

EFFICIENCY AND LIFE IMPROVEMENT OF CYLINDER & PISTON BY THERMAL BARRIER COATING USING FINITE ELEMENT ANALYSIS

Submitted In partial fulfilment of the requirements for the award of Bachelor of
Engineering Degree in Automobile Engineering

By

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**DEPARTMENT OF AUTOMOBILE ENGINEERING
SCHOOL OF MECHANICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of R.DOMINIC MATHEW (Reg:No:37860008) and AKASH M. GLADIN(Reg:No.37860002)who carried out the project entitled"**EFFICIENCY AND LIFE IMPROVEMENT OF CYLINDER & PISTON BY THERMAL BARRIER COATING USING FINITE ELEMENT ANALYSIS**" under our supervision from October 2020 to March 2021.

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DECLARATION

We R.DOMINIC MATHEW (Reg: No.37860008) and AKASH M. GLADIN (Reg:No.37860002) hereby declare that the Project Report entitled “**EFFICIENCY AND LIFE IMPROVEMENT OF CYLINDER & PISTON BY THERMAL BARRIER COATING USING FINITE ELEMENT ANALYSIS**” done by us under the guidance of **Mr. V JAYAPRAKASH, M. Tech., (Ph.D.,)** is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering Degree in Automobile Engineering.

DATE: Apr 2021

PLACE: CHENNAI

SIGNATURE OF THE CANDIDATE

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ABSTRACT

Various recent developments has been progressing in the field of Automotive domain to have improved efficiency, better fatigue life, reduced weight using advanced materials and reduced emissions.

Thermal Barrier Coating, hereafter called as TBC is a recent development made in this effort by using coated materials which has very less thermal conductivity properties compared to conventional materials used in automotive engines like Grey Cast Iron, Aluminum etc.

These material coating is applied over the piston and cylinder surface as a thin layer to reduce metal to metal contact between the Piston and the cylinder. Due to its lower thermal conductance properties, it reduces the temperature delta between the cylinder head and the Piston there by reducing the thermal induced stresses and have a better efficiency and improved life.

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CHAPTER 1

INTRODUCTION

Internal Combustion Engines form a major part of the automotive domain due to their varied usage.

But the thermal efficiency of these engines has still lot more scope to improve and hence also to reduce the emission gases on to the atmosphere.

Various recent developments have been progressing in the field of the Automotive domain to have improved efficiency, better fatigue life, reduced weight using advanced materials, and reduced emissions.

Temperature differences between the Engine Head and the piston-cylinder have played a major role in inducing thermal stresses and hence play a vital role in predicting the life of an I.C. Engine. This temperature gradient has to be reduced for a better life and increased efficiency.

This project focuses on increasing the thermal efficiency of an I.C. Engine by using Thermal Barrier Coatings.

Thermal Barrier Coating, hereafter called TBC, is a recent development made in this effort by using coated materials which has very less thermal conductivity properties compared to conventional materials used in automotive engines like Grey Cast Iron, Aluminum, etc.

This material coating is applied over the piston surface as a thin layer to reduce metal-to-metal contact between the Piston and the cylinder. Due to its lower thermal conductance properties, it reduces the temperature delta between the cylinder head and the Piston thereby reducing the thermal-induced stresses and has better efficiency and improved life.

Modeling of the I.C. Engine (Cylinder and Piston) will be created in CATIA tool (an acronym of **computer-aided three-dimensional interactive application**) is a multi-platform computer-aided design (CAD)/computer-aided manufacturing (CAM)/computer-aided engineering (CAE) software.

The simulation of the I.C. Engine with and without the application of TBC over piston surface will be carried out using Finite Element Methods. Ansys will be used for this Finite Element calculation. It is a commercial Finite Element Tool that can perform steady-state structural analysis and thermal analysis study to predict the temperature distribution inside the I.C. Engine.

Two different analyses are carried out on the same I.C. Engine with and without the TBC coating. Same loads and boundary conditions will be used to analyze the Engine. The thermal distribution is studied on both configurations to understand the effect of the usage of these coatings. Also to estimate structurally the life improvement and improved efficiency.

1.1 THERMAL BARRIER COATING

Thermal Barrier Coating is basically a ceramic coating that basically has the properties to resist the temperature conduction from one surface to the other. It basically has lower thermal conductance properties. Also, they have higher thermal efficiency compared to the base metal used for manufacturing I.C. Engines. Due to these significant properties, the I.C. Engines coated with these TBCs have a better life, improved efficiency, and lower emission. They also have good adhesion capabilities to the base metal so that the structural integrity in the overall composition is maintained.

These 100 μ m to 2mm coatings serve to insulate components from large and prolonged heat loads by utilizing thermally insulating materials, which can sustain an appreciable temperature difference between the load-bearing alloys and the coating surface. In doing as such, these coatings can take into higher working temperatures while restricting the thermal exposure of structural components, expanding part life by diminishing oxidation and thermal fatigue.

Thermal barrier coatings ordinarily comprise four layers: the metal substrate, metallic bond coat, thermally grown oxide (TGO), and ceramic topcoat. The ceramic topcoat is commonly made out of yttria-stabilized zirconia (YSZ), which is attractive for having low conductivity while staying stable at ostensible working temperatures

regularly found in applications. This ceramic layer makes the thermal gradient of the TBC and keeps the lower layers at a lower temperature than the surface.

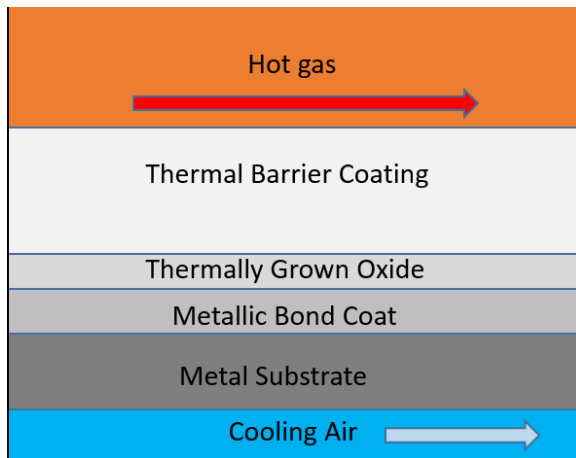


Fig 1.1: Pictorial representation of the layers of TBC.

There are several types of TBCs available in the market. They are

1. YSZ
2. Mullite
3. Alumina
4. $\text{CeO}_2 + \text{YSZ}$
5. Rare earth zirconates
6. Rare earth oxides
7. Metal Glass Composites

These different types of TBC have varied use in different applications based on the properties as explained below.

1. YSZ is the most broadly contemplated and utilized TBC on the grounds that it gives phenomenal execution in applications like diesel motors and gas turbines. Also, it was one of only a handful few stubborn oxides that could be stored as thick movies utilizing the then-referred innovation of plasma spraying.[8] As for properties, it has low warm conductivity, high warm development coefficient, and low, warm stun obstruction. In any case, it has a genuinely low working constraint of 1200C because of stage flimsiness and can erode because of its oxygen straightforwardness.

- 2.
3. Mullite is a compound of alumina and silica, with the recipe $3\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2$. It has a low thickness, alongside great mechanical properties, high warm solidness, low warm conductivity, and its consumption and oxidation safe. In any case, it experiences crystallization and volume constriction above 800°C , which prompts breaking and delamination. Thusly this material is reasonable as a zirconia elective for applications like diesel motors, where surface temperatures are generally low, and temperature varieties across the covering might be huge.
4. Just α -stage Al_2O_3 is steady among aluminum oxides. With a high hardness and compound idleness, yet high warm conductivity and low, warm development coefficient, alumina is frequently utilized as an expansion to a current TBC covering. By joining alumina in YSZ TBC, oxidation and consumption opposition can be improved, just as hardness and bond strength without critical change in the versatile modulus or sturdiness. One test with alumina is applying the covering through plasma showering, which will in general, make an assortment of precarious stages, for example, γ -alumina, at the point when these stages at last change into the stable α -stage through warm cycling, a huge volume change of $\sim 15\%$ (γ to α) follows, which can prompt microcrack arrangement in the covering.
- 5.
6. CeO_2 (Ceria) has a higher warm development coefficient and lower warm conductivity than YSZ. Adding ceria into a YSZ covering can altogether improve the TBC execution, particularly in warm stun obstruction. This is undoubted because of less bond coat pressure because of better protection and a superior net warm extension coefficient. Some adverse consequences of the expansion of ceria incorporate the diminishing of hardness and sped-up pace of sintering of the covering (less permeable).
- 7.
8. $\text{La}_2\text{Zr}_2\text{O}_7$ additionally alluded to as L.Z., is an illustration of an uncommon earth zirconate that shows potential for use as a TBC. This material is stage stable up to its dissolving point and can, to a great extent endure opportunities

on any of its sublattices. Alongside the capacity for site replacement with different components, this implies that warm properties might actually be custom fitted. Despite the fact that it additionally has low, warm conductivity contrasted with YSZ, it likewise has a low, warm development coefficient and low sturdiness.

9.

10. The combination of uncommon earth oxides is promptly accessible, modest, and may have a guarantee as successful TBCs. The coatings of uncommon earth oxides (ex: La_2O_3 , Nb_2O_5 , Pr_2O_3 , CeO_2 as fundamental stages) have lower warm conductivity and higher warm development coefficients when contrasted with YSZ. The primary test to defeat is the polymorphic idea of most uncommon earth oxides at raised temperatures, as stage flimsiness will, in general, contrarily sway warm stun opposition.

11.

12. A powder combination of metal and ordinary glass can be plasma-showered in a vacuum, with an appropriate piece bringing about a TBC similar to YSZ. Moreover, metal-glass composites have predominant bond-coat

- -
 -
 -
- adherence, higher warm development coefficients, and no open porosity, which forestalls oxidation of the bond coat.

1.2 PROCESS FLOWCHART

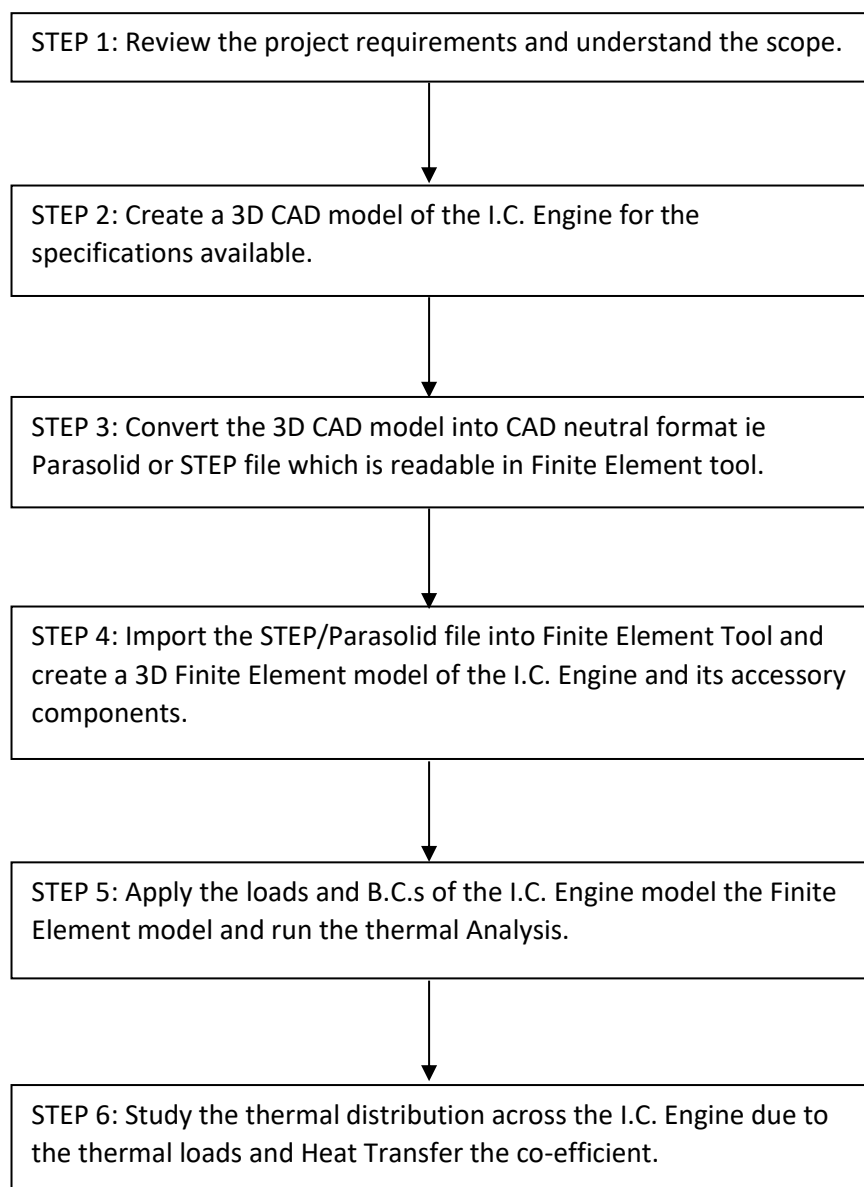
This project focuses on the calculation of the efficiency and life improvement study of automotive engines by thermal barrier coating using finite element methods using multiple steps.

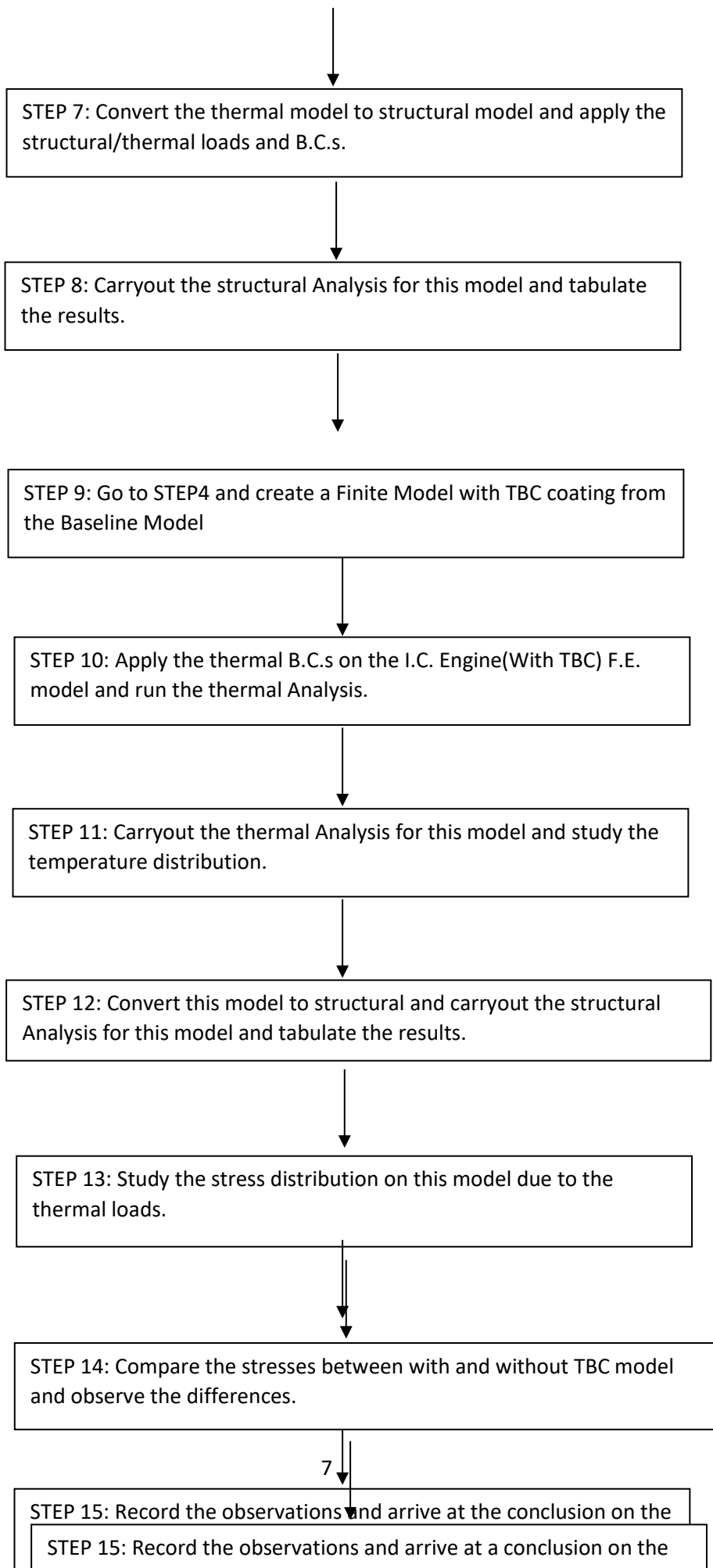
These multiple steps involve creating a CAD-based 3D model of the I.C. Engine with its integral components using specifications, export the solid model as Parasolid or

STEP file using CAD translation/ convertors. Create a Finite Element model using the exported CAD file, apply appropriate loads and B.C.s on the 3D model and analyze it for thermal Analysis for two models- one baseline model without TBC and the other model coated with TBC. Compare the thermal results and record the observations.

Convert the model into a structural model and analyze both the models with structural loads and compare the structural results. Record the observations and estimate the improvement in the TBC coated model over the baseline model.

The flowchart given below shows the project steps involved in the complete cycle of this project in a step-by-step manner. Step 1 to 8 is for the Baseline model and Step 9 to end is for the TBC coated model.





1.3 COMPUTER AIDED DESIGN MODEL:

Computer-aided design (CAD) is the utilization of P.C. frameworks to help in the creation, alteration, investigation, or advancement of a plan. Computer-aided design programming is utilized to build the profitability of the creator, improve the nature of configuration, improve correspondences through documentation, and to make an information base for assembling. Computer-aided design yield is regularly as electronic records for print, machining, or other assembling activities.

Computer-aided design

is a significant modern craftsmanship broadly utilized in numerous applications, including auto, shipbuilding, and aviation ventures, mechanical and structural plan.

There are two kinds of 3D Solid Modeling

1. Parametric demonstrating permits the administrator to utilize what is alluded to as "plan purpose". The items and highlights made are modifiable. Any future alterations can be made by changing how the first part was made. In the event that an element was proposed to be situated from the focal point of the part, the administrator ought to find it from the focal point of the model. The component could be found utilizing any mathematical item effectively accessible in part. However, this arbitrary position would crush the plan expectation. In the event that the administrator plans the part as it works, the parametric modeler can make changes to the part while keeping up mathematical and useful connections.

2. Immediate or Explicit demonstration gives the capacity to alter math without a set of experiences trees. With direct displaying, once a sketch is utilized to make math, the sketch is joined into the new calculation, and the fashioner simply adjusts the math without requiring the first sketch. Similarly, as with parametric demonstrating, direct displaying can incorporate connections between chose math (e.g., intersection, concentricity).

1.4 CATIA INTRODUCTION :

CATIA is one of the world's leading CAD/CAM/CAE packages. Being a solid modeling tool, it not only unites 3D parametric features with 2d tools but also addresses every design- through- manufacturing process. Besides providing an insight into the design content, the package promotes collaboration between companies and provides them with edges over their competitors.

CHAPTER 2

LITERATURE SURVEY

2.1 M Azadi^{1,2}, M. Baloo^{2,3}, G. H. Farrahi^{*1}, S. M. Mirsalim^{2,3}:

Studied the thermal barrier coating effects on diesel engine performance and components lifetime

This paper summarizes the coating system has effects on fuel consumption, power and the combustion efficiency, pollution contents, and the fatigue lifetime of engine components. Usually, there are several beneficial influences by applying ceramic layers on the combustion chamber, including the Piston, the cylinder head, the cylinder block, intake, and exhaust valves, by using a plasma thermal spray method. Finally, they concluded that the proper type of coating system could be created from two layers of coatings, including a layer made of NiCrAlY with 150 microns thickness and another layer made of ZrO₂-8%Y₂O₃ with 300 microns thickness. In this case, the fuel consumption reduces, the engine power and the combustion efficiency increase, pollution contents decrease, and the fatigue lifetime of engine components such as the cylinder head and the Piston improves.

2.2 S. Kumar, S. Kant, N. M. Suri, R.verma (1):

Studied the Effects of Thermal Barrier CoatingsDieseland Gas turbine engines

This paper summarizes that the Future demands for significantly higher Engine operating temperature, fuel efficiency, and better engine reliability are the driving force behind the development of Thermal barrier coatings (TBCs). Conventional thermal barrier coating (TBC) systems consist of a thermally grown oxide (TGO) sandwiched between topcoat and bond coat. This bond coat is bonded to a metal substrate. Zirconia-yttria-based oxides and (Ba, Sr)Al₂Si₂O₈ (BSAS)/mullite-based silicates have been used as thermal barrier coating materials. Finally, they conclude that the future need to reduce NO_x pollution together led to continues innovation in the field of engine thermal barrier coatings and associated technologies. Thermal barrier coatings(thin layer about 100 microns for gas turbines and thick layer about 1mm for diesel engines) will play a crucial role in advanced gas turbine and diesel

engines because of their ability to further increase engine operating temperature and reduce cooling requirements, thus help to contribute to achieving a significant reduction in fuel consumption, emission, oil consumption, engine noise, Components temperature, and cost, while increasing heat engine efficiency or performance with component reliability and durability.

2.3Raghu (1), Girishkumar G S (2), K Chandrashekara (3):

Studied the Effect of Thermal Barrier Coating on Diesel Engine Performance

This paper summarizes the use of thermal barrier coating materials in the automotive industry has been found to yield a significant effect on the efficiency of engines. The higher the operating temperature more will be the efficiency of the system. However, much higher temperatures demand it enhanced temperature-resistant materials to be used. Yttria Stabilized Zirconia material is used as Coating for the engine piston crown and cylinder liner by Plasma Spraying technique. Finally concluded that the applications of thermal barrier coatings to various components of the combustion zone of an engine such as piston and cylinder liner had produced significant improvements in thermal and mechanical efficiency and other performance parameters of the Engine, like specific fuel consumption. Thus this paper explores various aspects, effects, and applications of thermal barrier coating in Piston, cylinder liner, and Diesel engine performance. So this paper serves as a complete reference guide for the researchers who work on the improvement of diesel engine performance.

2.4K.Thiruselvam:

Experimental study on Thermal Barrier Coatings in Internal Combustion Engine:

This paper summarizes the depletion of fossil fuel resources at a faster rate in the present world of economic competitiveness is generating an essential demand for an increase in efficiency of internal combustion engines. The use of Coating in the automotive industry has been found to yield a significant effect on the efficiency of engines. The higher the operating temperature more will be the efficiency of the system. However, much higher temperatures demand it enhanced temperature-resistant materials to be used. This paper presents a review of the various aspect and usage of thermal insulating materials (commonly known as thermal barrier coatings). Finally, they concluded that the applications of thermal barrier coatings to various

components of the 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.

2.5 Prof. Dipak C. Gosai(1), Mahesh M. Chudasama (2) :

the Application of TBC Materials in I.C. Engine Combustion Chamber

This paper summarizes the Thermal barrier coating (TBCs) applications in Internal combustion engines Chamber performed to select a proper type and to find coating effects. The TBC coating technique has effects on the specific fuel consumption, the power and the combustion characteristic, pollution contents, and the Thermal fatigue lifetime of engine components.

Usually, there are several beneficial influences by applying ceramic layers on the combustion chamber, including the Piston, the cylinder head, the cylinder block, intake, and exhaust valves, by using a plasma thermal spray method. In this article, all effects, merits, and demerits of TBCs are investigated based on the presented articles. Finally, they concluded that low thermal conductivity Coating materials such as Abradables, Polymer Fillers, MCrAlY Alloys, Carbides Cermets on the engine piston, combustion chamber gives the maximum thermal efficiency in Engine a reduce the emission from Engine.

TBCs were first used towards the end of 1950 as protection on ductwork and rocket nozzles within experimental projects at NASA. TBC's began first in military service but progressed to civilian engines around the mid to late '70s. By the 21st century, thermal barrier coatings have become integral to almost every modern aero turbine and stationary gas turbine produced.

CHAPTER 3

RESEARCHED METHODOLOGY

3.1 INTRODUCTION TO CATIA:

CATIA- Computer Aided Three Dimensional Interactive Application

CATIA, developed by **Dassault Systems, France**, is a completely re-engineered, next-generation family of CAD /CAM/CAE software solutions.

CATIA serves the basic design task by providing different workbenches. Some of the workbenches available in this package are

- **Part Design workbench**
- **Assembly Design workbench**
- **Drafting workbench**
- **Wireframe and Surface Design workbench**
- **Generative shape design workbench**
- **DMU kinematics**
- **Manufacturing**
- **Mold Design**

PART DESIGN WORKBENCH

The Part workbench is a parametric and feature-based environment in which you can create solid models. In the part Design workbench, you are provided with a tool that converts sketches into other features are called the sketch-based features.

ASSEMBLY DESIGN WORKBENCH

The Assembly Design workbench is used to assemble the part by using assembly constraints. There are two types of assembly design,

Bottom-up

Top-down

In the bottom-up assembly, the parts are created in part workbench and assembled in assembly workbench.

In the top-down assembly, the parts are created in the assembly workbench itself.

3.2 WIREFRAME & SURFACE DESIGN:

The Wireframe and surface design workbench is additionally a parametric and highlight-based climate. The instruments accessible in this workbench are like those in the part workbench, with the lone distinction that the device in this climate are utilized to make fundamental and advanced surfaces.

Note: While creating surface, we are considering that the surface having a negligible thickness

3.3 DRAFTING WORKBENCH

The Drafting workbench is utilized for the documentation of the parts or the congregations made through drawing.

There are two sorts of drafting methods:

Generative drafting

Interactive drafting

The generative drafting method is utilized to consequently produce the drawing perspectives on parts and congregations.

In intelligent drafting, you need to make the drawing interactive with the sketcher to create the perspectives.

DMU KINEMATICS

This workbench manages the overall movement of the parts. DMU Kinematics Simulator is an autonomous CAD item devoted to mimicking gathering movements. It tends to the plan survey climate of advanced models (DMU) and can deal with a wide scope of items from customer merchandise to huge auto or aviation projects just as plants, boats, and large equipment.

TERMS AND DEFINITIONS

Some of the important terms and definitions in CATIA are discussed below.

3.4 FEATURE-BASED MODELLING

The feature is defined as the smallest building block that can be modified individually. A model created in CATIA is a combination of a number of individual features, and each feature is related to the other feature directly or indirectly, and therefore it can be modified at any time during the design process. This provides greater flexibility to the design.

3.5 PARAMETRIC MODELLING

The main function of this property is to derive the selected geometry to a new size or shape without considering its original size or shape. You can change or modify the shape and size of any feature at any stage of the design process.

ASSOCIATIVITY

As mentioned earlier, CATIA has different workbenches such as Part Design workbench, Assembly Design workbench, and Drawing workbench. There exists bidirectional associativity between all these workbenches. This associativity ensures that if any modification is made in the model in any one of the workbenches of CATIA, it is automatically reflected in the other workbenches immediately.

CATPart

CATPart is a file extension associated with all the files that are created in Sketcher, Part Design, and Wireframe and Surface Design workbenches of CATIA V5.

CATProduct

CATProduct is a file extension associated with all the files that are created in the Assembly Design workbench of CATIA V5.

CATDrawing

CATDrawing is a file extension associated with all the files that are created in the Drafting workbench of CATIA V5.

The CAD model of the I.C. Engine with the Piston was created in a commercial 3D CAD Software called CATIA. A Parametric Model of the I.C. Engine was created from basic 2D curves and converting them into 3D solids using many options in CAD like Extrude and Revolve and Pattern. Stress concentration location was avoided by creating a blend in the model at all sharp edges to avoid singular stresses. The engine specifications were used to create the overall dimensions of the CAD model with the accurate bore dimensions. The model was so created in Parametric so that the model can be changed or modified according to the change in the specification at a later stage if anything is required.

Asymmetric model of the I.C. Engine is used with symmetric Boundary Conditions since the model is completely symmetric about the planar center as shown in below

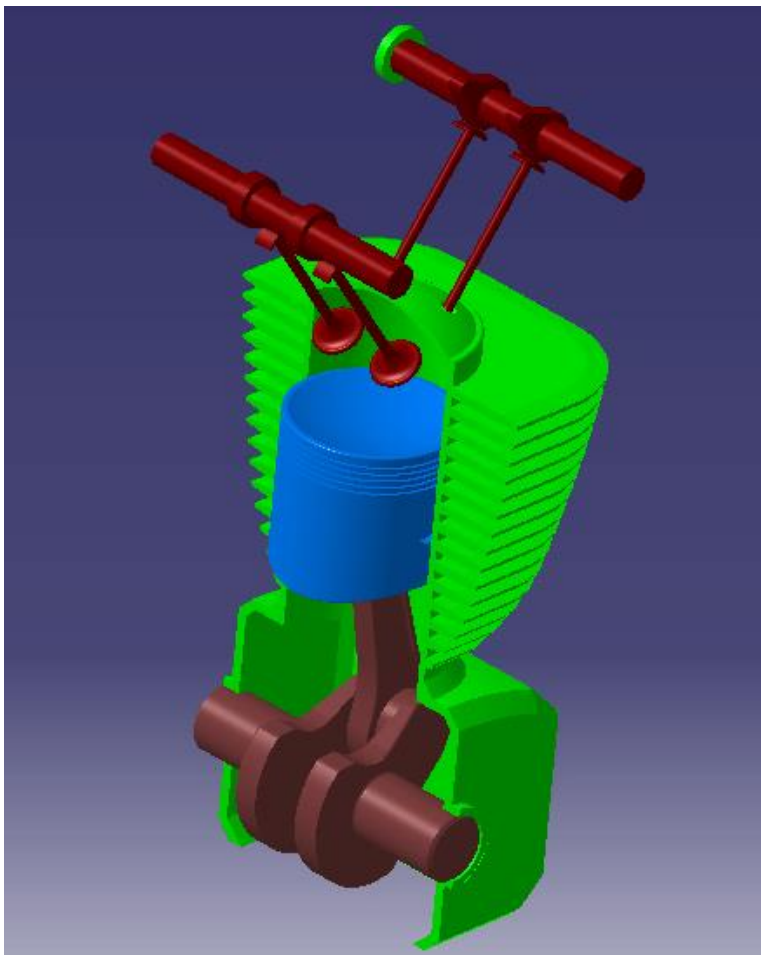


Fig.3.1 CAD Model of Ic Engine

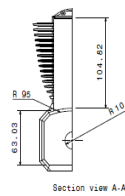
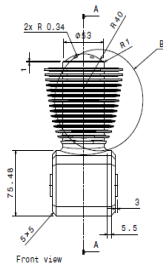
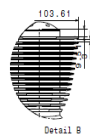
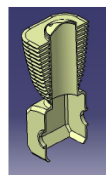
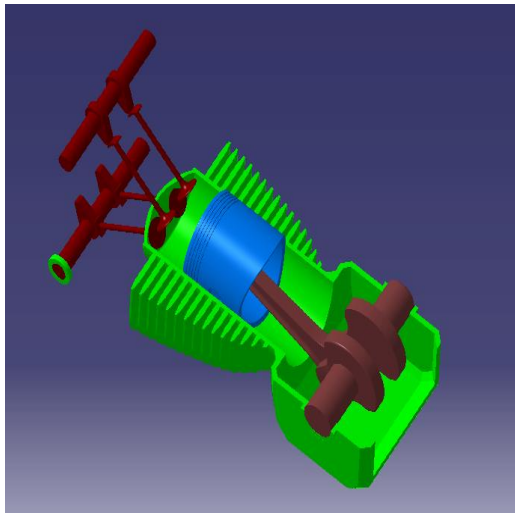
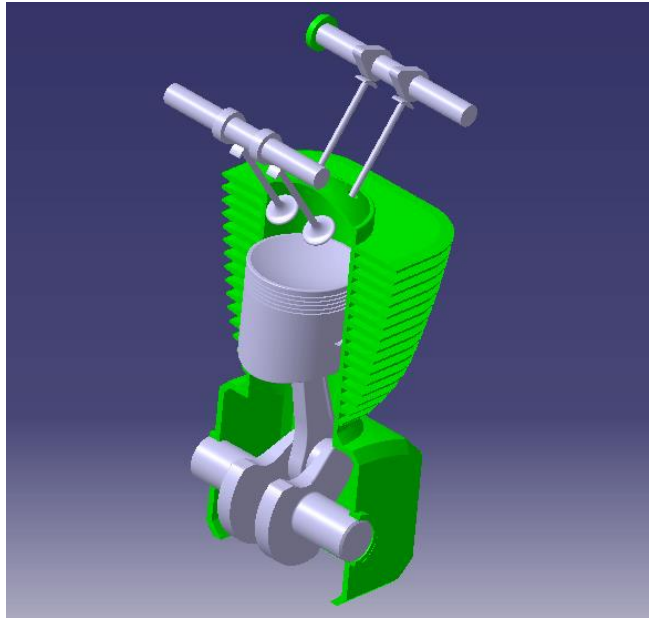
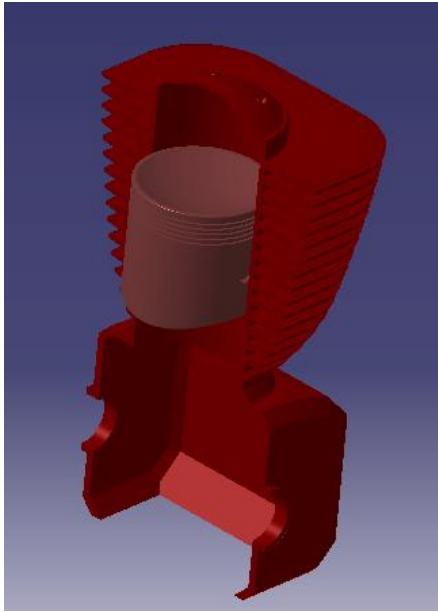
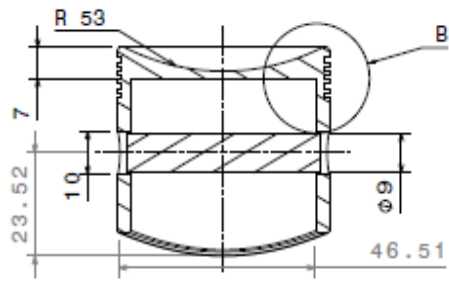
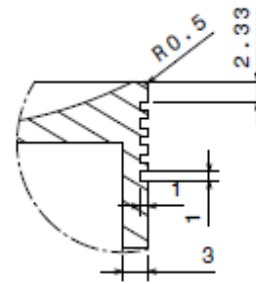


Fig 3.2 Cylinder Base

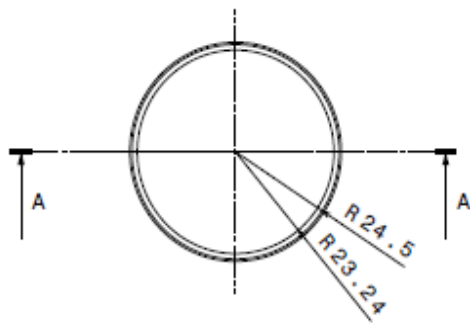
CYLINDER CASE



Section view A-A



Detail B



Front view

PISTON

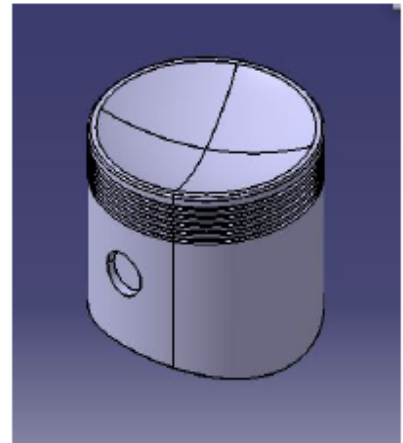


Fig 3.3 Piston

CHAPTER 4

FINITE ELEMENT ANALYSIS

History:

The inception of limited technique can be followed to the framework examination of designs where the idea of dislodging or firmness network approach was presented. Limited component ideas were created dependent on designing techniques in the 1950s. The limited component strategy acquired its genuine stimulus during the 1960s and 1970s by the developments of John Argyris with co-workers at the University of Stuttgart, Ray W. Clough with co-workers at the University of California, Berkeley, Olgierd Zienkiewicz with co-workers Ernest Hinton, Bruce Irons, and others at the University of Swansea, Philippe G. Ciarlet at the University of Paris and Richard Gallagher with co-workers at Cornell University. The original works such as those by Argyris and Clough became the foundation for today's finite element structural analysis methods. Earlier books such as by Zienkiewicz and more recent books such as by Yang give a comprehensive summary of developments in finite-element structural Analysis. Implementing the method in software is described in the classic text by Smith, Griffiths, and Margetts.

Definition:

The finite element method (FEM) is an incredible procedure initially created for the numerical solutions of complex issues in primary mechanics, and it stays the technique for decision for complex frameworks. In the FEM, the underlying framework is displayed by a bunch of suitable limited components interconnected at focuses called hubs. Components may have actual properties like thickness, coefficient of warm development, thickness, Young's modulus, shear modulus, and Poisson's proportion. The Finite Element Model becomes the input for the analytical problem, which uses various numerical methods to solve the displacement equations from one node to another for a structural problem. Some types of commonly used Finite Element Analysis are

1. Thermal Analysis to predict the thermal distribution of the overall model to understand and predict the flow characteristics.
2. Modal Analysis to extract the natural frequencies and mode shapes of the overall structure and so predict the modes of failure.
3. Linear and nonlinear (e.g., elastic-plastic) static stress/displacement analysis (buckling, thermal loading, quasi-static Analysis)
4. Dynamic stress/displacement analysis (modal and transient modal dynamic analysis, nonlinear transient Analysis, e.g., impact)
5. Nonlinear stress analysis for the simulation of manufacturing processes, e.g., metal forming
6. Contact analyses to simulate contact between parts and assemblies
7. Analyses of a welded and/or bolted connections
8. Fatigue and fracture analysis
9. Sub-modelling to study a local part of a larger model
10. Roll-over and falling-object protective structures
11. Steel & reinforced concrete buildings/frames. • Analyses of structures due to fire.

In this project, we have made use of the Thermal and Structural Analysis to predict the thermal distribution and structural behavior of the model due to the usage of Thermal Barrier Coating.

4.1 PRACTICAL ASSUMPTION OF FEA:

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces. Hence it has to be backed with certain approximations and assumptions for the tool to solve the numerical solutions.

From the application point of view, it is important to model the system such that:

- Symmetry or anti-symmetry conditions are exploited in order to reduce the size of the domain.
- Displacement compatibility, including any necessary irregularity, is guaranteed at the hubs, and ideally, along the component edges too, especially

when adjoining components are of various sorts, material, or thickness. The similarity of relocations of numerous hubs can, for the most part, be forced through limitation relations—When such a feature is not available in the software package, a physical model that imposes the constraints may be used instead.

- Elements' behaviors capture the dominant actions of the actual system, both locally and globally.
- The element mesh is sufficiently fine to have worthy exactness. To survey precision, the lattice is refined until the significant outcomes show little change. For higher exactness, the viewpoint proportion of the components ought to be as near solidarity as could really be expected, and more modest components are utilized over the pieces of higher pressure angle.
-
- Appropriate help imperatives are forced with unique consideration paid to hubs on evenness tomahawks.

Huge scope business programming bundles regularly give offices to creating the lattice, graphical showcase of info and yield, which enormously work with the check of both information and understanding of the outcomes.

4.2 APPLICATIONS OF FEA:

The strategy is regularly utilized as an option in contrast to the test technique set out in numerous principles. The strategy depends on the reason that a rough answer for any unpredictable designing issue can be reached by partitioning the construction/segment into more modest, more sensible (limited) components. The Finite Element Model (FEM) is examined with a characteristically more noteworthy exactness than would somehow or another be conceivable utilizing regular hand investigations, since the genuine shape, burden and imperatives, too as material property blends, can be determined with a lot more prominent precision than that utilized in traditional hand estimations.

An assortment of specializations under the umbrella of the mechanical designing order (like aeronautical, biomechanical, and auto enterprises) regularly utilize coordinated FEM in the plan and advancement of their items. A few present-day FEM bundles incorporate explicit segments like warm, electromagnetic, liquid, and underlying workplaces. In a primary reenactment, FEM helps massively in delivering solidness and strength representations and, furthermore, in limiting weight, materials, and expenses.

FEM permits the point-by-point representation of where designs twist or curve and show the circulation of stresses and removals. FEM programming gives a wide scope of recreation alternatives for controlling the intricacy of both demonstrating and investigating a framework. Also, the ideal degree of exactness required and related computational time necessities can be overseen at the same time to address most designing applications. FEM permits whole plans to be developed, refined, and enhanced before the plan is fabricated.

This incredible plan device has essentially improved both the norm of designing plans and the procedure of the planning cycle in numerous mechanical applications. The presentation of FEM has significantly diminished an opportunity to take items from idea to the creation line. It is essentially through improved starting model plans utilizing FEM that testing and advancement have been sped up. In rundown, advantages of FEM incorporate expanded exactness, improved plan, and better understanding into basic plan boundaries, virtual prototyping, fewer equipment models, a quicker and more affordable plan cycle, expanded profitability, and expanded income

The strategy is involved three phases

(A) Pre-handling, in which the expert builds up a limited component lattice of the math and applies material properties, limit conditions, and loads

(B) Solution, during which the program determines the overseeing lattice conditions (firmness $\times$ uprooting = load) from the model and addresses the relocations, strains,

and stresses. This is the situation in implied code applications. On the other hand, express codes can be utilized, generally for high strain rate designing issues.

(C) Post-handling, in which the examiner acquires results ordinarily as disfigured shapes, form plots, and so on which help to check the legitimacy of the arrangement.

4.3 FINITE ELEMENT TOOL:

The student version of the FEA package named Ansys has been used. Ansys is the commercial FEA tool used for this Analysis which is widely available in the market.

ANSYS Mechanical software is a comprehensive finite element analysis (FEA) tool for structural Analysis, including linear, nonlinear, dynamic, hydrodynamic and explicit studies. It provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems. In addition, ANSYS Mechanical Enterprise offers thermal Analysis and coupled-physics capabilities involving acoustic, piezoelectric, thermal–structural and thermo-electric Analysis.

4.4 ELEMENT TYPE USED:

Various finite element types were used in this Analysis appropriately to model to component behavior more realistically. The basic characteristics of the Elements used in this Analysis are listed below.

SOLID 185: Used to model the Piston and Cylinder

SOLID185 Element Description SOLID185 is utilized for 3-D demonstrating of strong constructions. It is characterized by eight hubs having three levels of opportunity at every hub: interpretations in the nodal x, y, and z headings. The component has pliancy, hyperelasticity, stress solidifying, creep, huge redirection, and huge strain abilities. It additionally has blended detailing ability for recreating distortions of almost incompressible elastoplastic materials, and completely incompressible hyperelastic materials. SOLID185 is accessible in two structures: • Homogeneous Structural Solid (KEYOPT(3) = 0, the default) - See "SOLID185 Homogeneous Structural Solid Element Description" . • Layered Structural Solid (KEYOPT(3) = 1) - See "SOLID185 Layered Structural Solid Element Description" (p. 966). See SOLID185 in the Mechanical APDL Theory Reference for additional insights regarding this component. A higher-request adaptation of the SOLID185 component is SOLID186. SOLID185

Homogeneous Structural Solid Element Description SOLID185 Structural Solid is appropriate for displaying general 3-D strong constructions. It takes into account crystal, tetrahedral, and pyramid degenerations when utilized in unpredictable areas. Different component innovations, for example, B-bar, consistently decreased mix, and improved strains are upheld.

The component is characterized by eight hubs and the orthotropic material properties. The default component facilitate framework is along worldwide headings. You may characterize a component arrange framework utilizing ESYS, which shapes the reason for orthotropic material bearings. Component loads are depicted in Nodal Loading . Pressing factors might be contribution as surface burdens on the component faces. Positive pressing factors act into the component. Temperatures might be contribution as component body loads at the hubs. The hub I temperature $T(I)$ defaults to TUNIF. In the event that any remaining temperatures are unknown, they default to $T(I)$. For some other information temperature design, unknown temperatures default to TUNIF. Comparative defaults happens for fluence aside from that zero is utilized rather than TUNIF. KEYOPT(6) = 1 sets the component for utilizing blended definition. For subtleties on the utilization of blended plan, see Applications of Mixed u-P Formulations in the Element Reference. You can apply an underlying pressure state to this component through the INISTATE order. For more data, see Initial State in the Basic Analysis Guide. As depicted in Coordinate Systems , you can utilize ESYS to arrange the material properties and strain/stress yield. Use RSYS to pick yield that follows the material facilitate framework or the worldwide arrange framework. For the instance of hyperelastic materials, the yield of anxiety is consistently as for the worldwide Cartesian arrange framework instead of following the material/component facilitate framework. The impacts of pressing factor load solidness are consequently included for this component. In the event that an unsymmetrical grid is required for pressure load firmness impacts, use NROPT,UNSYM.

TABLE:4.1:-

--	--

Nodes	I, J, K, L, M, N, O, P
Degrees of Freedom	UX, U.Y., U.Z.
Real Constants	None, if KEYOPT(2)=0, Hourglass Stiffness Scaling factor, if KEYOPT(2)=1 (1.0 by default, or if set to 0.0)
Material Properties	EX, EY, EZ, (PRXY, PRYZ, PRXZ or NUXY, NUYZ, NUXZ), ALPX, ALPY, ALPZ, DENS, GXY, GYZ, GXZ, DAMP
Surface Loads	Pressures: face 1 (J-I-L-K), face 2 (I-J-N-M), face 3 (J-K-O-N), face 4 (K-L-P-O), face 5 (L-I-M-P), face 6 (M-N-O-P)
Body Loads	Temperatures: T (I), T (J), T (K), T (L), T (M), T (N), T (O), T (P)
Special Features	Plasticity, Stress stiffening, Large deflection, Large strain
KEYOPT(2)	0 - Selective reduced integration (B-bar method). 1 - Uniform reduced integration with hourglass control

SOLID185 uses the standard $\bar{\epsilon}$ method where volumetric strain terms at the Gauss integration points are replaced by the average volumetric strain of the elements. This method is also known as the selective reduced integration method. Using this method helps to prevent mesh volumetric locking in nearly incompressible cases. See Section 14.185 of the ANSYS Theory Reference for more information.

Note-Since this element does not have extra shapes, it can exhibit shear locking in bending types of applications. In such situations, the use of KEYOPT(2)=1 is recommended, which uses uniform reduced integration technique with hourglass stiffness for controlling hourglass modes. This option is the same as SOLID45 with KEYOPT(2)=1.

When the uniform reduced integration option is used, you can check the accuracy of the solution by comparing the total energy (SENE label in ETABLE) and the artificial energy (AENE label in ETABLE) introduced by hourglass control. If the ratio of:

$$\frac{\text{artificial energy}}{\text{total energy}} < 5\%$$

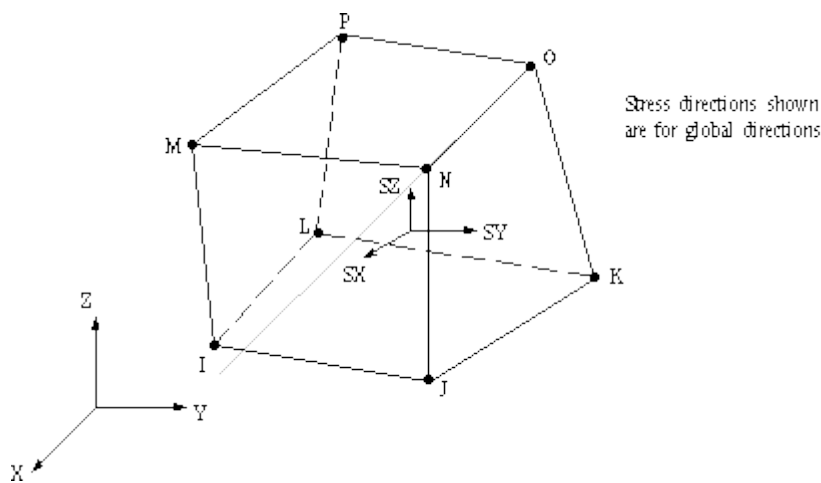
the solution is generally acceptable. If the ratio exceeds 5%, refine the mesh. The total energy and artificial energy can also be monitored by using the OUTPR, VENG command in the solution phase.

The solution output associated with the element is in two forms:

- nodal displacements included in the overall nodal solution
- additional element output as shown in Table 4.185-2

Several items are illustrated in Figure 4.1. See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2.2.2.2 of this manual for more information. .

Figure 4.1 SOLID185 Stress Output



The following notation is used in Table 4.1:

A colon (:) in the **Name** segment demonstrates the thing can be gotten to by the Component Name strategy [**ETABLE**, **ESOL**] (see Section 2.2.2). The **R** segment shows the accessibility of the things in the outcomes document (**R**), a **Y** demonstrates that the thing is consistently accessible, a number alludes to a table commentary which portrays when the thing is restrictively free, and a - shows that the thing isn't accessible.

Table 4.2 SOLID185 Element Output Definitions

Name	Definition	O	R
<i>E.L.</i>	Element number	-	Y
<i>NODES</i>	Nodes - I, J, K, L, M, N, O, P	-	Y
<i>MAT</i>	Material number	-	Y
<i>VOLU:</i>	Volume	-	Y
<i>CENT: X, Y, Z</i>	Global location XC, YC, Z.C.	-	Y
<i>PRES</i>	Pressures P1 at nodes J, I, L, K; P2 at I, J, N, M; P3 at J, K, O, N; P4 at K, L, P, O; P5 at L, I, M, P; P6 at M, N, O, P	-	Y
<i>TEMP</i>	Temperatures T(I), T(J), T(K), T(L), T(M), T(N), T(O), T(P)	-	Y
<i>S:INT</i>	Stress intensity	-	Y
<i>S:EQV</i>	Equivalent stress	-	Y
<i>EPEL: X, Y, Z, X.Y., Y.Z., X.Z.</i>	Elastic strains	Y	Y
<i>EPEL: 1, 2, 3</i>	Principal elastic strains	-	Y
<i>S: X, Y, Z, XY, YZ, XZ</i>	Stresses	Y	Y
<i>S: 1, 2, 3</i>	Principal stresses	-	Y
<i>EPPL: X, Y, Z, X.Y., Y.Z., X.Z.</i>	Average plastic strains	-	1
<i>NL:EPEQ</i>	Average equivalent plastic strain	-	1
<i>NL:SRAT</i>	Plastic yielding (1=actively yielding, 0=not yielding)	-	1
<i>NL:HPRES</i>	Hydrostatic pressure	-	1

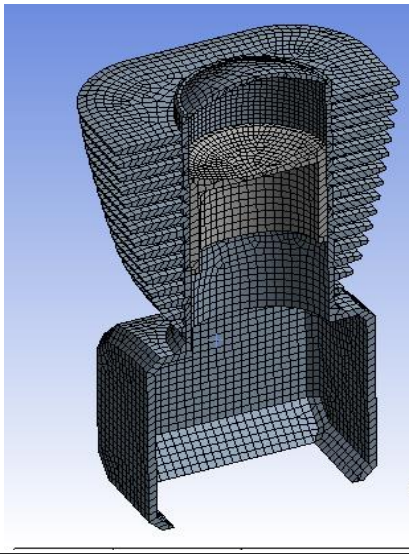
1. Nonlinear solution, output only if the element has a nonlinear material

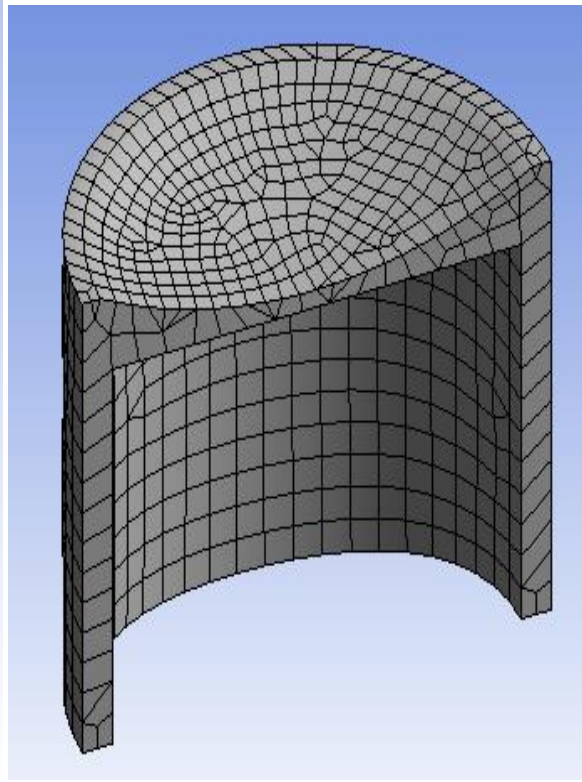
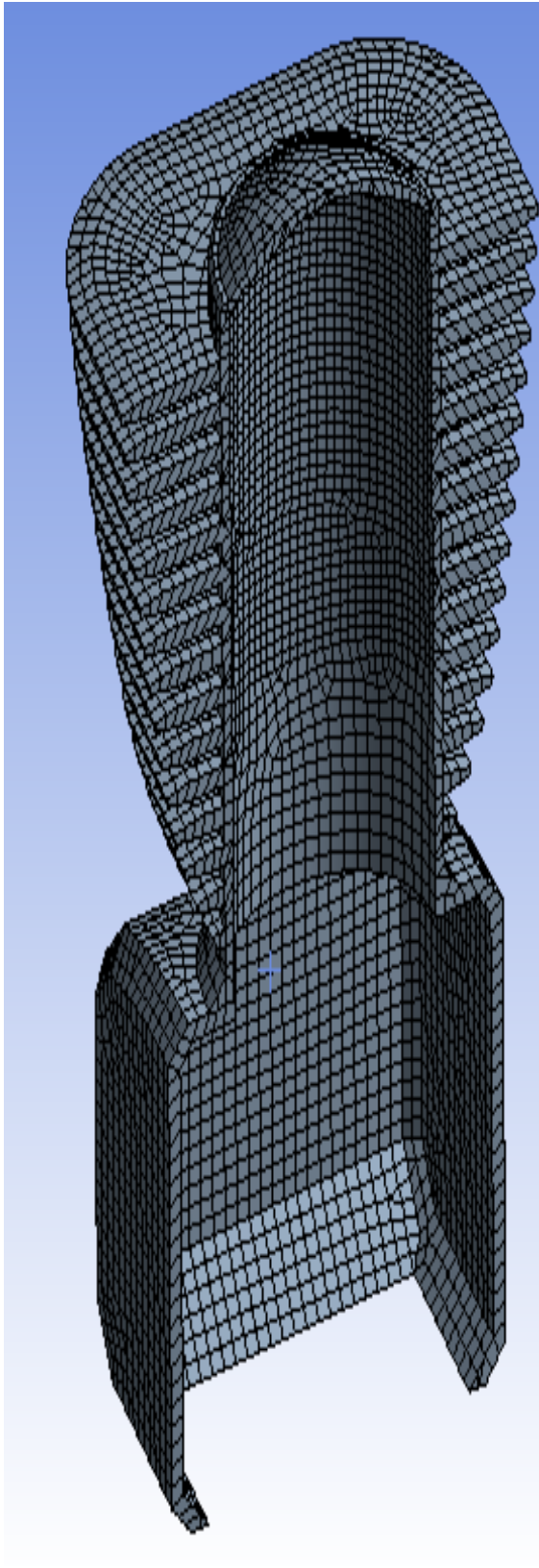
Table 4.1 lists output available through the **ETABLE** command using the Sequence Number method. See Chapter 5 of the *ANSYS Basic Analysis Procedures Guide* and Section 2.2.2.2 of this manual for more information. The following notation is used in Table 4.1:

4.5 CONTACT 174 INPUT DATA:

CONTA174 is u

Fig 4.2 Meshed Model





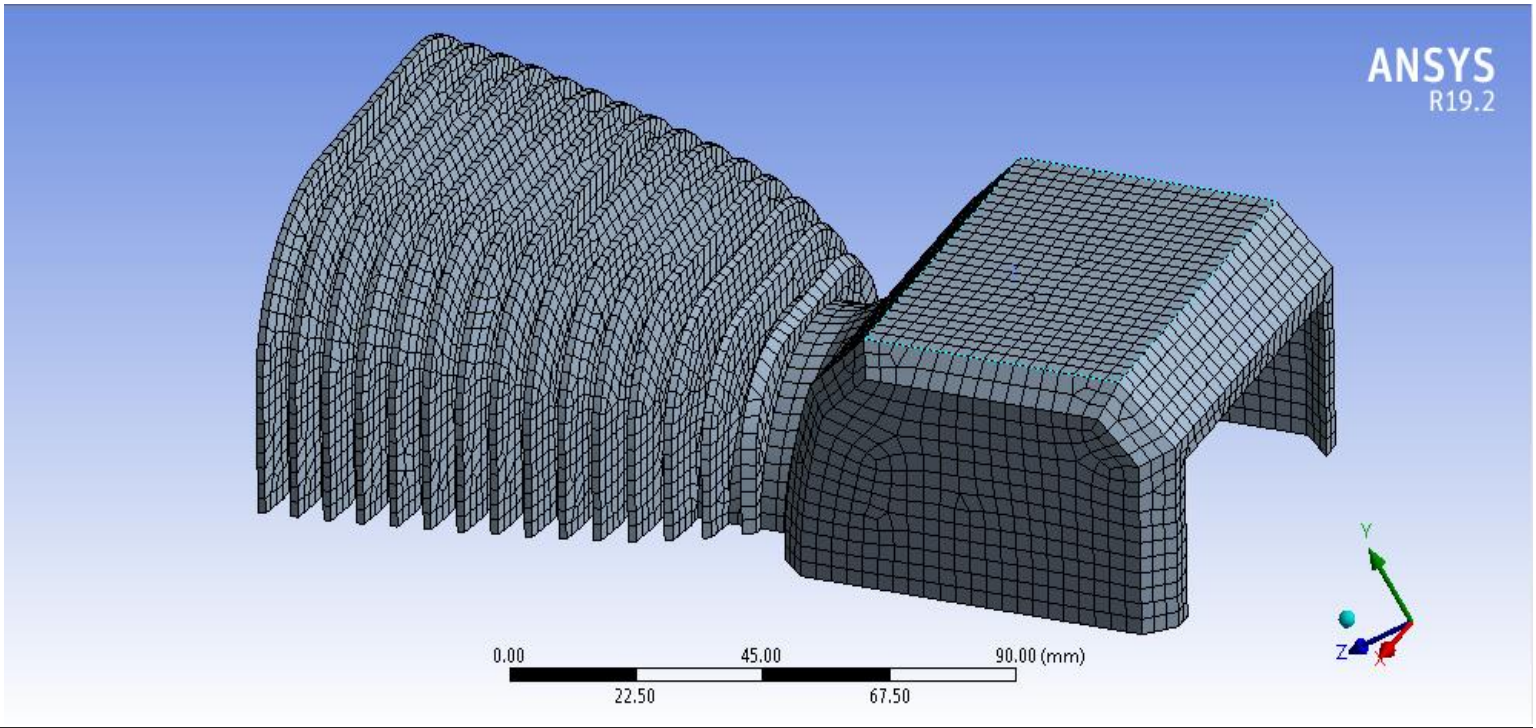
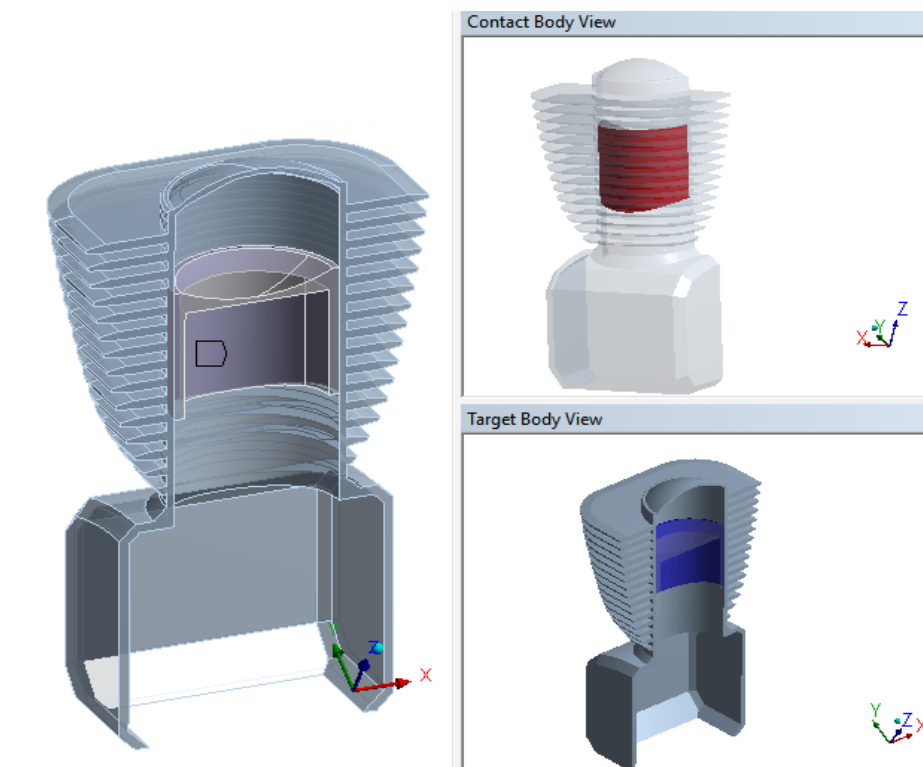
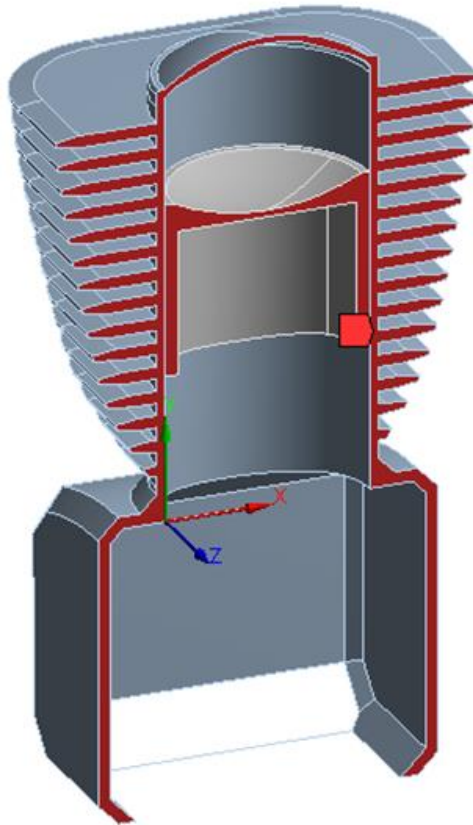


Fig 4.3 Contact Between Cylinder And Piston



Symmetry Region

 Symmetry Region



- utilized to address contact and sliding between 3-D "target" surfaces (TARGE170) and a deformable surface, characterized by this component. The component is pertinent to 3-D underlying and coupled

Properties of Outline Row 3: Aluminium-Silicon Alloy				
	A	B	C	D E
1	Property	Value	Unit	 
2	 Density	2680	kg m ⁻³	 
3	 Isotropic Elasticity			
4	Derive from	Young's Modulu...		
5	Young's Modulus	1.1E+11	Pa	 
6	Poisson's Ratio	0.28		
7	Bulk Modulus	8.3333E+10	Pa	
8	Shear Modulus	4.2969E+10	Pa	
9	 Field Variables			
10	Temperature	Yes		
11	Shear Angle	No		
12	Degradation Factor	No		
13	 Isotropic Thermal Conductivity	154	W m ⁻¹ K ⁻¹	 
14	 Specific Heat	850	J kg ⁻¹ K ⁻¹	 

field contact investigations.

- The component is situated on the surfaces of 3-D strong or shell components with mid side hubs (SOLID87, SOLID90, SOLID98, SOLID122, SOLID123, SOLID186, SOLID187, SOLID226, SOLID227, SOLID231, SOLID232, SHELL132, SHELL281, and MATRIX50).
- The component has similar mathematical attributes as the strong or shell component face with which it is associated (see Figure 4.1). Contact happens when the component surface infiltrates one of the objective portion components (TARGE170) on a predefined target surface. Coulomb erosion, shear pressure grinding, and client characterized rubbing with the USERFRIC subroutine are permitted. The component additionally permits the division of reinforced contact to mimic interface delamination.
- CONTA174 Input Data
- The calculation and hub areas appear in Figure 4.1. The component is characterized by eight hubs (the fundamental strong or shell component has midside hubs). It can decline to a six hub component relying upon the state of the fundamental strong or shell components. On the off chance that the basic strong or shell components don't have mild side hubs, use CONTA173 (you may in any case utilize CONTA174 however you should drop all midsize hubs). See Quadratic Elements (Midsize Nodes) in the Modeling and Meshing Guide for more data on the utilization of midsize hubs. The hub requesting is reliable with the hub requesting for the hidden strong or shell component. The positive type is given by the right-hand rule circumventing the hubs of the component and is indistinguishable from the outer ordinary heading of the fundamental strong or shell component surface. For shell components, the equivalent nodal requesting among shell and contact components characterizes upper surface contact; else, it addresses base surface contact. Recall the objective surfaces should consistently be on their outward typical bearing. See Generating Contact Elements in the Contact Technology Guide for more data on creating components consequently utilizing the ESURF order.

- The 3-D contact surface components (CONTA173 and CONTA174) are related to the 3-D objective section components (TARGE170) through a common genuine steady set. ANSYS searches for contact just between surfaces with a similar genuine consistent set. For either inflexible adaptable or adaptable get in touch with, one of the deformable surfaces should be addressed by a contact surface. See Designating Contact and Target Surfaces in the Contact Technology Guide for more data.
- In the event that more than one objective surface will connect with a similar limit of strong components, you should characterize a few contact components that share a similar calculation yet identify with isolated (targets which have distinctive genuine consistent numbers), or you should consolidate two objective surfaces into one (focuses on that share similar genuine steady numbers).
- CONTA174 upholds isotropic and orthotropic Coulomb contact. For isotropic grinding, determine a solitary coefficient of rubbing, M.U., utilizing either T.B. order input (suggested) or the M.P. order. For orthotropic erosion, indicate two coefficients of grating, MU1, and MU2, in two head bearings utilizing T.B. order input. (See Contact Friction (T.B., FRIC) for more data.)
- For isotropic contact, the relevant facilitate framework is the default component arrange framework (noted by the R and S tomahawks in the above figure).
-
- For orthotropic grating, the vital bearings are resolved as follows. The worldwide facilitate framework is utilized as a matter of course, or you may characterize a neighborhood component arrange framework with the ESYS order. (These are portrayed by the xo and x tomahawks in the above figure.) The primary head course is characterized by extending the principal bearing of the picked organized framework onto the contact surface. The second head course is characterized by taking a cross result of the primary head bearing and the contact typical. These headings likewise follow the inflexible body revolution of the

contact component to accurately demonstrate the directional reliance of grinding. Be mindful so as to pick the facilitate framework (worldwide or neighborhood) so the main bearing of that framework is inside 45° of the digression to the contact surface.

- On the off chance that you need to set the arrange bearings for isotropic grinding (to the worldwide Cartesian framework or another framework through ESYS), you can characterize orthotropic rubbing and set $MU1 = MU2$.
- To characterize a coefficient of rubbing for isotropic or orthotropic erosion that is subject to temperature, time, typical pressing factor, sliding distance, or sliding relative speed, utilize the TBFIELD order alongside T.B., FRIC. See Contact Friction (TB,FRIC) for more data.
- To execute a client characterized contact model, utilize the T.B., FRIC order with TBOPT = USER to indicate grating properties and compose a USERFRIC subroutine to register erosion powers. See User-Defined Friction (T.B., FRIC, USER) for more data on the best way to utilize this component. See additionally the Guide to ANSYS User Programmable Features for an itemized depiction of the USERFRIC subroutine.
- To display liquid entrance loads, utilize the SFE order to determine the liquid pressing factor and liquid infiltration beginning stages. For more data, see Applying Fluid Pressure-Penetration Loads in the Contact Technology Guide.
- To show appropriate force move and energy balance among contact and target surfaces, sway requirements ought to be utilized in transient powerful examination. See the portrayal of KEYOPT(7) beneath and the contact component conversation in the Theory Reference for the Mechanical APDL and Mechanical Applications for subtleties.
- To demonstrate division of fortified contact with KEYOPT(12) = 2, 3, 4, 5, or 6, utilize the T.B. order with the CZM name. See "Debonding" in the Contact Technology Guide for more data.
- When all is said in done, bent contact and target surfaces can be all around approximated by quadratic request contact and target components. Nonetheless, in specific conditions (for instance, when

the mid side hubs don't lie precisely on the underlying bent calculation in light of the fact that an outsider lattice generator was utilized), utilizing a faceted surface instead of the genuine bent math can altogether influence the exactness of contact stresses. A discretionary mathematical revision can be utilized for two sorts of bent surfaces (circular and revolute) through SECTYPE and SEC DATA segment orders. The characterized math remedy can be applied to explicit contact components by means of a part I.D. (SECNUM order). For subtleties, see Geometry Correction for Contact and Target Surfaces in the Contact Technology Guide.

- CONTA174 Assumptions and Restrictions
-
- The 3-D contact component should concur with the outside surface of the fundamental strong or shell component.
- This component is nonlinear and requires a full Newton iterative arrangement, whether or not enormous or little diversions are determined. An exemption for this is when MPC reinforced contact is indicated ($\text{KEYOPT}(2) = 2$ and $\text{KEYOPT}(12) = 5$ or 6).
- The ordinary contact solidness factor (FKN) should not be so enormous as to cause mathematical flimsiness.
- FTOLN, PINB, and FKOP can be changed between load steps or during restart stages.
- You can utilize this component in nonlinear static or nonlinear full transient examinations.
- Furthermore, you can utilize it in modular investigations, eigenvalue clasping examinations, and symphonious examinations. For these examination types, the program accepts that the underlying status of the component (i.e., the status toward the fruition of the static prestress investigation, assuming any) doesn't change.
- This component permits birth and passing and will follow the birth and demise status of the hidden strong, shell, shaft, or target components.

- The USERFRIC subroutine (client characterized grating) must be utilized with punishment-based distracting contact (i.e., KEYOPT(2) = 0, 1, or 3).
-
- 4.6 SURF 154 – THERMAL LOAD:
- SURF154 might be utilized for different burden and surface impact applications. It could be overlaid onto a territory face of any 3-D component. The component is material to 3-D primary investigations. Different loads and surface impacts may exist all the while.
- SURF154 Input Data
- The calculation, hub areas, and the facilitate framework for this component are appeared in Figure 4.1. The component is characterized by four to eight hubs and the material properties. A three-sided component might be framed by characterizing copy K and L hub numbers as portrayed in Triangle, Prism, and Tetrahedral Elements. The default component x-hub is corresponding to the I-J side of the component.
- The mass and volume estimations utilize the component thicknesses at hubs I, J, K, and L (genuine constants TKI, TKJ, TKK, and TKL, individually). Thickness TKI defaults to 0.0, and thicknesses TKJ, TKK, and TKL default to TKI. The mass computation utilizes the thickness (material property DENS, mass per unit volume) and the genuine consistent ADMSUA, the additional mass per unit region.
- The pressure solidness grid and burden vector computations utilize the in-plane power per unit length (contribution as genuine steady SURT) and the versatile establishment firmness (contribution as genuine consistent EFS); the EFS utilizes pressure-per-length (or power per-length-cubed) units. The establishment solidness can be damped, either by utilizing the material property DAMP as a multiplier on the firmness or by straightforwardly utilizing the material property VISC.
- See Node and Element Loads for a portrayal of component loads. Pressing factors might be contribution as surface burdens on the

component faces as demonstrated by the circumnavigated numbers on Figure 154.2. SURF154 permits complex pressing factor loads.

- Faces 1, 2, and 3 [KEYOPT(2) = 0]. Positive estimations of tension on the initial three faces act in the positive component arrange bearings (with the exception of the ordinary pressing factor which acts in the negative z heading). For face 1, positive or negative qualities might be eliminated as mentioned with KEYOPT(6) to recreate the brokenness at the free surface of a contained liquid. For faces 2 and 3, the course of the heap is constrained by the component facilitate framework; thusly, the ESYS order is regularly required.
- Faces 1, 2, and 3 [KEYOPT(2) = 1]. Pressing factor loads are applied to the component faces as per the neighborhood organize framework, as follows: face 1 the nearby x way, face 2 in the nearby y heading, and face 3 in the local z course.

-

• 4.7 ERRORS AND LIMITATION:

- Errors associated with Finite Element Analysis can be classified in three groups:
- Modelling errors are introduced via simplifying assumptions made in the formulation of the mathematical (usually simplified) representation.
- Discretisation errors occur a continuous mathematical model is discretised into a F.E. model.
- Solution errors arise from the process of the numerical solution of the F.E. equations.
-
- It should also be noted that errors can be made by users incorrectly interpreting the results
- Like any other approximate numerical method, the solution produced by finite element analysis contains a certain amount of error. The magnitude of the error is highly dependent on the type, size, and accuracy of the model used for the Analysis. That's why not all finite element models are created equal.

- Indeed, the educational and industrial experience of the analyst and the sophistication of the software are the two most critical factors in obtaining reliable results. Validation of a F.E. model is carried out by comparison of the results with measured test data and/or by values obtained by other independent means (hand calculations or other F.E. program).
- 4.8 FINITE ELEMENT MODEL SETUP:
- A half symmetric model of the TBC has been used for the Analysis to reduce the overall mesh size and the Degree of Freedoms.
- A node is a coordinate location in space where the degrees of freedom (DOFs) are defined. The DOFs for this point represent the possible movement of this point due to the loading of the structure. The DOFs also represent which forces and moments are transferred from one element to the next. The results of a finite element analysis, (deflections and stresses), are usually given at the nodes. So more the DOFs, more the model size and computational capacity. Hence symmetric options are used to reduce the DOF size.
- 4.9 LOADS & BOUNDARY CONDITIONS:
- Meshed Model:
-
-
- No of elements 28,744, No of Nodes 5,541
-
- Contact Established Between cylinder and Piston using Contact and Target Elements
- Contact problems are non linear in nature due to the changing contact stiffness during the load transfer and requires high computational resources to run the model.
- Standard surface to surface contact used between the cylinder head and the piston surface to define the transfer of loads from Cylinder head to Piston and vice versa as shown in Figure below.
-
-

-
-
- Thermal Analysis :
-
- Symmetric conditions applied on the cut face of the Cylinder head with Piston using the Symmetric Boundary conditions option in Ansys
- 4.10 MATERIALS USED FOR ANALYSIS:
- The most widely used materials for construction of I.C. Engines are Grey Cast Iron, Aluminium alloys and steels in some parts. Close-grained cast iron is the material most commonly used for liner construction. Some liners are plated on the wearing surface with porous chromium, because chromium has greater wear resistant qualities than other materials
- Material Used for the Analysis is Aluminum Silicon Alloy
- Material Properties
- TABLE:
-
-
-
-
-
- Thermal Analysis –Without Coating
- Assumptions Made In Thermal Analysis By Finite Element Method
- Among the various numerical methods available for mathematical modelling, the Finite Element Method (FEM) has been chosen due to its high degree of accuracy.
- The following assumptions are made for each of the I.C. Engine models when performing the thermal Analysis on them using ANSYS software.
- The initial temperature of the I.C. Engine is 373 K.
- The heat flux linked with the walls of I.C. Engine is 10 E6 W/m^2
- The average temperature of the I.C. Engine combustion chamber walls is 1300K

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

THERMAL ANALYSIS

Loads- Initial Temperature

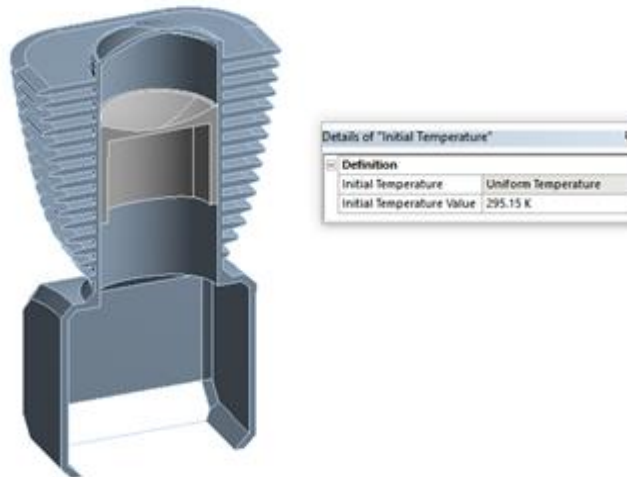


Fig 4.4 Thermal Analysis Initial Load Temperature

THERMAL ANALYSIS

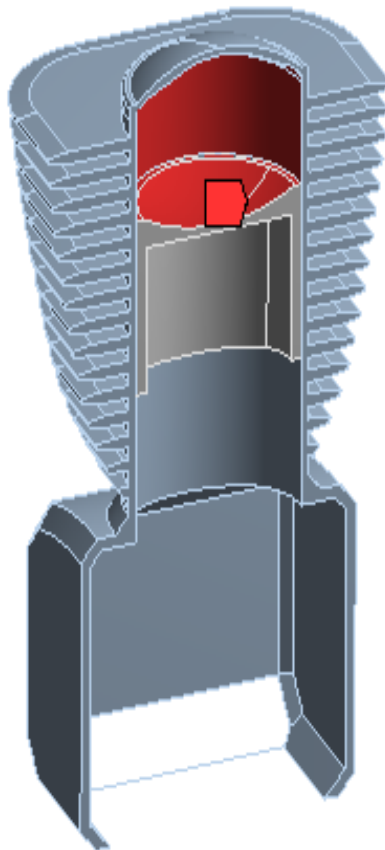
Loads- Temperature

B: Transient Thermal

Temperature

Time: 1. s

 Temperature: 1300. K



Details of "Temperature"

[-] Scope

Scoping Method	Geometry Selection
Geometry	14 Faces

[-] Definition

ID (Beta)	128
Type	Temperature
Magnitude	Tabular Data
Suppressed	No

[-] Tabular Data

Independent Variable	Time
----------------------	------

Geometry / **Print Preview** / **Report Preview** /

Tabular Data

	Steps	Time [s]	☒ Temperature [K]
1	1	0.	373.
2	1	1.	1300.
*			

Loads- Convection

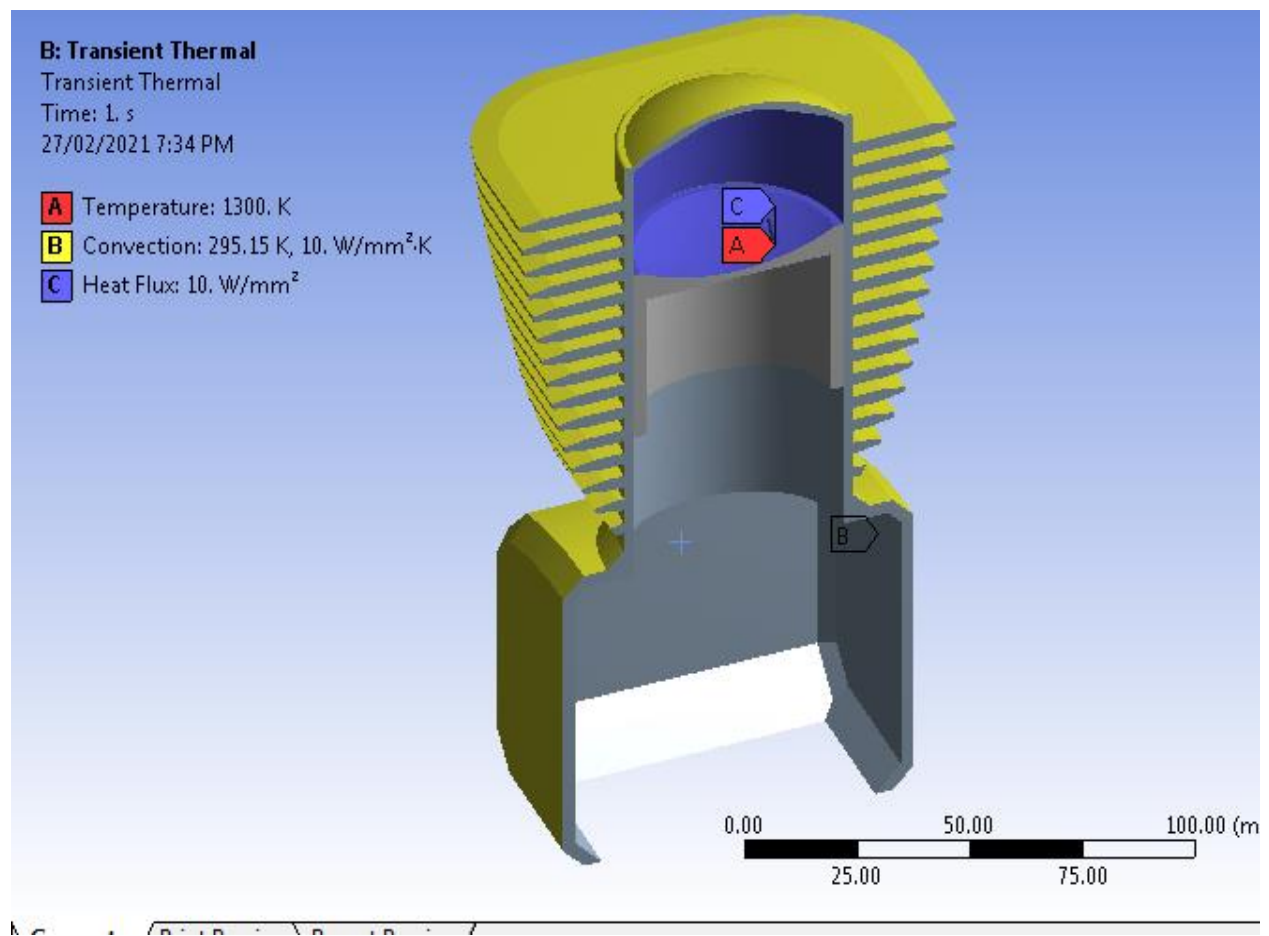


Fig 4.5 Loads- Convection

Loads- Heat Flux

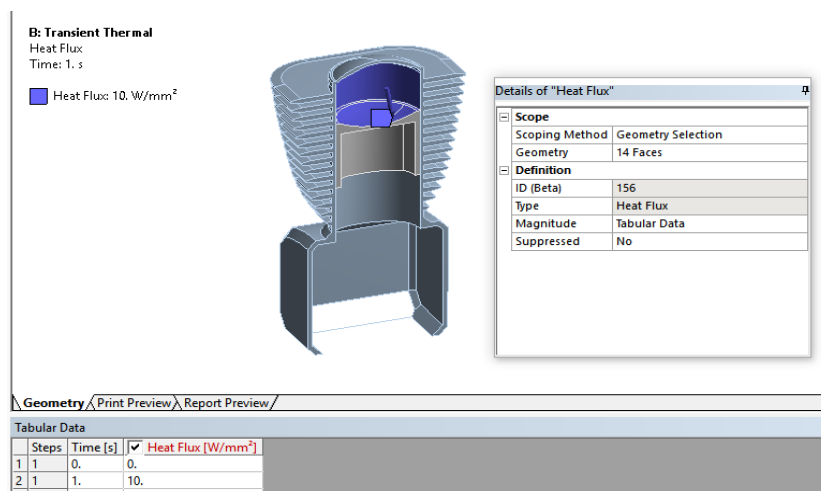


Fig 4.6 Loads- Heat Flux

4.11 THERMAL ANALYSIS BEFOR COATING:

Temperature distribution of the without TBC model was studied to understand the heat transfer from one component to other ie from Cylinder head to Piston and Piston to cylinder head.

Though the maximum temperature is 1300 K, we can find a temperature variation across the piston outer surface to the cylinder head. This variation plays an important role in inducing the thermal stresses in the cylinder head.

Temperature distribution results

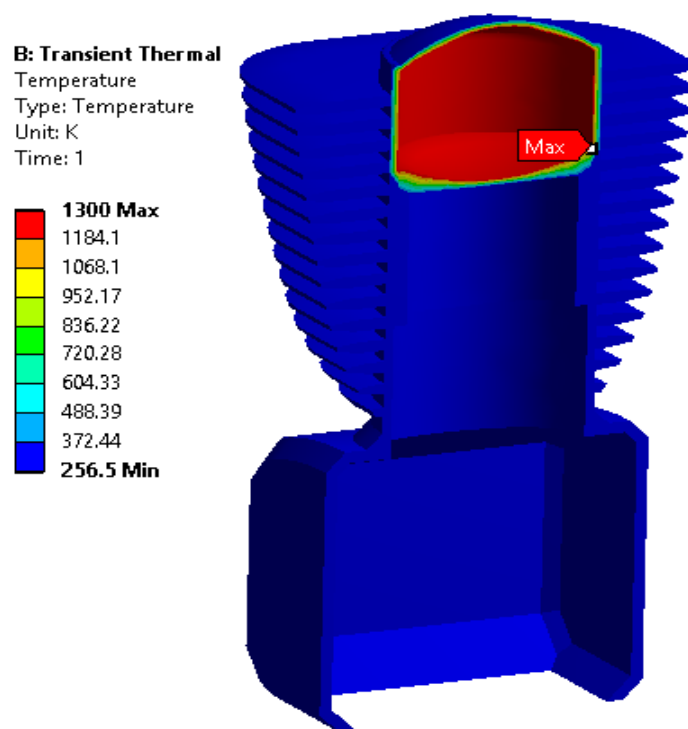


Fig 4.7 Coating Applied Inner Surface of Cylinder

4.12 TBC MATERIAL:

TBC Material used for Analysis:

We have used the Rare earth zirconates as the thermal barrier coating material in our Analysis due to its low conductive properties and high density to withstand repeated loads.

Zirconia is an extremely refractory material. It offers chemical and corrosion inertness to temperatures well above the melting point of alumina. The material has low thermal conductivity.

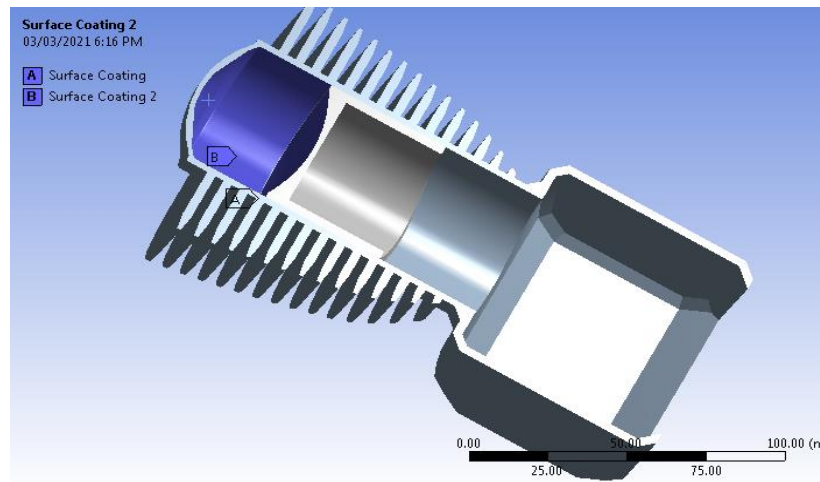
4.13 KEY PROPERTIES OF ZIRCONIA:

Zirconates have the below superior properties when compared to other ceramics

1. Use temperatures up to 2400°C
2. High density
3. Low thermal conductivity (20% that of alumina)
4. Chemical inertness
5. Resistance to molten metals
6. Ionic electrical conduction
7. Wear resistance
8. High fracture toughness
9. High hardness

Thermal

Properties of Outline Row 5: Zirconia				
	A	B	C	D E
1	Property	Value	Unit	
2	 Density	5600	kg m ⁻³	 
3	 Isotropic Elasticity			
4	Derive from	Young's Modulu...		
5	Young's Modulus	2.5E+11	Pa	
6	Poisson's Ratio	0.32		
7	Bulk Modulus	2.3148E+11	Pa	
8	Shear Modulus	9.4697E+10	Pa	
9	 Field Variables			
10	Temperature	Yes		
11	Shear Angle	No		
12	Degradation Factor	No		
13	 Isotropic Thermal Conductivity	2.5	W m ⁻¹ K ⁻¹	
14	 Specific Heat	400	J kg ⁻¹ K ⁻¹	



Analysis is performed on the internal combustion engines made of Aluminum Silicon Alloy material with a coating of TBC material on the inner side of the combustion chamber walls. The thickness of each Coating is 1000 microns (1 mm).

4.14 THERMAL ANALYSIS WITH COATING:

A well-established thermal barrier coating is Strontium Zirconate which has a higher thermal stability of up to 1573K. The Aluminum Silicon Alloy 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 I.C. Engine, the heat distribution is observed as shown in the figure.

MATERIAL PROPERTIES COATING MATERIAL

Coating material applied over the inner surface of cylinder and apex surface of Piston

Thermal Results: With TBC coating

Temperature distribution of the with TBC model was studied to understand the heat transfer from one component to other ie from Cylinder head to Piston and Piston to cylinder head.

Though the maximum temperature is 1300 K, we can find a temperature variation across the piston outer surface to the cylinder head. This variation plays an important role in inducing the thermal stresses in the cylinder head.

The temperature gradient across the piston outer surface and cylinder head has changed drastically and we could see a smooth gradient at that location.

Temperature Distribution with Coating

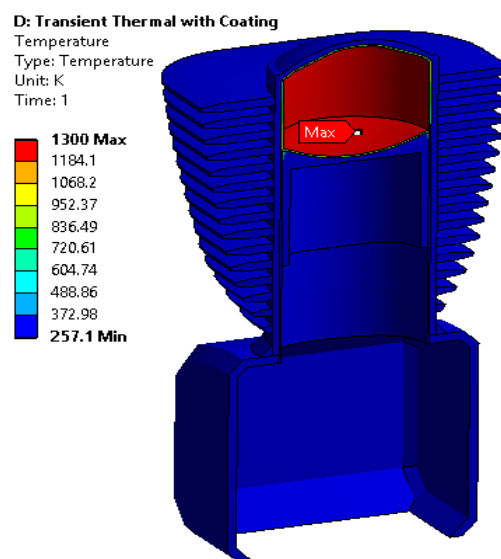


Fig 4.8 Temperature Distribution with Coating

4.15 THE OVERVIEW OF COUPLED FIELD ANALYSIS:

A sequentially coupled physics analysis is the combination of analyses from different engineering disciplines which interact to solve a global engineering problem. For convenience, the solutions and procedures associated with a particular engineering discipline [will be referred to as] a physics analysis. When the input of one physics analysis depends on the results from another analysis, the analyses is called coupled field analysis.

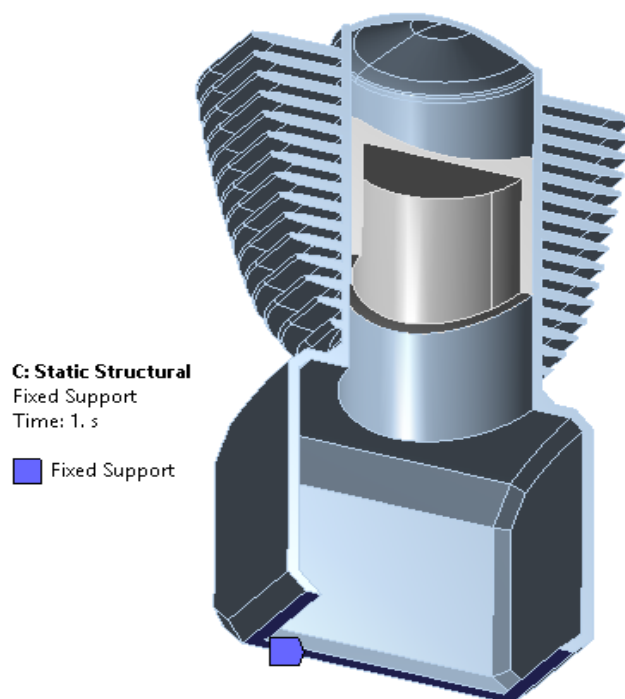
Although the geometry must remain constant, the element types can change. For instance, thermal elements are required for a thermal analysis while structural elements are required to determine the stress in the link. It is important to note,

however that only certain combinations of elements can be used for a coupled physics analysis.

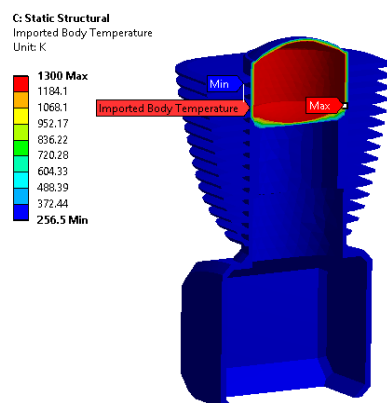
4.16 STRUCURAL ANALYSIS BOUNDARY CONDITION:

Structural Analysis: Without TBC coating

A structural analysis was carried out by including the temperature loads from the thermal



Analysis into the structural model. This is called a coupled field analysis in which the output from one Analysis becomes the input for the other Analysis. In our case the



thermal results file which has the extension of .rth can be directly read into structural loads module as structural loads.

Structural Boundary Conditions: Without TBC coating

Structural Analysis is the determination of forces and deformations of the structure due to applied loads. Structural design involves the arrangement and proportioning of structures and their components in such a way that the assembled structure is capable of supporting the designed loads within the allowable limit states

Structural boundary conditions were used to simulate the physics of the model by constraining the bottom face of the cylinder head surface in all directions. This is called as fixed support which does not allow the cylinder head to move in any direction.

Structural contact elements between the cylinder head and Piston were defined to have force transfer from the cylinder head to Piston. These are surface to surface contacts simulated using Non linear contact elements in Ansys, by which the load acting on the cylinder head will be transferred completely to the Piston as well in normal direction.

Structural Boundary Conditions used in the model

Structural Analysis results (Without TBC coating)

The structural analysis results of the without TBC model was reviewed after the Analysis to see if it makes sense in the real physics of the component. Spike or spurious stresses were not found in the model and the overall behavior of the model was looking reasonable.

A max stress of 80 MPa is observed in the without TBC model and an average distributed stress of 72 MPa found occurring in the cylinder inner chamber.

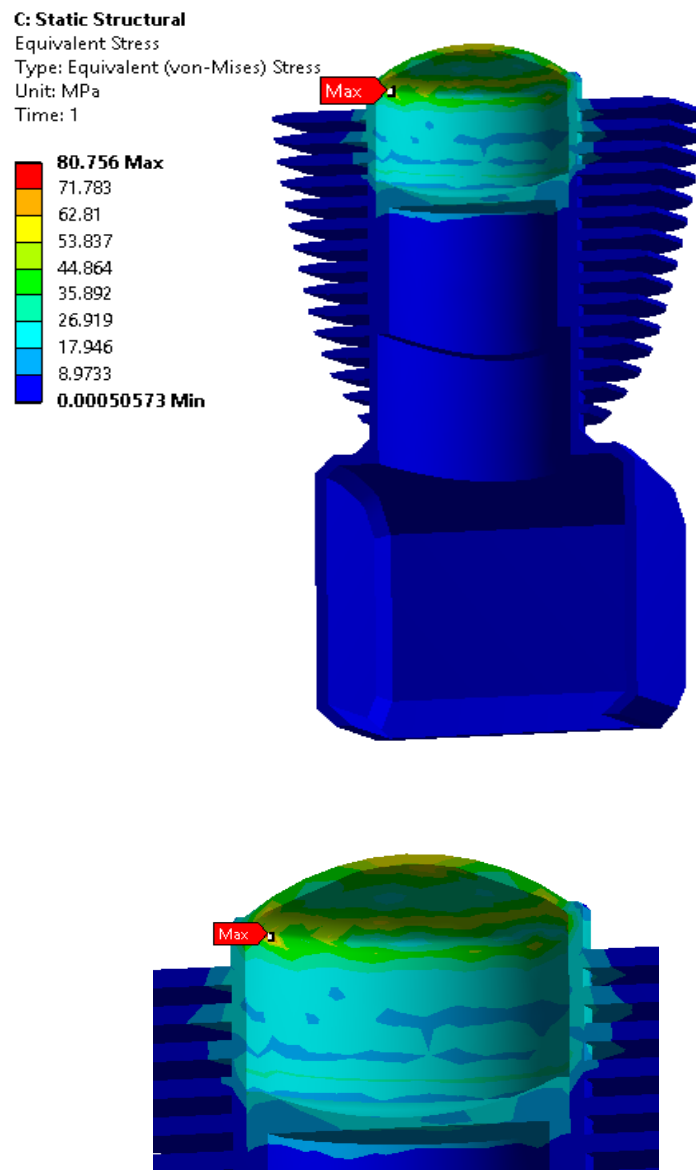


Fig 4.10 Structural Analysis Without TBC

Structural Analysis results (With TBC coating)

The structural analysis results of the with TBC model was reviewed after the Analysis to see if it makes sense in the real physics of the component. Spike or spurious stresses were not found in the model and the overall behavior of the model was looking reasonable.

A max stress of 73 MPa is observed in the without TBC model and an average distributed stress of 60 MPa found occurring in the cylinder inner chamber.

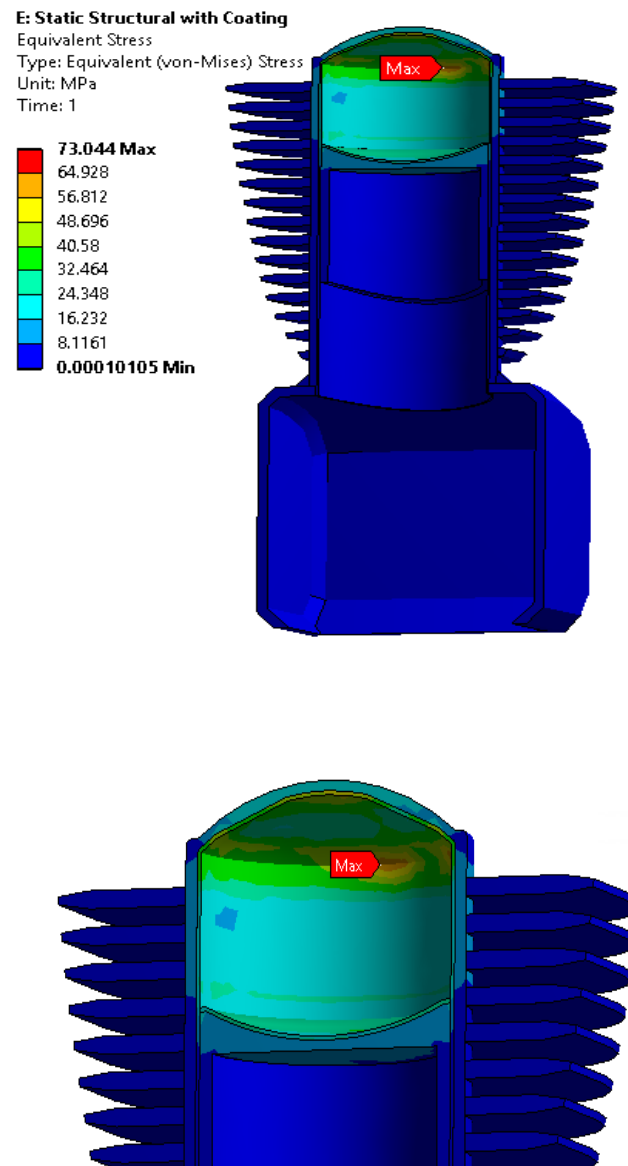


Fig 4.11 Structural Analysis With TBC

CHAPTER 5

RESULT & CONCLUSION

Results Summary and Comparison:

Structural results are interpreted in such a way that the results summary makes real meaning and allow the analyst to come to a logical solution.

S.No	Without TBC Model(Mpa)		With TBC Model (Mpa)	
	Peak Stress	Averaged Stress	Peak Stress	Averaged Stress
1	81	72	73	60

The above results shows a tremendous improvement in stress due to the usage of Thermal Barrier coating in the without TBC model. This sums up to around 17% reduction in stress which will drastically improve the durability of the component. As well it also helps in complete combustion taking place at higher temperatures with less emission to the atmosphere.

Hence it is proven and easily understood that the usage of Thermal Barrier coating proves effectively.

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