INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 5, Issue 3)
Available online at: www.ijariit.com

Numerical and thermal analysis of ceramic coated M550D x Drive Sedan

Brijesh Kumar
brijeshsvn2@gmail.com
Goel Institute of Technology and Management, Lucknow, Uttar Pradesh

Anil Yadav
anilyadav01.27@gmail.com
Goel Institute of Technology and Management, Lucknow, Uttar Pradesh

ABSTRACT

The piston is considered to be one of the important parts of the internal combustion engine. It is a part which bears the pressure of the combustion of the gas inside the cylinder. Normally they are made up of cast iron which bears the gas weight. It is used to deliver the power via linking rod to the main shaft of the engine. Now a days they are made of aluminum alloy to keep it light weight. As the top surface of the piston has to bear the load, it is prudent to cover it with some coating material so that it could bear the thermal load. Piston made up of gray cast iron coated with ceramic material (MgZrO3) which is bonded by special material (NiCrAl) is intended for M550d x Drive sedan by machine design approach to resolve the dimensions of the piston and then it is modelled in ANSYS Work bench 17.1. The pressure of the 5 N/mm^2 is applied on the piston. The equivalent stresses are found to be same for both coated and non-coated piston. Thermal analysis of both coated and the non-coated piston is done. The properties like equivalent stresses, temperature variation and total twist under pressure and thermal load are resolute with the change in the thickness of ceramic coating material. It is completed that ceramic coated piston is able to handle the thermal load and is indifferent towards the structural load.

Keywords— *IC engine, Piston, ANSYS, Ceramic coated, M550d x Drive sedan*

1. INTRODUCTION

The piston is cylindrical in shape and is capable of taking pressure energy produce by the gases burnt inside the cylinder to power the crank shaft through the connecting rod in a continuous manner. The piston also performs compression of gasses inside the cylinder along with the exhaust of gasses after the complete combustion process. All the activities, mentioned above happen simultaneously one after the other. It is a reciprocating member which runs the shaft of the engine by transferring energy.

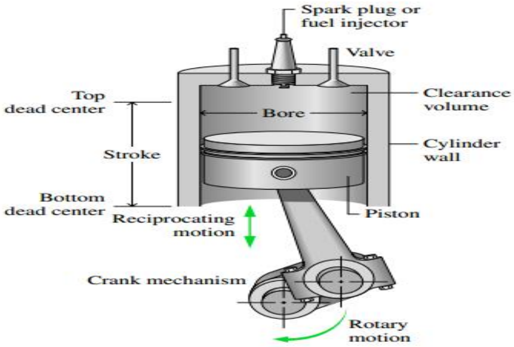

Fig. 1: Different parts of the piston

1.1 Parts of the piston

The above mentioned pistons are open at mouth end and consist of the following parts:

1.1.1 Piston Head: The piston head or crown may be of three types. Depending upon the design of the combustion chamber, they are of flat type, convex type or concave type. It is used to bear the pressure generated by gases in the cylinder.

1.1.2 Piston rings: They are used to lock the cylinder and prevents charge leakage past the piston.

1.1.3 Skirt: The function of the skirt is to acts as a bearing for the side thrust, developed by the connecting rod on the walls of the engine cylinder.

© 2019, www.IJARIIT.com All Rights Reserved

1.1.4 Gudgeon pin: Piston pin or **wrist pin** are the common names of gudgeon pin**.** It is used to join the piston to the connecting rod in an IC engine.

1.2 Piston head

It is designed by considering the following two facts. It should have enough strength to overcome the straining effect produced by gas pressure. It is developed by Combustion blast inside the engine cylinder, and the heat obtained from the combustion should be dissipated to the cylinder walls and fins as quickly as possible.

From the first fact that is, straining effect due to gas pressure, the thickness of head is found by assuming it as a circular disc, flat plate in nature, of uniform thickness which is considered to be fixed at the external edges and subjected to a uniformly distributed load (UDL) due to the pressure of gas over the complete area of the piston.

1.3 Piston rings

Typically, the three compression ring and an oil ring are connected in the form of a set of piston ring which makes an interpersonal motion. The compression ring prevents the blow-by incident. Combustion gas flows in the crankcase from the combustion chamber at high pressure. The main function of the oil ring is to prevent the excess of lubricant in the internal wall of the cylinder liner. The main function of the piston ring is to split the combustion chamber from the rest of the engine. Some assumptions should be made before designing piston rings. The first piston ring should not be far behind from the piston head. This enhances the drainage gap between piston and cylinder walls, thus increasing the leakage of hydrocarbon compounds found in the fuel into exhaust gases. The number of rings depends primarily on the height of the piston and depends on the pressure received during combustion. At medium speed, the first ring takes 75% of the whole pressure. The choice of a number of rings should be the result of careful analysis, with one hand, depending on the gas which passes in the crankcase should be minimal, on the other, the number of rings determines the mass of the piston, engine height and friction loss. The next figure shows some examples of some designs in the piston rings and also the oil flowing while working. Figure 2. Examples of piston rings and design A), B) Oil pumping through rings, C) D) Scrapping oil for piston) Difference between the piston ring and piston). At the time of the piston movement, the BDC side, the rings in Figure are in the position as shown. With scraped oil filling the clearance gap between piston rings and grooves. In TDC position the piston moves above the rings of the movement while the movement is shown as fig. 2 (b). Oil, which thus runs along TDC, is eventually burnt in the combustion chamber of the IC engine. The excretion of toxic components in exhaust gases increases with the use of burn oil and is not economical, the emission is in the form of hydrocarbons. Burning oil also creates a sludge, carbon deposits in the internal walls of the chamber, which easily ignites.

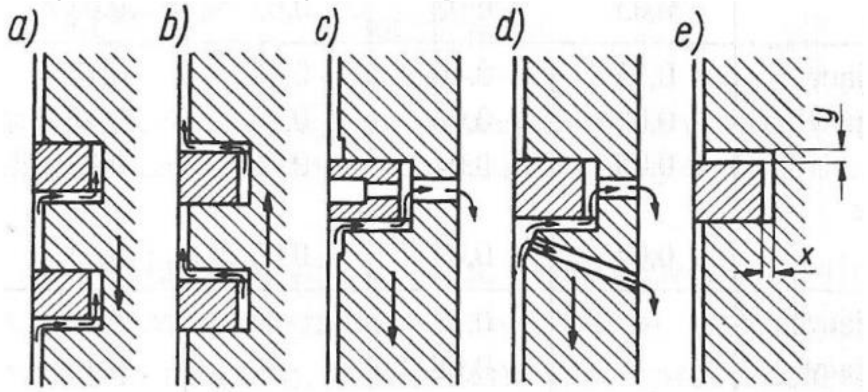

Fig 2: Examples and design of piston rings

1.4 Piston Barrel

A piston is the main part of reciprocating engines & pumps, gas compressors and pneumatic cylinders and other similar mechanisms based machines. It is the moving component that is contained in a cylinder and is ended tight by piston rings so that gas does not leak out.

1.5 Piston skirt

The part below the oil ring section of the piston is known as ***a skirt of the piston*** *or* ***piston skirt.*** It acts as bearing to the side thrust. The length of the skirt of the piston is found in such a manner that the pressure on bearing does not exceed 0.25 N/mm^2. The maximum thrust is obtained at the time of expansion stroke. The tenth part of the maximum gas load is equivalent to side thrust on cylinder liner for the piston design.

1.6 Ceramic coatings

Ceramics are a special class of material, mostly inorganic type, which usually used clay as raw material to make tiles and bricks. They are basically of two types glazed and unglazed. The glazing is done by dipping the tiles or the bricks into the aqueous solution of oxides of tin and lead. They are heat treated to get the desired properties like strength, thermal resistant or resistance to wear. The desired properties are achieved by varying the process of heat treatment. Due to these properties, they find application in several areas like automotive, industries, space, defense, atomic energy and many more. In industry, they find application in making the protective layer around the furnaces. In space, thermal insulated tiles are used on the outer surface of the rockets. In defense, they find application in the manufacturing of armored vehicles. They are also used in isolating the radiation produced during an atomic reaction. They also find application in an internal combustion engine, in which several parts possess thermal coatings. Here, we are mainly concerned with their application in the IC engine.

© 2019, www.IJARIIT.com All Rights Reserved

The thermal barrier coating is popularly known as TBC. Coating is applied on the IC engine parts as a protective coating, which reduces the frictional wear and protects it from the heat generated due to combustion in the engine cylinder. There are several types of advance coatings which are used now a days. They are of silicon oxide (sio_2), alumina (Al_2O_3), Zirconia (ZrO_2), silicon carbide (SiC) type. Zirconia based coatings are beings as a thermal coating inside the cylinder lining and on the piston surface. To enhance the properties of zirconia, it is mixed with magnesium. Here, we are mainly focusing on $MgZro_3$. This thermal barrier coating (TBC) works like insulating material and is applied to the piston head, which is able to prevent the loss of excess heat of combustion. The main work of the coating is to distribute the heat uniformly along the surfaces of the piston. This creates the different heat zones on the surface of the piston. The temperature of these heat zone acts as a starting point for the convective heat analysis.

These TBC solves the primary problem of loss of heat when it is made up of conventional materials.

1.7 Overall behaviour of ceramics coating to IC engine

This decreases the high temperature which is resting in cycle .it have regularly applied force on the cylinder wall .which is protect the corrosion of the IC engine parts, this technique is better technology used in now days to tactics is improve the proper performance of the engine part, many matured are used as water is like collect to decrease the drumming effected of combustion chamber. The ceramics are used in ancient time in the war time to the protection of human use in the home wall to produce human friendly environment. those techniques is used now days in engine part to enhance the performance of the to reduce hitting effaces use the coting material in IC engine which is not conducting friendly of thermal heat , glass has also low thermal conductive but not other parameter fulfill for piston working. The application of ceramics is used now days in the engine, turbine ladle. this technology is use in aerospace rockets and satellites and space sip for the protection of the surfaces to developed high heat due to air frication but in IC engine high temperature satiation there are conduction convocation and radiation will occur in combination chamber to reduce this effect use move on ceramics property material. The normal thinness of ceramics coating film is range from 50 mm to several micron meters. It depends up on the process of coating application recently si3n4, sic, diamond likes coating .boron nitride and cerium oxide are used to coat the metal parts .ceramics coating are tough & having a high level of lubricity. But due to the oxidation process, ceramics material is used under the temperature of 1200 deegree centigrade the effectiveness of actual coating depends on mechanical comical and physical bonds which determine the coating adheres and ultimate strength of ceramics layer. Ceramics coating materials are used,

(a) Surface seals
(b) Critical seals
(c) Bearing condemnation reduction
(d) Thermal shock

1.7.1 Advantages

(a) Increase the life time of parts
(b) Corrosion resistant
(c) Reduction of heat on high-temperature components
(d) Reduce the frication
(e) Improving the thermal & acidic corrosion
(f) Improving the appearance of the surface.

1.8 Ceramics coating material

The ceramics are in organic non-metallic materials which have high melting points relative to other materials and hence these require high temperature for processing.

Ceramics material is brutal in nature and all so comically inert having long life .ceramics coating is liquid polymer which is applied by hand to the outer surface of recycle .this coating bind together with recycles factory points and results in treating a layer of protection .ceramics coating provide high performance of sides layers on metals and alloys to protect them from corrosion wear, heat, insulation, frication etc. In the 20^{th} century, new ceramics material known as advanced ceramics which is the composition of sic , Al2O3 , ZrO2, MgO and tungsten carbide, alumina– titania oxide etc.

Ceramic coting is done by various method

(a) Thermal spray coating
(b) Plasma – spray coating
(c) Sputter coating
(d) Dry-film lubricants etc
(e) Detonation gun
(f) Oxygen – acetylene powder
(g) Oxygen – acetylene rod

2. PROBLEM FORMULATION

BMW has adopted an aluminum piston developed by Federal-Mogul for use in its M550d xDrivesedan. The piston meets the strength and thermal performance requirements of very high-power diesel engines that have been designed to reduce CO_2 emissions and improve fuel economy.

These diesel engines also offer improved dynamic concert, but their power output of more than 90kW/liter is a challenge for the pistons. BMW, reportedly the first automaker to adopt the new piston, will use it for its triple-turbo 3.0-liter diesel engine, the

N57D30S1, diesel engine at a specific power output of 93kW/liter. The material used in the design process is gray cast iron. During combustion, the temperature insides the cylinder reaches the 650° C, which acts as thermal load. The said piston is analyzed for thermal load. With the application of $MgZrO_3$ Ceramic coating, there is a development of heat zone on the surface of piston, which acts as convective boundary conditions. Variation of temperature is determined using the above constraints. Simulations were carried out to obtain the change in parameters like equivalent (Von Mises) stresses, deformation and the maximum temperature of the surface with the change on coating thickness.

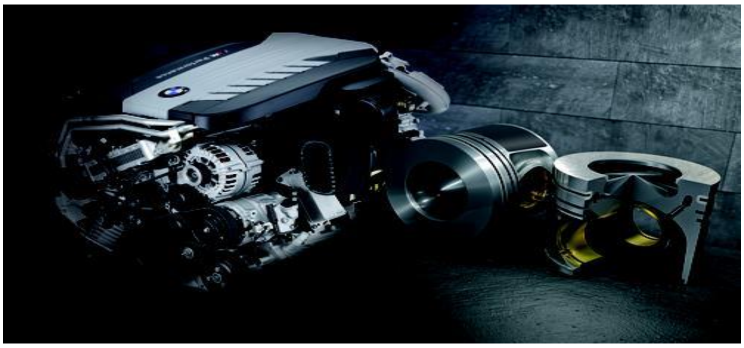

Fig. 3: Schematic of ($MgZrO_3$) ceramic coated piston

3. MODELLING OF PISTON

The piston is modelled in ANSYS design modeler with the help of dimensions which are determined above using machine design approach. The modelling requires dimension used to create sketches which are extruded or revolved to convert it into the desired three dimensional model.

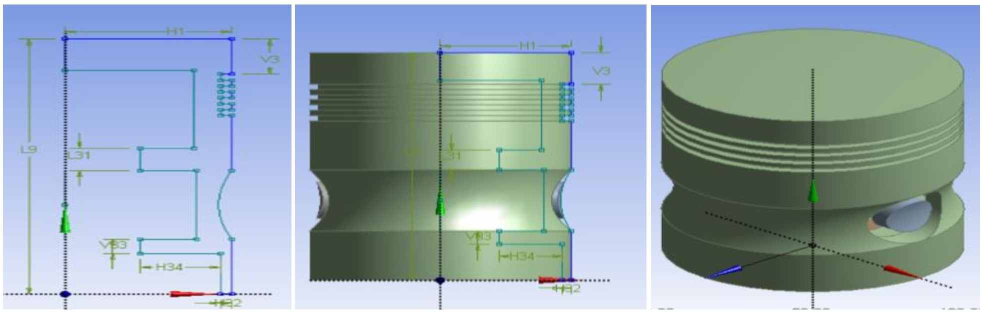

Fig. 4: Sketch of piston sketch (Front view) Uncoated piston (Isometric view)

After preparing the sketch it is revolved about y axis. The desired 3D model piston is achieved as depicted in the figure.

3.1 Project schematic

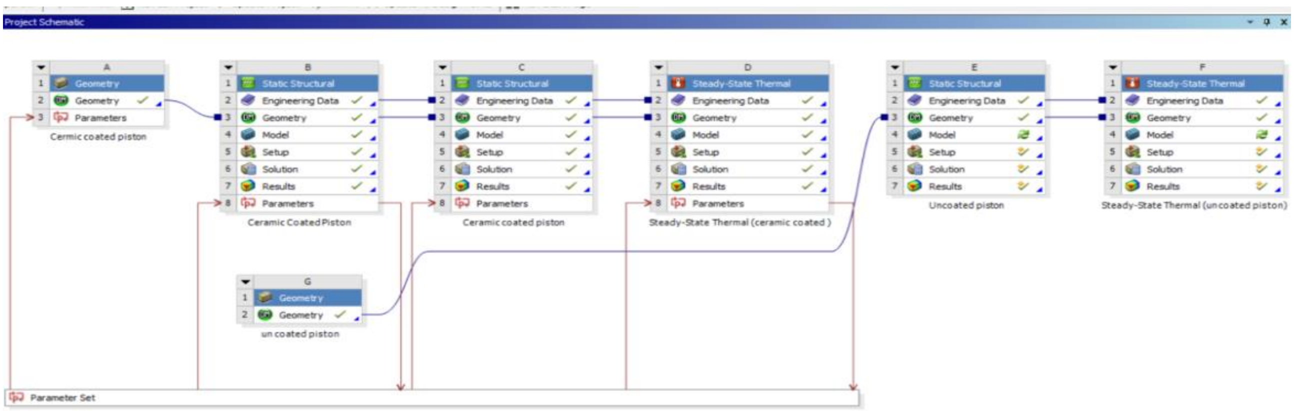

Fig. 5: Project schematic of structural and thermal analysis for coated and un-coated piston

4. STRUCTURAL ANALYSIS OF UNCOATED PISTON

4.1 Meshing

Networking is a method in which the solid model is divided into several small parts. These parts are called "elements" and are called heads as nodes. With a combination of these nodes and elements, a mesh is formed. Here our object is automatically divided into a grid of SOLID 186 and SOLID 187. The number of items is 4661 and the number of the contract is 10698 for the unpainted piston. The problem grid must be checked correctly to see any defects arising from solid modeling or quality side. General defects in solid modeling are free edges, opening in a drawing which leads to poor mesh. Network quality is checked through many parameters such as aspect ratio, connectivity, and network element types.

© 2019, www.IJARIIT.com All Rights Reserved

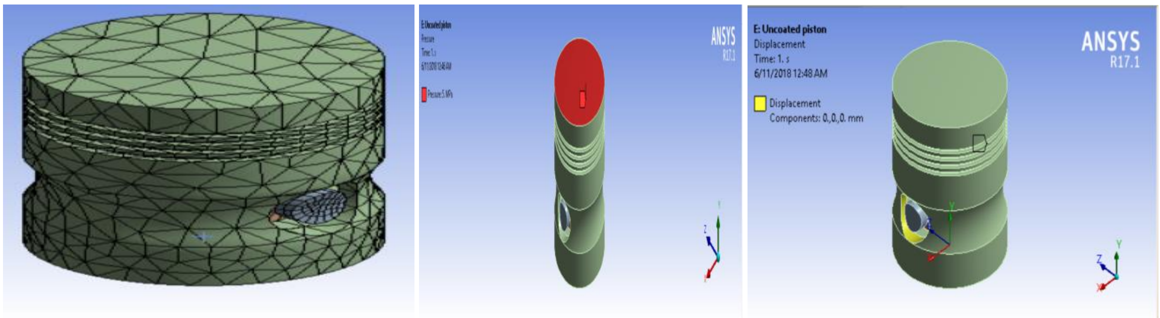

Fig. 6 (a) Meshing of piston (b) All degrees of displacement in X, Y, Z are set to zero

4.2 Boundary conditions for uncoated piston

During the combustion, the gases burnt inside the cylinder produces pressure load of 5N/mm^2, which acts on the uncoated piston top surface, which is shown in the diagram

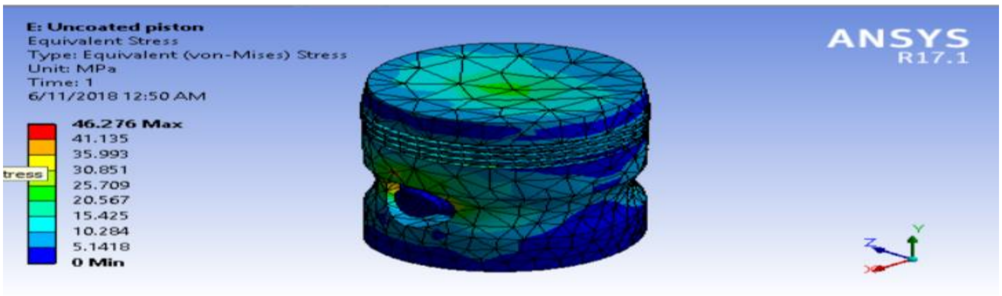

Fig. 7: Equivalent Stresses of Uncoated Piston

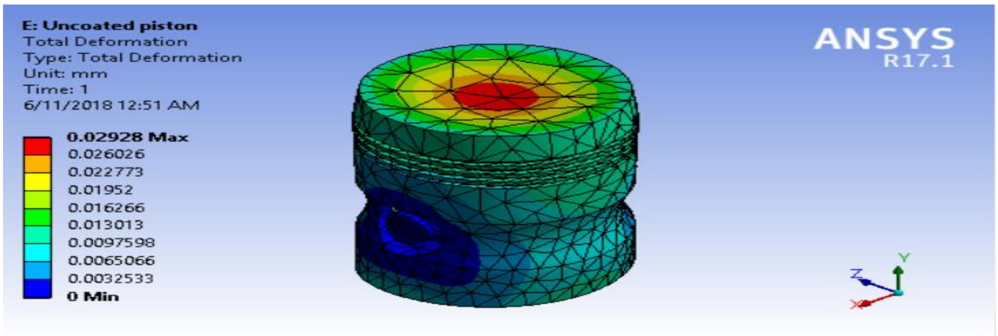

Fig. 8: Total Deformation of Uncoated Piston

4.3 Static structural analysis of $MgZrO_3$ coated piston of M550d xDrive Sedan

4.3.1Material Properties: The material selected for manufacturing of piston is gray cast iron, coated with $MGZrO_3$ ceramic material bonded with some bonding material. Three material is used for the designing of the piston. The properties of the material are given in table 1 below.

Table 1: Material properties of different material

SNo.	Property	Gray cast iron	$MgZrO_3$ (ceramic material)	NiCrAl (bonding material)
1	Young's Modulus(MPa)	110000	46000	90000
2	Poisson's ratio	0.28	0.2	0.27
3	Thermal Conductivity (W/mm°C)	52	8	12
4	Thermal expansion coefficient(1/°C)	0.000011	0.0008	16
5	Density (Ton/mm3)	7.2×10^{-09}	5.6×10^{-09}	7.8×10^{-09}
6	Specific heat(J/kg°C)	460	650	764

After modelling of the piston is opened in the model mode and meshing of the piston is started.

4.3.2 Meshing: Aries is a technique in which the solid model is divided into several smaller parts. These parts are called "elements" and the corners are called nodes. Aries are formed with the combination of these nodes and elements. Here our object is divided into three main parts such as Piston, Bonding Material (NiCrAl) and MgZrO3 ceramic coating), the net of SOLID 186 and SOLID 187 has been made. The number of elements is 12488 and the number of nodes is 66648. Coated piston The formed trap should be properly verified to detect any defects arising from solid modelling or quality factor. In solid modelling, there are common faults-free edges, which open in a sketch, which leads to bad traps. The quality of the mesh is verified by several parameters, such as aspect ratio and connectivity, and mesh element type. The consequences of follow-up processing will be an error if the permissible limit is crossed with the quality check of the element.

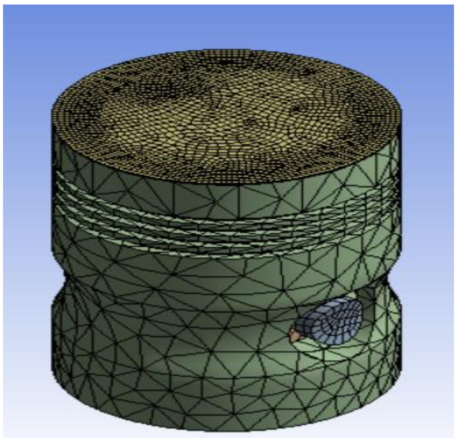

Fig. 9: Meshing of ($MgZrO_3$) ceramic coated piston

4.4 Boundary conditions

During the combustion, the gases burnt inside the cylinder produces pressure load of 5N/mm^2, which acts on the ($MgZrO_3$) coated piston top surface, which is shown in figure 10.

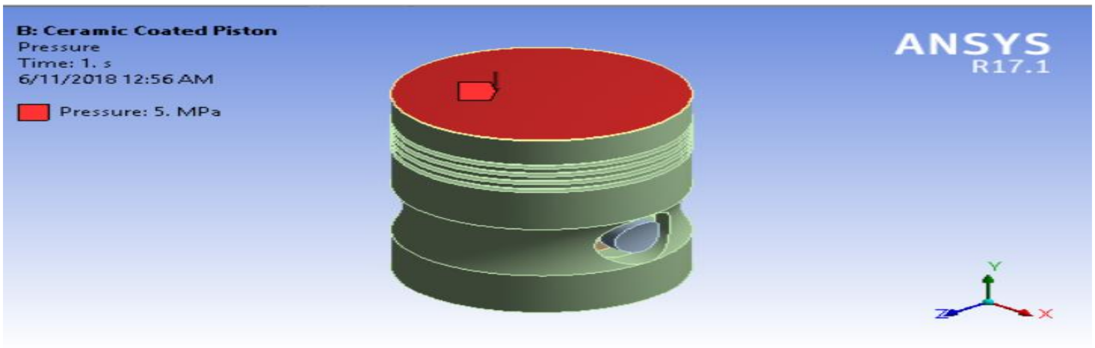

Fig. 10: Application of the pressure on the top land of the Piston

Displacement in X, Y and Z directions are set to zero as follows

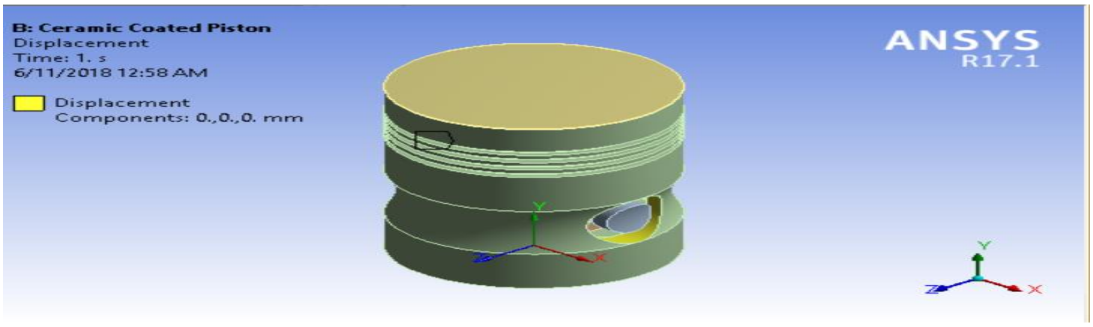

Fig. 11: All degrees of displacement in X, Y, Z are set to zero

4.5 Equivalent Stresses and Total Deformation

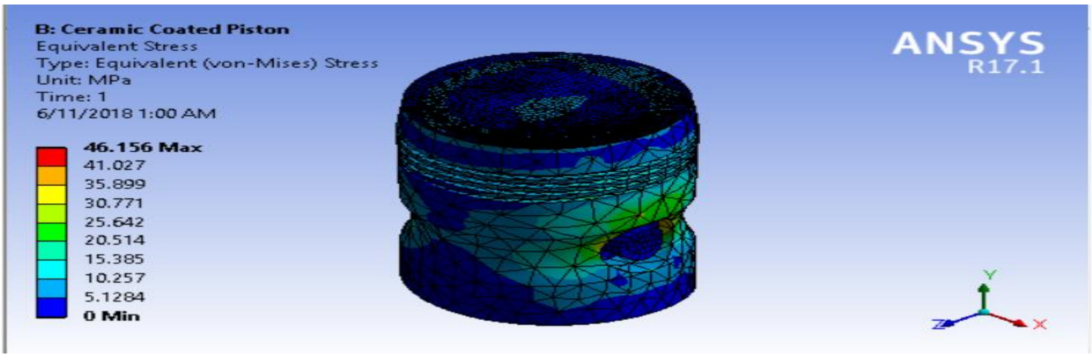

Fig. 12: Equivalent Stresses of ceramic coated Piston

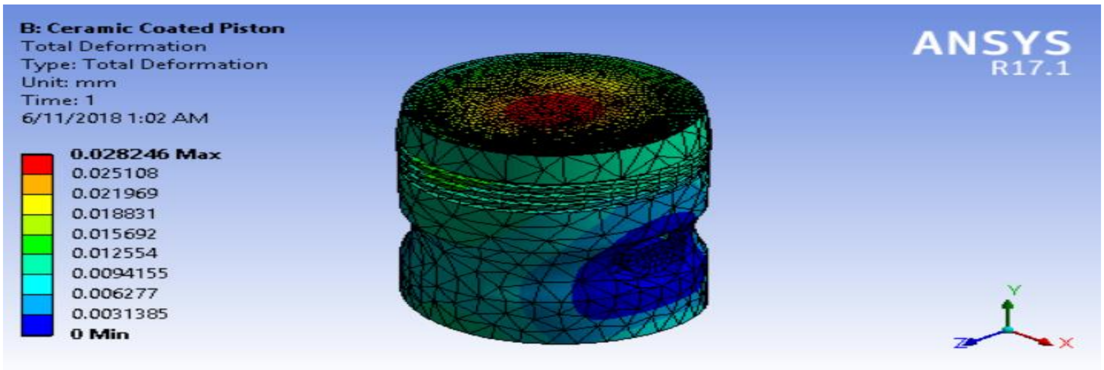

Fig. 13: Total Deformation of MgZrO3 Ceramic coated Piston

4.5 Thermal analysis of uncoated piston

Heat is transferred by three ways conduction, convection and Radiation. Conduction happens in solid, convection phenomenon takes place in fluids and radiation requires no medium for the transfer of heat. Here convection is the method by which heat is transferred to the surrounding. The gases in the cylinder form the heat zones and convection currents are set up. These heat zones act as the initial loading condition for the analysis of piston thermally. The values of the heat transfer coefficients and bulk temperatures are considered for the said analysis. The values for it were obtained from the literature available.

4.6 Applying Thermal Load

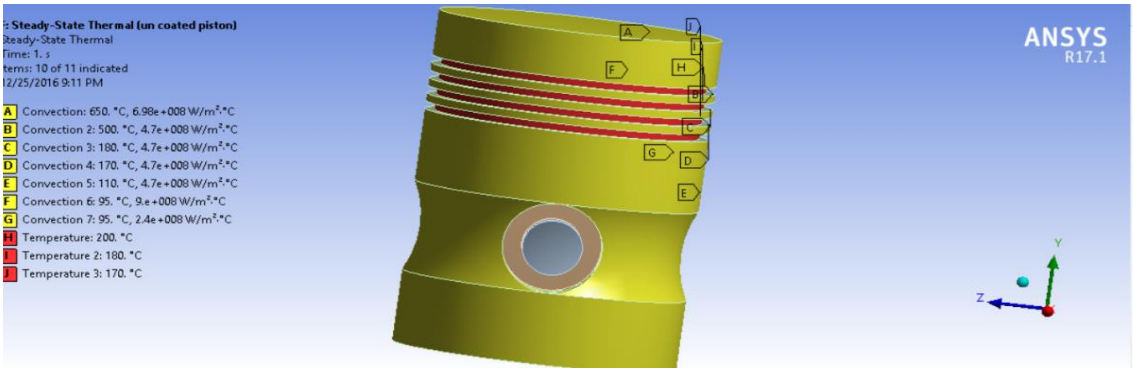

Fig. 14: Convective Thermal load on Piston (uncoated)

4.7 Variation of temperature

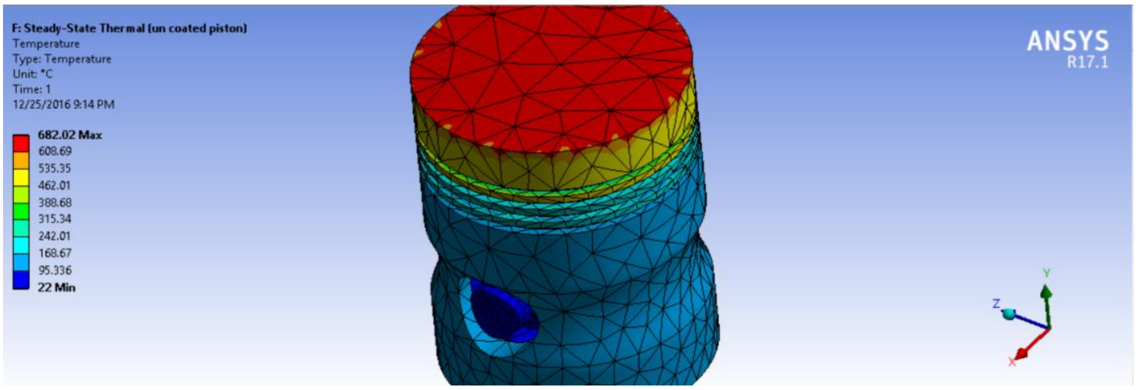

Fig. 15: Variation of temperature Piston (uncoated)

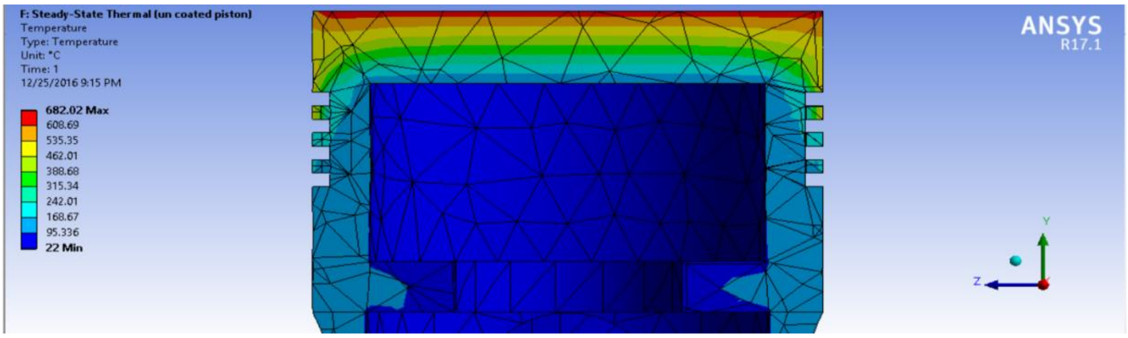

Fig. 16: Sectional view of Temperature variation on Piston (uncoated)

© 2019, www.IJARIIT.com All Rights Reserved

4.8 Thermal analysis of piston having $MgZrO_3$ coating

4.8.1Applying Thermal Load

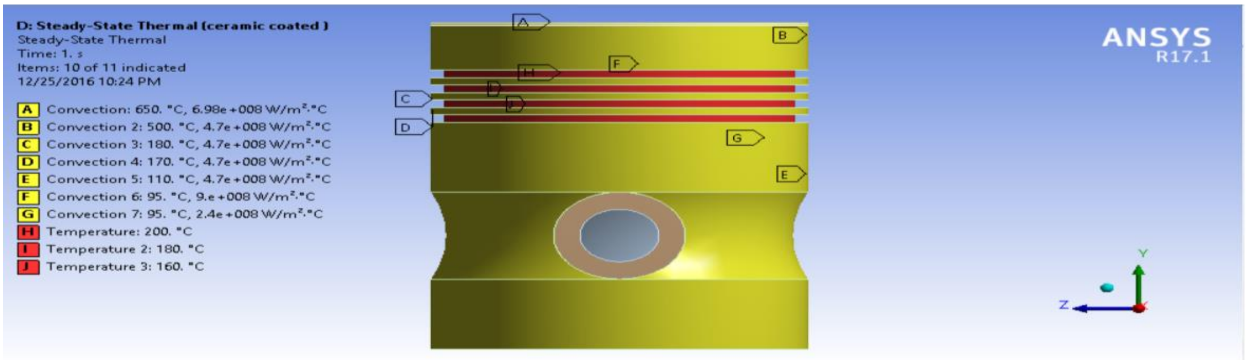

Fig. 17: Convective thermal load on $MgZrO_3$ coated Piston

4.8.2Variation of temperature

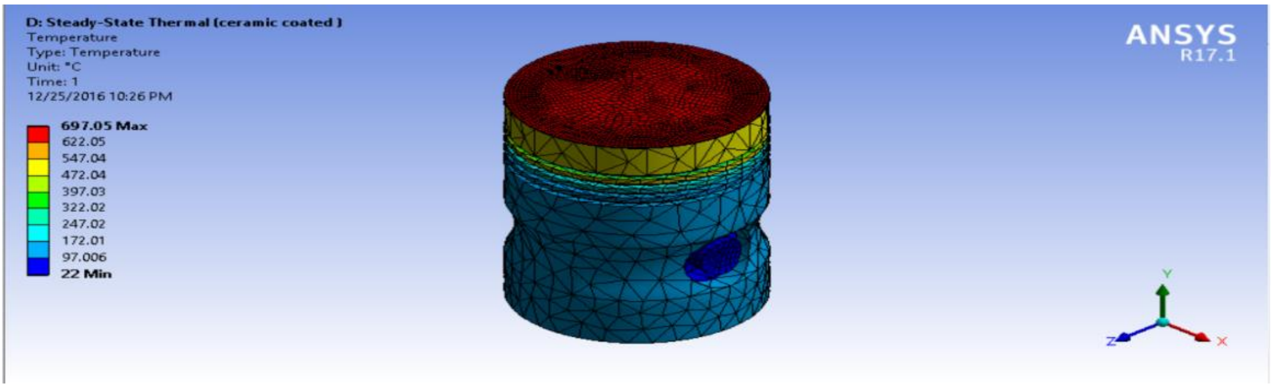

Fig. 18: Temperature variation on $MGZrO_3$ coated Piston

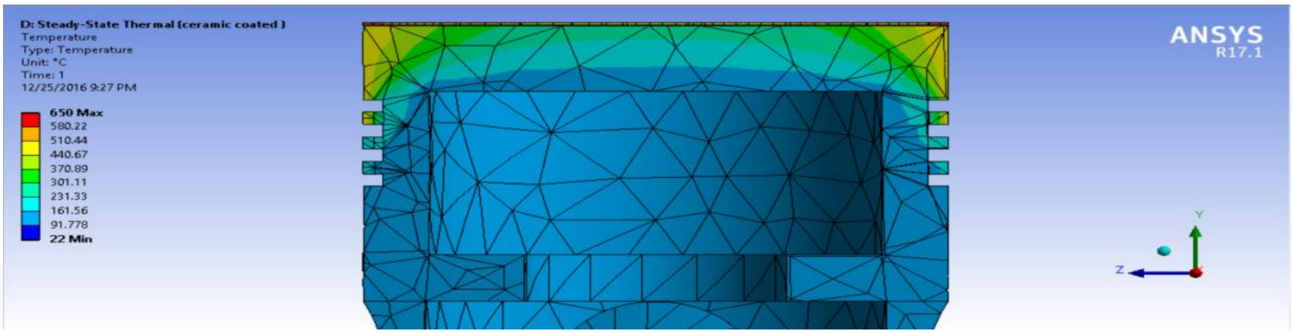

Fig. 19: Sectional view of temperature variation on $MgZrO_3$ coated Piston

4.9. Design of experiment

To understand the variation in the equivalent stresses, Total deformation and the maximum temperature of the ceramic coated piston with the application of different layers of coat thickness. The design of the experiment is used. This enables us to determine the values of the unknown without actually doing any change in the dimensions of the geometrical design. So, remodelling is not done again and again.

Table 2: Table of Design experiment

Table of Design Points

	A	B	C	D	E	F
1	Name	Update Order	P1 - Extrude8.FD1	P2 - Temperature Maximum	P3 - Equivalent Stress Maximum	P4 - Total Deformation Maximum
2	Units		mm	C	MPa	mm
3	DP 0 (Current)	1	0.6	697.05	46.156	0.028246
4	DP 2	3	0.9	694.01	46.114	0.028011
5	DP 3	4	1.2	685.2	46.174	0.027784
6	DP 5	6	1.5	686.17	46.256	0.027511
7	DP 6	7	1.8	681	46.264	0.027309
8	DP 7	8	2.1	686.05	46.216	0.027054
9	DP 8	9	2.4	681.16	46.223	0.026789
10	DP 10	11	0.8	694.08	46.116	0.028106
11	DP 11	12	1	694.54	46.087	0.027948
12	DP 12	13	1.1	690.35	46.107	0.027866

4.10 Variation of temperature with respect to coat thickness

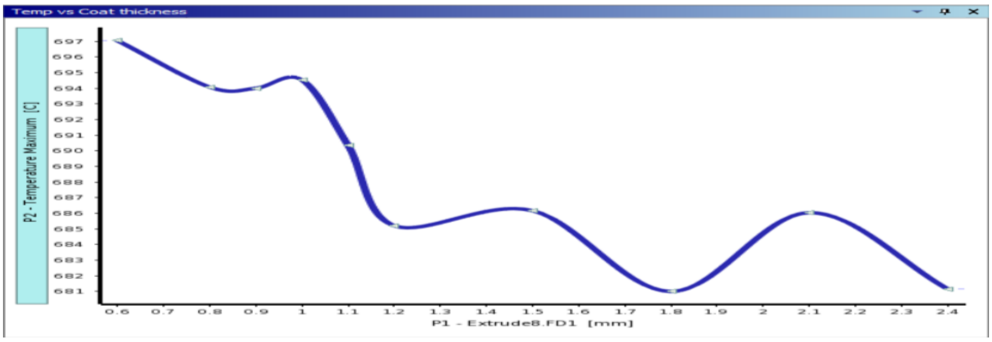

Fig. 20: Graph showing the changing temperature with the change in coating thickness of $MgZrO_3$

4.11 Variation of Equivalent stress with respect to coat thickness

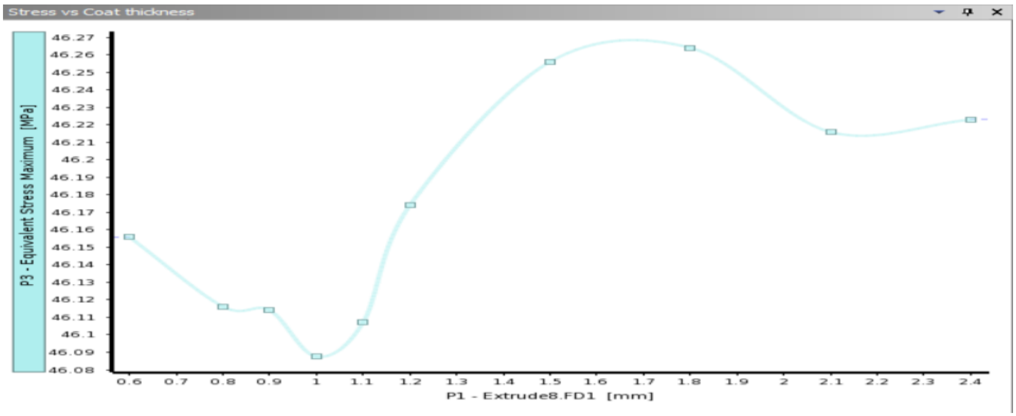

Fig. 21: Graph showing the change in Equivalent (Von Mises) stresses to the coating thickness of $MgZrO_3$

4.12 Change in Total Deformation to coat thickness

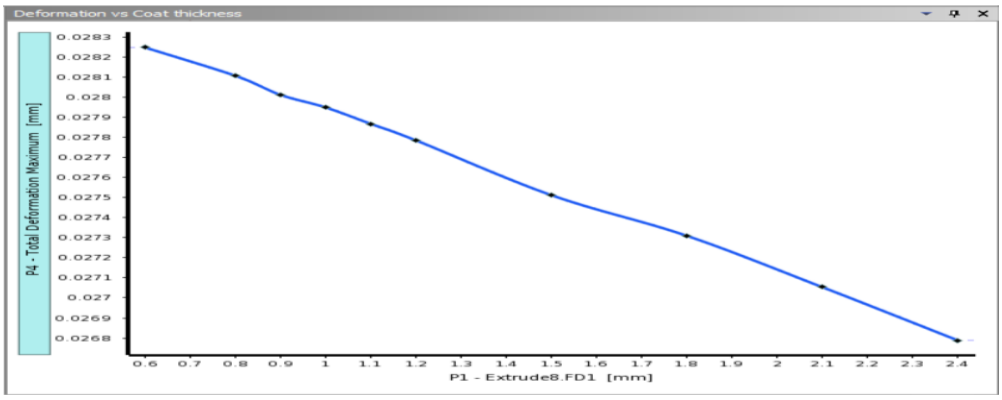

Fig. 22: Figure showing the change in deformation to the coating thickness of $MgZrO_3$.

5. CONCLUSION

The Static structural and the thermal analysis of the piston of M550d xDrive sedan, made up of the grey cast iron and is coated with the ceramic material ($MgZrO_3$) is glued by (NiCrAl) material is performed. On the basis of results, The following conclusion could be drawn from it are

- Bending stress is about 46 MPa. The change in tension bending with changes in the thickness of the layers is very small and is almost steady compared to the voltage equal to an uncoated piston (Figure 4.11). We can say that the thickness of the layer does not affect the tension bending. With the increase in the thickness of the coating of ceramic material, the piston's maximum temperature decreases
- The temperature of the piston crown was found in the inner range from 600 to 700C but with the application of ceramic coating, the piston top ground temperature was found to be 200 less lower than the top surface of the coating this proves that ceramic coating is helpful in the form of thermal barrier and reduced the heating problem of engine.
- With the increase in coating thickness, there are decreases in total deformation.

6. REFERENCES

[1] Muhammet Cerit, Mehmet Coban, "Temperature and thermal stress analyses of a ceramic-coated aluminium alloy piston used in a diesel engine", *International Journal of Thermal Sciences*, vol.77, pp.11-18 (2014).

[2] S. H.Chan, K. A.Khor, "The effect of thermal barrier coated piston crown on engine characteristics", *Journal of Materials Engineering and Performance, vol.9*, pp.103-109 (2000).
[3] T. Hejwowski ·, A. Weroriski, "The effect of thermal barrier coatings on diesel engine performance", *Vacuum*, vol.65, pp.427-432 (2002).
[4] P.M. Pierz, "Thermal barrier coating development for diesel engine aluminium pistons", *Surface and Coatings Technology*, vol.6, pp.60-66 (1993).
[5] Ekrem Buyukkaya, "Thermal analysis of functionally graded coating Al-Si alloy and steel pistons", *Surface and Coatings Technology*, vol.202, pp.3856-3865 (2008).
[6] F.S. Silva (2004), "Fatigue on engine pistons – A compendium of case studies, science direct", *Engineering Failure Analysis*, vol.13, pp.480-492 (2006).
[7] Ekrem Buyukkaya, Muhammet Cerit, (2007) Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method, *science direct, Surface & Coatings Technology* 202 (2007) 398–402
[8] Adnan Parlak, Idris Cesur, Vezir Ayhan, Barış Boru and Görkem Kökkülünk,(2014) Comparison for Performance and Exhaust Emissions of Steam Injected and Thermal Barrier Layer (TBL) Coated Piston Spark Ignition Engine *ISBN*: 978-1-61804-221-7.
[9] Kuldeep Singh, Dr O.P. Jakhar, (2014) "The Behavior of Temperature on Insulated (MgZrO3) Diesel Engine Piston with ANSYS", *ISSN* 2250-2459**.**
[10] Vikram A. Mistry, Dipak C. Gosai, Dr H.J. Nagarsheth,(2014), Temperature Distribution Analysis of MgZrO3 Coated and Conventional IC Engine Components using FEM, Volume 2, Issue 2 *ISSN* 2321-9939