DESIGN AND OPTMIZATION OF PISTON USED UNCOATED ALUMINIUM ALOY-6061 AND COATED WITH CERAMIC MATERIAL USING CATIA & ANSYS

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ABSTRACT

The objective of the present work is to focus on the thermal analyses on an uncoated aluminum alloy-6061and coated with ceramic material, on piston. The outcome of coating ceramic materials on the thermal behaviors of the pistons are explored. The design and finite element analysis performed by CAD software Catia & CAE software Ansys. The primary objective is to investigate and explored thermal stress distribution of piston on the actual engine running conditions during combustion process.in this work defines the mesh optimization used of finite analysis method to be expecting the higher stress and important place on the components. In this work, the primary emphasis is placed at the study of thermal behavior of silicon material coatings acquired by using a commercial coads, ANSYS, on piston surfaces. The analysis is performed to reduce the stress concentration of the piston.

Keywords:-CatiaV5R16, Vonmisses stress, Aluminu-6061, Silicon Coating, ANSYS, Meshing, Modeling

1.0 INTRODUCTION

In internal combustion engine, for effective utilization of heat without much heat transfer, the combustion chamber should be insulated. Because of insulation, temperatures reach very high values. Conservative materials cannot withstand such high temperatures in IC engine. Hence this solutions is to use ceramic coatings on the piston, which help to reduce heat transfer and with stand higher temperatures. A Piston is part of reciprocating IC engines, it is moving component this is contained by using a cylinder and is made gasoline-tight by using piston ring.in ic engine its work to transfer pressure from increasing fuel inside the cylinder to the crank shaft through a connecting rod.in this work indicates the As an essential component in an engine, piston endures the cyclic fuel stress and the inertial forces at work, and this operating situation can also cause the fatigue damage of piston, such as piston side wear, piston head/crown cracks and so forth. The investigations indicate that the finest strain appears at the higher stop of the piston and pressure awareness is one of the in particular motive for fatigue failure. However piston overheating-seizure can best arise when something burns or scrapes away the oil movie that exists between the piston and the cylinder wall. The objective of the present work is to focus on the structural analysis of ceramic coated piston, working under thermal and mechanical loads. Thermal analysis is a department of materials science wherein the properties of substances are studied as they trade with temperature. FEM approach is generally used for thermal analysis.

2.0 MATERIALS

2.1 Conventional Piston Materials

During the early years, cast iron was used as piston material because of its good wear properties, but it has high specific weight, causing increased inertia effects. Later on Aluminum alloy 6061 containing came into existence. It helps in the higher strength and reduced expansion. Generally two configurations of used in Aluminum alloy. They are eutectic and hypereutectic, containing 12% and 22% respectively. If insulating the components of combustion chamber. Due to insulation, the components cannot with stand the higher temperatures resulting in failure. In order to prevent this risk, ceramic coatings are employed which can resist high temperatures to work efficiently as Aluminum alone cannot withstand high temperatures.

2.2 Ceramic Coatings

Ceramic Coatings are used as a protective coating on or in between the engine parts, which result in reduction of friction, increase wear resistance and improve heat shielding. All these factors have noticeable influence on the performance parameters and the component life in a vehicle. These coatings help the components to interact in more uniform and compatible fashion. Zirconium based ceramic coatings are widely used. Zirconium along with Magnesia or Yttria has very good mechanical properties, impact and thermal shock resistance. Zirconium-based ceramic coatings are used as thermal barrier coatings owing to their low thermal conductivity and their

relatively high coefficients of thermal expansion compared to other ceramics which reduce the detrimental interfacial stresses.
The problem in the combustion chamber with conventional materials is that most of the heat generated in an engine will be lost through heat transfer. Hence, the solution is to make the components insulate and withstand high temperatures in the combustion chamber. By TBCs, burning of gases in an engine can be done more efficiently by raising the temperature of the air-fuel mixture.
Thermal barrier coatings (TBC) aids in increasing the thermal efficiency of the engine as the heat rejections to surroundings are low with ceramics. The excess heat can be used for improved burning of the air-fuel mixture and reduction in emissions. These coatings have high thermal durability so it is not necessary to cool them immediately like it has to be done for conventional materials. Wear and corrosive properties are very much better than regularly used component materials. Lower heat transfer from the combustion chamber due to coatings helps in using the in-cylinder heat more efficiently. More heat can be transferred to exhaust system. This heat can be used for heat recovery systems for generation of power etc. although installing such heat recovery systems require additional effort. Low thermal conductivity ceramics can be used to control temperature distribution and heat flow in a structure. These coatings also help in reducing the cold start emissions.

3.0 MODELLING OF PISTON

The modelling of piston in step with the system and specification which might be given in system design and records hand books. The scale are designed in terms of SI units. The stress implemented on piston head, temperatures of numerous regions of the piston, heat glide, stresses, traces, duration, piston thickness, hole diameter, etc. A layout concerns to a piston the subsequent factors need to be consideration follows.

Method for piston design parameters

The modes of piston design includes the following steps:

- Piston head thickness (t_H)
- Heat flows by head (H)
- Ring circular thickness (t_1)
- Ring axial thickness (t_2)
- Top area width (b_1)
- Ring area width (b_2)
- Barrel thickness (t_3)

1.0 Piston head thickness (t_H)

The piston head thickness determine the following Grahoff's formula.

$$t_H = D\sqrt{\frac{3}{16} * \frac{P}{\sigma_t}} \text{ (in mm)}$$

1.2 Heat flows by head (H)

Heat flow by the head of piston is determined the following formula

$$H = 12.56 * t_H * K * (T_c - T_e) \frac{KJ}{Sec}$$

1.3 Ring circular thickness (t_1)

$$t_1 = D\sqrt{\frac{3 * P_w}{\sigma_t}}$$

1.4 Ring axial thickness (t_2)

The thickness of the rings may be taken as $\mathbf{t_2 = 0.7t_1 \text{ to } t_1}$
Let assume t_2 =5mm
Minimum axial thickness (t_2)

$$t_2 = \frac{D}{10 * n_r}$$

n_r = number of rings

Top area width (b_1)
The width of the top land varies from
$\mathbf{b_1 = t_H \text{ to } 1.2 * t_H}$

Ring area width (b_2)
Width of other ring lands varies from
b_2 =$\mathbf{0.75 * t_2 \text{ to } t_2}$

Barrel thickness (t_3)
$\mathbf{t_3 = 0.03 * D + b + 4.5mm}$

Table shown as, following calculations are expressed above these formula

S No	Dimensions design-1	in mm
1	Piston length (L)	145
2	Piston bore diameter (D)	130
3	Ring circular thickness (t_1)	4.46
4	Ring axial thickness (t_2)	5
5	Barell thickness (t_3)	11.34
6	Top area width (b_1)	10.54
7	Ring area width (b_2)	4

Table1: Measurements of design before optimization

The parameters of the piston are determined used for cad modelling the piston in CATIA V5.in the above methods the ribs within the piston are not considered, so as make the piston version simple in its layout. In modelling a piston thinking about all factors will become tedious process. For this reason, a symmetric design is developed the usage of the following parameters.
The piston are modelled by using CATIA V5 R19 software which is shown in Figure 1.

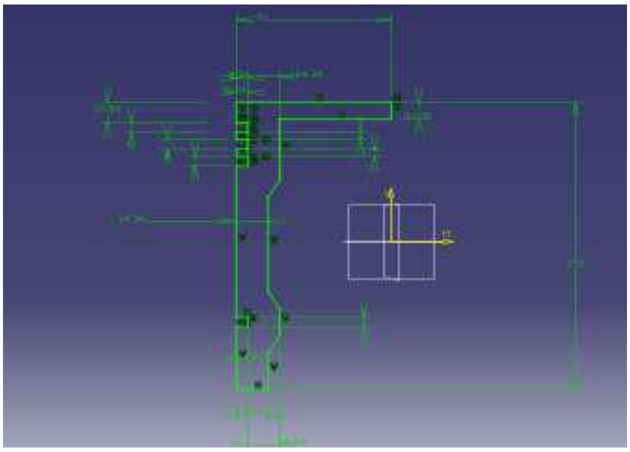


Figure 1: Piston before optimization

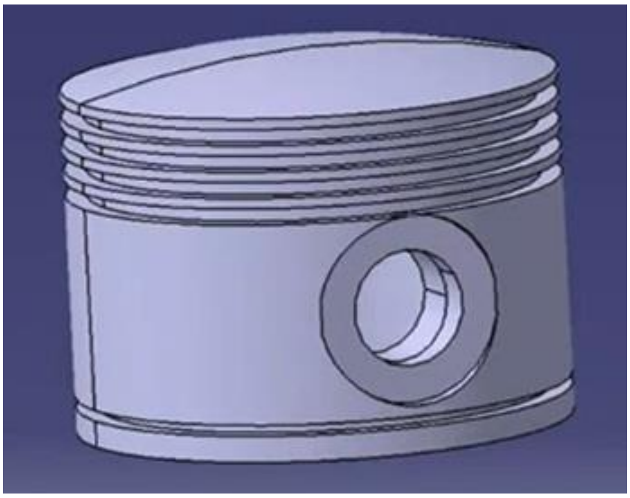


Figure 2: Piston Model

4.0 CAD modelling and Finite Element Analysis of Piston

Piston design starts with the description of the piston geometry by 3D Computer aided design software. This geometry In IGES format is imported to ANSYS FEA Software and analyzed below the predicted carrier situations earlier than whatever is made. That hurries up the layout and testing system, decreases the lead time to create new pistons designs, and produces a higher product. The concept in the back of finite evaluation is to divide a version piston into a fixed finite wide variety of elements. Computer software program generates and predicts the overall stiffness of the whole piston. Reading the facts its miles possible expect how the piston will behave in a real engine and allows the engineer to look wherein the stresses and temperatures could be the finest and how the piston will behave. Evaluation of the piston is carried out to optimize the stresses and minimize the weight using ANSYS. The mathematical model of optimization is hooked up firstly, and the FEA is done by using the usage of the ANSYS software. Based totally on the analysis of premier result, the stress concentrates on the piston has grown to be compare, which gives a higher reference for redecorate of piston.

5.0 Before optimization meshing of piston

Used 20 node in Element named Tetrahedron solid 90.the length of the element is taken as 5, then overall wide variety factors were 57630 and nodes had been 91176 observed in meshed model

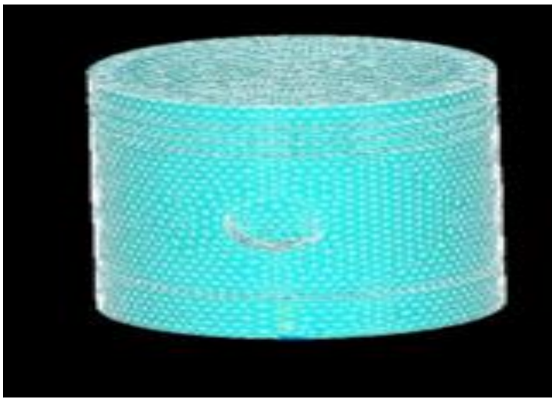


Figure 3: Meshed Piston Model

6.0 GEOMETRIC & THERMAL PROPERTIES OF USING PISTON MATERIAL

It is essential to analyze the piston temperature dissemination so that you can manipulate the thermal stresses and deformations within suitable tiers. As a good deal as 60% of the overall engine mechanical energy misplaced is generated by piston ring meeting. The piston skirt surface slides on the cylinder bore. A lubricant film fills the clearance among the surfaces. The small values of the clearance boom the frictional losses and the excessive values boom the secondary motion of the piston. Maximum of the inner Combustion (IC) engine pistons are product of an aluminum alloy which has a thermal enlargement coefficient, 80% better than the cylinder bore fabric manufactured from solid iron. The thermal and geometric homes are as proven in below:

Property	Aluminium Alloy-6061	Silicon
Modulus of elasticity	70e3 Mpa	220e3 Mpa
Poisson Ratio	0.31	0.35
Thermal Conductivity	234 W/mK	7 W/mK
Co-efficient of thermal expansion	23e-6 /K	10e-6 /K

Table2: Properties of materials

7.0 APPLYING BOUNDARY CONDITIONS

The piston is split into the areas defined through a sequence sealing rings for grooves. the situations of boundary conditions for mechanical simulation have been described because the pressure appearing on the complete area of piston head it is required to load positive facts on material that refer to both thermal and mechanical properties to the tied mechanical-thermo calculations. The temperature load is applied on exclusive areas and strain carried out on piston head. The areas like piston head and piston ring regions are carried out with high quantity of heat (160°C- 200°C). The convection values at the piston wall degrees from 232W/mK to 1570W/mK.and the operating stress is 2Mpa.

8.0 PISTON OPTIMAZITION

Next creating a correct finite detail model a method for the optimization workflow become described. Target of the optimization became to attain a mass discount of the piston. Goal function: minimize mass challenge to constraints:

(i) Maximum Vonmisses stress<Allowable or design stress

(ii) Engineering limitations

(iv) After carrying out static structural analysis the stresses in each loading conditions were studied and then area where excess material can be removed were decided so that maximum vonmisses stress does not exceed allowable and factor of safety is kept above 1.5

(v) Following reasons where scope for material removal

- Thickness of the circular ring
- Thickness of the axial ring
- Barrel thickness
- Top area width
- ring area width

9.0 PISTON DESIGN AFTER OPTOMIZATION

The meshing of the piston design after optimization is accomplished with the same detail shape and size i.e., taken earlier than optimization. The entire number elements had been 78221 and nodes had been 47286 exposed in model mashed.

S No	Dimensions design-2	in mm
1	Piston length (L)	145
2	Diameter of cylinder bore D)	130
3	Circular ring thickness (t_1)	3.26
4	Axial ring thickness (t_2)	3.36
5	Barrel thickness (t_3)	9.05
6	top area width (b_1)	10.11
7	ring area width (b_2)	3.12

Table3: measurements of design after optimization

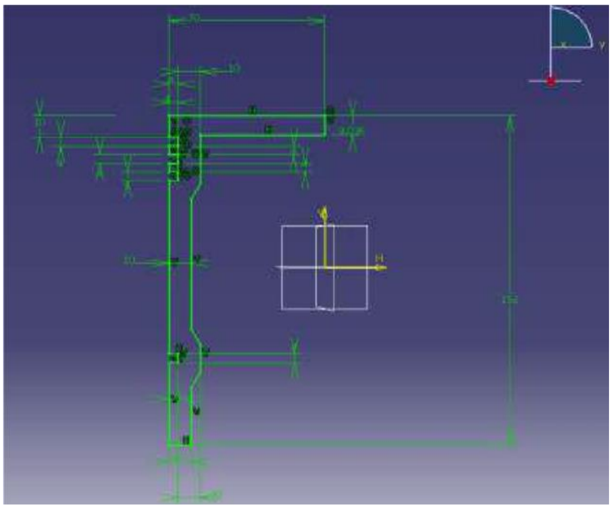


Figure 4: Piston after optimization

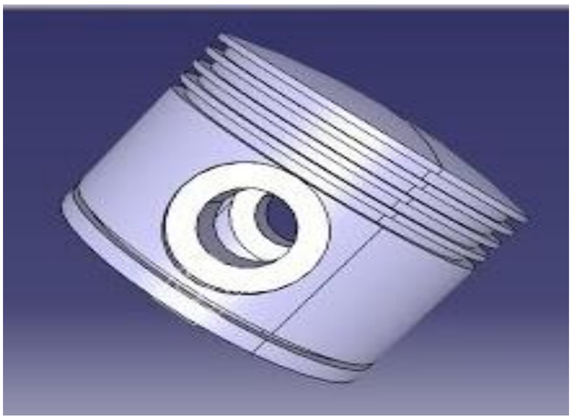
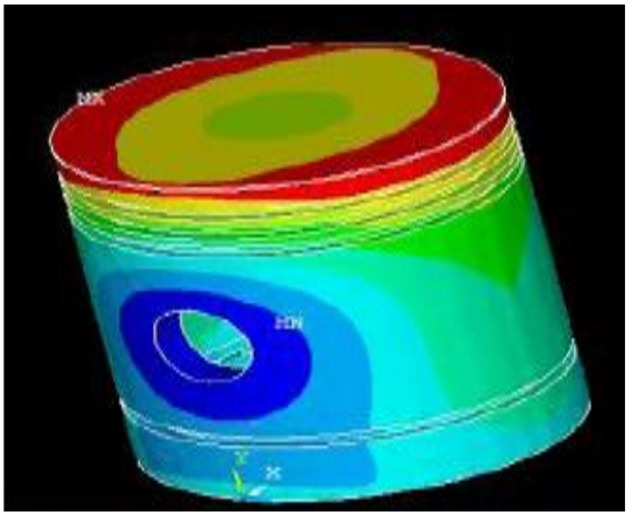


Figure 5: Piston model after optimization

10.0 RESULTS AND DISCUSSIONS

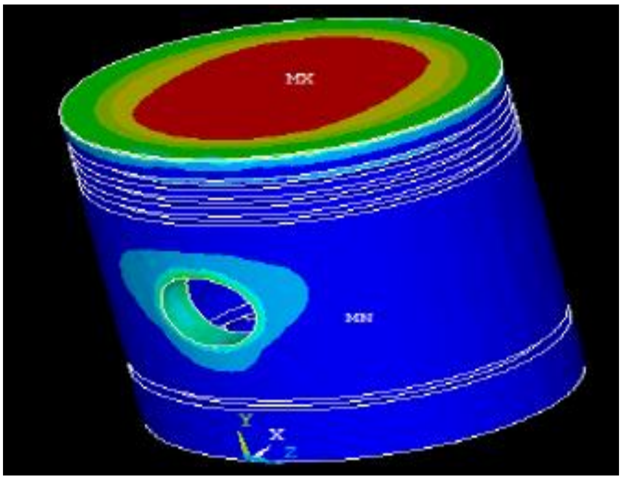
Analysis the methods of substance into smaller parts or breaking a complex topic to advantage a better information of it. The current version is passed through Thermal analysis and accompanied by way of Static analysis, together known as as Coupled field analysis. The meshed issue is analyzed to locate the thermal stresses of the piston. The factor is subjected to the have an impact on top of the piston of heat conduction and heat convection to side lands etc. the following pictures are proven for resulted deformation and vonmisses stresses before and after optimization.

Vonmisses & distortion before optimization



DMX= 0.049982, SMX=0.049982

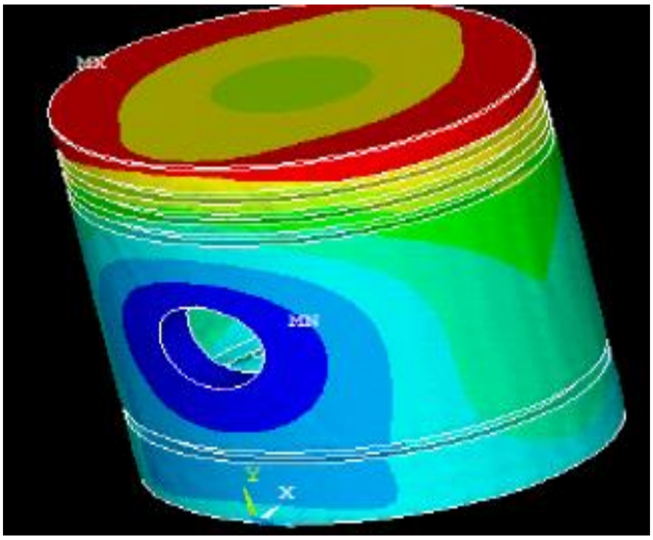
Figure 6: Resultant distortion



DMX=0.049982, SMN=0.020304, SMX=85.6439

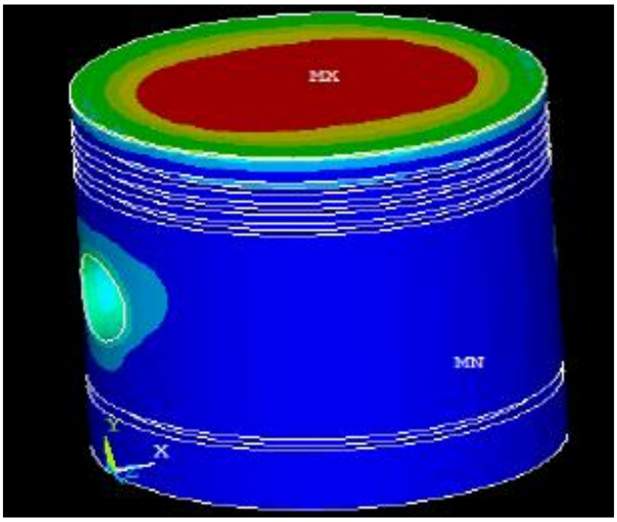
Figure 7: Vonmisses Stress

Distortion and Vonmisses Stress after Optimization



DMX=0.025881, SMX=0.025881

Figure 8: Resultant Deformation



DMX= 0.033645, SMN= 0.013198, SMX= 55.6685

Figure 9: Vonmisses Stress

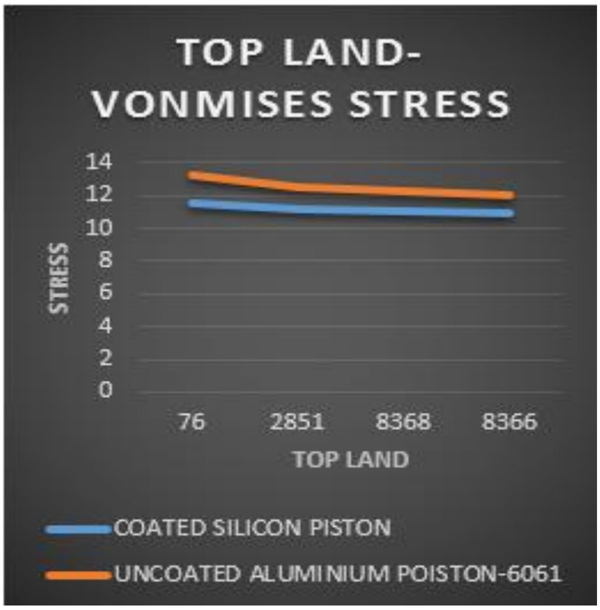


Figure 10.Comparision vonmises stress between uncoated aluminium -6061, coated with silicon material

The optimized values after optimization using ANSYS are given in the following Table

S. no	Parameter	Before optimization	After optimization	Design consideration
1	Circular ring thickness (t_1)	4.46 mm	3.26 mm	4 mm
2	Axial ring thickness (t_2)	5 mm	3.36mm	4 mm
3	Barrel thickness (t_3)	11.34 mm	9.05 mm	9 mm
4	Top area width (b_1)	10.54 mm	10.11 mm	10 mm
5	Ring area width (b_2)	4 mm	3.12 mm	3 mm
6	Vonmisses stress	85.6439 Mpa	55.6685 Mpa	56-86 Mpa
7	Deflection	0.049982 mm	0.025884 mm	0.025884 mm

The diameter 130mm and span 145mm are assumed to be constant. It is not significant that the versions in piston diameter and span of the piston. The piston circular thickness has affected in size and the temperature and warmth go with the flow are very excessive to this length of thickness. Before optimization parameter value is known as 4.46mm & found after parameter optimization value is 3.26mm.These parameter value is rounded to next parametric value i.e., 4mm and is consideration for design. The piston ring axial thickness value is before optimization as 5mm, it's miles changed to a few 3.36mm value after optimization, then the increasingly more heat and stress carried out via groves as it's far very close to the piston head. Next highest parametric value i.e., 4mm is consideration for design.

The extreme barrel thickness before optimization is 11.34mm is affected to dimensions variations after applying boundary conditions like temperature, pressure, and loads, then parametric value is changed to 9.05mm and lively to next largest value i.e., 9mm occupied into consideration. The initial value i.e. previously optimization is 10.54 mm. and is modified after applying pressure which is carried on the crown head i.e. top surface of the piston as an end result the shape of the piston top surfaces becomes similar to bowl. The parametric value after optimization is received as 10.11mm and it is rounded to 10mm.these value suitable and considerable for design. The width of the alternative properties near piston ring are 4mm in size and is changed because of heat and pressure applied on rings by groves. The value after optimization is 3.12mm and is rounded to 3mm.

CONCLUSIONS

Piston skirt may additionally seem deformation at this work, which typically reasons crack on the higher stop of piston head. due to the deformation, the best stress concentration is produced on the higher end of piston, the conditions of affairs will become extra serious when the stiffness of the piston isn't always enough, and the crack normally regarded at the point A which may additionally gradually make bigger or even purpose splitting along the piston vertical. The strain distribution on the piston particularly depends on the deformation of piston. Therefore, if you want to decrease the stress concentration, the piston crown have to have sufficient toughness to decrease the deformation.

[1] The most desirable mathematical model which comprises deformation of piston skirt and piston crown.
[2] The Finite element analysis is conceded for popular piston system utilized in diesel engine and the results of analysis suggest that the most stress has modified from 85 Mpa. And highest deformation has been reduced from 0.049982mm to 0.025884mm.
[3] The von-Mises stress decreases with the increase in the coating thickness on the surface of the piston
[4] It can be concluded that the Thermal Stress Distribution is a function of coating thickness. With increase in thickness, the maximum temperature increases on piston crown.

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