Thermal Analysis of Diesel Engine Cylinder Liner & Design Modification using Finite Element Analysis

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Abstract— This paper aims to utilize alternative approach of computational methods such as Finite Element Analysis, to understand behavior of cylinder liner subjected to high temperature and gas pressure. Utilizing this capability, the paper aims to identify possible design optimization of cylinder liner with alternative material and gain weight reduction, without affecting the structural and thermal strength.

Key words: Finite Element Analysis, Diesel Engine Cylinder Liner

I. Introduction

Improving engine life and performance remain critical for the present automotive industry scenario. Increasing pressure from regulatory authorities to bring down emission levels and improvise fuel economy points to developing better, efficient engines for the future. Cylinder liner being a part of engine is exposed to high temperatures and is directly related to the overall performance. Better heat carrying capacity, light weight and cost-effective design are some of the features required for the IC engine of today and the future. To further study the effects and importance of cylinder liners, and possible ways to optimize the design to meet performance goals, an exhaustive research was conducted across diverse areas.

II. Problem Definition

Previous research from several scholars suggests that design optimization can be performed on the cylinder liner considering thermal and structural parameters. Finite element approach can be utilized to identify critical stress regions and subsequent deformation. It is possible to optimize liner using alternative material to make it light weight. Also, it is possible to use FEA technique to further reduce material without affecting stress and deformation values to obtain weight reduction.

III. Methodology

To conduct FEA on the cylinder liner, following methodology is adopted:

1) Selecting the liner model and material
2) Performing necessary experimental calculations
3) Developing CAD model of the cylinder liner
4) Importing the geometry to ANSYS environment
5) Applying boundary conditions
6) Performing structural and thermal analysis
7) Comparing the results of different materials
8) Selecting the best material for optimization
9) Performing design changes for weight reduction
10) Finalizing the design

IV. Model Selection

A. *Engine Specifications*

To perform the thermal studies using finite element analysis, the cylinder liner from the following engine is selected:

Type	4 stroke, Single Cylinder Diesel Engine
Max. output	3.5 KW
Compression Ratio	16.5 :1
Bore	87.5 mm
Stroke Length	110 mm
Cooling Medium	Water
Engine rpm	1500 rpm

Table 1: Engine Specifications

B. *Model Dimensions*

The geometrical dimensions of the cylinder liner model are as mentioned in the table below:

Inner Diameter	87.6 mm
Outer Diameter	102 mm
Thickness	14.4 mm
Length of the liner	204 mm
Material	Grey Cast Iron

Table 2: Cylinder Liner Dimensions

C. *Material Properties*

The material for the liner is grey cast iron grade 60 with following physical properties:

Density	7100 kg/m^3
Specific Heat	0.46 kJ/kg ^{0}C
Thermal Conductivity	46 W/m ^{0}C
Tensile Strength	430 MPa
Yield Strength	276 Mpa
Young's Modulus	206 Gpa
Max. Service Temperature	551^{o}C

Table 3: Physical Properties of Grey Cast Iron Grade 60

V. Diesel Engine Test Rig Setup

A. *Experimental Setup*

The setup consists of single cylinder, four stroke, Multi-fuel, research engine connected to eddy current type dynamometer for loading. The operation mode of the engine can be changed from diesel to Petrol or from Petrol to Diesel with some necessary changes. In both modes the compression ratio can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Setup is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements.

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Fig. 1: 4-Stroke, Single Cylinder Diesel Engine Test Rig

To measure the readings, the engine was made to operate for 30 minutes first. Following data were found from the test setup:

Load	11.26 N-m
Speed	1464 rpm
Fuel Rate	1.38 kg/Hr
Air Rate	22 m^3/Hr
Water Flow	37.7 cc/sec
tw1, water inlet to Calorie meter	39.7 ^{0}C
tw2, water outlet from Engine Jacket	34.7 ^{0}C
tw3, water outlet from Calorie meter	55.9 ^{0}C
te4, exhaust Gas inlet to Calorie meter	199 ^{0}C
te5, exhaust Gas outlet from Calorie meter	190.8 ^{0}C
t1, ambient Temperature	36.1 ^{0}C
Air Fuel Ratio, AFR	17.87
Load	11.26 N-m
Speed	1464 rpm

Table 4: Test Rig Observation

B. Analytical Calculations

Following empirical relations were used to calculate required cylinder wall temperature-

1) Air is considered as ideal gas, from ideal gas the isentropic compression is given by-

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$$

2) Heat release by the combustion (Q)

$$Q = m_f * LHV\ (low\ heat\ value\ of\ fuel)$$

3) Stoichiometric combustion equation of fuel-

$$C_{12}H_{23} + 18.5\left(O_2 + \frac{0.7}{0.3}N_2\right) \rightarrow 12CO_2 + 13H_2O + 43.167N_2$$

4) Mass Fraction (Ym)

$$\frac{molecular\ weight\ of\ fuel}{molecular\ wt.\ of\ fuel + molecular\ wt.\ of\ O + molecular\ wt.\ of\ N}$$

5) Gas Temperature (T_g)

$$Y_m * Q = m_a * C_p(T_g - T_2)$$

6) Woschni's Equation for Heat Transfer Co-efficient (h)

$$h = 2.43(V_P)^{1/3}(pT_g)^{1/2}$$

7) Cylinder Wall Temperature (T_w)

$$Q = hA(T_g - T_w)$$

8) Mean Piston Speed (Sp)

$$S_p = \frac{2lN}{60}$$

9) Surface Area of the cylinder (A)

$$A = \pi dl$$

Based on the above empirical relations, following data was calculated:

Mass flow rate of fuel for one cycle, m_f	3.006× 10^{-5} kg/s
Volumetric flow rate of air	22 m^3/hr
Mass flow rate of air for one cycle, m_a	5.69 × 10^{-4} kg/ s
Temperature at the end of compression stroke, T_2	948.31 K
Heat release by the combustion for one cycle, Q	1303 J/ s
Temperature of the gas, T_g	1142.82 K
Heat transfer coefficient for one cycle, h	97.30 W/m^2K
Cylinder wall temperature, T_w	903.68 K

Table 5: Analytical Calculation Results

VI. FEA ANALYSIS

A. CAD Modelling

The CAD model for the cylinder liner was developed using PTC Creo 2.0 for further investigation using finite element analysis.

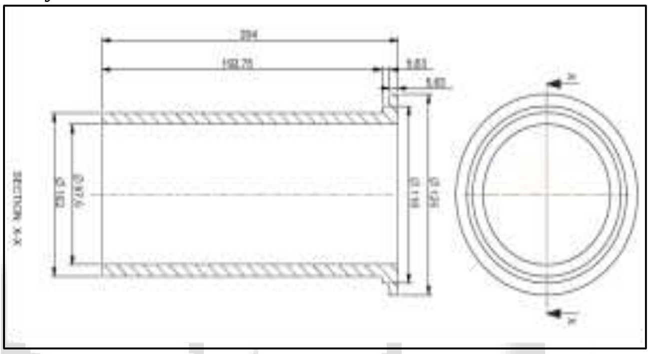

Fig. 2: CAD Model for Cylinder Liner

B. Thermal and Structural Analysis

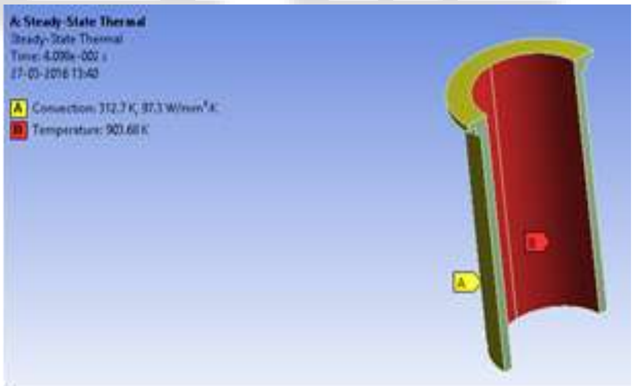

Fig. 3: Applying thermal boundary conditions

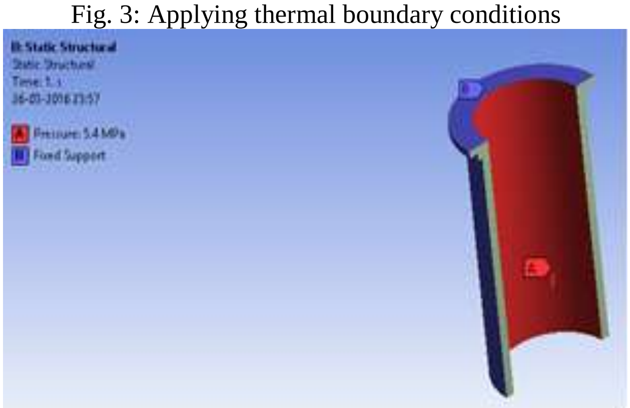

Fig. 4: Applying Structural Boundary Conditions

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C. Results

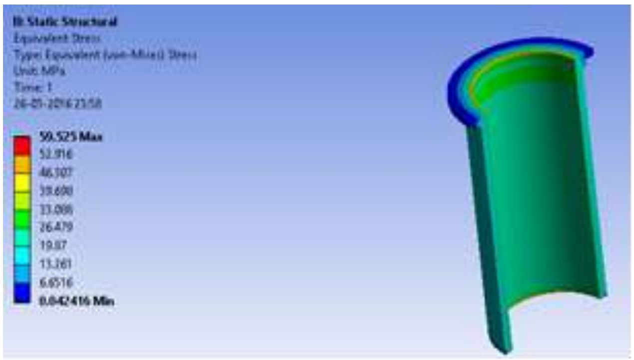

Fig. 5: Equivalent Von-Mises Stress for CI Liner

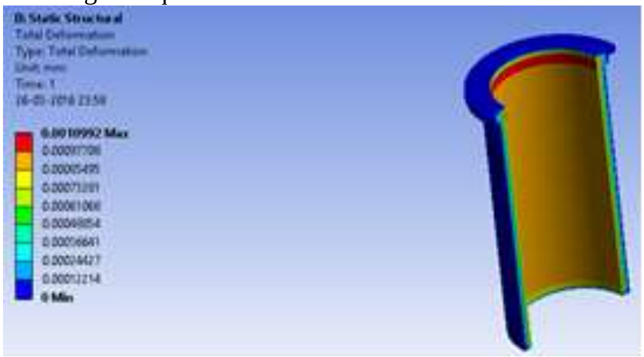

Fig. 6: Total Deformation for CI Liner

D. Alternative Material Selection

For a comparative study, three different materials are selected i.e. Cast Stainless Steel, NiAlBr Alloy and Carbon Steel. The comparative results are as shown in the table VI.

Material	Heat Flux (W/mm^2)	Stress (MPa)	Deformation (mm)
Cast Iron	0.0801	59.52	0.0001
Carbon Steel	0.1047	64.76	0.0012
Cast Stainless Steel	0.0329	92.69	0.0017
NiAlBr Alloy	0.0329	65.52	0.0018

Table 6: Cylinder Liner Material Comparison

VII. DESIGN OPTIMIZATION

Based on the material comparison, it is observed that Cast Iron is suitable material for further optimization as it develops minimum stress and deformation. The optimization trials are performed thus with Cast Iron with an objective to reduce the weight without compromising with excessive stress and deformation.

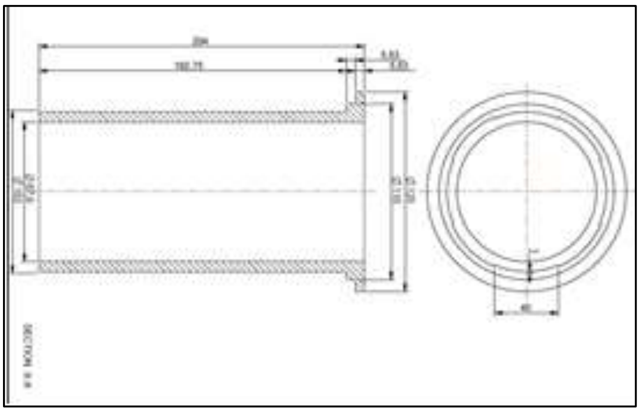

Fig. 7: Vertical slots around the external liner surface

Fig. 8: Equivalent stress on optimized liner design

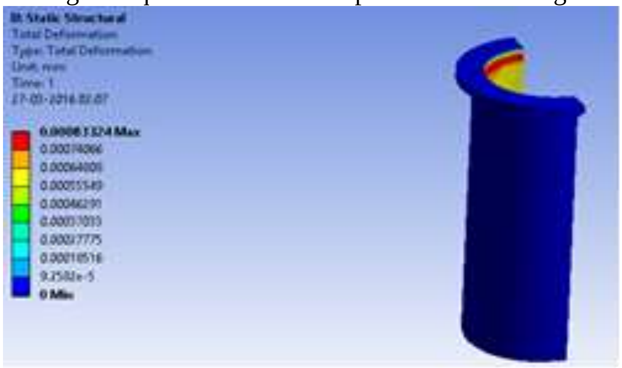

Fig. 9: Total deformation on optimized liner design

VIII. RESULTS AND CONCLUSION

Based on the trials performed, it is observed that cylinder liner design can be optimized for weight reduction opportunities. By applying vertical slots on the external surface of the liner, the weight of the liner was reduced to approximately 7% and no significant change in the stress and deformation was observed.

Hence, with the methodology discussed here, it is possible to reduce the weight of the liner without generating excessive stress and deformation. The methodology outlined in this paper provides opportunities to carry out future work to improve the overall performance of the IC engine. Some of the possible opportunities are highlighted below:

- Performing fatigue life estimation for the proposed design
- Utilizing the methodology to optimize other IC engine components
- Evaluating the engine performance and emission with new liner design

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