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Thermal Barrier Coating for an Internal Combustion Engine with Various Coating Material and Analysis Using 3D Finite Element Software

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ABSTRACT

The aim of this project is to increase the thermal efficiency and reducing heat loss of the single cylinder CI Engine by introducing Thermal barrier coating (TBC) in inner cylinder of the combustion chamber. The TBC materials has low thermal conductivity and high thermal stability, hence they possess low heat transfer through the wall of the combustion chamber there by heat loss is reduced and thermal efficiency in increased. This design project will be executing in CAD/CAE software. Firstly, the engine is designed by using Creo Parametric 2.0 software. Secondly, a designed engine is analysed with and without TBC material in inner cylinder of the combustion chamber by using 3D finite element software (ANSYS). A comparison study is made by parameters such as temperature distribution and heat loss. Then finally, the results obtained from all thermal simulations are compared with each other.

Keywords- thermal analysis; thermal barrier coating

I. INTRODUCTION

Internal combustion engines are the integral part of every automotive, we come across in our day-to-day life. The reliability of IC Engines, especially diesel based; make them the most widely used prime mover in automobiles. However, they are having very poor thermal efficiency. IC engines are constantly being modified in order to meet the rising demand for more efficient generation of power. The increasing pollution levels caused due to vehicular emissions also stress the need for intense research. It has been observed that there is an undesirable heat loss of more than 15% in an IC Engine through its combustion chamber walls and piston and about 19-22 Percent of fuel energy is rejected to coolant fluid this heat loss can be avoided by making use of TBC materials. Ceramics have a higher thermal durability than metals. Therefore, it is usually not necessary to cool them as fast as metals. Low thermal conductivity ceramics can be used to control temperature distribution and heat flow in a structure [3] [9].

Thermal barrier coatings (TBC) provide the potential for higher thermal efficiencies of the engine, improved combustion and reduced emissions. In addition, ceramics show better wear characteristics than conventional materials. Lower heat rejection from the combustion chamber through thermally insulated components causes an increase in available energy that would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could be also utilized [10] [12].

A lot of experimental study has been done to utilize these ceramic properties to improve thermal efficiency by reducing heat losses, and to improve mechanical efficiency by eliminating cooling systems. When cylinder-cooling losses are reduced, more of the heat is delivered to the exhaust system. This effective recovery of energy by exhaust improves the thermal efficiency of low heat rejection engine (LHR). However, installing heat recovery systems needs considerable effort. A lot of changes are necessary in the engine configuration. Even without heat recovery systems, some of the heat is converted to piston work and increases thermal efficiency. Therefore, LHR engines without exhaust heat recovery systems are worth to study. In this design project, the thermal barrier coating material is introduced in the wall of the IC Engine which could greatly improve the thermal efficiency of the engine. The effect of various TBCs is studied by creating a CAD Model of prototype engine by Creo Parametric 2.0 software and the heat transfer across the interface has been analysed using analysis software (ANSYS). The results obtained from the analysis of different TBCs used in the IC Engine Model have been tabulated. Using these results, the thermal efficiencies of IC Engine with different TBCs are interpreted.

II. ENGINE MODELING AND MATERIAL ASSIGNMENT

2.1. Proposed TBC Materials

The following three TBC materials were chosen based upon its properties.

1. Barium Lanthanum Titanate (BLT)
2. Strontium Zirconate
3. Yttrium Stabilized Zirconia (YSZ)

The TBC Materials should have lower thermal conductivity and relatively high melting point with low density. Then only it can with stand the higher temperature and possess low heat loss.

2.2. Engine Materials

The most widely used materials for construction of IC Engines Are Grey Cast Iron, Aluminium alloys and steels in some parts. In this Analysis, the grey Cast Iron is used for the Engine block and Aluminium alloy is used for Piston. The properties used in analysis are as shown.

2.3. IC Engine Modelling

The prototype of IC Engine model was created by using PTC Creo Parametric 2.0 and imported into ANSYS 12.0. The commercially used piston's dimensions was measured by Vernier calliper and the piston is designed according to the measured dimensions. The combustion chamber was designed as a prototype model, because the aim of this project is to reduce the heat loss through walls of the combustion chamber by applying TBC materials.

The cut view of the prototype IC Engine model shown below.

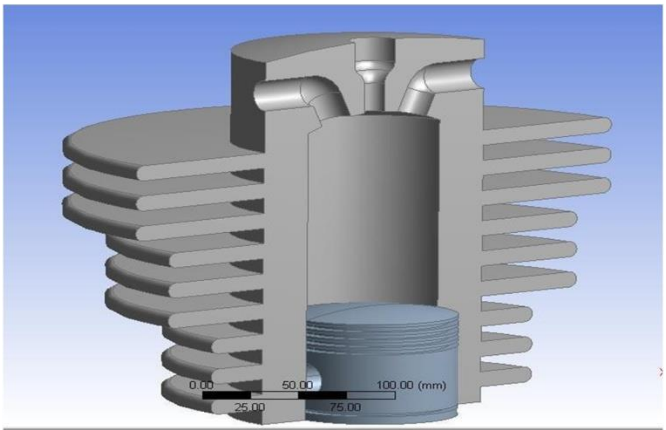

fig. 2.3 (a) The front view of the IC Engine model was represented as following diagram.

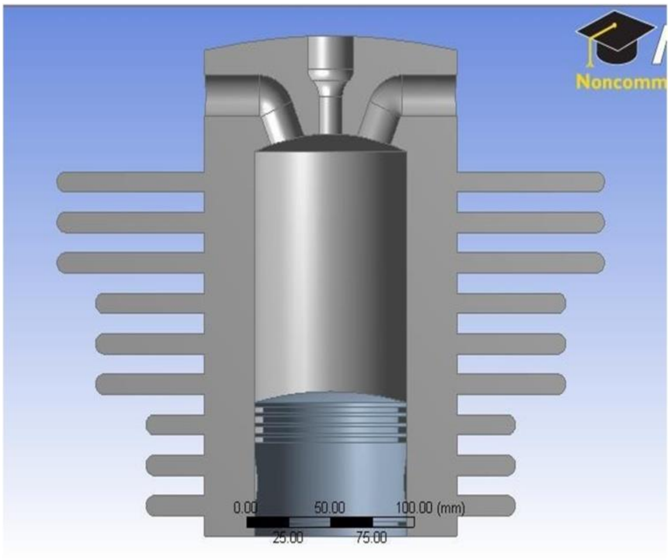

Fig. 2.3 (b)

2.3.1. TBC Coated IC Engine

The TBC coating is done in the Creo parametric 2.0 software. The thickness of the coating is taken from the literature survey 1000 microns (1mm) thickness of TBC is coated in the Combustion Chamber of the piston as shown in the following Diagram. The dark golden colour represents TBC of the IC Engine.

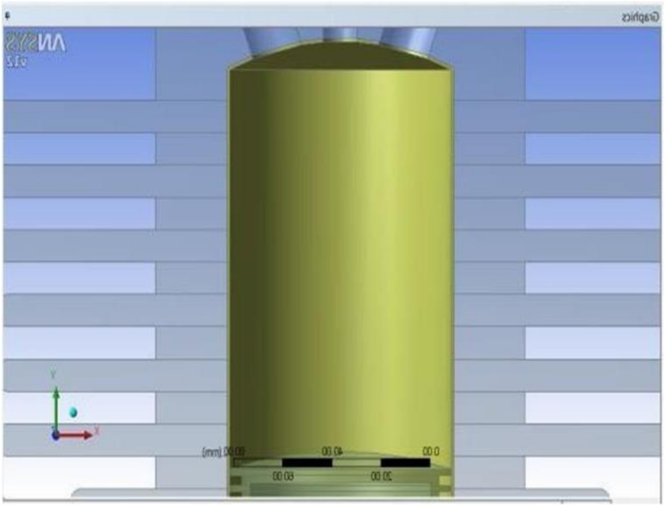

Fig. 2.3.1

2.4. Discretization

The discretization (Meshing) of the IC Engine was done in the ANSYS 14.0 Software package with high degree of fine mesh and obtain approximately 13,05,884 Nodes and 8,36,102 elements in each case of thermal analysis. The meshed model is then refined to ensure uniform element size throughout the structure of the Internal Combustion Engine and is made ready for thermal analysis simulations.

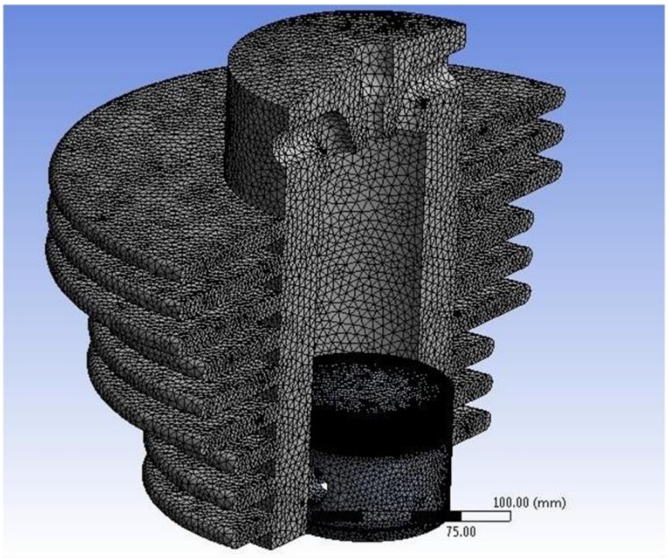

Fig. 2.4 (a)

The front view of the meshed IC Engine is shown in the following figure

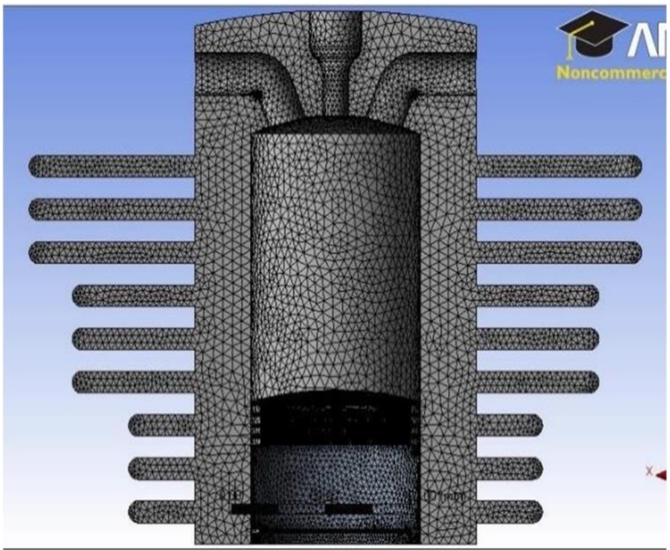

Fig. 2.4 (b)

2.4.1. Discretization of Piston

The discretization of piston by high degree of fine mesh is shown in the below diagram. The quality and size of the mesh of both piston and combustion chamber is high. The meshed model is then refined to ensure uniform element size throughout the structure of the piston.

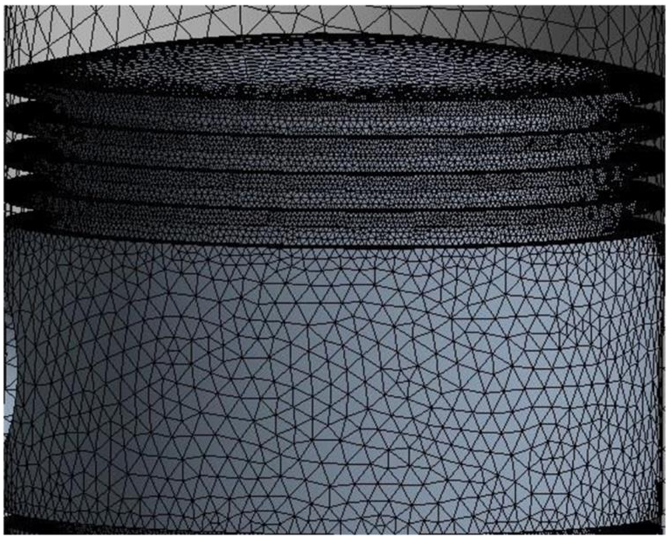

Fig. 2.4.1

III. TRANSIENT THERMAL ANALYSIS

3.1 Thermal Analysis of the IC Engine

The following assumptions are made for each of the IC Engine models when performing the thermal analysis on them using ANSYS software.

The initial temperature of the IC Engine is 100ºC. The average temperature of the IC Engine combustion chamber walls are 3000ºC.

The heat generated due to friction is neglected and the effect of piston motion on the heat transfer is neglected.

Firstly, thermal analysis on uncoated IC Engines is performed in order to visualize the thermal distribution throughout the body. The thermal analysis is performed for a period of 60 seconds in steps of one second. Then, the TBC coated IC engine is analysed by the coating thickness of 1000microns (1mm).

3.1.1 Temperature Distribution of IC Engine without Coating

The state of temperature distribution in the internal combustion engine without TBC at the end of 60 seconds is as shown in figure.

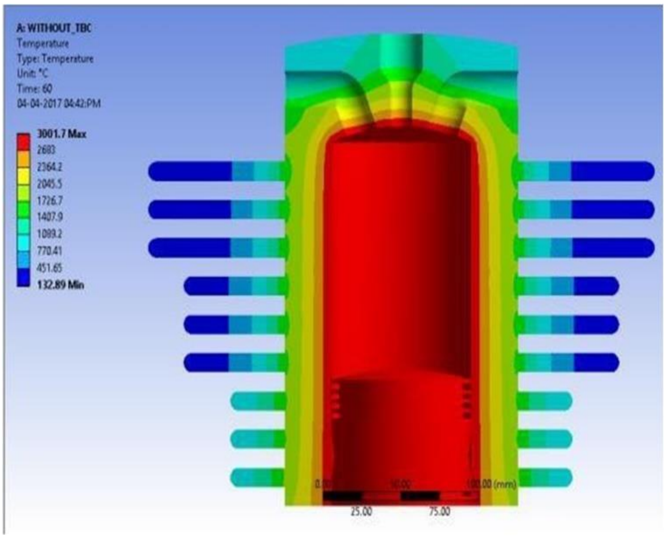

Fig. 3.1.1

The figure shows that without the use of TBC material, there is higher heat transfer is occurred. The region area of heat transfer is maximum at near the wall of the combustion chamber. Red colour region indicates the maximum temperature passes through the wall.

3.1.2 Heat Flux of the IC Engine without Coating

The state of Heat flux in the internal combustion engine without TBC at the end of 60 seconds is as shown in figure.

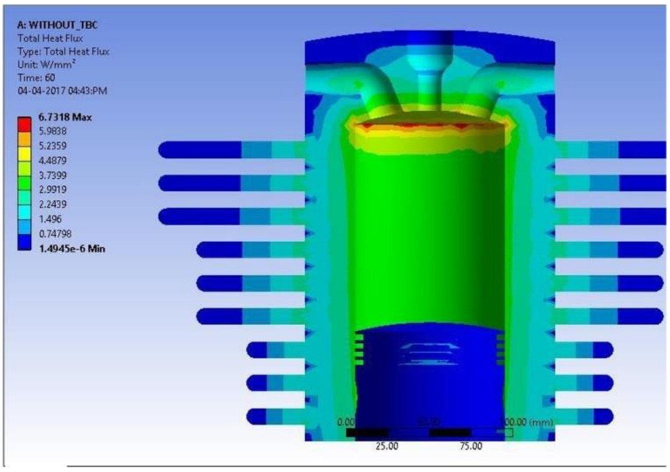

Fig. 3.1.2

The maximum heat flux is obtained in the edges of the combustion chamber. About 6.7318 W/mm² heat flux is obtained without the TBC coating.

3.2 Thermal Analysis of SZ Coated IC Engine

A well-established thermal barrier coating is Strontium Zirconate which has a higher thermal stability of up to 1573K. The IC Engine is coated with Strontium Zirconate on its combustion chamber walls completely and thermal analysis is carried out as before. At the end of 60 seconds of thermal simulation over the Strontium Zirconate coated IC Engine, the heat distribution and heat flux is observed and captured.

3.2.1. Temperature Distribution of SZ Coated IC Engine

The state of Temperature distribution in the SZ coated Internal Combustion engine at the end of 60 seconds as shown in figure.

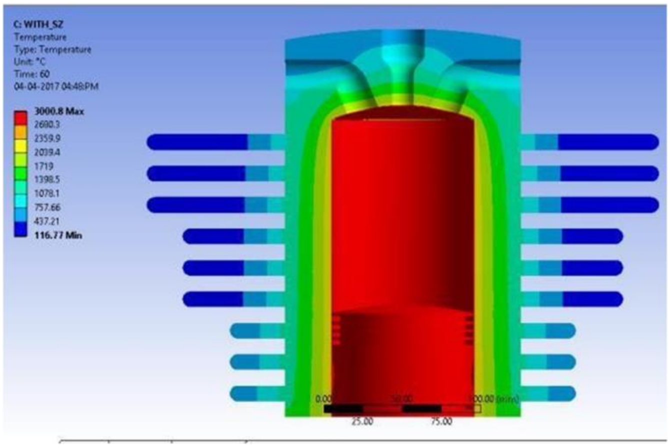

Fig.3.2.1

With Strontium Zirconate TBC coating, there is much lesser heat transfer is obtained. The yellow region indicates the temperature distribution after the Strontium Zirconate thermal barrier coating is reduced.

3.2.2. Heat Flux of SZ Coated IC Engine

The state of Heat flux in the SZ Coated internal combustion engine at the end of 60 seconds is as shown in figure.

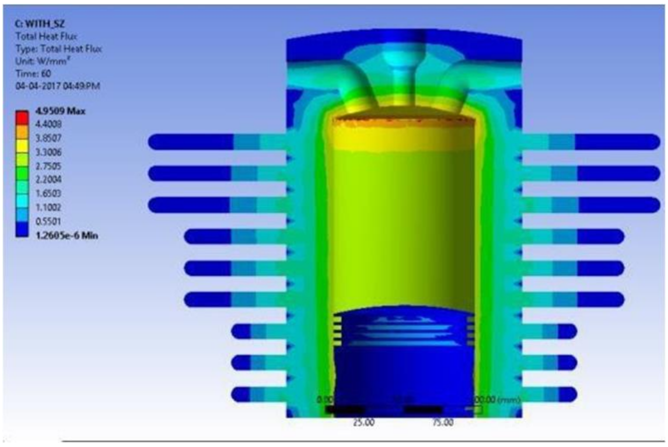

Fig. 3.2.2

The maximum heat flux is obtained in the edges of the combustion chamber. About 4.9509 W/mm² heat flux is obtained with the SZ coating.

3.3 Thermal Analysis of YSZ Coated IC Engine

YSZ is one of the TBC material widely used in steam turbine and aerospace applications. It can resist phase transition up to 1430K with thermal conductivity of 2.2 W/mK. At the end of 60 seconds of thermal simulation over the Strontium Zirconate coated IC Engine, the heat distribution and heat flux is observed and captured.

3.3.1. Temperature Distribution of YSZ Coated IC Engine

The state of temperature distribution in the YSZ Coated internal combustion engine at the end of 60 seconds is as shown in figure.

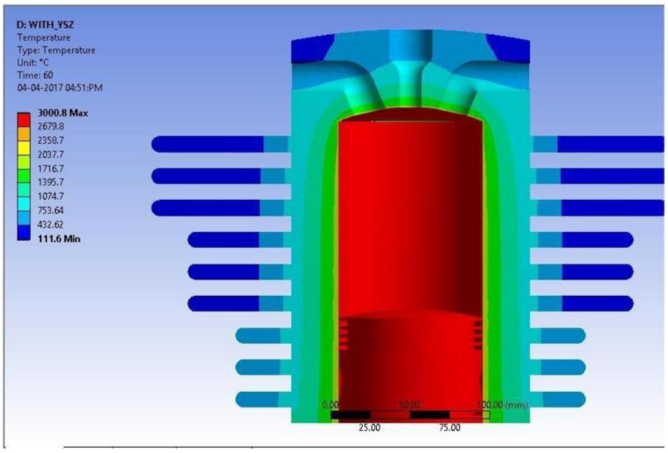

Fig. 3.3.1

The figure shows that with the use of YSZ material, there is much lower heat transfer is occurred. The region area of heat transfer is minimum at near the wall of the combustion chamber. Red colour region indicates the maximum temperature passes through the TBC material. Green colour region shows that the heat transfer is low after the coating.

3.3.2. Heat Flux of YSZ Coated IC Engine

The state of Heat flux in the YSZ Coated internal combustion engine at the end of 60 seconds is as shown in figure.

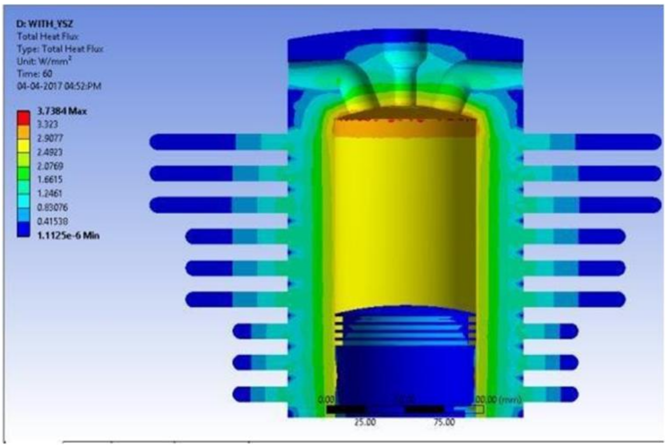

Fig. 3.3.2

The maximum heat flux is obtained in the edges of the combustion chamber. About 3.7384 W/mm² heat flux is obtained with the YSZ coating.

3.4 Thermal Analysis of BLT Coated IC Engine

Barium Lanthanum Titanate (BLT) is relatively a new found thermal barrier coating material which has approximately 25% more thermal stability than Strontium Zirconate. It can resist phase transition up to 1773K with thermal conductivity of 0.7 W/mK. At the end of 60 seconds of thermal simulation over the BLT coated IC Engine, the heat distribution and heat flux is observed and captured.

3.4.1. Temperature Distribution of BLT Coated IC Engine

The state of temperature distribution in the BLT Coated internal combustion engine at the end of 60 seconds is as shown in figure.

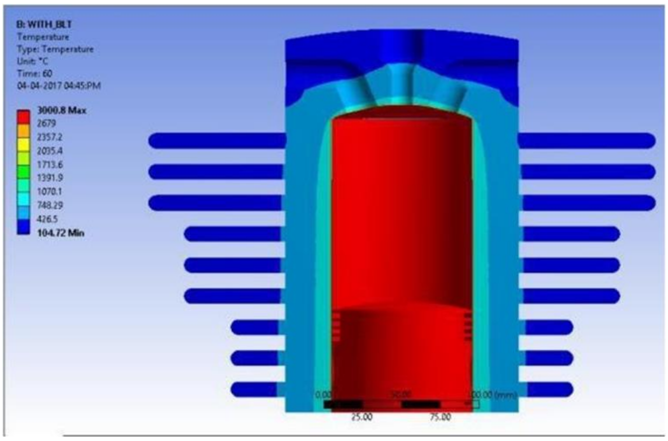

Fig. 3.4.1

The figure shows that with the use of BLT material as the TBC, there is very lower heat transfer is occurred. The region area of heat transfer is maximum at TBC coating of wall of the combustion chamber. Red colour region indicates the maximum temperature possess only in the TBC material.

3.4.2. Heat Flux of BLT Coated IC Engine

The state of Heat flux in the BLT Coated internal combustion engine at the end of 60 seconds is as shown in figure.

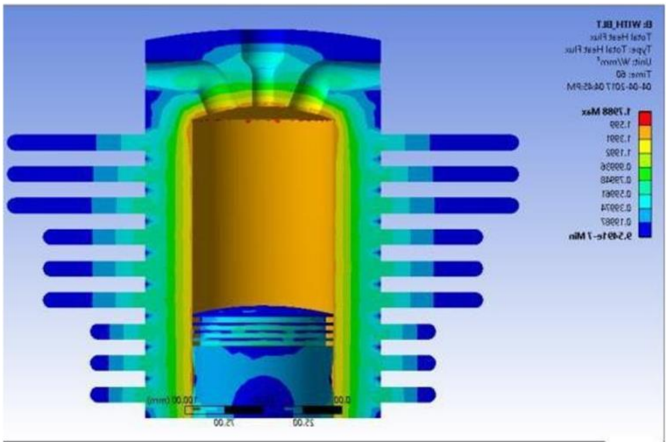

Fig.3.4.2

The maximum heat flux is obtained in the edges of the combustion chamber. About 1.7988 W/mm² heat flux is obtained with the BLT coating, which is very lower and it possess lesser heat transfer.

IV. RESULTS AND DISCUSSION

know, lower heat rejection from the combustion chamber through thermally insulated components causes an increase in available energy which in turn would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could also be utilized by using turbocharger. Hence, we can say that the use of Strontium Zirconate TBC will increase the thermal efficiency of the IC Engine. When SYZ TBC is used, the heat dissipated into the engine body is further reduced than in the case of Strontium Zirconate. In the case of BLT, which has lower thermal conductivity (K=0.7 W/make) and high melting point than other two materials. Hence it makes the better of two proposed TBC coated engine models when it comes to improving its thermal efficiency.

At the end of 60 seconds simulation, the results of temperature distribution and heat flux obtained for IC Engine discussed are as tabulated.

1. Comparison of Temperature Distribution

The following are shows the comparison of all the temperature distribution across the wall of the combustion chamber of the IC Engine.

Without Thermal Barrier Coating (TBC) there is large region of heat transfer is occurred. The Strontium Zirconate coating provides lesser amount of maximum temperature region compared to without coating. Yttrium Stabilized Zirconia (YSZ) coated Engine provides lesser heat transfer compared to SZ. After the coating region, there is lower temperature distribution across the combustion chamber. Because of the low thermal conductivity BLT coating possess very less amount of maximum temperature region, when compared to all other TBC materials.

2. Comparison of Total Heat Flux

The following shows the comparison of all the heat flux across the wall of the combustion chamber of the IC Engine. Maximum of 6.7318 W/mm² heat flux is obtained without the TBC coating. And about 4.9509 W/mm² heat flux is obtained with the SZ coating. 3.7384 W/mm² heat flux is obtained with the YSZ coating. Only 1.7988 W/mm² heat flux is obtained with the BLT coating, which is very lower and it provides lesser heat transfer.

3. Heat flux Graph

The comparison heat flux of all the results are shown below in the graphical manner

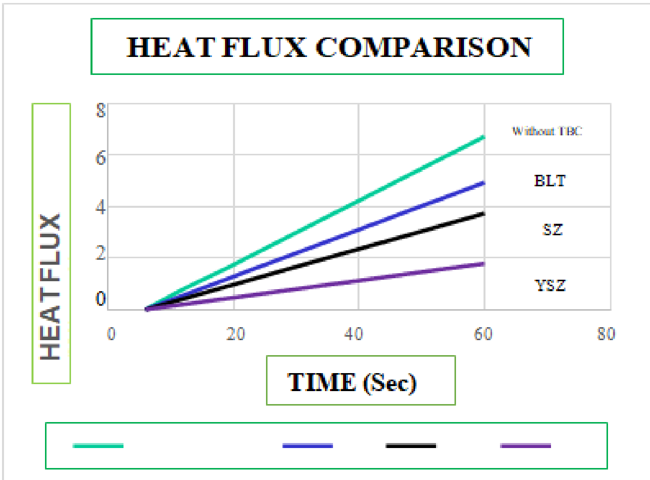

Fig. 4.3

The graph is drawn by taking Time Step in X-Axis, and Resultant Heat flux is taken in the Y- Axis. The heat flux is gradually increased with respect to the time step.

V. CONCLUSION

The 3D Finite Element Thermal Analysis is performed on the four different models of IC Engines. Upon the thermal analysis, we can see that the use of

TBCs greatly reduced the heat dissipation through engine body during combustion. From this results we can say

- ✓ The use of TBCs in IC Engines will definitely improve the thermal efficiency.
- ✓ BLT TBC is found to be the most viable TBC material for use in diesel based IC Engine, on account of its high thermal phase stability and low thermal conductivity.
- ✓ Smaller engine cooling system is sufficient.
- ✓ The liner would show lesser wear because of higher hardness of TBC materials

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