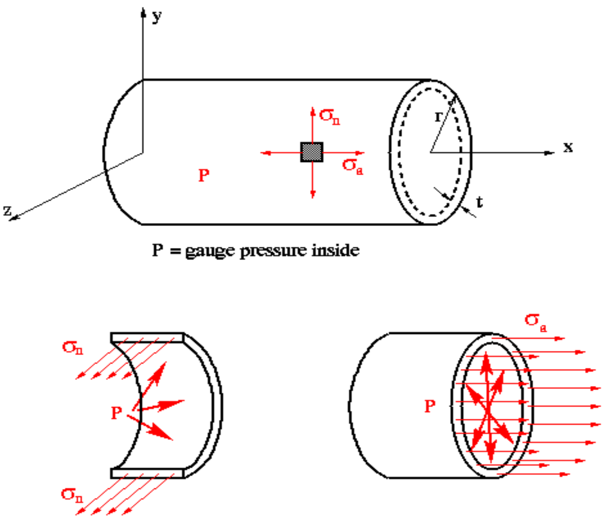

Figure 3 : Hoops Stress

All Max stress in cylinder liner for open ends by using Birnies method.

$$S = \frac{P[(1-\mu)\, di^2 + (1+\mu) d_0^2]}{[d_0^2 - d_i^2]} \quad ......[1]$$

Where, P-maximum inner pressure,N/mm2

μ-poisson's ratio

di-inner diameter,mm

do-outer diameter,mm

do=70mm,

di=65.5mm,

P=60 bar,

μ=0.27 [cast iron]

$$S = \frac{60[(1-0.27)65.5^2 + (1+0.27)70^2]}{[70^2 - 65.5^2]} \quad .....[2]$$

S=93 n/mm^2

Stress on the outside the surface,

$$S_0 = \frac{aE[(T_i - T_o)(1 - {}^{m}/_{3})]}{2(1-\mu)} ...[3]$$

Where,

a=coefficient of linear expansion

E=modulus of elasticity,

Ti= Temperature inside cylinder=550^{0}F,

To=temperature outside cylinder=81^{0}F,

m=do/di=0.078

So=6.5*10^{-6}*13*10^6 (550-81)(1-0.078/3)/2(1-0.27)

So=26440 psi=182.29 N/mm^2

Stress at inside surface:

$$S_i = \frac{-aE[(T_i - T_o)(1 + {}^{m}/_{3})]}{2(1-\mu)} ...[4]$$

Si=-6.5*10^{-6}*13*10^6 (550- 81)(1-0.078/3)/2(1+0.27)

Si=-27850 psi=-192.01 N/mm^2

(neagative sign indicates that the stress in compressive)

So=26440 psi=182.29 N/mm^2 Si=-27850 psi=-192.01 N/mm^2

Combined stress

Combined stress=hoop stress+maximum thermal stress

=93+292.527

=383.35 N/mm^2

III. RESULTS AND DISCUSSION

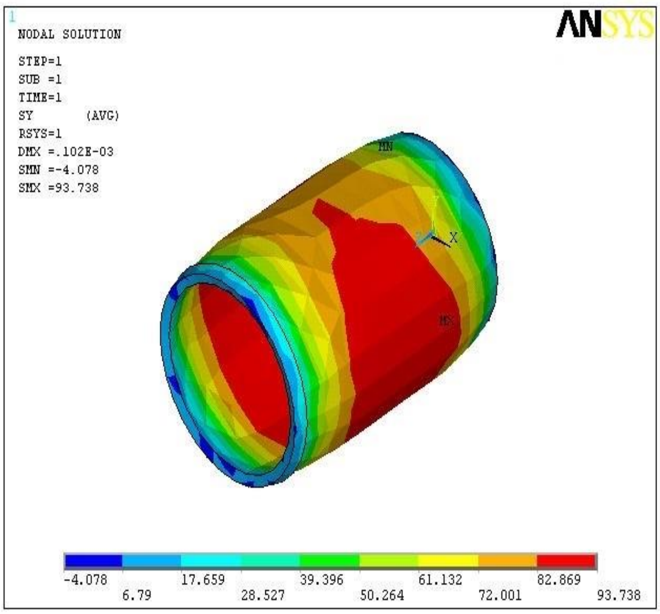

Figure 4(a). Nodal solution

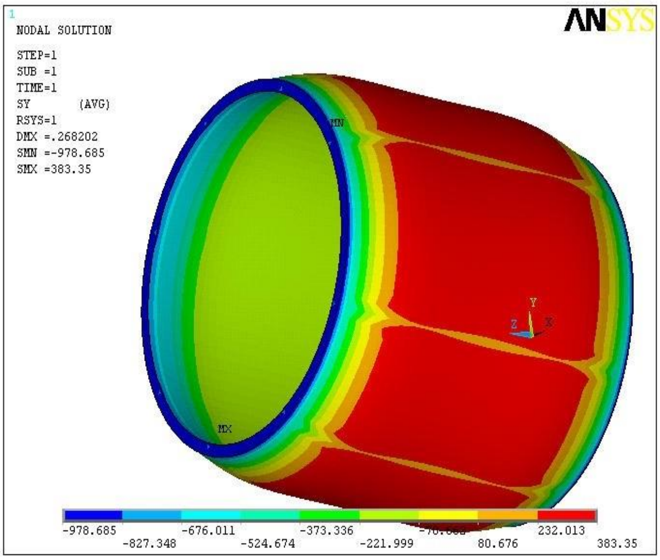

Figure 4(b): Sequential Coupled Analysis - ANSYS Multi-field solver

The ANSYS Multi-field solver, available for a large class of coupled analysis problems.It is an automated tool for solving sequentially coupled field problems. It supersedes the physics file-based procedure and provides a robust, accurate, and easy to use tool for solving sequentially coupled physics problems. It is built on the premise that each physics is created as a field with an independent solid model and mesh. Surfaces or volumes are identified for coupled load transfer. A multi-field solver command set configures the problem and defines the solution sequencing. Coupled loads are automatically transferred across dissimilar meshes by the solver. The solver is applicable to static, harmonic, and transient analysis, depending on the physics requirements. Any number of fields may be solved in a sequential (or mixed sequential-simultaneous) manner.

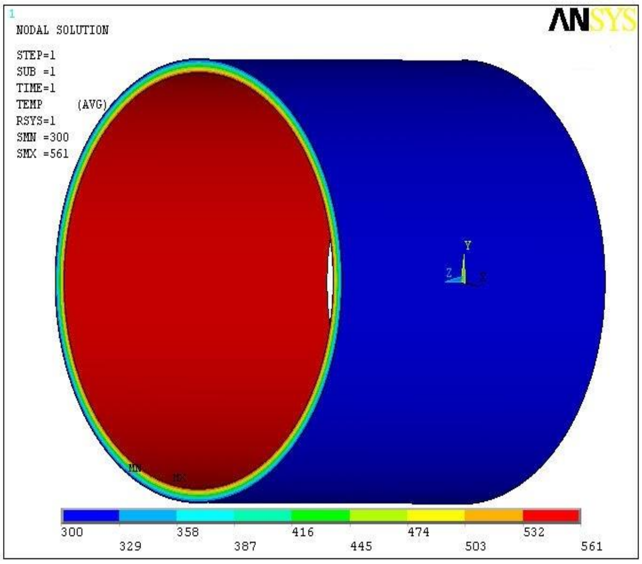

Figure 4(c): Temperature distribution along the thickness of liner is shown in the Nodal Solution

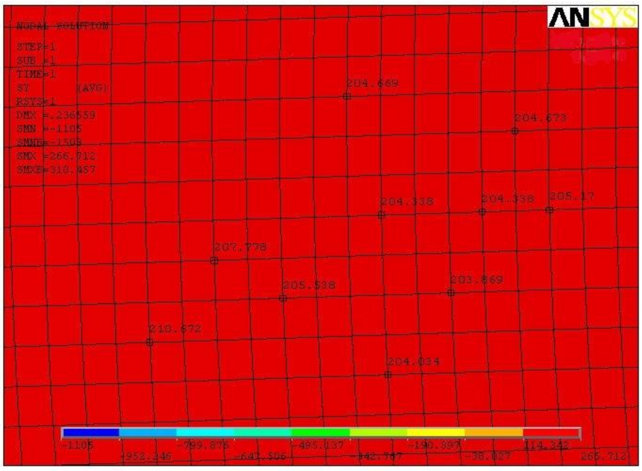

Figure 4(d) : Max .thermal stress on Different Nodes of outside surface

Here thermal stress on Nodes of outside surface of liner is about 204 N/mm2 Analytically we got 182.29 N/mm² and -192.01 N/mm² thermal stress on outside and inside surface of liner respectively. One of the reason for difference in analytical and actual value is Element mesh size.

We have performed this analysis by taking 2 Element mesh size. Taking closer mesh size (0.0002 to 0.0005) we will get similar result as obtained analytically.

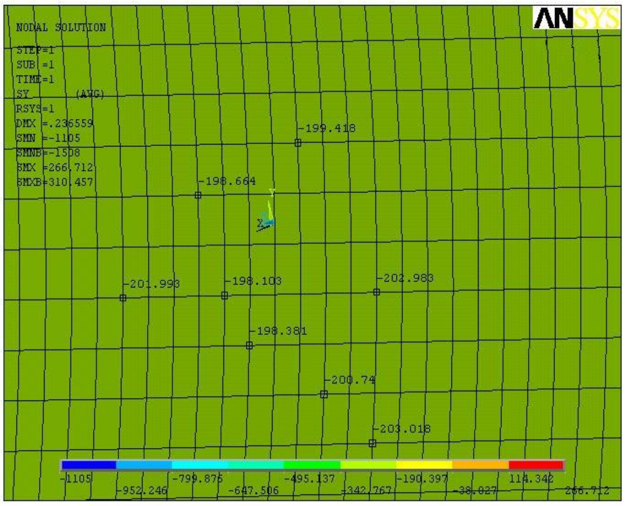

Figure 4(e) :Max .thermal stress on Different Nodes of inside surface

On average the stress on node of inside surface is found as -198 N/mm^2

1. An examination of the internal surface of the cylinder sleeve revealed an elevated number of cavities close to the top centre area, which acted as a stress concentrators reducing the resistance of the component, creating crack nucleation spots.
2. Various micro structural test performed out the result of that test shows that their is un uniform heating of uniform material or uniform heating of un uniform material
3. This unbalanced heating produce thermal stresses in cylinder liner of an Internal combustion engine
4. Additionally there were internal differences in the microstructure of the cylinder liner which indicates the different cooling conditions occurred during its manufactured, providing a secondary failure mechanism due to material fragility
5. by using FEA it is proved that stresses produced in liner (thermal stress, hoop stress, combined stress) find analytical method are same by FEA. i.e. FEA and analytical stress are exactly similar.

IV. CONCLUSION

For Analysis of Dry cylinder Liner we have used SOLID 45 and SOLID 70 brick element for Thermal Analysis respectively. From the Analysis results we are concluding following conclusions

1. Hoop stress obtained by using ANSYS is nearly similar to analytical calculations.
2. Maximum stresses are on outside surface of Liner.
3. When Thickness of Liner is reduced, Hoop Stress increase and Thermal Stress Decrease
4. the material used for cylinder liner must be uniformly heated i.e. micro structure of cylinder liner material must be homogeneous.
5. the material selected for a cylinder liner must have lowest thermal expansion coefficient because thermal expansion coefficient is directly proportional to thermal stress produced in cylinder liner of an IC engine
6. by observing and careful scientific study on chemical wear phenomenon conclude that the amount of sulphur contain in the fuel must be as low as possible because excessive quantity of sulphuric acid is directly affects the chemical erosion in the cylinder liner of IC engine.

V. FUTURE SCOPE

i. For Analysis we have used SOLID 45 and SOLID 70 Brick element for Structural and Thermal respectively. Scope is for using 20 Node SOLID 90 for thermal and 20 Node solid 92 for structural.
ii. Advanced Materials for Liner can be used such as GOE323 (GJL) is a micro alloy cast iron with flake graphite.GOE330 (GJV) is a compacted graphite cast iron and belongs to the group of ductile cast irons.
iii. We have performed the Analysis by using Sequential Coupled Analysis. ANSYS Multi-field solver; it can also be performed by using Direct Coupled-Field Analysis.
iv. We have used linear method due to isotropic material property; Non Linear method by considering alloying elements can be used.

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