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MODELING AND STATIC THERMAL ANALYSIS OF IC ENGINE PISTON USING FININTE ELEMENT METHOD WITH THERMAL BARRIER COATING MATERIALS

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• Abstract: Piston is considered to be one of the important parts of an internal combustion engine. It is a part which bears the pressure & temperature of the combustion of the gas inside the cylinder.

• The project aims at to increase the performance of the engine by using the Thermal Barrier Coating (TBC). Now a days widely using Internal combustion engines High temperature produced in an I.C engine may contribute to high thermal stresses.

• The literature survey shows that ideal piston consumes heat produced by burnt gases resulting in decrease of Engine overall Efficiency. The Aim of the project is UNICORN 150CC engine is considered and TBC material with 0.4mm thickness is coated on the piston crown. 3D modeling of the piston and crown surface design is done 3D designing using the catia software.

• 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.

I INTRODUCTION

1.1 INTRODUCTION OF IC ENGINE PISTON

Automobile components are in great demand these days because of increased use of automobiles. The increased demand is due to improved performance and reduced cost of these components. R&D and testing engineers should develop critical components in shortest possible time to minimize launch time for new products. This necessitates understanding of new technologies and quick absorption in the development of new products. A piston is a component to reciprocating IC-engines. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. As an important part in an engine, piston endures the cyclic gas pressure and the inertial forces at work, and this working condition may cause the fatigue damage of piston, such as piston side wear, piston head/crown cracks and so on.

The investigations indicate that the greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure. On the other hand piston over heating-seizure can only occur when something burns or scrapes away the oil film that exists between the piston and the cylinder wall.In Internal Combustion Engines, most of the heat generated during combustion process is absorbed by piston. This is direct heat loss to the piston. This reduces Indicated Power and in turns the performance of Internal Combustion Engine. Engine coating with a ceramic thermal barrier can be applied to improve reliability and durability of engine performance and efficiency in Petrol engines. In a conventional diesel engine, about 30% of the total energy is rejected to the coolant and it was reported that the engine coating may be a good solution. Main advantages of the engine coating concept were such as improved fuel economy, reduced hydrocarbon, smoke and carbon monoxide emissions, reduced noise due to lower rate of pressure rise and high energy in the exhaust gases. Thermal barrier coatings are generally applied on the cylinder head, piston and valves by plasma spray method. Coating these parts with ceramic also limits the negative effects of wear, friction, heating, corrosion and oxidation. It was also reported in a theoretical diesel cycle analysis that more the heat transfer decreases, the less energy will be lost, thus increasing the work output and the thermal efficiency. In another study, with engine coating an increase in engine power and decrease in specific fuel consumption, as well as significant reduction in exhaust gas emissions and smoke density have been addressed in comparison to the uncoated engine. Using the coated piston, the required temperature in the combustion chamber will be maintained. This will reduce the heat loss to the piston. This reduction in the heat loss will be used to burn the un-burnt gases there by reducing the polluted exhaust gases.

1.3 CERAMIC COATED COMBUSTION CHAMBER :

The engine exhaust temperature has increased in the case of TBC engine (from 4100C to 4280C) which promotes better energy recovery .The insulation of the combustion chamber with ceramic coating influences the performance and exhaust emissions of the CI engine. The insulation modifies the boundary conditions for the combustion process which in turn shortens the ignition delay period hence lowers the fuel consumption, reduces the heat loss and increases the exhaust temperature, which in turn influences the engine performance and emissions. Ceramic coatings provide potential for higher engine thermal efficiencies, longer life and higher reliability of engine components. Thermal barrier coatings offer the possibility of reducing particulate emissions.

1.4 PISTON FUNCTION:

The piston is an element of power transmission in engine cylinder, the energy bounded up in fuel is rapidly converted into heat and pressure during combustion process. In short period of time heat and pressure valve increase greatly, the piston has a task of converting released energy in to mechanical work. The usual structure of the piston is a hallow cylinder and closed on one side with the segment piston head with ring belt, pin bas and skirt. The piston head transfers the gas forces (fuel air mixture) from combustion chamber resulting pin boss, piston pin, and connecting rod to crankshaft .

II LITERATURE REVIEW

[1]. EkremBuyukkaya, Department of Mechanical Engineering, Esentepe Campus, Turkey.. Thermal analysis of functionally graded coating AlSi alloy and steel pistons... Thermal analyses were employed to deposit metallic, cermet and ceramic powders such as NiCrAl, NiCrAl+MgZrO3 and MgZrO3 on the substrate. The numerical results of AlSi and steel pistons are compared with each other. It was shown that the maximum surface temperature of the functional graded coating AlSi alloy and steel pistons was increased by 28% and 17%, respectively.

[2]. Imdat Taymazinvestigated the effect of thermal barrier coatings on diesel engine performance his results indicate a reduction in fuel consumption and an improvement in the efficiency of the diesel engine.

[3]. P. M. Pierz investigated the thermal barrier coating development for diesel engine aluminum piston he found that the resulting predicted temperatures and stresses on the piston, together with material strength information, the primary cause of coating failure is proposed to be low cycle fatigue resulting from localized yielding when the coating is hot and in compression.

[4]. O. Altun ,Mechanical Engineering Department , Turkey., Investigated in Problems for determining the thermal conductivity of TBCs by laser-flash method., Laser-flash method is the most widely used experimental technique to determine the thermal conductivity of APS TBCs at high temperatures. The research contributes to better understanding and recognition the importance of sample preparation in laser-flash method.

[5] S. C. Mishra., Laser and Plasma Technology Department, Mumbai, India. Investigated in Microstructure, Adhesion, and Erosion Wear of Plasma Sprayed Alumina–Titanium Composite Coatings.. Adhesion strength value of the coating varies with operating power. The trend of erosion of the coatings seems to follow the mechanism predicted for brittle materials. Coating deposited at 18kW power level shows a higher erosion rate than that of the sample deposited at 11kW power level

[6]. H.W. Grunling and W. Mannsmann, ABB Kraftwerrke AG, KallstadterStz 1, 6800 Mannheim 31, Germany., investigated in Plasma sprayed thermal barrier coatings for industrial gas turbines: morphology, processing and properties. The properties of thermal barrier coating systems depend strongly on the structure and phase composition of the coating layers and the morphology of and the adhesion at the ceramic-metal interface. They have to be controlled by the process itself, the process parameters and the characteristics of the applied materials.

[7]. A. J. Slifka, National Institute of Standards and Technology, Boulder. Thermal-Conductivity Apparatus for Steady-State, Comparative Measurement of Ceramic Coatings, and an apparatus has been developed to measure the thermal conductivity of ceramic coatings. Since the method uses an infrared microscope for temperature measurement, coatings as thin as 20 _m can, in principle, be measured using this technique. This steady-state, comparative measurement method uses the known thermal conductivity of the substrate material as the reference material for heat-flow measurement.

[8]. Dongming Zhu Ohio Aerospace Institute, Cleveland, Ohio. Effect of Layer-Graded Bond Coats on Edge Stress Concentration and Oxidation Behavior of Thermal Barrier Coatings.. A low thermal expansion and layer-graded bond coat system, that consists of plasma-sprayed FeCoNiCrAI and FeCrA1Y coatings and a high velocity oxy fuel (HVOF) sprayed FeCrAIY coating, was developed for minimizing the thermal stresses and providing excellent oxidation resistance.

[9]. S. Alphine', M. Derrien, Thermal Barrier Coatings: the Thermal Conductivity challenge. In this paper, the importance of the challenge associated with the control of the thermal conduct why of thermal barrier coatings for turbine engines hot stages is being reviewed. It is firstly illustrated by the description of a practical aeronautic coated and uncoated turbine blade design exercise. The various contributions to TBC thermal conductivity are then reviewed.

S Pal, A Deore, A Choudhary etc all.[10], has focused and make easier to choose best coating materials for engine coating purposes and for best operating properties during its service period. The best powder among yttria, alumina and zirconia to be used as a piston coating material i.e., the one resulting in lowest heat flux and low side skirt and bottom temperature has been chosen for the coating purpose. This work then analyses the coated sample for its surface properties such as hardness, roughness, corrosion resistance and micro structural study.

III PROJECT OVER VIEW

3.1 OBJECTIVE OF THE PROJECT

1. Analytical design of pistons based on design formulae and empirical relations.
2. 3-D piston models are created in Catia v5
3. Meshing and analysis of piston is done in ANSYS Workbench 16.2.
4. Various stresses are determined by individually performing structural analysis, thermal analysis and thermo mechanical analysis.
5. Various zones or regions where chances of damage in piston are possible are analyzed.
6. Comparison is made between the 6 cases materials
7. Case 1: Mgzr03 is piston crown and Al-sic is a piston material
8. Case 2: Mgzr03 is piston crown and TI64ALV is a piston material
9. Case 3: Mgzr03 is piston crown and AL4032 is a piston material
10. Case 4: Ni-cr-al is piston crown and Al-sic is a piston material
11. Case 5: Ni-cr-al is piston crown and TI64ALV is a piston material
12. Case 6: Ni-cr-al is piston crown and AL4032 is a piston material
13. 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.

3.2 METHODOLOGY:

- Design of piston, using specification of four stroke single cylinder engine of HONDA UNICORN 150cc motorcycle Piston created in catia work bench.
- IGS Format imported in to the Ansys workbench .
- Perform the static and steady state thermal analysis.
- Follow the 3 steps Pre-processor, solution, post-processor.
- Analysis of piston using FEA method.
- Generate meshing in modal and Apply boundary conditions in setup.
- Select the best Material for piston material in 6 cases.

3.3 DESIGN CONSIDERATIONS FOR A PISTON

In designing a piston for an engine, the following points should be taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

3.4 MATERIAL PROPERTIES

MATERIAL PROPERTIES	DENSTIY(g/cm³)	POSSIONS RATIO(u)	YOUNGS MODULUS(Gpa)	THERMAL CONDUCTIVITY w/m.k	SPECIFIC HEAT J.Kg/m3
AL4032	2..6	0.33	79	142	870
Ti-6Al-4V	4.4	0.33	113	7.3	553 J
AL-SIC	2.7	0.34	190	160	826
MGZro3	5.6	0.2	46	0.8	400
NI-CR-AL	7.8	0.27	90	16.1	764

3.5 SPECIFICATION OF THE UNICORN ENGINE

In this work, a piston of two wheeler 150cc Honda Unicorn Engine is considered with specifications as: Engine type air cooled 4-stroke, Bore × Stroke (mm) = 57×58.6, Displacement = 149.5CC. Maximum Power = 13.8bhp at 8500rpm, Maximum Torque = 13.4Nm at 6000rpm, Compression Ratio = 9.35/1.Theoretical designing of piston was done using standard design procedure. The piston specifications are shown table 2.

3.6 DESIGNING OF PISTON:

Consider a 150cc engine Engine type air cooled 4-stroke Bore × Stroke (mm) = 57×58.6

Displacement = 149.5CC

Maximum Power = 13.8bhp at 8500rpm

Maximum Torque = 13.4Nm at 6000rpm

Compression Ratio = 9.35/1

3.7PISTON PARAMETERS

Thickness of piston head	7.31 mm
Radial thickness of piston ring	2 mm
Axial thickness of piston ring	1.6 mm
No of piston rings	4
Width of top land	8.04 mm
Width of ring land	1.28 mm
Radial depth of piston ring groove	2.4 mm
Thickness of piston barrel at top end	8.61 mm
Thickness of piston barrel at open end	1.827 mm
Piston pin dia.	17.1 mm
Diameter of piston boss	30.62 mm
Length of Skirt	34.2 mm
Total length of piston	52.48 mm

IV **INTRODUCTION OF CATIA**

Welcome to **CATIA (Computer Aided Three Dimensional Interactive Application)**. As anew user of this software package, you will join hands with thousands of users of this high-end CAD/CAM/CAE tool worldwide. If you are already familiar with the previous releases, you can upgrade your designing skills with the tremendous improvement in this latest release.

CATIA V5, developed by Dasssault Systems, France, is a completely re-engineered, Next-generation family of CAD/CAM/CAE software solutions for Product Lifecycle Management. Through its exceptionally easy-to-use and state-of-the-art user interface, CATIA V5 delivers innovative technologies for maximum productivity and creativity, from the inception concept to the final product. CATIA V5 reduces the learning curve, as it allows the flexibility of using feature-based and parametric designs.

4.2 DESIGNING OF THE MODEL: DESIGN PROCEDURE IN CATIA WORK BENCH:

Create the half piston profile in sketcher workbench next go to exist work bench (part design) now go to the sketched based features and go to shaft option apply angle 360 after create the planes offset to xy planes create the circles and apply pocket around the up to surface now go to mirror option apply mirror finally as shown the figure below:

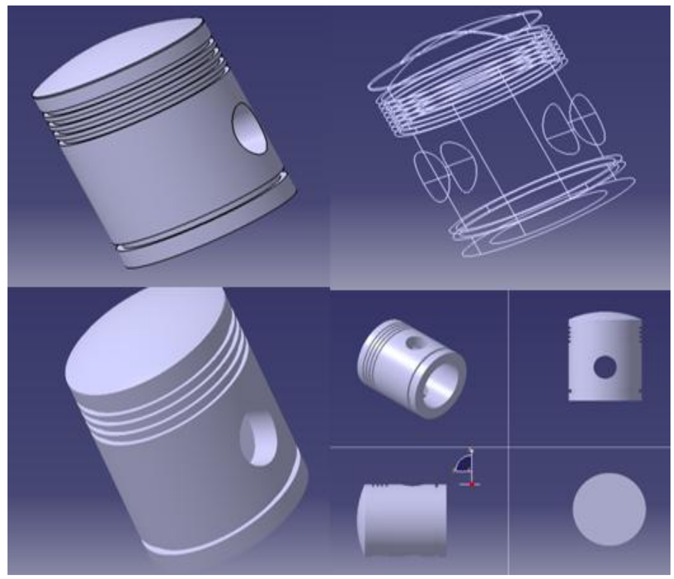

Figure 2 DESIGN PROCEDURE IN CATIA

V INTRODUCTION TO ANSYS

ANSYS is a large-scale multipurpose finite element program developed and maintained by ANSYS Inc. to analyze a wide spectrum of problems encountered in engineering mechanics**.**

STATIC ANALYSIS:

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many building codes).

Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include:

_ Externally applied forces and pressures

_ Steady-state inertial forces (such as gravity or rotational velocity)

_ Imposed (nonzero) displacements

_ Temperatures (for thermal strain)

_ flounces (for nuclear swelling)

VI FINITE ELEMENT METHOD

6.1 INTRODUCTION

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called "Finite Elements". The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called "Nodes" or "Nodal Points". Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called "shape functions". This will represent the displacement with in the element in terms of the displacement at the nodes of the element.

The Finite Element Method is a mathematical tool for solving ordinary and partial differential equations. Because it is a numerical tool, it has the ability to solve the complex problems that can be represented in differential equations form. The applications of FEM are limitless as regards the solution of practical design problems.

6.2 PROCEDURE OF STATIC ANALYSIS & THERMAL ANALYSIS:

Create the geomentry in catia workbench and save the file in igs format and open ansys workbench apply engineering data(material properties), create or import the geomentry, apply model(meshing),apply boundary conditions(setup) shown the results(stress,deformation,heat flux).

6.3 ANALYSIS OF PISTON:

Frictionless support at pin bore areas and fixed all degree of freedom. Downward pressure (14.06 MPa) due to gas load acting on piston head. The piston is analyzed by giving the constraints they are Pressure or structural analysis and Thermal analysis.

6.4 STRUCTURAL AND THERMAL ANALYSIS OF PISTON:

Combustion of gases in the combustion chamber exerts pressure on the head of the piston during power stroke. The pressure force will be taken as boundary condition in structural analysis. Fixed support has given at surface of pin hole. Due to the piston will move from TDC to BDC with the help of fixed support at pin hole. So whatever the load is applying on piston due to gas explosion that force causes to

1. Maximum pressure load at the top surface of the piston crown 14.06 Mpa
2. Temperature at the top surface of the piston crown 600^{O}C and ambient temperature is 29^{o}c, Convection is $0.002 w/mm^2$
3. Piston pin holes are fixed DX = DY = DZ = 0

MESH:

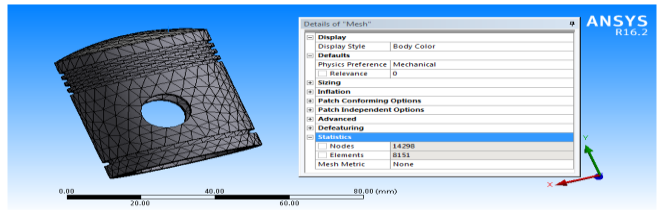

Figure 3 MESH: NODES : 14298 ,ELEMENTS: 8151

BOUNDARY CONDITIONS

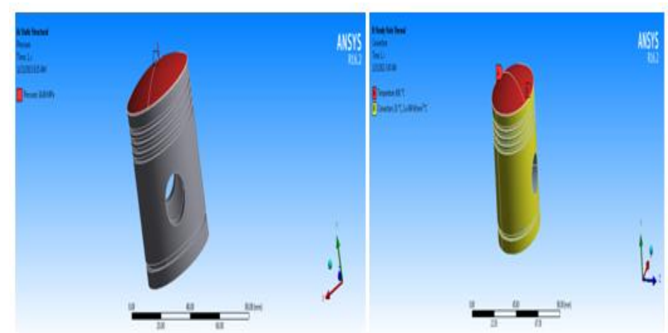

Figure 4 Boundary conditions of piston

VII RESULTS AND DISCUSSIONS

The constructed piston in catia is analyzed using ANSYS V16.2 and the results are depicted below. Combustion of gases in the combustion chamber exerts pressure on the head of the piston during power stroke. Fixed support has given at surface of pinhole. Because the piston will move from top dead center to bottom dead centre with the help of fixed support at pinhole.

1. Case 1: Mgzr03 is piston crown and Al-sic is a piston material
2. Case 2: Mgzr03 is piston crown and TI64ALV is a piston material
3. Case 3: Mgzr03 is piston crown and AL4032 is a piston material
4. Case 4: Ni-cr-al is piston crown and Al-sic is a piston material
5. Case 5: Ni-cr-al is piston crown and TI64ALV is a piston material
6. Case 6: Ni-cr-al is piston crown and AL4032 is a piston material

7.1 MGZRO3+AL4032 :

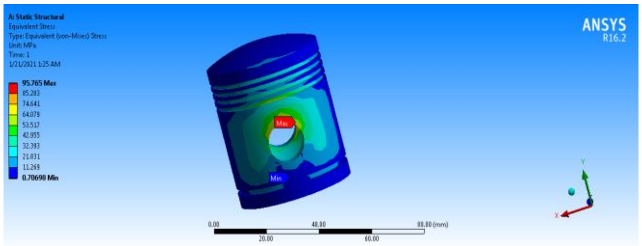

Figure 5 Von-misses stresses of Mgzro3+ AL4032 Material

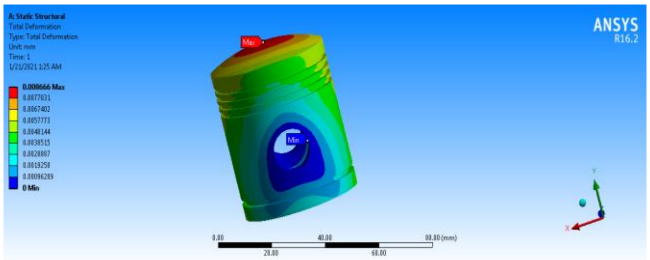

Figure 6 TOTAL DEFORMATION OF Mgzro3+ AL4032 MATERIAL

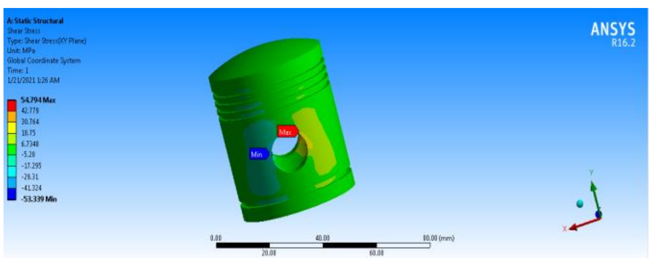

Figure 7 SHEAR STRESS OF Mgzro3+ AL4032 MATERIAL

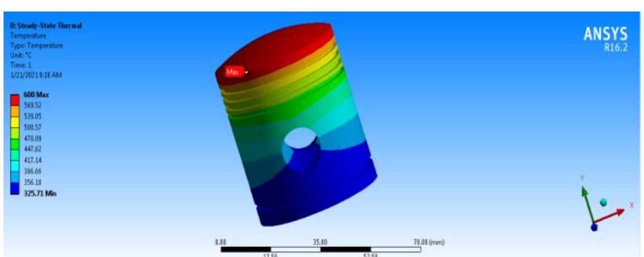

Figure 8 TEPERATURE DISTRIBUTION OF Mgzro3+ AL4032 MATERIAL

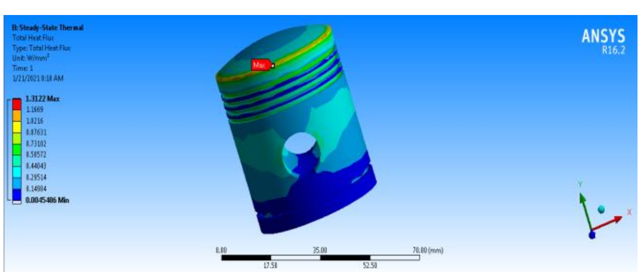

Figure 9 TOTAL HEAT FLUX OF Mgzro3+ AL4032 MATERIAL

7.7 TABLE 2 RESULTS

MATERIAL PROPERTIES	VON-MISSES STRESS(Mpa)	TOTAL DEFORMATION(mm)	SHEAR STRESS(Mpa)	TEMPERATURE DISTRIBUTION(°c)	TOTAL HEAT FLUX (W/mm2)
MGZRO3+AL4032	95.765	0.00866	54.794	325.71	1.3111
MGZRO3+ TI-6AL-4V	95.135	0.00860	54.433	329.43	1.2889
MGZRO3+ALSIC	93.875	0.0084	53.712	323	1.323
NI-CR-AL+AL4032	91.985	0.0083	52.631	314	1.3809
NI-CR-AL + TI-6AL-4V	90.094	0.0081	51.55	319	1.35
NI-CR-AL +ALSIC	88.582	0.0079	50.468	306	1.43

Figure 10RESULTS

VIII CONCLUSION

Design and static thermal analysis is done using unicorn 150 bike dimensions, The applications of thermal barrier coatings to various components of combustion zone of an engine such as piston and cylinder liner has produced significant improvements in thermal and mechanical efficiency and other performance parameters of the engine like specific fuel consumption and reduces exhaust emission. Thus this project explores various aspects, effect and application of thermal barrier coating in piston, cylinder liner, SI engine This project work concerned with the design and Static & thermal analysis of 0.4mm ceramic coated Piston. While comparing Mgzro3+AL4032, Mgzro3+Ti-6al-4V, Mgzro3+Al-sic, Ni-cr-al+Al4032, Ni-cr-al+Ti-6Al-4v, Ni-cr-al+Al-sic these materials, It is found that is NI-CR-AL+ALSIC MATERIAL better suited for high temperature applications. On evaluating the contours for temperature distribution, heat flux & Deformation & von-misses stress Shear stresses values are less compared to the remaining materials. Finally indicates that the piston coated with thermal barrier materials shows a lot of heat resistant ability which can lead to better utilization of heat produced in the combustion chamber as heat dissipation will be lesser which ultimately can improve the engine efficiency.

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