Modelling and Thermal Analysis of Exhaust Manifold of Multi Cylinder Engine Using Ansys

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Abstract: The exhaust manifold of an IC engine plays a key role in effective functioning of the engine exhaust system. The burnt, hot exhaust gases at higher temperatures from the engine flows through the exhaust manifold to the catalytic converter. Due to the flow of hot exhaust gases, the heat gets dissipated through the manifold walls. It develops an enormous amount of thermal stresses, which leads to formation of cracks and eventually reduces the life of the manifold. The objective of the work is to suggest a suitable and fine ceramic coating powder in terms of thermal resistance. Steady state thermal analysis is done using Ansys to determine the temperature distribution and other thermal variables that vary over time. And it is found that model with zirconium dioxide (ZrO_2) exhibits excellent thermal resistant properties than any other.

***IndexTerms* - Ceramic Coating, Heat Dissipation, Thermal Stresses, Thermal Resistant.**

I. INTRODUCTION

It is well known that exhaust manifold is placed very next to the engine exhaust valve, so the high temperature and high pressure exhaust gases from the engine gets passed through the manifold. In the engine heat dissipation, 1/3rd amount of heat is transferred through exhaust, 1/3rd through piston, remaining 1/3rd water. The hot and burnt exhaust gases from the cylinder having a higher temperatures. So manifold subjected to an enormous thermal stress over its life period. So a proper consideration for designing an exhaust manifold is necessary. Because higher heat dissipation will leads to formation of cracks and high temperature corrosion is also occurred. It demands a replacement of the existing manifold with a new one, which is an economical one.

The work main motive is to reduce the heat dissipation through the manifold which eventually reduces the thermal stress acting upon the manifold.it can be achieved by the ceramic coating. The analysis is carried out to find the optimised coating.

II. EXHAUST MANIFOLD

An exhaust manifold is a series of pipes that are usually connected directly on the engine cylinder head. It is an integral part of the exhaust system. Hot exhaust gases from the exhaust ports on the cylinder head is passed through the pipes and into a single collector pipe. Exhaust manifolds is a necessary part of the exhaust system. Their design is optimized to ensure exhaust gases go with the flow efficiently from the engine combustion chamber without any back pressure. Depending on the type engine, a vehicle will have either one or two exhaust manifolds connected to it. Exhaust manifolds are either made from cast iron or any one form of steel. The vast majority of exhaust manifolds are constituted of cast iron, as it is reasonably low priced and lasts a very long time. The drawbacks to CI manifolds are that they are usually heavy and tend to get brittle with age and exposure to the heat cycles of an engine. Stainless steel exhaust manifolds are the more expensive, however are rust resistant and totally long lasting.

III. LITERATURE REVIEW

The exhaust manifold of an IC engine plays a crucial role in engine gas filling process. So many researches understood that this Area needs further improvement of performance of the exhaust system. The major researches are focusing on heat dissipation and back pressure reduction and some of them are summarized below.

B.Dhanasakkaravarthi1 et al (2018) has designed and analyzed the flange in stainless steel exhaust manifold. They found that the manifolds today using are the pipes that are welded together to flange. But due to large thermal stresses acting on the manifold, the welded connections gets cracked and welded joints gets broken. They analyzed the alternate methods for connections into flange for manifold and the alternates are analyzed using Ansys and CFD to find the optimized solution.

Mr.Chandan H S et al (2017) conducted thermal modal analysis of engine exhaust manifold for different materials to find the optimized material for exhaust manifold. The exhaust manifold with grey cast iron, stainless steel are analyzed using finite element analysis method. Investigated the exhaust manifold with different materials. Temperature distribution, heat flux and modal analysis is carried out for two materials. He concluded that the stainless steel material exhibits better temperature distribution, heat flux properties than other materials.

V. Ashok Kumar, M. Madhavi et al (2016) done the thermal analysis on internal combustion engine. Exhaust manifold modelled by PRO-E design software. Thermal analysis done for the exhaust manifold by cast iron, stainless steel, silicon nitride& zinc oxide. CFD analysis is done to determine the heat transfer rate, mass flow rate, pressure drop and thermal analysis to determine the temperature distribution, heat flux with different materials.

IV. PROBLEM IDENTIFICATION

- **A.** Due to flow of high temperature, pressure gases (Higher heat dissipation) large amount of **thermal stresses** acting on the manifold pipes.
- **B.** Cracks in the connections.
- **C.** Reduction in material durability.
- **D.** Blow holes on the surface.

So better coating material in terms of thermal resistance and temperature distribution is founded and analyzed for proposed model.


Figure 01, 02: cracks in connections due to thermal stress

V. LAYOUT OF THE WORK

(Model and thermal analysis of the exhaust manifold to find optimized coating)

Modelling of the exhaust manifold with the standard dimensions in CATIA V5

↓

Apply the ceramic coating of alumina, Titania, zirconia to the manifold

↓

Import the file into ANSYS workbench, input the Material Properties and apply the Boundary conditions, run the solution.

↓

Obtain the temperature distribution and heat flux results, Compare the results To find optimized coating

Coatings which are going to analyzed are:

1. Aluminum oxide (AL_2O_3)
2. Titanium dioxide (TiO_2)
3. Zirconium dioxide (ZrO_2)

VI. MODELLING OF THE MANIFOLD

The exhaust manifold of a four cylinder diesel engine model was taken into consideration for dimensions. The measurements were taken out and the exhaust manifold is modelled in CATIA V5 for the standard dimensions. The existing model is then coated with different ceramic coatings with 1000microns thickness in CATIA V5. Then the model is saved with the extension .stp to import into the Ansys workbench.

2D MODEL

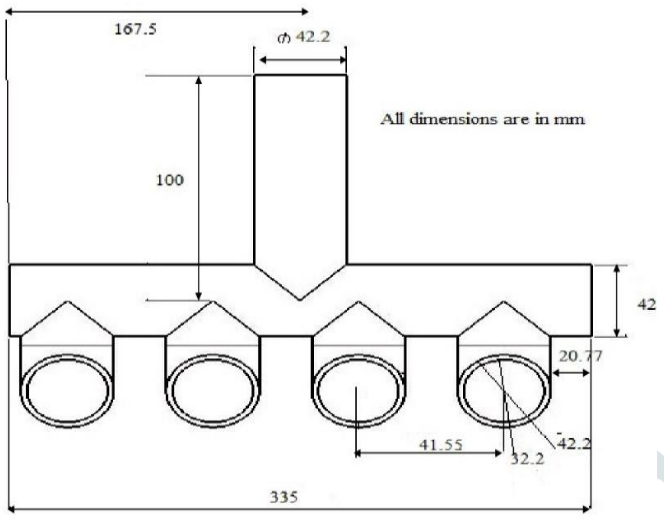


figure 03: 2D model

3D MODEL

CATIA V5 modelling software is used for the 3D modelling of the exhaust manifold with standard dimensions. And the final 3D modeled manifold is shown below with standard dimensions.

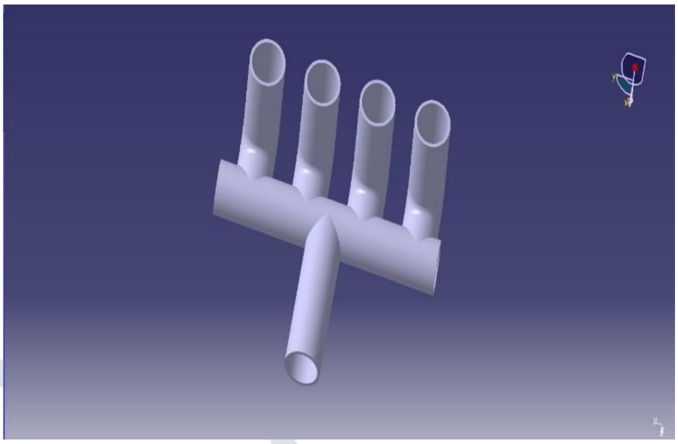


figure 04: 3D model

MESHING MODEL

	UNCOATED	COATED
Mesh Size	20mm	20mm
No. of Elements	40880	64670
No. of Nodes	201181	128706
Mesh type	Tetrahedral	Tetrahedral

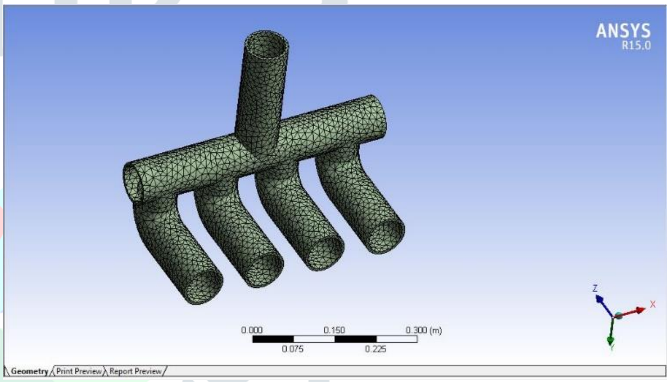


figure 05: mesh model

BOUNDARY CONDITIONS

Temperature : 600°C (inlets)
Convection : 22°C, 600 W/m^2 °C (outside surface)
Heat flow : 600W
Coating thickness: 1000microns (fixed thickness)

VII. THERMAL ANALYSIS

1. WITHOUT COATING:

TEMPERATURE DISTRIBUTION

From the below **fig06**, thermal analysis of existing exhaust manifold model without any coating, we came to know that the temperature distribution is between in the range of following.

Maximum temperature: 600°C
Minimum temperature: 589.7°C (manifold wall temperature)

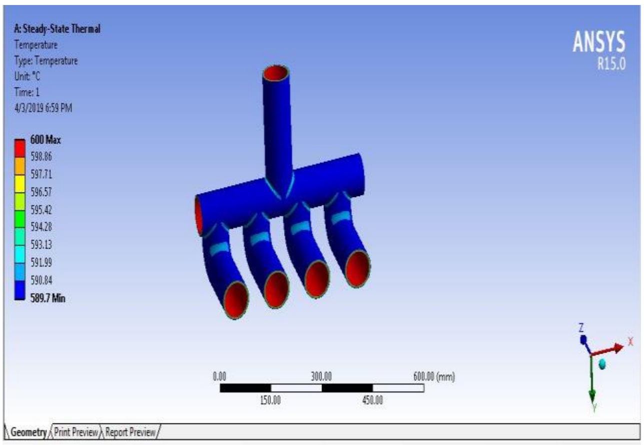


fig06: temperature distribution

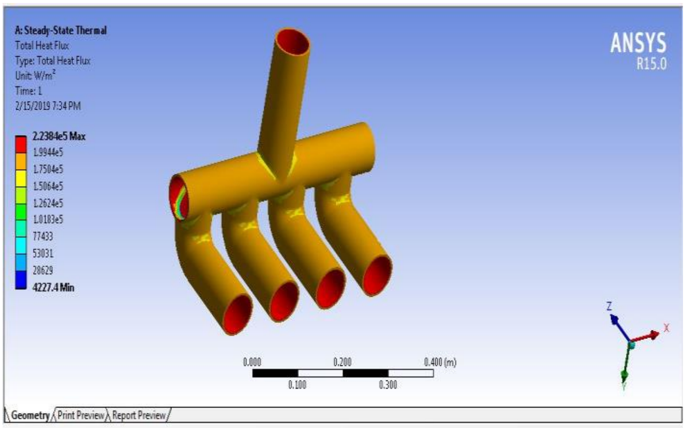


fig07: heat flux

HEAT FLUX

From the analysis **fig07**, the heat flux range in the exhaust manifold is found to be:

Maximum heat flux : 2.238 e5 W/m^2

Minimum heat flux : 4227.4 W/m^2

2. **TITANIA COATING: ($TI0_2$)**

TEMPERATURE DISTRIBUTION

With the coating of titanium dioxide of 1000microns thickness the thermal analysis is carried out and the temperature Distribution in the manifold in **fig 08**, is found to be: maximum temperature: 600^{O}C minimum temperature: 581.38^{O}C (manifold Wall temperature).The minimum temperature gets reduced from 589^{o}c (Without coating temperature) to 581^{o}c (manifold wall Temperature). So that the heat Dissipation with Titania is reduced by 1.35%.

HEAT FLUX

Obtaining the total heat flux range inside the manifold from **fig 09** we get,

Maximum heat flux: 7.668 e^5 W/m^2

Minimum heat flux: 14604 W/m^2

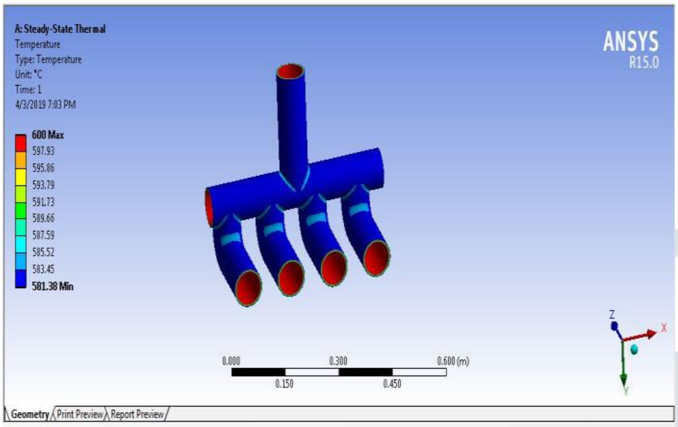


fig08: temperature distribution with TIO_2

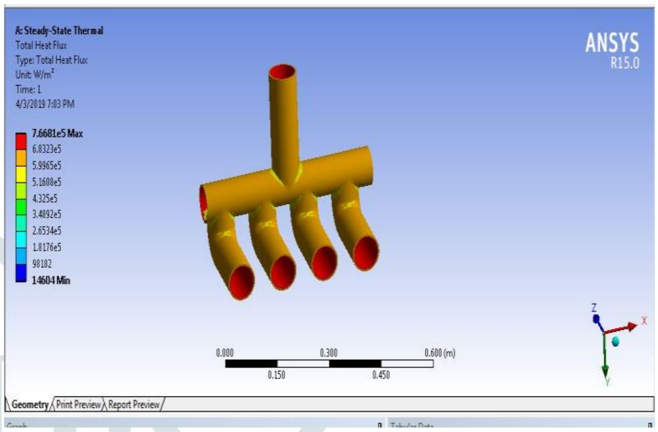


fig09: total heat flux with TIO_2

3. **ALUMINA COATING:(AL_2O_3)**

TEMPERATURE DISTRIBUTION

With the coating of aluminum oxide of 1000microns thickness the thermal analysis is carried out and the temperature distribution in the manifold from **fig10**, is found to be, Maximum temperature: 600^{O}C minimum temperature: 584.68^{O}C from these it can say that the temperature distribution is reduced from 589.67^{o}C(Without coating temperature) to 584.64^{o}C. So that the heat dissipation with Alumina coating is reduced by 0.08%.

HEAT FLUX

Obtaining the total heat flux range inside the manifold with alumina coating from **fig11** we get,

Maximum heat flux: 6.3105 e^5 W/m^2

Minimum heat flux: 11978 W/m^2

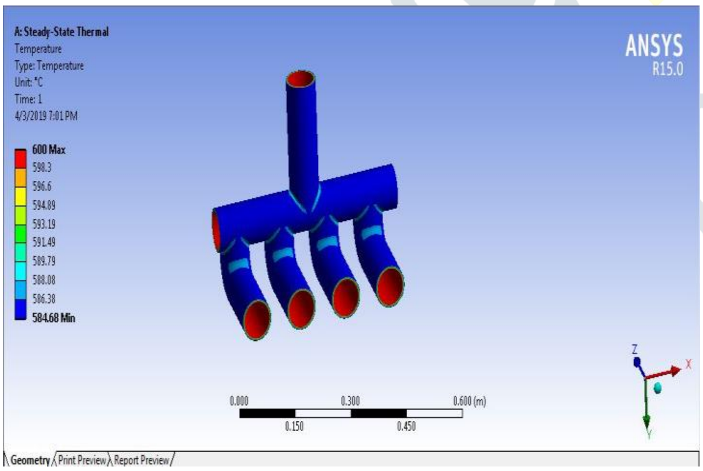


Fig10: temperature distribution with AL_20_3

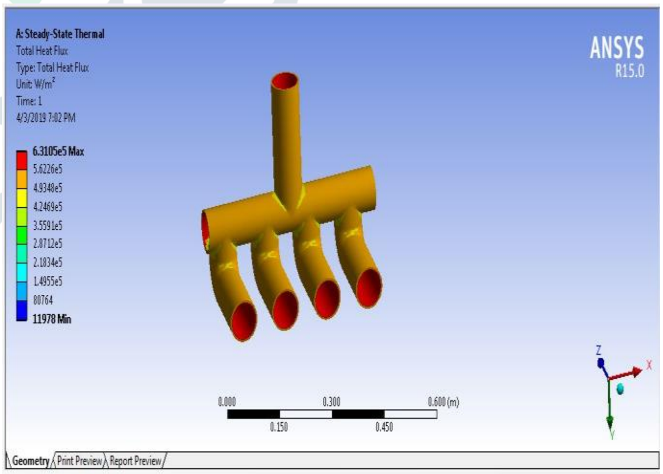


fig11: total heat flux with AL_2O_3

4. **ZIRCONIA COATING:** *($Zr0_2$)*

TEMPERATURE DISTRIBUTION

With the coating of zirconium dioxide of 1000microns thickness the thermal analysis is carried out and the temperature distribution in the manifold from the **fig12** is found to be:

Maximum temperature: 600^{O}C minimum temperature: 563.92^{O}C from these it can say that the temperature distribution is reduced from 589.67^{o}c (Without coating temperature) minimum temperature to 563.92^{o}c. So that the heat dissipation with Zirconia coating is reduced by 4.45%.

HEAT FLUX

Obtaining the total heat flux range inside the manifold from the **fig13** we get,

1. Maximum heat flux: 1.4862 e W/m^2
2. Minimum heat flux: 28486 W/m^2

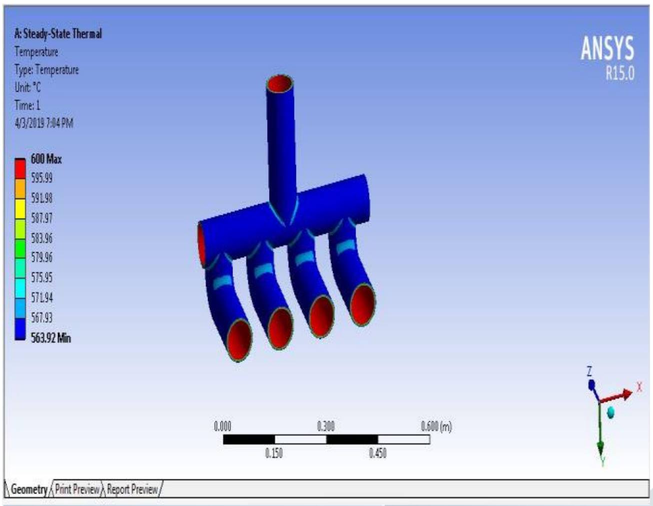


Fig12: temperature distribution with Zr0$_2$

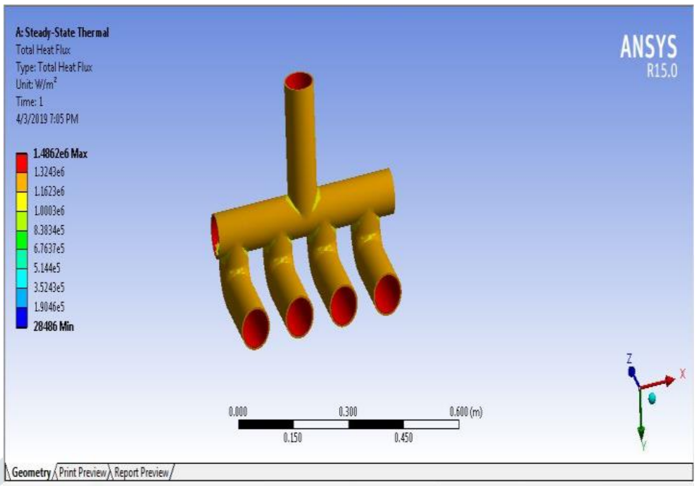


fig13: total heat flux with Zr0$_2$

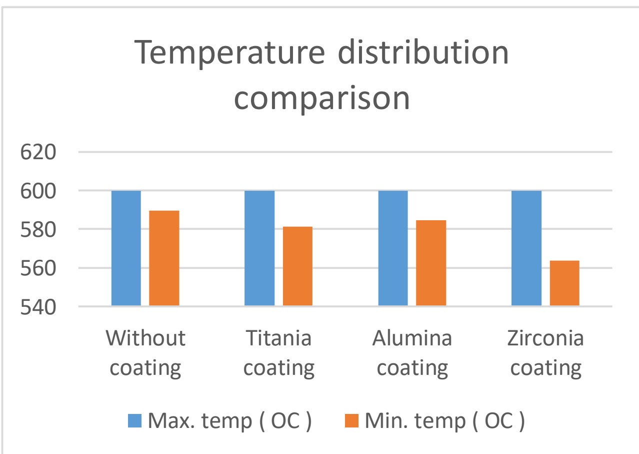
VIII. RESULT ANALYSIS

1. TEMPERATURE DISTRIBUTION

Sl. No	Type of coating	Max. temp (^{O}C)	Min. temp (^{O}C)	Reduction in surface temp (^{O}C)
1.	Without coating	600	589.67	10.33
2.	Titania coating	600	581.38	18.52
3.	Alumina coating	600	584.68	15.32
4.	Zirconia coating	600	563.92	**36.08**

2. TOTAL HEAT FLUX

Sl.No	Type of coating	Max. heat flux W/m^2	Min. heat flux W/m^2
1.	Without coating	2.2384 e5	4227.4
2.	Titania coating	7.6685 e5	14604
3.	Alumina coating	6.3105 e5	11978
4.	Zirconia coating	**1.4686 e6**	**28486**



THERMAL ANALYSIS RESULT:

From the above result analysis it is found that the model with zirconia coating exhibits much better results than other coatings. It Is almost 36 ^{o}C temperature gets reduced. i.e. 4.45% of heat dissipation gets reduced with the zirconia coating. And also it exhibits the highest total heat flux rate. So the zirconia ceramic coating is selected for future work.

CONCLUSION

The exhaust manifold of a four cylinder engine was investigated for thermal analysis using Ansys workbench. The thermal analysis concludes that model with zirconia coating exhibits the better results than other coating powders in terms of temperature distribution and total heat flux variables. So Zirconium dioxide coating is recommending for the future work.

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