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MODELING AND ANALYSIS OF A CERAMIC COATED IC ENGINE PISTON HEAD

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Abstract: A piston is one of the most important parts of an internal combustion engine. This part supports the combustion pressure of the gas in the cylinder. They are generally made of cast iron, which can withstand pressure. Recently, aluminum alloy is used for weight reduction. Since the top surface of the piston needs to support the load, it is recommended to cover it with a coating material. Ceramic coatings are increasingly used for protection between various engine parts to increase wear resistance, reduce friction and improve heat shielding. In this work, the pistons were designed with the software CATIA. The complete design was imported into ANSYS software and analyzed. Thermal analysis of the piston was performed by choosing an aluminum alloy as the piston material and coating it with different coating materials such as silicon carbide, titanium carbide and magnesium zirconium to a thickness of 1 mm. It was observed that the temperature of the coated piston crown was higher than that of the uncoated piston, and that the temperature also increased with increasing coating thickness. Results were presented in tabular form and compared to find the most suitable design.

***Keywords* - IC engine piston, ANYSY & ceramic coating.**

I. INTRODUCTION

The input energy of an internal combustion engine consists of three parts: The energy consumption of the coolant, the energy used for useful work, and the energy lost by the exhaust gases, and only 1/3 of the total energy is converted into work. Therefore, by converting these heat losses into useful work, the efficiency and overall performance of internal combustion engines can be improved. To minimize heat transfer and improve internal combustion engine performance, the technology was introduced to insulate pistons, cylinder heads, combustion chambers and valve surfaces with thermal barrier coating materials. The engine is the heart of the vehicle and the piston is the main part of the engine. Over the past decades, TBCs have been used to improve the efficiency and performance of various mechanical components. TBC not only provides thermal fatigue protection, but also reduces heat dissipation from the engine. It also protects the piston from corrosive attack, thermal stress and high heat release, reducing heat flow to the piston and fuel consumption. TBCs are applied to hot parts and heat transfer surfaces of gas turbines and internal combustion engines to improve their performance. The temperature of other parts of the engine will also rise or fall when the coating is applied to any part of the engine. Heat transfer phenomena in internal combustion engines have always been the subject of research due to their complexity. Convection is chosen as the main mechanism for heat transfer in the analysis. Before applying a ceramic coating to an automotive part, the surface of the part is usually treated with a finisher or grit blast to remove rough exterior surfaces and accumulated contaminants. After the clean bottom layer is exposed, the part is often heated in an oven to reduce the molecular porosity. Without this treatment, contaminants left over from the initial stage can be brought to the surface and delaminate the coating layer from the substrate. Traditional ceramic automotive coatings such as titanium and tungsten are typically applied with gravity spray guns. Gun nozzles tend to be narrow to allow for precise job control. Solvent-based coatings are typically sprayed at low pressure and liquid-based coatings at high pressure, but in both cases the process takes place in a spray booth. Careful control of the thickness of the ceramic layer is important when spraying, as the coating must be very thin and evenly distributed so that it does not run off.

II. LITERATURE REVIEW

Dr. I. Satyanarayana et.al [1] The goal of this project is to determine both temperature and thermal stress distributions in ceramic coating on a steel alloy piston crown to improve the Thermal efficiency of a diesel engine. For changing the design here they added 0.4mm thickness material on the top surface. In static conditions when they applied 6Mpa pressure on existing piston (steel) produced 180.73MPa by changing design and adding zirconium coating we reduced it to 158.72Mpa nearly 22MPa stress have been reduced but in real time conditions these results are not enough so we have analyze these models with thermal loads. Finally, we conclude steel with sio2 ceramic coated piston will satisfy both static and thermal conditions. And it increases the piston efficiency compared with the uncoated steel alloy piston.

Syed Arif Ali et.al [2] In this work, the piston is designed using the software CATIA V5R20. The complete design is imported into ANSYS 14.5 software and analyzed. We applied a 1mm coating with various coating materials such as Ni-Cr-Al and MgZrO3, selected aluminum alloy and titanium alloy for the piston material, and conducted thermal analysis of the piston. The maximum heat flux distribution when the piston material is Al alloy and the coating material is Mg-Zr-O3, equivalent to 71.513 W/mm2. Mg-Zr-O3 coating materials are preferred over others.

S. Krishnamani et.al [3] The purpose of this work is to determine the temperature profile of plasma-sprayed yttria-stabilized zirconia and magnesia-stabilized zirconia (MgZrO3). A temperature distribution analysis was performed for a ceramic layer thickness of 0.3 mm on the piston crown surface. A 32% and 20% increase in the peak temperature of the outer surface of the ceramic piston with the material MgZrO3 is observed for the yttria-stabilized zirconia-coated piston compared to the conventional aluminum alloy piston. It was concluded that the substrate temperature of pistons coated with MgZrO3 and yttria-stabilized zirconia decreased by 25% and 17% compared to uncoated aluminum alloy pistons. The lowering of the substrate surface temperature by the coating improves the heat-to-work conversion efficiency of the engine.

S. Srikanth Reddy et.al [4] In this study, we first perform a thermal analysis of a conventional diesel piston made of aluminum-silicon alloy for Design 1 and Design 2 parameters. Second, a thermal analysis is performed on a piston coated with a zirconium material using a commercial code, namely ANSYS. The main goal is to investigate and analyze the heat load distribution of the piston under real engine conditions during the combustion process. A structural model of the piston is created using Computer Aided Design NX/Catia software. In addition, finite element analysis is performed using the computer-aided simulation software ANSYS. As a result of performing FEA on a standard piston model used in diesel engines, it was found that the maximum stress of 85 MPa changed. Up to 55MPa. Also, the maximum deformation was reduced from 0.051762 mm to 0.025884 mm.

M. Mathan babu et.al [5]: In this paper, the thermal analysis of a conventional (uncoated) diesel piston made of aluminum-silicon alloy and steel is investigated. A commercial code called ANSYS is then used to perform a thermal analysis of a piston coated with the MgO-ZrO2 material. Finally, compare the results for four different pistons. Investigate the influence of coatings on the thermal behavior of pistons. The maximum surface temperature of pistons coated with materials with low thermal conductivity has been shown to improve by approximately 48% for AlSi alloys and 35% for steels.

Shukla Mangal Mai et.al [6] In this work, static structural and thermal analyzes of a Mercedes-Benz piston made of gray cast iron and bonded with a ceramic (MgZrO3) (NiCrAl) material are performed. The equivalent stress is approximately 46 MPa. Temperatures at the piston crown were found to range from 600°C to 700°C, but with the application of the ceramic coating, the temperature of the piston top land just below the coating was found to be 150°C lower than the top surface. This proves that ceramic coatings can serve as insulation. The total deformation decreases as the coating thickness increases.

Ekrem Buyukkaya et.al [7] In this work, we first investigate the thermal analysis of a conventional diesel piston made of aluminum-silicon alloy and steel. A commercial code called ANSYS is then used to perform a thermal analysis of a piston coated with the MgO-ZrO2 material. Finally, compare the results for four different pistons. Investigate the influence of coatings on the thermal behavior of pistons. The maximum surface temperature of pistons coated with materials with low thermal conductivity has been shown to improve by approximately 48% for AlSi alloys and 35% for steels.

Ekrem Buyukkaya et.al [8] In the study of this paper, the thermal behavior of functionally graded coatings on AlSi and steel piston materials was investigated using a commercial code called ANSYS. Metal, cermet and ceramic powders such as NiCrAl, NiCrAl + MgZrO3 and MgZrO3 were deposited on substrates using thermal analysis. Compare numerical results for AlSi and steel pistons. The maximum surface temperature of functionally graded coatings on AlSi alloy and steel pistons was shown to increase by 28% and 17%, respectively.

Vinod Kumar Yadav et.al [9] In this work an attempt is made to reduce the thermal and structural stress intensity by coated the piston with ceramic material. The zirconia-based ceramic coatings are used in this work. Firstly. the structural and thermal stresses analyses are investigated on a conventional (uncoated) piston made of aluminum alloy namely A2618. Secondly the structural and thermal analyses are performed on the piston coated with zirconium material using the ANSYS software. The main objective is to investigate and analyze the structural and thermal stress distribution of the piston at the real engine condition during combustion process. The result showed that coated piston with ceramic material has better performance in stress and deformation in comparison with the aluminum alloy named A2618 under the joint action of the thermal and mechanical loads.

Jai Kumar Sharma et.al [10] Al-Si pistons are used in this analysis. The crown coating uses lanthanum cerate (La2Ce2O7) as the ceramic material. For thermal analysis, the layer thickness ranges from 0.4 to 1.6 mm. For coated pistons, a 0.4 mm thick coating increases the maximum temperature by 45.5%. The top surface temperature increases with coating thickness, and the substrate surface temperature and stress also decrease. Lanthanum Serrate is a better ceramic material than magnesium zirconate due to its lower thermal conductivity. Numerical analysis of the ceramic-coated piston clearly shows that La2Ce2O7 contributes to the temperature rise of the piston. Finite element modeling clearly shows that the piston temperature depends on the coating thickness. The maximum temperatures obtained were found for all coating thicknesses considered on the surface of the piston crown.

S. Srikanth Reddy et.al [11] This work focuses on studying the thermal behavior of functionally graded coatings obtained using the commercial code ANSYS on aluminum and zirconium coated aluminum piston surfaces. An analysis is performed to reduce the stress concentration on top of the piston. H. (Piston head/crown and piston skirt and sleeve). A structural model of the piston is created using Computer Aided Design NX/Catia software. In addition, finite element analysis is performed using the computer-aided simulation software ANSYS.

Lokesh Tadisetti et.al [12] In this project taking 6 different Cases regular piston materials (Al-sic, TI64ALV, AL4032 and 2 TBC Materials (Mgzr03, Ni-cr-al). Finite Element analysis is used to calculate stresses, strains, deformations, temperature distributions and heat flux distribution on piston crown. Finally concluded the which material is the suitable for the Internal combustion engine based on the results.

Selvam M et.al [13] In this work, the purpose of an experimental study on ceramic coatings on diesel engine components is to evaluate their effective efficiencies for various loads. It runs on a Kirloskar single-cylinder diesel engine. In addition, engine performance, emissions, and combustion were analyzed by processing coated pistons with diesel (D100) and biodiesel (B100) engine operation. Yttria-stabilized zirconia is a ceramic agent applied to the piston using a plasma spray coating process. Test results based on a comparison of coated and uncoated pistons show that the coated pistons perform very effectively, resulting in improved braking thermal efficiency over all applied load spectrums and fuel-specific shown to reduce consumption.

K. Sathish Kumar et.al [14] In this article, FEM is used to evaluate the stress distribution in the piston of a four-stroke engine. Finite element analysis is performed using FEM software. A coupling matrix analysis is performed to calculate the stresses and deflections due to thermal loads and gas pressures. These stresses are calculated for two different materials. Results are compared for both materials and the best is suggested.

M. Gamal Fouad et.al [15] In this study, a commercial software called Ansys is used to perform a 3D thermal finite element analysis on gasoline engine pistons to investigate the thermal behavior of uncoated and coated pistons. The temperature distribution is a function of coating thickness, and a high temperature is observed to occur in the center of the top surface of the uncoated piston. Furthermore, it was clearly established that the temperature developed on the top surface of the coated area is higher than that on the uncoated piston surface. The substrate temperature is observed to decrease as the coating thickness increases.

Ravindra Gehlot et.al [16] This paper deals with a steady-state thermal analysis of a diesel engine piston coated with a ceramic coating with a hole in its surface. From the above analysis, it is clear that TBC contributes to the temperature rise of the piston. The highest temperatures on the topcoat and substrate occur at the center of the bulb and around the bulb. The temperature increases from the bottom of the flask to the top. A coated piston has a significantly higher temperature than an uncoated piston, and then increasing the hole radius increases the surface temperature.

Tadeusz Hejwowski et.al [17] This paper presents the results of investigating the thermal fatigue resistance of thermal barrier coatings (TBC). His two groups of dual-layer thermal barrier coatings (TBC) were investigated. ZrO2-8%Y2O3, Al2O3-40%TiO2 or Al2O3-40%ZrO2 top plasma sprayed powder frames with ZrO2-30.O, Al2O3-40%TiO2 and Al2O3-30%MgO. The extent of his TBC degradation experienced in thermal fatigue testing was assessed in erosion testing and his SEM studies. Flame spray coatings have been found to be more susceptible to damage than plasma spray.

Dr. S. Karthikeyan et.al [18] The persistence of the adverse effects of emissions can be largely controlled through technological advances in reducing emissions. Many researchers are attracted to engine emissions control by employing metallic coatings on the surfaces of the combustion chamber. Some researchers have even tried ceramic coatings on components such as pistons and engine heads. This type of metal coating acts as a thermal insulator, which reduces the heat transfer rate from the combustion chamber by returning heat only to the combustion chamber. and regulate emissions. This research paper discusses various trends and innovations related to metallic coatings in automotive engine applications. The results are inevitable in the realm of increased engine performance and significantly reduced engine emissions.

Hafiz Liaqat Ali et.al [19] In this article, a simulation study was performed using the commercial software AVL Boost to analyze the impact of a thermal barrier coating (TBC) on the performance of a naturally aspirated single-cylinder compressed natural gas (CNG) engine. Results were performed on a conventional (uncoated) piston and two different pistons insulated with titanium dioxide (TiO2) and yttria-stabilized zirconium oxide (YSZ) insulating ceramics and coated with a thickness of 0.5 mm. I was. Simulation results have been validated. Results for the insulated piston showed superior performance to the uncoated piston in all operating conditions.

Nabeel Abdulhadi Ghyadh et.al [20] The purpose of this work was to compare the behaviour of the piston without and with coating layer on the top of piston under thermal and mechanical loads. The obtained results shows that the thermal and mechanical stresses induced in piston with coating layer are less as compare to the piston without coating layer. The coating material has been applied successfully to the engine piston as the thermal barrier coating of a diesel engine prevents excessive heat loss during combustion. Through the analysis, it is concluded that the main factor influencing the piston intensity is the temperature, thus providing basis for the optimization design of the piston.

From the literature, the following research gap is identified. Many researchers have conducted the experiments on Different ceramic materials but there was no research on other ceramic materials like silicon carbide(sic), titanium carbide and. This is the seed for this research work.

III. METHODOLOGY

3.1 Types of coating Methods

Application of ceramic coatings to substrates is a multi-step process. The preparation stages of cleaning, roughening and priming (or priming) have a huge impact on the success of your project. The actual effectiveness of the coating is highly dependent on the mechanical, chemical and physical bonds that determine the adhesion of the coating and the ultimate strength of the ceramic layer. In addition to chemical vapor deposition, the most common ceramic coating processes include: Plasma Spraying, Detonation Gun, Oxygen Acetylene Powder etc.

3.2 Project over view

Following steps are taken for the analysis of piston.

• Firstly, all the thermal and mechanical properties of the piston material, ceramic coating and bond coat materials in the engineering data section were defined.
• The topcoat thickness and the diameter of the bore, modeling of the piston was designed in the CATIA Software
• Then, in the model analysis section, the materials with their types were assigned.
• Meshing was created in this geometry.
• Convection boundary conditions were applied to investigate temperature on the top surface, bond coat surface.

IV. MODELING

4.1 piston parameters

The piston model is created by this following parameter as shown in below TABLE 1
These parameters are taken from the Ford EcoSport car

TABLE:1 Piston parameters

Description	values
Bore diameter	79mm
Stroke	76.4mm
Displacement	1498.5CC
Compression ratio	11:1
Maximum engine speed	6720rpm
Valves per cylinder	4

4.2 Modeling of the piston head

In this work, the piston was designed in the CATIA software. After doing the model in CATIA software. Save the file in IGES format continuing the further work in ANSYS software. 2D & 3D diagram of the piston head as shown in below figure 1 &2.

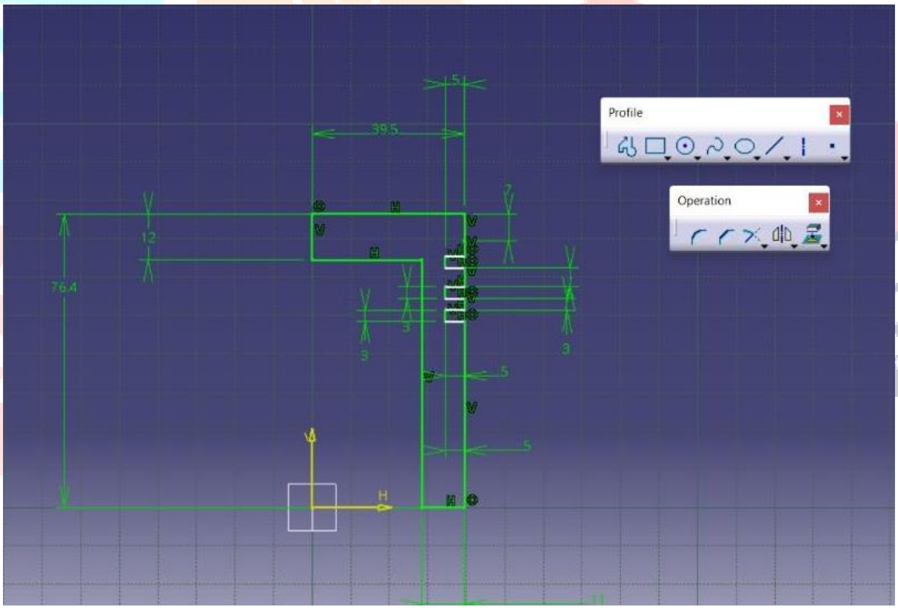

Fig 1: 2D view of the piston

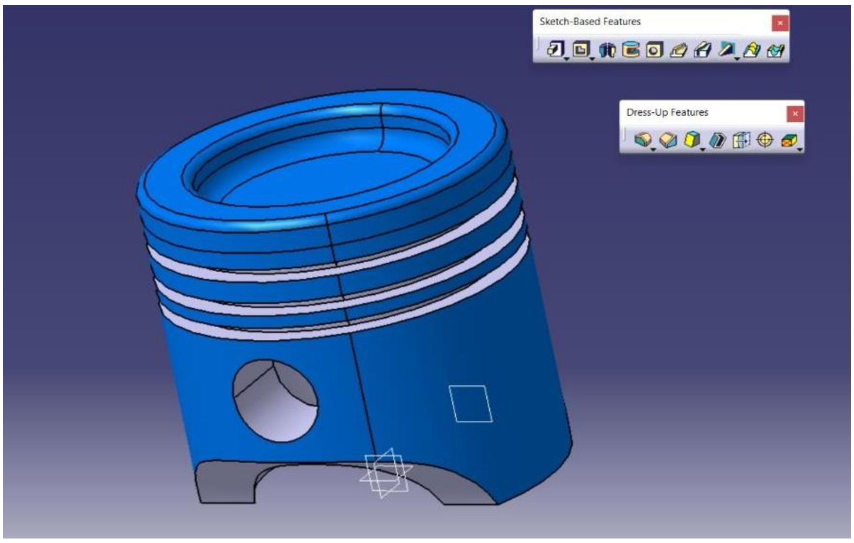

Fig 2: This figure represents the modeling of the piston by using CATIA software

4.3 Piston Coating

Coating is applied on the top of the surface with 1mm of thickness. Coating is applied to the piston in CATIA software after the completion of the part Design click on the Wire frame surface design. Select the plan and draw the line on the edges of the piston and then revolve the line by using shaft tool. Coating of the piston is shown in below figure 3

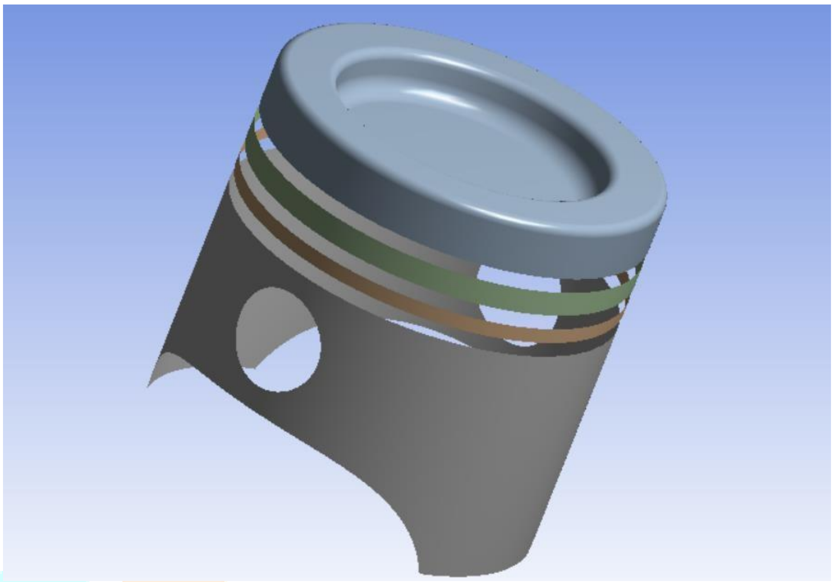

Fig 3: Piston coating

V. ANALYSIS

In this work, the piston model was designed in the CATIA software. The complete model is imported into ANSYS software and analyzed. In this analysis we were used steady-state Thermal analysis. Steady-state Thermal analysis performed on the uncoated and coated piston.

5.1 properties of the piston & ceramic materials

In this project, we choose aluminum alloy as the piston material. A piston is one of the most important parts of an internal combustion engine. This part supports the combustion pressure of the gas in the cylinder. Generally, they are made of cast iron that supports gas pressure. These days, they are made from aluminum alloys to save weight and we are used ceramic materials as $Mgzro_3$, silicon carbide and titanium carbide. The properties of the material as shown in below TABLE 2

TABLE 2: properties of the materials

Material	Al-alloy	$Mgzro_3$	Silicon carbide	Titanium carbide
Density(kg/m^3)	2700	5600	3200	4500
Thermal expansion 10^{-6}(^{o}c)	21	8	4.0	8.0
Thermal conductivity (w/mm^{o}c)	170	2e-4	120	110
Passion ratio (μ)	0.33	0.2	0.14	0.19
Specific heat (J/kg^{o}c)	910	6.5e+5	750	831

5.2 Analysis of the uncoated piston

Here we are using ANSYS for Steady state thermal for analysis of the Piston. We considered the piston material as Aluminum alloy and its thermal conductivity is 170W/mk In this we performed the analysis by considering with coating and without coating. In this we considered boundary condition as the Temperature is of 20000c. We got solution for Temperature, Total heat flux. As shown in below figures 4 & 5

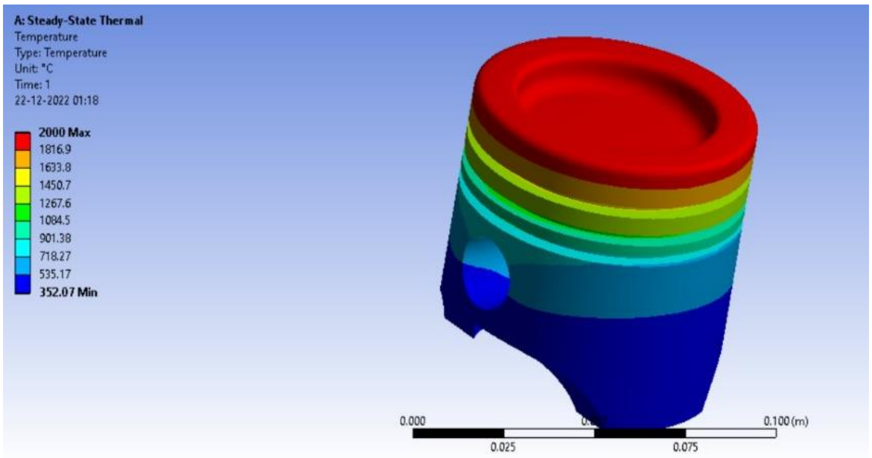

Fig 4: Temperature distribution of the uncoated piston

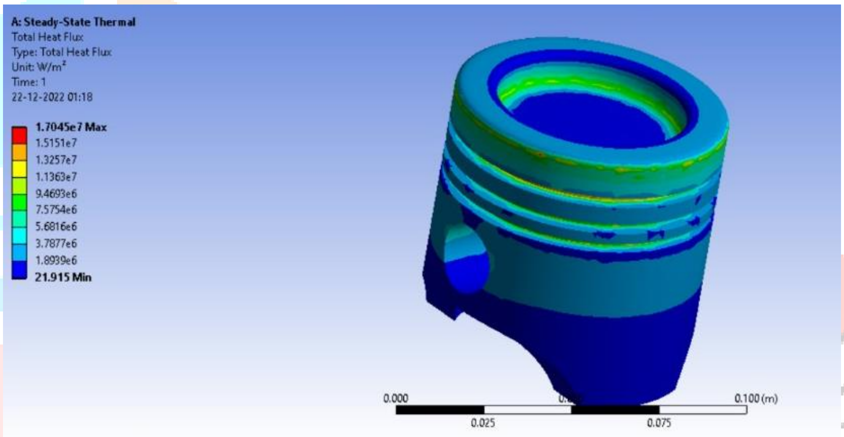

Fig 5: Total Heat flux distribution to the uncoated piston

5.3 Analysis of the piston coated with ceramic materials

In this project steady-state-thermal analysis are investigated on the coated piston. Three types of ceramic materials are coated on the top of the aluminum alloy piston. Ceramic materials are $Mgzr0_3$, Titanium carbide, silicon carbide.

5.4 Analysis of the Aluminum alloy piston Coated with $MgZrO_3$

- In this analysis Assign the material to the part body(piston) as Aluminum alloy and assign the $MgZro_3$ material to the coating surfaces and also add the coating thickness 1 mm in Details of geometry. Do meshing of the required size dimensions and solve it for mesh.
- Apply the boundary conditions Select the top of the piston Enter the temperature value as 20000c and select the sides of the piston enter the convection values as 2300 w/m2c. take another convection 2 select the total part and assign the value as 2300 w/m2c
- Right click on the solution insert the temperature and total heat flux and then solve.
- Click on the temperature and then later heat flux for the results as shown in below figures 6 & 7

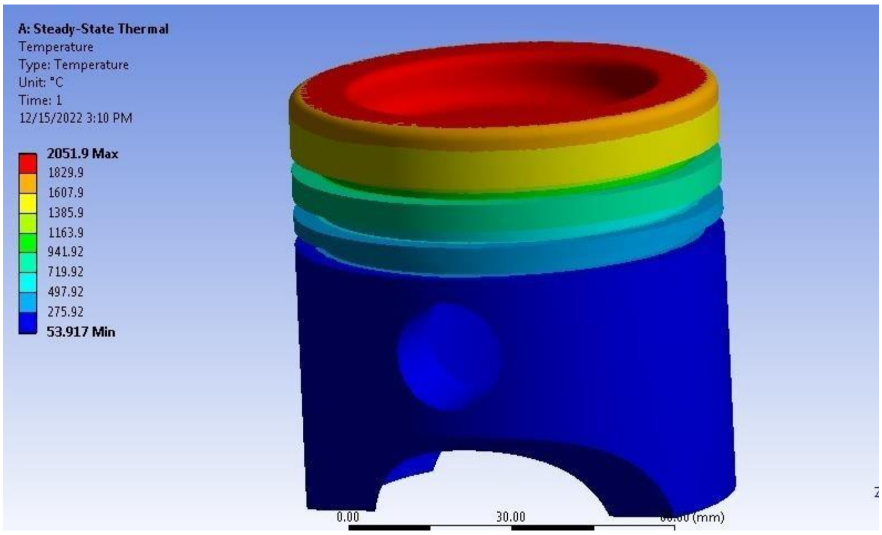

Fig 6: Temperature distribution of the piston coated with MgZr03

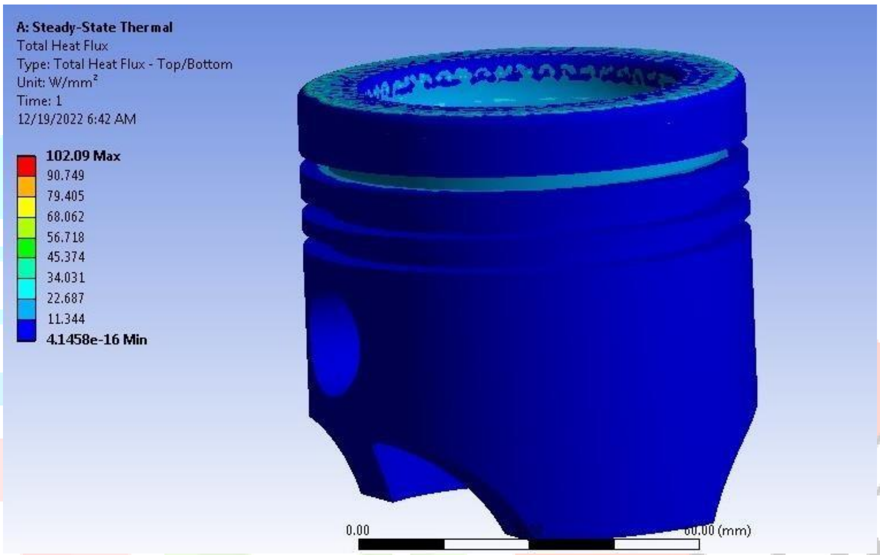

Fig 7: Total Heat flux distribution of the piston coated with MgZr03

5.5 Analysis of the Aluminum alloy piston Coated with Silicon carbide

In this analysis Assign the material to the part body (piston) as Aluminum alloy and assign the silicon carbide material to the coating surfaces and also add the coating thickness 1 mm. Repeat the same process for the silicon carbide which is previously done. As shown below figures 8 & 9

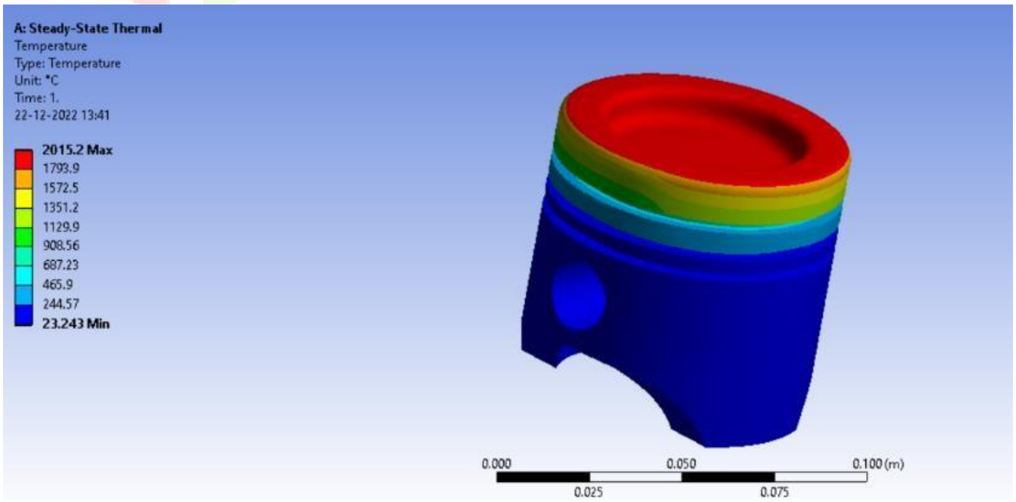

Fig 8: Temperature distribution of the piston coated with Silicon carbide

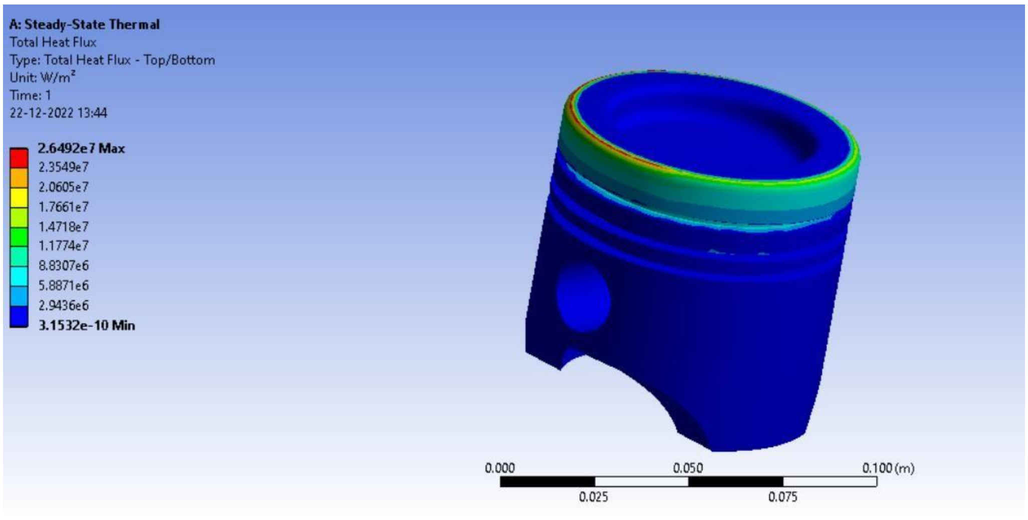

Fig 9: Total Heat flux distribution of the piston coated with Silicon carbide

5.6 Analysis of the Aluminum alloy piston Coated with Titanium carbide

In this analysis Assign the material to the part body (piston) as Aluminum alloy and assign the Titanium carbide material to the coating surfaces and also add the coating thickness 1 mm. Repeat the same process for also the Titanium carbide which is previously done. As shown in below figures 10 & 11

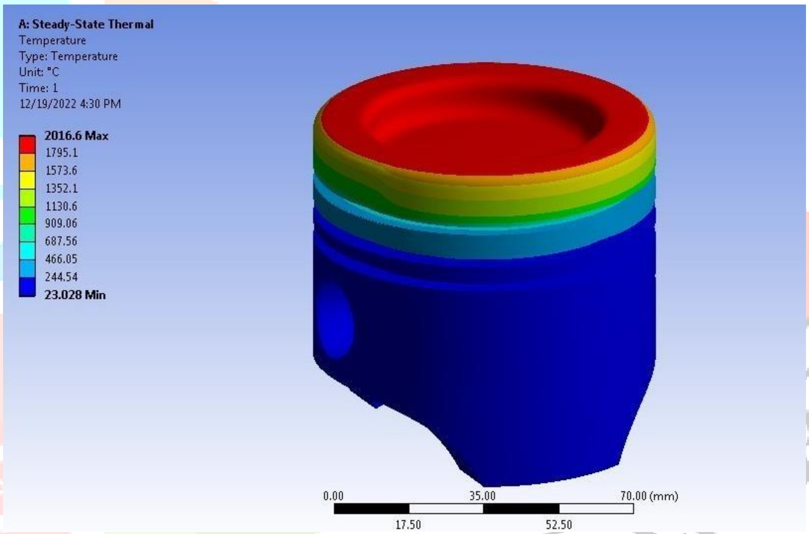

Fig 10: Temperature distribution of the piston coated with Titanium carbide

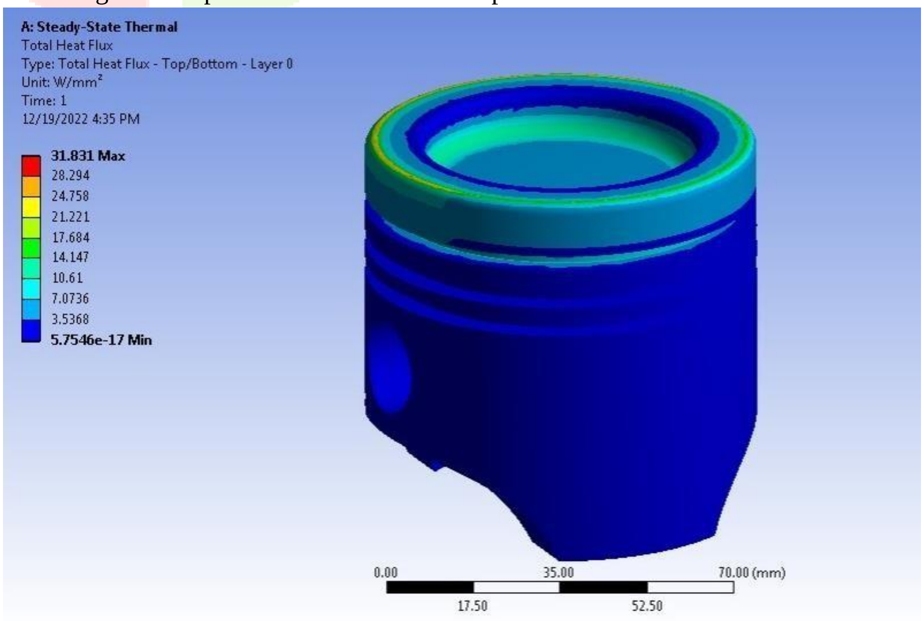

Fig 11: Total Heat flux distribution of the piston coated with Titanium carbide

VI. RESULTS AND DISCUSSION

Steady-State-Thermal analysis of piston was performed by choosing aluminum alloy as piston material and coating with different coating materials such as silicon carbide, titanium carbide and $Mgzro_3$ with a thickness of 1mm. 2000^0C is applied on the top of the piston. It is observed that the temperature on the coated piston crown is high when compared with the uncoated piston. Results are displayed in the below table and compared to find the most suitabledesign. As shown in the below TABLE 3.

TABLE 3: Results

S. No	Materials	Maximum Temperature(^{o}c)	Max heat flux (w/mm^2)
1.	Aluminum alloy	2000	$1.7e^7$
2.	Al-alloy with MgZr03	2051.9	102.9
3.	Al-alloy with Silicon carbide	2015.2	26.49
4.	Al-alloy with Titanium carbide	2016.6	31.83

The piston made with aluminum alloy without coating did not provide much heat distribution at any instant and maximum.

The maximum temperature and maximum heat flux distribution obtained when aluminum alloy coated with Mgzr03 material. Titanium carbide is also best suited material forcoating compared to silicon carbide. So, Magnesium Zirconium Oxide is the best suitable material for ceramic coatings.

VII. CONCLUSION

The following conclusion can be drawn from the analysis conducted in this work.

1. In our work, we have successfully done analysis on un coated piston and coated piston with different ceramic materials.
2. It is observed that the temperature on the coated piston crown is high when compared with the uncoated piston and also the temperature increases with increase in the coating thickness.
3. This project is done with three ceramic material and comparing with each other
4. In our Analysis, We Observe that All Three material are ceramic materials. The maximum temperature and maximum heat flux distribution obtained when aluminum alloy coated with Mgzr03 material. Titanium carbide is also best suited material for coating compared to silicon carbide. So, Magnesium Zirconium Oxide is the best suitable material for ceramic coatings.

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