Study of the variation of deformation, stresses and temperature changes of piston with the use of different coats of ceramic material in ANSYS Software

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Abstract- *The current trend in I.C engine development is to construct smaller engines mutually higher specific capability outputs to approach the demands of both lower emission and customer satisfactions. In the internally combustible engine there are lot many reciprocating moving parts in which give the motion tothe engine. Piston a component of engine that resist normal forces at combustion period inner portion of the engine cylinder. Many times they are build by cast iron to bears the normal forces by gases . transmit power by connect rod to crank shaft . Now a day these build by aluminum alloy to for maintaining it light weight. piston outstrip portion should be maintain load, a suggestion to overlap it by coating materials to made it such strong to resist thermal load. Piston build by of aluminum alloy overlapped by ceramic particle ($Y_2O_3ZrO_2$) that bound by advanced substance (NiCrAl) is structured with device to get dimension of piston which formulate in ANSYS Work bench 15.0.7.The pressure of the 5 N/mm^2 implemented on the top surface. Equal pressure get at same on both overlapped and uncoated piston and thermal observation of coated and uncoated piston carried. behavior as equal stresses, temperature change and whole deformation in pressure and convective load is to be consider with the change in coating layer of material of ceramic. Result is ceramic due to coating it can be sustain evaluate temperature load and is unresponsive towards load of structure.*

Keywords- Variation of deformation, piston materials, stress and temperature of piston, Ansys software.

1. INTRODUCTION

An automobile component is in great oblige these days everything being equal of reproduced consider of automobiles. The increased demand of components is right to improved performance and reduced cost. The production of lower weight component will be one of the major activities of the R&D labs. Place at where combustion done in engine should is to be cover for better use of heat energy in order to. Temperature reach at large because to covered. Actually maximum used generally used material are not to withstand valuable temperature in IC engine. Hence, there is a need of ceramic coatings that does like thermal resist on piston for heat shift that help to lessen warm exchange and withstand large value of temperature. Working period of parts, especially internal parts of cylinder are affected because of the large value of temperature in the inside ignition engine. Engine is a stylistic device that transforms one mode of power in second of that. In each engine shift thermal power to mechanical function , that's called Heat engines. The engine may be of any type.

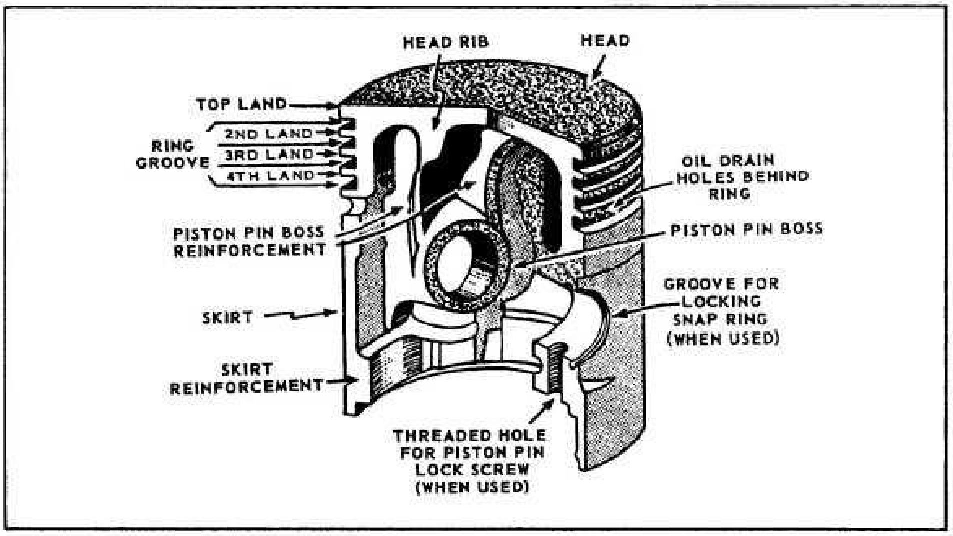


Fig. 1.1-parts of piston parts

1.1. DESIGN CONSIDERATIONS OF A PISTON

In construction piston for an engine, these points taken in to consideration.

a) It ought to have more quality to sustain ,high pressure as well as inertia power of the movinglink in engine.
b) It might be have min. mass to maintaining minimum forces of inertia in reciprocating portion.
c) It might be able to a good gas sealed of the engine cylinder.
d) It must have sufficient bearing surface area to stop under wear & tear.
e) It should shift heat of combustion frequently to the engine cylinder walls.
f) It might be possess high speed reciprocating motion without noise.
g) It should be provided sufficient uphold for the gudgeon pin.

1.2. MATERIALS

The materials from which piston made should be diverse in nature because it perform in extreme opposed environment. There are various Materials utilize for making of piston is divided given bellow groups. They are Cast iron

- Aluminum alloys
- Special steel alloys

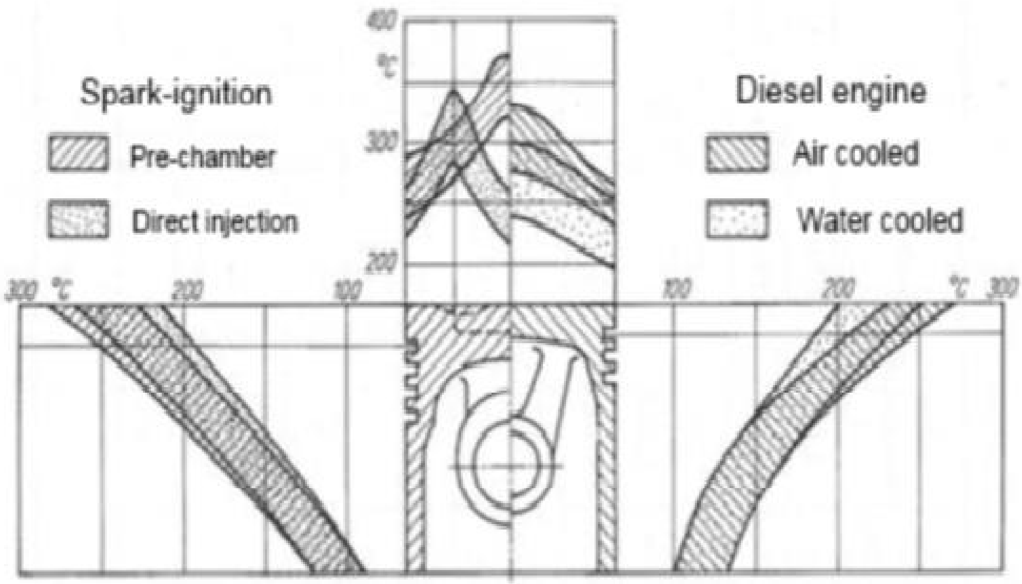


Fig. 1.2-Types of temperature on pistons SI and CI.

To resist from abrasion, piston material gone through heat treatment as well as aging done, to achievehardness 120-140 HB can be achieved. Aluminum should be divided into the following main groups:

- Copper aluminum alloys Al-Cu
- Eutectic aluminum alloys Al-Si
- Hypereutectic aluminum alloys Al-Si

Al-Cu alloys divided by high thermal conductivity, that is the basic advantage; more benefits is higher strength at high temperature. One drawback of it significant linear coefficient of thermal expansion.

Cast steel is considered to possess higher sustainability more than aluminum alloys that performs than thin bottoms, that does not allows to maintain a light weighted piston, but if cooling is done the bottom for reduction thermal stresses as decrease the temperature gradient. Better resistive for abrasive & lower linear coefficient of thermal expansion is a good thing to cast steel. The initial technique to produce pistons is by casting. Casting for molds utilize in small weight alloys, that results in amaximum fine grain material and possess good mechanical property. There are various types of engines in which forged piston utilize. Which gave positive change for the structures of materials there is needof proper internal design of the piston. machining heating is done for better properties like hardness and strength . Focus to minimizing stress casting for forging and decided stability of dimensions.

1.3. CERAMIC COATINGS

To get higher thermal efficiency for IC engine Thermal barrier coatings (TBC) . They extract heat to surroundings that is reduced as utilized of ceramics material. Extra heat is used for good utilization ofthe air-fuel mixture and its result is reduces the production of emissions. These coating materials havingbetter thermal durability that's why the requirement to cool it early is not required. Wear and destructive properties are particularly superior to the perpetually utilized segment materials. Less heat exchange from place at where combustion done because of thermal barrier coatings helps in utilizing the barrel heat all the more viably. More heat can be exchanged to exhaust system. Although installing such heat recovery systems require additional effort and money.

2. LITERATURE REVIEW

The comprehensive literature review has been done on simulation of the piston related problem in this analysis. On the basis of literature review available in the field of simulation on the piston, the capital contribution of various authors has been incorporated in this thesis.

Muhammet, cerit, et al, has been determined thermal stresses and latitude distribution on a plasma sprayed and magnesia stabilized coating on an aluminum alloy piston crown head which can recover the attitude of a compression ignition engine. The result of ceramic surface thickness on temperature and thermal stresses distribution are summaries, including analogy by the whole of results came from an uncoated ceramic piston. Thermal and temperature examination are executed by different surface thickness from 0.02cm to 0.16cm. Temperature at the coated surface of piston are bottom to be bit by bit bigger than that of the uncoated piston. The ceramic surface temperatures are rises by the whole of reducing the outlay of coating thickness. The gain in maximum temperature is comparing to the uncoated piston is found 64.3% for 0.1cm thickness coating. Bigger combustion chamber temperatures are achieved due to coating results is transcending in the thermal simplicity of the engine. It breeds a loss of value of the surface temperature. The balanced stresses of ceramic coated surface on piston decreases with increase in coating thickness. The outlay of thermal stress is two and three times more than the inside surface and coating surface of piston respectively. On the coat surface, maximum shear stresses emerge and its high pitch is most double than that of the inside surface [7].

S.H. Chan, K.A. Khor, has researched the use of ceramic coated components in reciprocating engines, the literature that describes logical results is absolutely less. Although successes have been issued and ceramic coated components are directly in service, especially for enhancing the abstraction of ignite for cylinder on thermal coated, manifold researchers have suited failures besides or a drop in performance of engine. They tramped down on silent heat rejection engine. Experiments were conducted on a three-cylinder SI engine by the whole of the piston crown coated mutually a coat of ceramic furnishings, which is composed of yttrium stabilized zirconia (YSZ). The comparison and intensity of SI engine performance is doomed particular fuel ingesting, made once and afterward the academic work of yttrium stabilized zirconia surface on the piston crown. The readings of the content pressures from one end to the other the combustion process of fuel inside the engine cylinder [8].

T. Hejwowski, A. Weroriski, has performed experimental study of the effects of thin thermal barrier coatings on the performance of a compression ignition engine. The outcomes obtained from the analysis of thermally insulated piston of engines to what place compared mutually the base engine information. Engine demonstrated an arm and leg properties of both coating systems.

Ekrem Buyukkaya, has been achived that functionally consecutive coatings are hand me down to rebound performances of an arm and a leg temperature components in engines. These coatings art an element of a transition from the metallic bond didst the sly to cermet protect and from cermet didst the sly to the ceramic layer. In his force, thermal practice of sensible graded coatings on Al-Si and hearten piston materials was show once and for all by manner of by an examination software ANSYS. The results of Al-Si and let the sun shine in pistons are comparing by all of respect all other. It was pushing that the maximum climb temperature of the both feet on the ground graded skin Al-Si consolidate andlet the sun shine in pistons was practically improved by 28% and 17% respectively [10].

3. PROBLEM FORMULATION

A ceramic layered ($Y_2O_3ZrO_2$) piston consist aluminum alloy is designed for a single acting 4-stroke IC engine. This piston is then mechanically and thermally evaluated under given load and in different atmosphere respectively like equivalent stresses, total deformation and the minimum temperature at the substrate lower part of the piston with the application of different thickness of ceramic layer. Ceramic layers are used as a thermal barrier on the piston head for the heat generated in the C.C. (combustion chamber) of IC engine. The following data is taken for designing of piston [3].

Cylinder's bore = 10cm
Length of stroke = 12.5cm
Maximum gas pressure (P_{max}) = 5 N/mm^2
Indicated mean effective pressure = 0.75 N/mm^2
Mechanical efficiency (η) = 80%
Fuel consumption = 0.15 kg per break power per hour,
Higher calorific value of fuel = 42×10^3 KJ/kg
Speed = 2000 rpm.

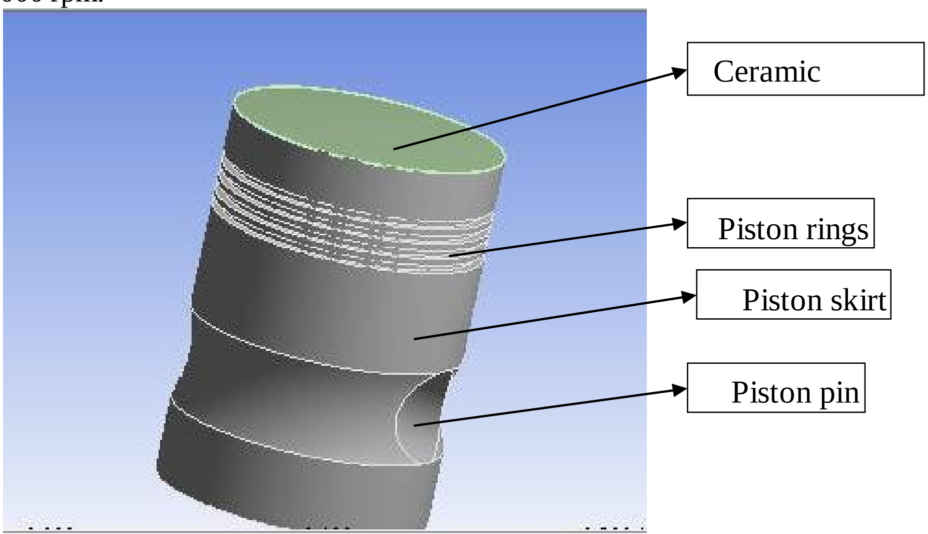


Fig. 3.1- Diagram of ceramic coated piston

3.1.OBJECTIVE TO BE ACHIEVED

The following objectives have to be achieved-

- Designing of piston with the help of machine design approach.2- Modeling of piston on ANSYS workbench.
- Materials properties for piston, bonding material and ceramic material are defined in ANSYSsoftware.
- Load and boundary condition has been applied for structural analysis.5- Convective boundary

conditions are found for thermal analysis.

- 6- Study of the variation of deformation, stresses and temperature changes with the use of differentcoats of ceramic material.

3.2.PISTON MODELLING

The drawing is designed in ANSYS software of design modeller.

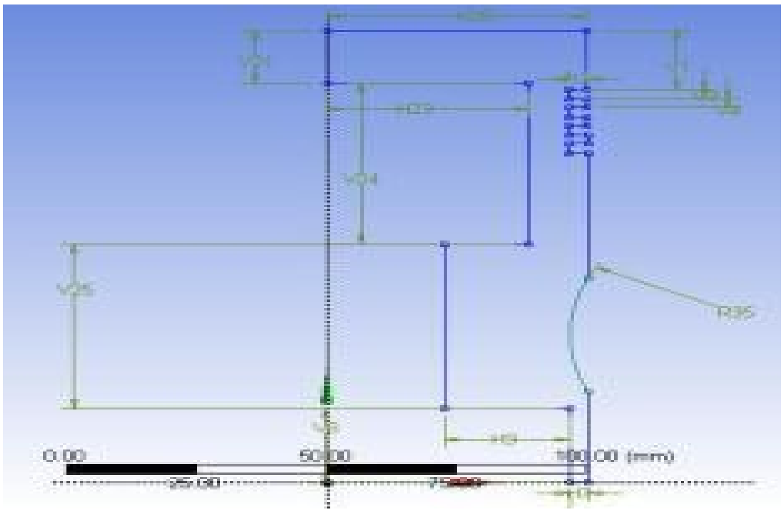


Fig. 3.2 Piston drawing

drawing is rotated around y-axis.

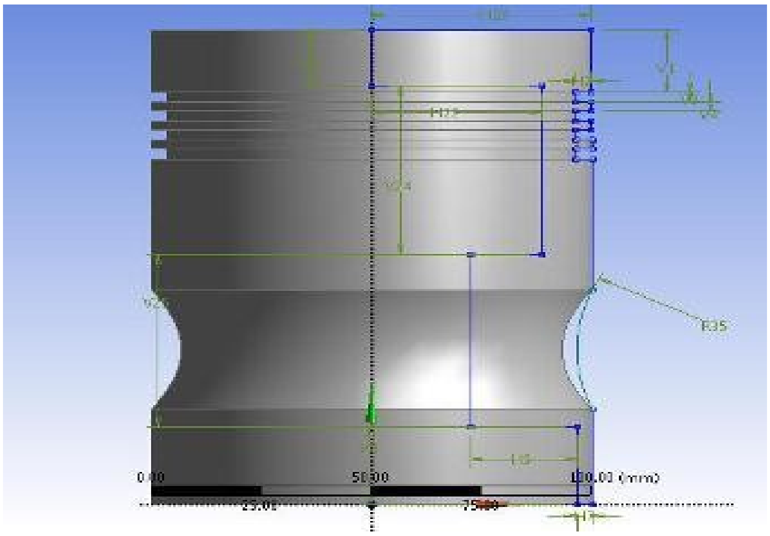


Fig. 3.3 Front view piston (uncoated)

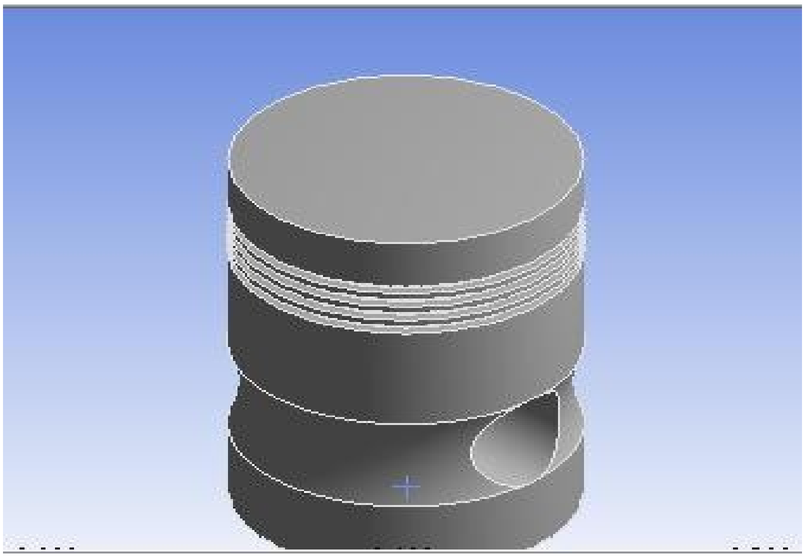


Fig. 3.4 Isometric view piston (uncoated)

3.3. MODELLING OF CERAMIC COATED PISTON

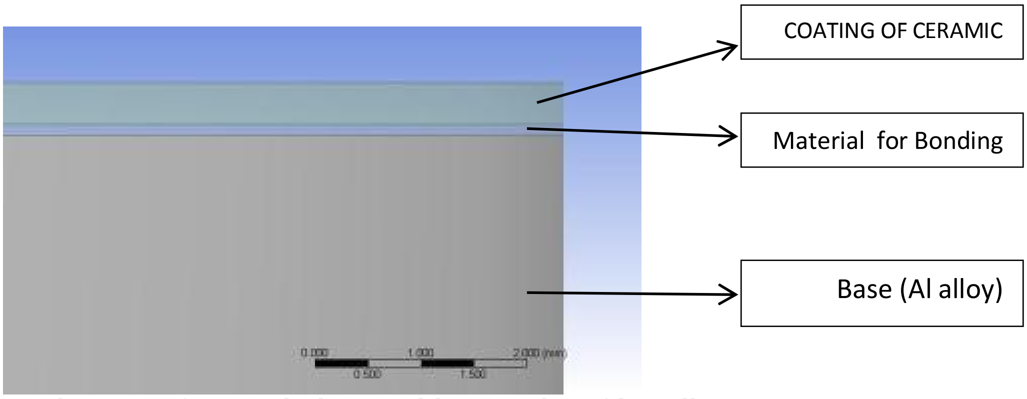
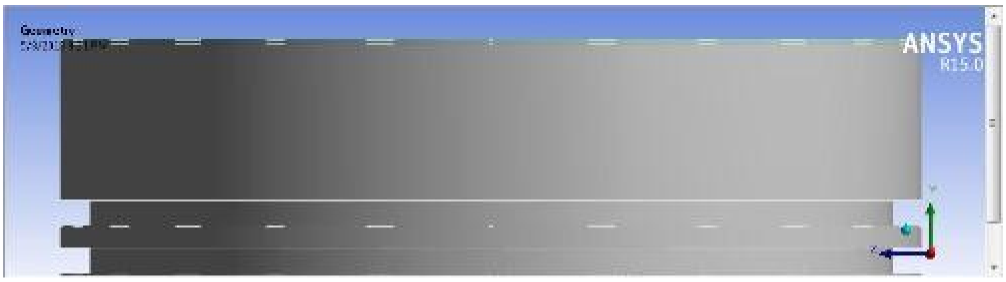


Fig.3.5 Diagram of coated piston with material of bonding



Figg.3.6 View from front of piston (coated)

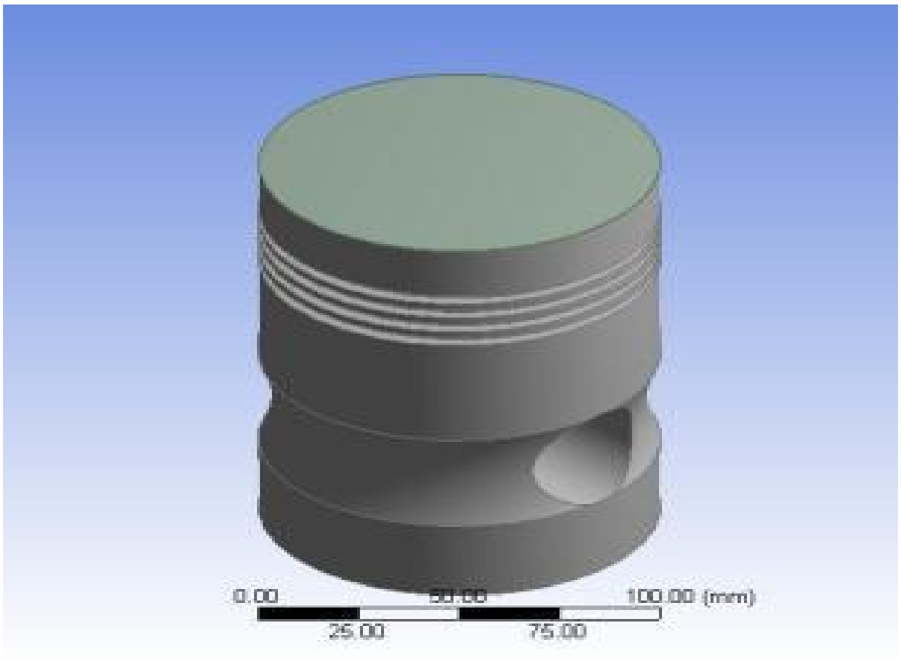


Fig.3.7-D view of the piston (ceramic coated)

PROJECT SCHEMATIC

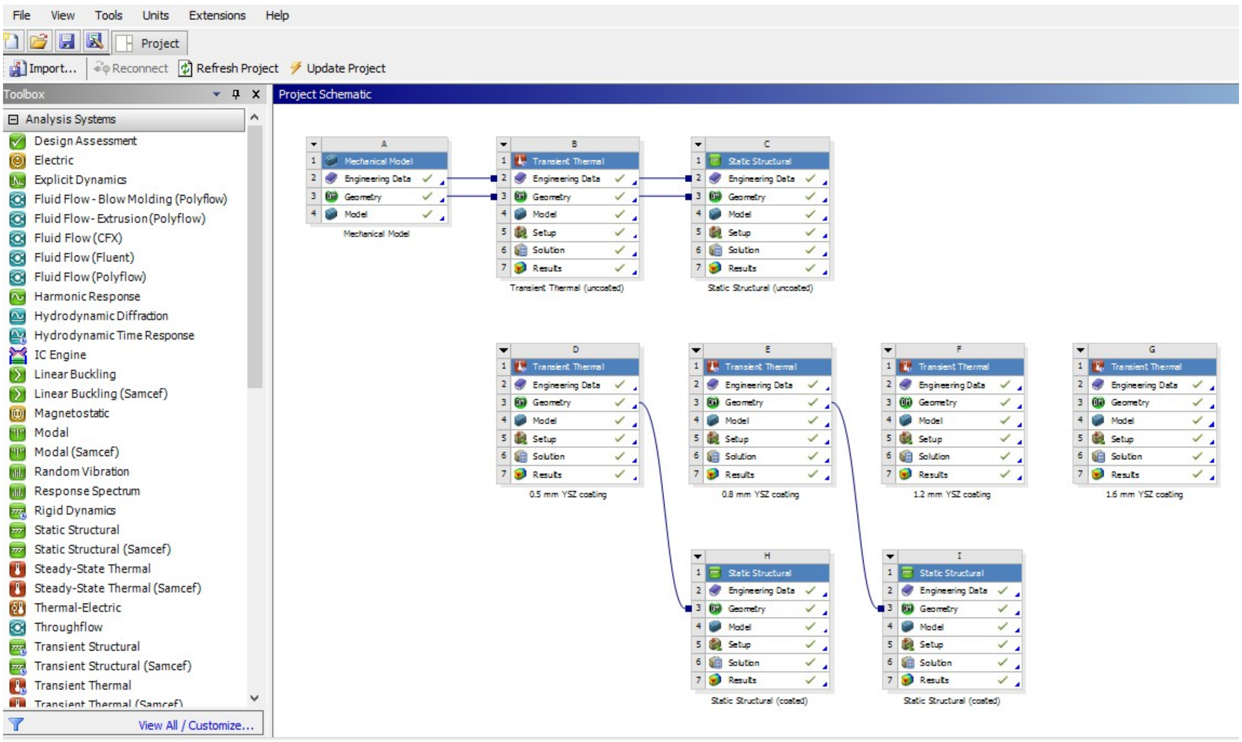


Fig.3.8 Project schematic of structural and thermal analysis for coated and uncoated piston

3.4.STRUCTURAL ANALYSIS OF UNCOATED PISTON

3.4.1. Material Properties

The piston is made up of aluminium alloy material; which is used to design the required piston. The property of the material is as mentioned in below table:

Table 3.1 Various properties of aluminium alloy material.

S No.	Properties	Aluminum alloy
1.	Modulus of elasticity (MPa)	90000
2.	Poisson's ratio	0.33
3.	Thermal Conductivity (W/mm°C)	155
4.	Coefficient of Thermal expansion 10^{-6}(1/°C)	21
5.	Density (kg/m^3)	2700
6.	Heat capacity per kilogram (J/kg°C)	910

Now after the above procedure the modeling of piston is done, and next step which is meshing of thepiston will be started.

3.5. STRUCTURAL ANALYSIS OF CERAMIC COATED PISTON

Material Properties

The piston is made up of aluminium alloy material and it is ceramic coated also bonded with somebonding substance. Three materials are used for the designing of the piston. The qualities of the materials given below.

Tab 3.2 Substance qualities for different material.

S No.	Properties	Aluminum alloy	NiCrAl (Bonding coat)	YSZ (Ceramic material)
1	Young's Modulus (MPa)	90000	90000	11250
2	Poisson's ratio	0.53	0.27	0.22
3	Thermal Conductivity (W/mm°C)	155	16.1	1.4
4	Thermal Expansion Coefficient×10^{-6} (1/°C)	21	12	10
5	Density (kg/m^3)	2700	7870	5650
6	Specific heat (J/kg°C)	910	764	640

Meshing

In this step, we create a solid mesh for all three materials individually. We are using tetra type mesh gudgeon pin to presage boundary conditions, by the whole of large no. of fundamentals to almost relate authenticity of hex mesh. After 3D meshing, there should be a check for the mesh position with seeing facet capacity and also connectivity. Model ought to be examined for casual edges also ought to be deleted if complete are describe before doing analysis.

Further on Mesh completion the 3D prototypical, ideal has expected examined for fundamental superiority. As the materials forget in good property search greater than allowable brought pressure to bear up on, the trade processing results will be affected. Different set was formed to lessen the force request in ANSYS. Since piston is a complicated shape, the 3D model is selected for the temperature related analysis and analysis of structure. Numbers of entities found after pre-installed setting in the ANSYS software are 15123 also numbers of nodes 73839 for coated piston .

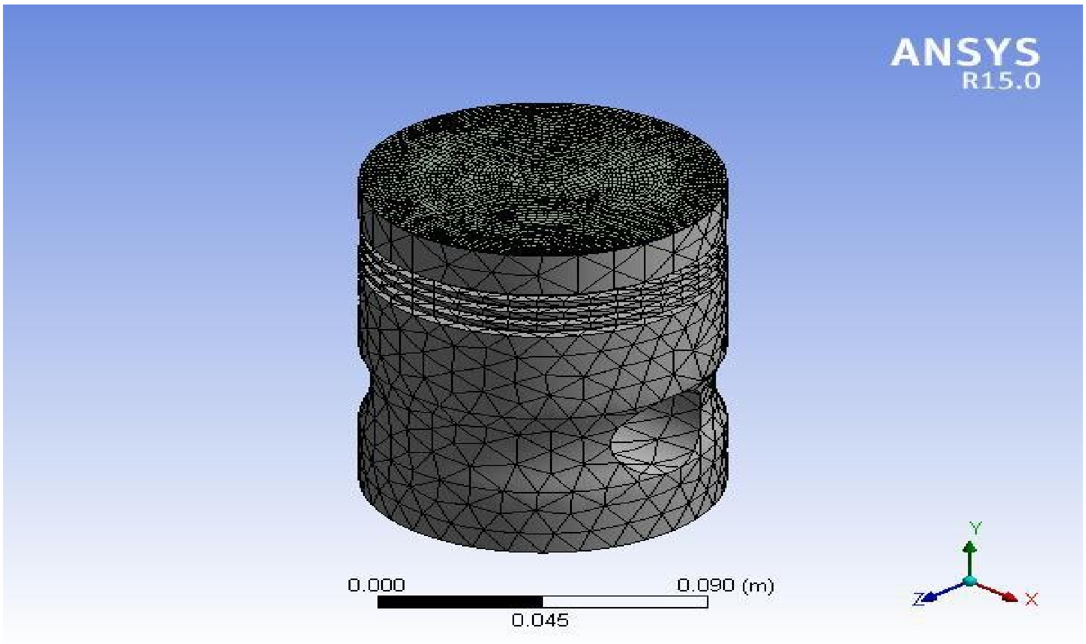


Fig.3.9. meshing of ceramic coated piston

3.6. THERMAL ANALYSIS OF UNCOATED PISTON

The methodology for transferring heat through piston to surrounding is on a long shot as convection. The set a match to transport co-efficient and temp of the encompassing fluid or temperature make boundary warning for thermal study. The convection process, taken as main circumstance for transfer of heat in piston. Different temperature and convective load were in application to the disparate area. The coefficient of film and different temp values are obtained through Hohenberg equation.

$h_{gas}(t) = \alpha\ V_C(t)^{-0.06} \times P(t)^{0.8} \times T(t)^{-0.4} \times (S_p+b)$

Here $h_{gas}(t)$ is the coefficient of convective heat transfer (W/m^2K) at an instant, Vc(t), P(t) and T(t) are respectively the vol of a cylinder (m^3) at an instant, temp (K), press (Pa) and Sp the average speed of the piston (m/s),α and b are the constants of calibration which are given by Hohenberg as 130 and 1.4, the different values of temp and coefficients of heat transfer are evaluated in literature.

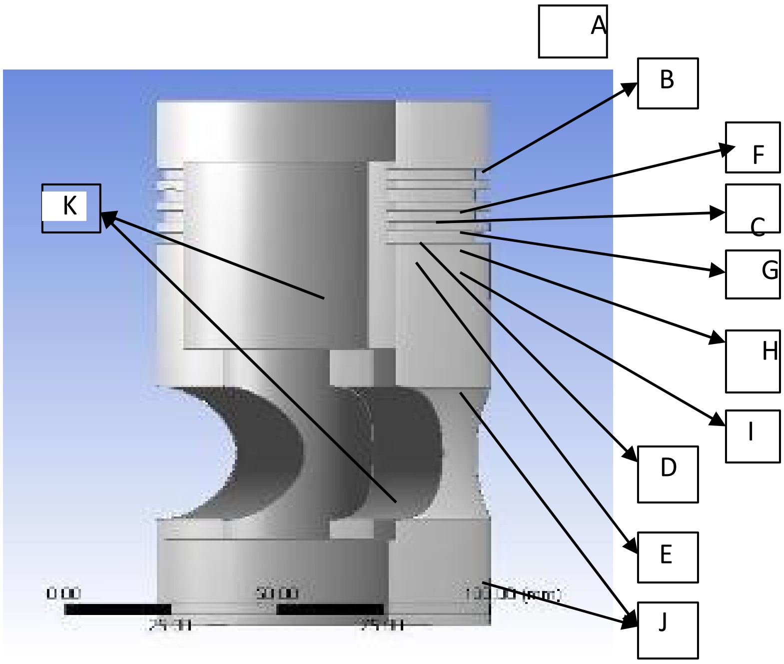


Fig.3.10 Thermal boundary regions.

Prior to the application of the boundary conditions notice few postulations are restrained.

- There is no twisting in rings.
- The rings and sidestep are easily surrounded in recess and no cavity takes place.
- Convective heat transfer through oil film is not considered.

Table 3.3 Convective boundary conditions .

Regions	Coefficient of Heat transfer [w/m^2°C]	Temp [°C]
A	700	700
B	500	225
C	400	180
D	400	170
E	400	160
Ring-F	400	200
Ring-G	400	180
Ring-H	400	160
Ring-I	400	140
J	1500	110
K	1500	110

APPLYING THERMAL LOAD

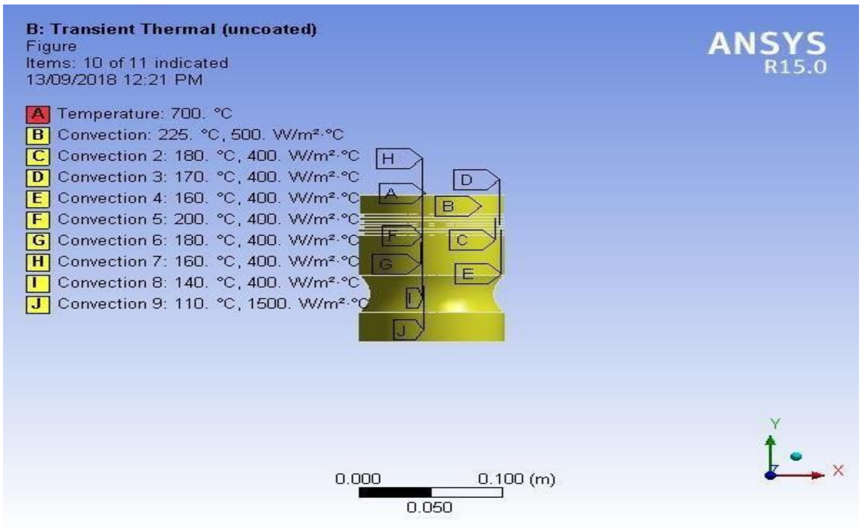


Fig.3.11 Thermal convective load application on uncoated piston

In the above figure the thermal convective load is applying on different region of the uncoatedpiston before the thermal analysis of piston.

3.7. VARIATION OF TEMPERATURE

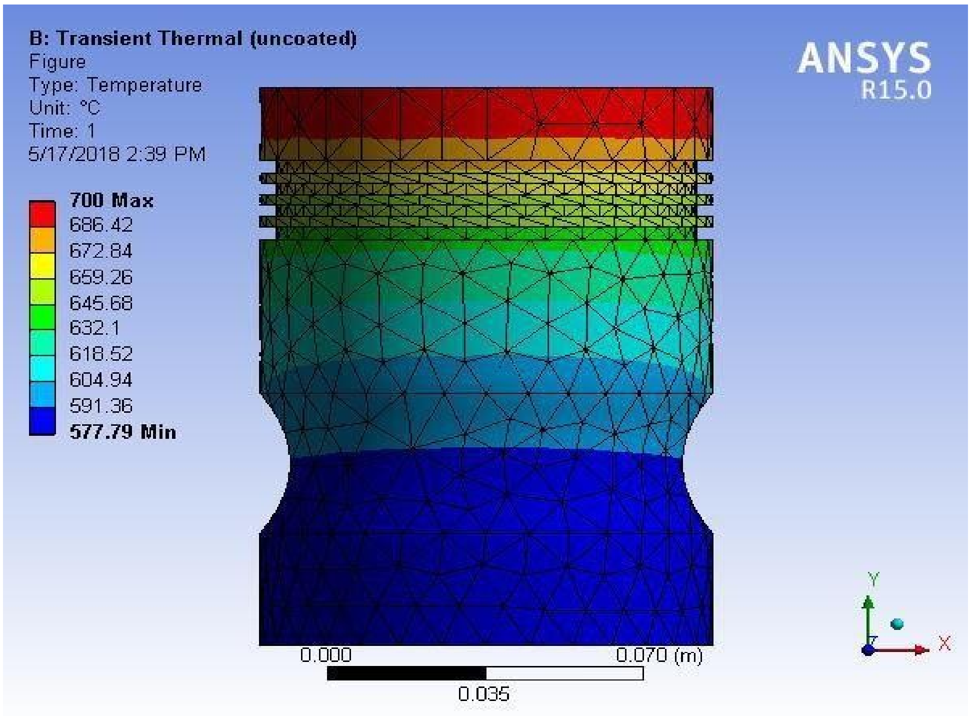


Fig. 3.12 Variation of temperature on uncoated piston

The above figure shows the temperature variation on different region of the piston after thermally analyzing the piston, which exihibits 700°C max temp on the best place that is known for the uncoated piston and 577.79°C minimum temperature on lower portion of uncoated piston.

3.8. THERMAL ANALYSIS OF CERAMIC COATED PISTON

The transient thermal investigation is completed keeping for the determination of the temp. dispersion of Aluminium alloy piston which has surface coating of yttrium zirconium oxide ($Y_2O_3ZrO_2$). In IC engine piston mechanical stresses and temperature fatigue occur. Because of an arm and a leg temperature ridge some temperature stresses is swollen in piston. Transient temperature cut and try secondhand for verifying chief temp. inside piston advantage.

APPLYING THERMAL LOAD

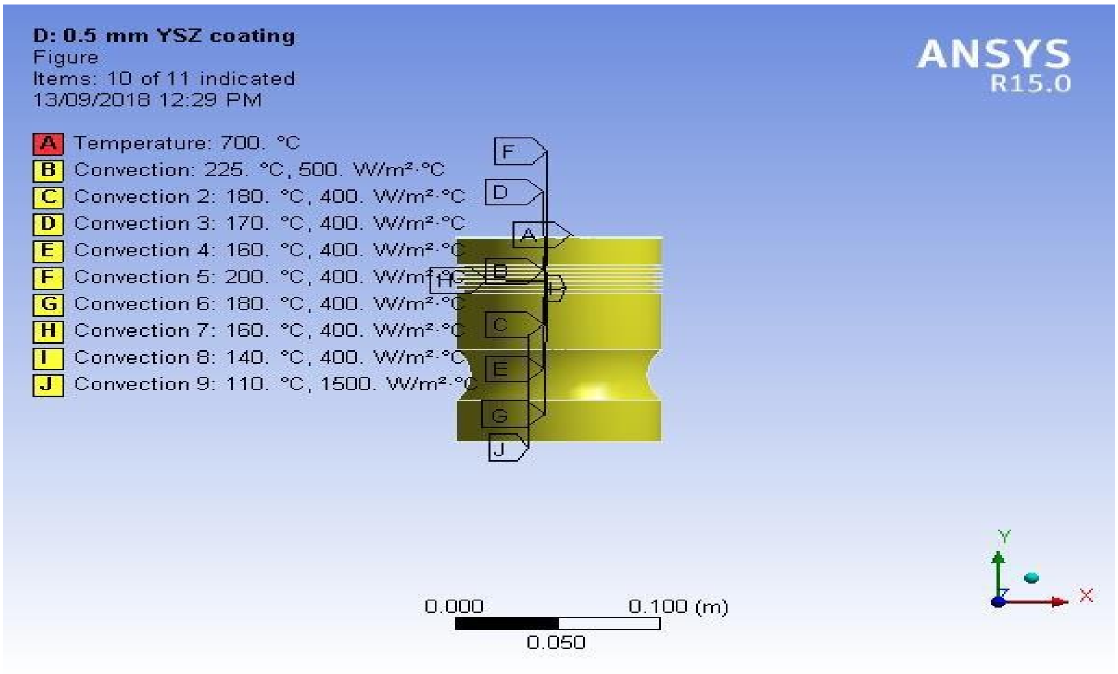


Fig. 3.13. Application of thermal convective load on 0.5 mm ceramic coated piston

In the above figure the thermal convective load is applying on different region of the ceramiccovered piston before the thermal analysis of piston.

VARIATION OF TEMPERATURE

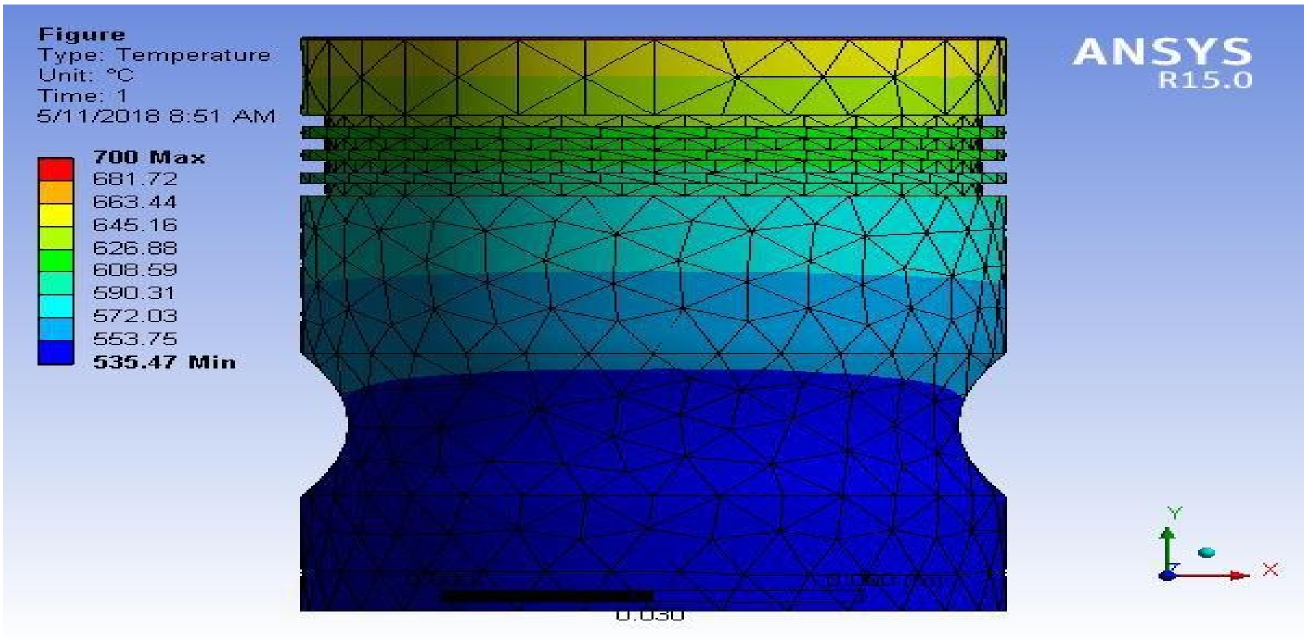


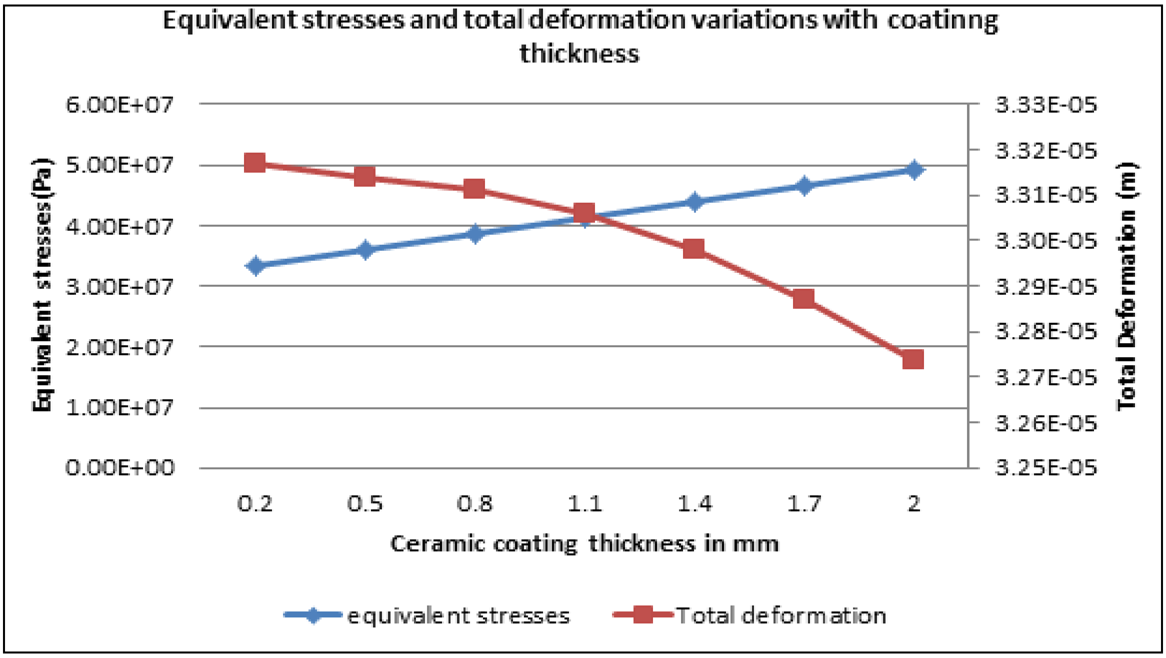
Fig. 3.14 Variation of temperature on 0.5 mm ceramic coated piston

The above figure shows the temperature variation on different region of the piston after temperature examination of ceramic covered piston, which shows 700°C max temp. on the uppersurface of the coating and 535.47°C minimum temperature on lower portion of coated piston, which decreases with the increase in coating thickness.

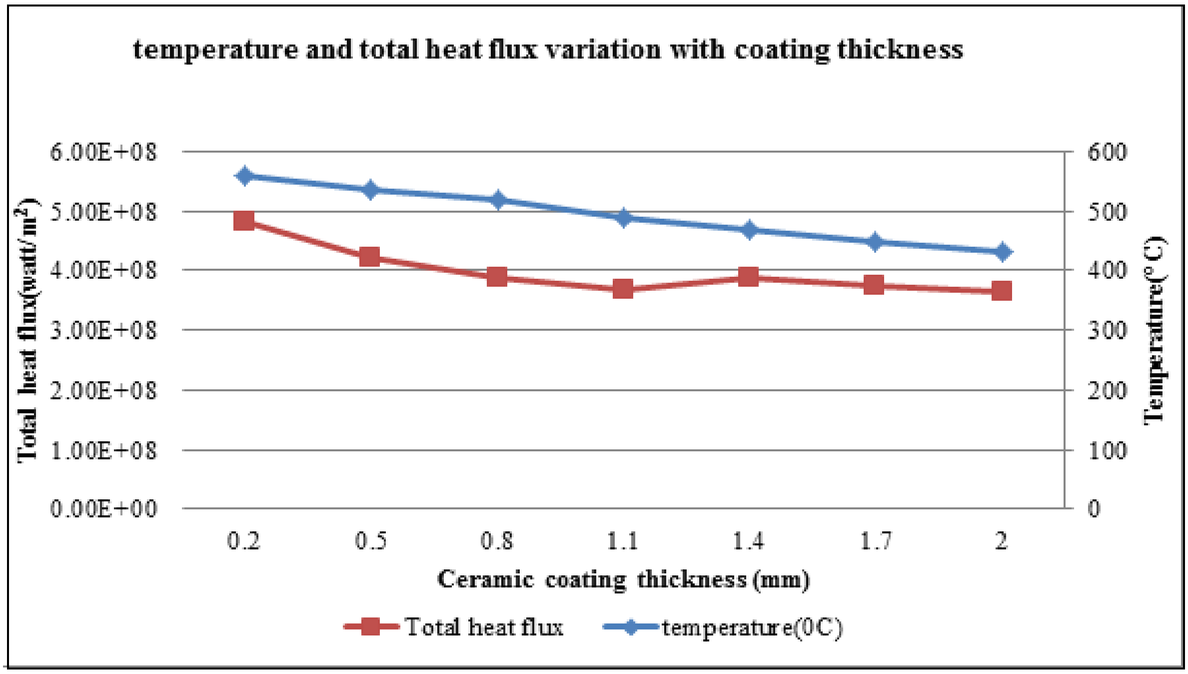
4. RESULT AND DISCUSSION

The finite element way of doing thing is secondhand to explain the temperature dissolution for uncoated and yttrium zirconium oxide ceramic covered piston. For this reason transient thermal examination has been done by commercial approach ANSYS. The temperature selection for the coated and uncoated piston is uncovered in figure.4.20 and figure. 4.22, the highest temperature generate at the piston's top land and lowest temperature is at the lower surface of thepiston. The values of highest and lowest temperature for uncoated piston are 700ºC and 577.79ºCrespectively. The maximum temperature for both is 700ºC and the minimum latitude of thepiston substrate for uncoated is 577.79ºC and for coated piston is 535.47ºC which is decrease in temperature from top land of piston to the bottom surface of piston is approximately 23.57% which is more than the uncoated piston approximately 6.12%. The result validated from the literature review [20]. In this literature review piston material structural steel is used as a piston material and yttrium partially stabilized zirconium (Y-PSZ) is used as a ceramic coating, in this analysis the lower surface temperature is decreased by 3.42ºC or 1.17%.

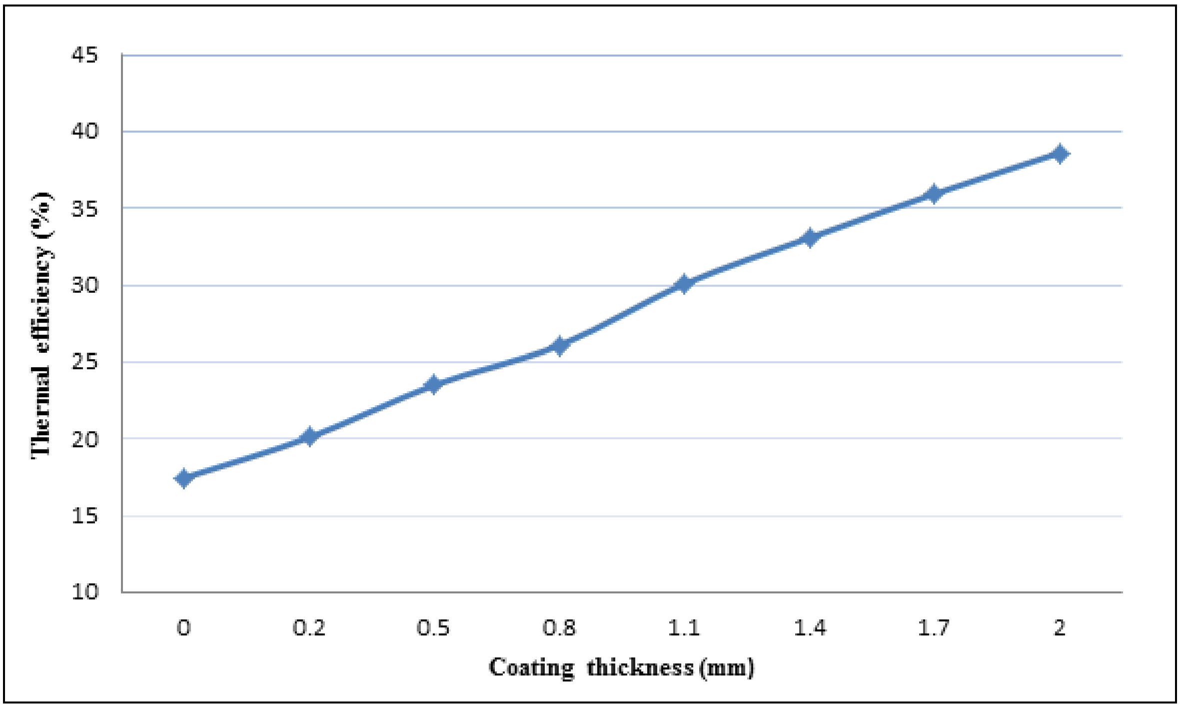
Variation of Equivalent stresses and total deformation with respect to coating thickness



Variation of base surface of piston temperature and total heat flux regarding to coatingthickness



Variation of thermal efficiency with coating thickness



The above graph shows that thermal efficiency is increases with the increase in coating thickness. At the zero coating thickness thermal efficiency is 17.46% and at 2.0 mm thickness coating thermal efficiency is 38.58%.

5. CONCLUSION AND FUTURE SCOPE

Some points may be summarized from the functions of mechanical and thermal observation of the piston which is made up of Al alloy and is covered with the ceramic material (YSZ) bonded by NiCrAl. It was also observed that there was no significant correlation of thickness of coating on equivalent stress as changes observed with coating and without coating were insignificant and is almost constant 37.5 Mpa. However the minimum temperature experienced by the substrate (base metal) of piston was inversely related to the coat thickness. Significant temperature drop between the crown and piston land was observed and therefore it can be inferred that with the increase in thickness of the ceramic coating there was significant drop in total deformation. So it can be said that experimenting of different coating materials of varying thickness can generate superior temperature resistance which can reduce the cost of covering the piston by a single material.

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