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EXTENDING THE LIFE OF PISTON BY USING CRUST OF HIGH TEMPERATURE BEARING MATERIAL AND ANALYZING BY FINITE ELEMENT ANALYSIS

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Abstract: Internal combustion engine is consist of a very important part piston which is made up of Aluminium alloy. In internal combustion engine during combustion very high temperature and pressure is there inside the cylinder which piston has to bear range of temperature is 600^{0}c-2000^{0}c and pressure is upto 50 bar .Due to high temperature and pressure high thermal and high structural force per unit area in the piston is produced inside the engine cylinder and if these force per unit area exceeds the designed limit values, the failure of piston take place. To increase the bearing capacity of piston we have To use some improved form of material of piston having high thermal and high structural force per unit area of piston. In this work we are increasing the thermal and structural force per unit area capacity by using CIC(high performance ceramics) material. By using ANSYS we are going to analysis CIC(high performance ceramics) material with aluminium alloy namely A2618.Firstly the structural and thermal force per unit area analyses are investigated on a conventional (uncoated) piston made of aluminum alloy namely A2618. Secondly the structural and thermal analyses are performed on the piston coated with CIC(high performance ceramics) material by means of commercial code ANSYS. The effects of coating on the thermal behaviors of the piston are investigated. Our objective is to study the thermal and structural force per unit area on piston during combustion process.

INTRODUCTION

Automobile components are in great demand these days because of increased use of automobiles. The increased demand is due to improved performance and reduced cost of these components. Research & development and testing engineers should develop critical component in shortest possible time to minimize launch time for new products. This necessitates understanding of new technologies and quick absorption in the development of new product. A piston is a component of reciprocating IC engines. It is moving component that is contained by a cylinder and is made gas- tight by piston rings. The piston of an internal combustion engine receives the impulse from expanding gas and transmits it to the connecting rod. The combustion of gas on the top of piston generates considerable amount of heat and the piston must also transmit heat to the cylinder walls from where it is absorbed by cooling water or air. The modern IC engines run around 5000 rpm and hence will generate considerable inertia force which can be controlled if piston is light weight. In an engine its purpose is to transfer force is to transfer from expanding gas in the cylinder to the crank shaft via a piston rod or connecting rod. It is the important part in an engine, piston endures the cyclic gas pressure and the inertial force at work and this working condition may cause the fatigue damage of piston, such as piston side wear, piston head/crown cracks and so on. The investigation indicates that the greatest stress appears on the upper end of the piston and stress concentration is one of the main reasons for fatigue failure. On the other hand piston overheating – seizure can only occurs when something burns or scrapes away the oil film that exists between the piston and the cylinder wall. A piston is a component of reciprocating engines, reciprocating pump and gas compressors a moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to piston for the purpose of compressing or ejecting the fluid in the cylinder.

The engine pistons are the most loaded elements of the internal combustion engine. They must satisfy the requirements concerning durability and functionality. Therefore a new type of material with high strength properties at high temperatures is still searched. In addition the new materials should be characterized by a low hysteresis- the difference of the coefficient of thermal expansion for heating and cooling are not supposed to be significant. It allows increasing the piston resistance to fatigue damage and thermal shocks.

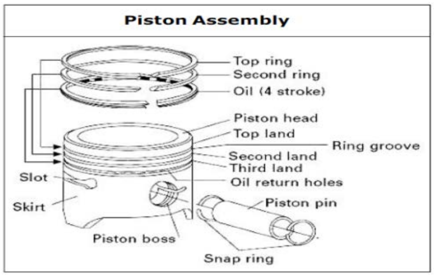

Fig.1.1 Piston Assembly

Engine piston is most complex part compared to other components in an automobile sector. Still lots of research work have been conducting on piston regarding material composition, geometry and manufacturing technique. The function of the internal combustion engine piston is to receive the energy from expanding gasses after during combustion and transmit it to the crankshaft by means of connecting rod. Piston expands appreciably when it gets heated during the operation so actual clearances need to be given otherwise it will lead to engine seize. And hence to avoid this case pistons are made up of cast aluminum alloy matrix with the combination of reinforcement in different weight percentage. For the better result here, I am replacing the conventional piston material (uncoated) with coated material. The CIC(high performance ceramics) material ceramic coatings are used as thermal barrier coatings owing their low conductivity and their relatively high coefficient of thermal expansion. The addition of coating material to the aluminum matrix improves the tensile strength, compressive strength, hardness and thermal behaviors. The coated material is having more factor of safety compare to uncoated alloy material because of more yield strength at elevated temperature due to presence of the coating in the alloys.

Compared to traditional aluminum alloys, aluminum alloys coated with CIC(high performance ceramics) material have better stiffness, creep resistance and wear resistance. They find application mainly in the automotive industry, aerospace industry and marine industry. The construction of vehicles is a discipline in which both economic and ecological aspects are of essential importance. One of the design criteria is the endeavor to reduce the structure's weight and thus to reduce the fuel consumption. Composite produced at an industrial scale are used for manufacturing of cylinder sleeves, pistons, brake drum and disks. Research on the prospects for composite materials development in combustion engines, especially regarding the materials intended for pistons, was under taken also in polish research and scientific centers.

Energy conservation and efficiency have always been the quest of engineers concerned with internal combustion engines. Even the petrol engine rejects about two thirds of the heat energy of the fuel, one-third to the coolant, and one third to the exhaust, leaving only about one-third as useful power output. Theoretically if the heat rejected could be reduced, then the thermal efficiency would be improved. Low Heat Rejection engines aim to do this, by reducing the heat lost to the coolant.

Thermal Barrier Coatings in petrol engines lead to advantages including higher power density, fuel efficiency, and multi fuel capacity due to higher combustion chamber temperature. Using thermal Barrier Coatings can increase engine power and decrease the specific fuel consumption and increase the exhaust gas temperature. Although several systems have been used as thermal barrier coatings for different purposes, CIC(high performance ceramics) material has received the most attention. Several important factors playing an important roles in thermal barrier coatings lifetimes including thermal conductivity, thermal, chemical stability at the service temperature, high thermo- mechanical stability to the maximum service temperature and the thermal expansion coefficient.

Computer aided engineering tools allows engineers to design product and to simulate these designs for residual stress, structural response, pre-processing fatigue and similar effects on the machine component. Computer aided engineering allows engineers to load the component at its extreme conditions and simulate its response or otherwise it is not possible to do it because of safety limitations of cost consideration. Particularly for automobile component computer aided engineering help to analyze them for crash simulation, creep and fatigue test on virtual component leading to reduction in time consuming trial and error procedure for design the prototype and it also helps us to reduce the cost of manufacturing. The leading manufactures have accepted simulation as a part of early design process with prototyping and testing are done to ultimately verify the designs. Piston design is carried out with the help of computer aided engineering tool and various stresses such as maximum principal stresses, minimum principal stresses, von misses stresses, total deflection occurred during working condition are evaluated. The parameters used for the simulation are operating gas pressure and material properties of piston.

The dissertations describe the materialistic optimization with using finite element analysis technique to predict the higher stress and critical region on the component. The optimization is carried out to reduce the stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve). With using computer aided design (CAD), unigraphic (UG NX-8) software the structural model of a piston will be developed. Furthermore, the finite element analysis performed with using ANSYS software.

LITERATURE REVIEW

Modern trends in automobile sector are to develop internal combustion engine of increased power capacity. Reduce the structures weight is one of the endeavor design criteria to reduce the fuel consumptions. This has been made possible by improved engine design. Improvements include increased uses of lightweight materials namely ultra-high tensile strength steels, aluminums and magnesium alloys, carbon-fiber reinforced composite material and polymers. The addition of this lighter weight material is especially important if more complex parts are manufactured as a single unit. Next 10-20 years an additional 20%to 40% reduction in overall weight without neglecting the safety aspect seems to be possible. Cuddy M.R [1] in the year 1997 has reported that for every 10% weight reduction of the vehicle, a comprehensive improvement in fuel consumption of 6% to 8% is expected. Improved engine design needs optimized engine component. Sophisticated tools are required to analyze engine components. Engine piston is one of the crucial component among the entire automotive component and other industry field components. Engine is the heart of automobile and piston is considered the most important part of an engine. Numerous sophisticated Aluminum piston analyses method has been reported in the past years. Silva F.S [2] in the year 2006 has analyzed fatigue damaged piston. Damaged starts at the crown, ring grooves, pin holes and skirt are assessed. An analysis of both thermal fatigue and structural or mechanical fatigue damages is presented and analyzed in this work. A linear static stress analysis using “cosmos” is used to determine the stress distribution during the combustion. Stresses at the piston crown and pin holes as well as stresses at the groove and skirt as a function of land clearances are also presented. EkremBuyukkaya [3] in the year 2007 has investigated a conventional (uncoated) diesel engine piston made of aluminum silicon alloy and steel. He will perform thermal analyses on piston coated with Mgo-ZrO2 material by using a commercial code ANSYS. Finally the result of four different pistons is compared with each other. The effects of coatings on the thermal behaviors of the piston are investigated. Result show that the maximum surface temperature of the coated pistons with the material which has low thermal conductivity is improved approximately 48% for AlSi alloys and 35% for the steel. Dr. NajimA.Saad [4] in the year 2008 has done the numerical analysis to analyze the stresses due to thermal cycle with different aluminum alloy of piston. Finite element method was used to determine the thermal stress on the piston. ANSYS5.4 Finite element code is used to carry out the modeling process and determine the coupling stresses. Two models with three dimensions are created. The first model is used to evaluate the temperature distribution through the piston volume and the second is used to evaluate the thermal stress distribution due to hear gradient and different materials. The result shows the maximum range of temperature is 43°C and increase with decreasing of material thermal conductivity. Thermal stress is concentrated on the piston edges and depends on the material type. P Gudimetal [5] in the year 2009 reported a CAD model of a damaged internal combustion engine piston and by using the finite element analysis tool ANSYS to perform a linear static and a coupled thermal-structural analysis of the component. Further, a parametric evaluation of the material properties in comparisons with operating condition is carried out to generate a relational database for the piston to arrive at optimal design solution under different operating condition. YanxiaWang [6] in the year 2010 has reported a solid model including piston and piston pin of a new designed of piston by Pro-E software and then the same model is analyzed by finite element method using ANSYS analysis tool. The thermo-mechanical coupling stress distribution and the deformation were firstly calculated considering the nonlinear material properties of piston and piston pin, the Newto-Raphson equilibrium iterative method is applied. Calculating results indicate that the maximum stress concentration is at the upper end of the piston pin boss inner hole and is mainly caused by the peak pressure of the fuel gas. Y Zeng[7] in the year 2010 setup a geometry model of a diesel engine piston in UG graphics. The temperature fields of the piston for burning diesel and DME (Dimethyl Ether Fueled Diesel Engine) separately are calculated using ANSYS 10.0. The result shows that the variation of the thermal loads by substituting diesel fuel with DME fuel is still within the thermal strength of material. The temperature of DME fueled diesel engine decreases along the piston axis from top to bottom. Temperature of the piston of DME fueled engine increase as a whole comparing with burning diesel. However, temperature field distribution has no significant change decreases and then increases from the combustion chamber center to edge and decreases again to the edge of the piston top. PiotrSzurgott[8] in the year 2011 was comparing the behavior of the combustion engine piston made of different type of materials under thermal load. A thermo mechanical Finite element analysis of the engine piston made of composite material was shown. The selected engine is installed in one of the popular polish tanks. The proposed new material is characterized by low hysteresis – the differences of the coefficient of thermal expansion for heating and cooling are not significant. A geometrical model of the piston was developed based on the geometry of the actual object which was scanned using a three dimensional laser scanner. The next step was to develop the solid geometrical model according to the dimensions obtained from the laser scanning and the processed cloud of points. The original pistons of the S12U engine are made of PA12 aluminum alloy. A new composite material with low hysteresis was also considered. Such material allows reducing the difference of the coefficient of thermal expansion for heating and cooling and it improves a dimensional stability of the piston, consequently. Finite elements were carried out using MSC software. Analysis is done in two stages. In first stage the piston FE model was heated from the initial temperature of 50°C (323K) to the maximum temperature resulted from the thermal boundary condition. After wards the final condition obtained for the last time step from the first stage were set as the initial condition to the second stage of the analysis. In this stage the piston was cooled to the temperature of 50°C. The temperature range from 50°C to the maximum values was determined on the basis of changes in the coefficient of thermal expansion. The result obtained result shows that the new composite piston has around 4 time's lower radial displacement than the actual one. Therefore, a dimensional stability of the piston is strongly improved. The radial component of the stress is also much lower for the new composite piston as well. MesutDurat[9] in the year 2012 has done a steady-state thermal stress analysis was performed to evaluate the temperature gradients in the standard and two different partially stabilized ceramic coated piston by using Abaqus finite element software. Sharp increase in the temperature of the coated area of the piston was observed as a result of FE simulation. Result conclude that annulus Y-PSZ coating may contribute better as compared to Mg-PSZ to decrease the cold start and steady state HC emission without auto ignition since the temperature in the area shows a local sharp increase. Singh Ajay Rai in the year 2014 was describing the stress distribution and thermal stresses of three different aluminum alloys piston by using Finite element method. The parameters used for the simulation are operating gas pressure, temperature and material properties of piston. The specification used for the study of these pistons belongs to four stroke single cylinder engine of Bajaj Kawasaki motorcycle. The material chosen for this work are A2618, A4032and Al-GHS1300 for internal combustion engine piston. Firstly the analytical calculation is done for the piston made up of these three materials (A2618, A4032 and Al-GHS1300) to decide the geometrical parameter of the piston. A 3D model is prepared based on the dimension calculated by analytical method. Finite element method is applied for static and thermal stress analysis using the ANSYS 12.1. The result observed shows that the weight and volume of AL-GHS 1300 is least among the three materials. Hence the inertia forces are less which enhances the performance of the engine. The factor of safety of Al-GHS 1300 is 6 which are much higher than the other material, so further developm In this dissertation work an attempt is made to reduce the thermal and structural stress intensity by coated the piston with other material by means of using commercial code, namely ANSYS. CIC(high performance ceramics) material is used for coating the piston. Firstly the structural and thermal stresses analyses are investigated on a conventional (uncoated) piston made of aluminum silicon alloy. Secondly the structural and thermal analyses are performed on the piston coated with CIC(high performance ceramics) material by means of commercial code ANSYS. The effects of coating on the thermal behaviors of the piston are investigated. The main objective is to investigate and analyze the structural and thermal stress distribution of the piston at the real engine condition during combustion process. The analysis is carried out to reduce the stress concentration on the upper end of the piston .i.e. piston head/crown and piston skirt and sleeve using ANSYS software. The result obtained is compared to select the better material for piston manufacturing.

The present work has been undertaken with the following objective.

- To design an IC engine piston by using Unigraphics (UG-NX8) software.
- Secondly, structural and thermal stresses analysis is performed using ANSYS 13 software.

Result obtained predict the comparison of maximum stress and critical region on the Aluminum alloy piston (uncoated) and the piston with coating (top portion of piston) which help us to select the best material based on the stress analysis result.

Results: 5.1 Result of stress distribution before coating of piston

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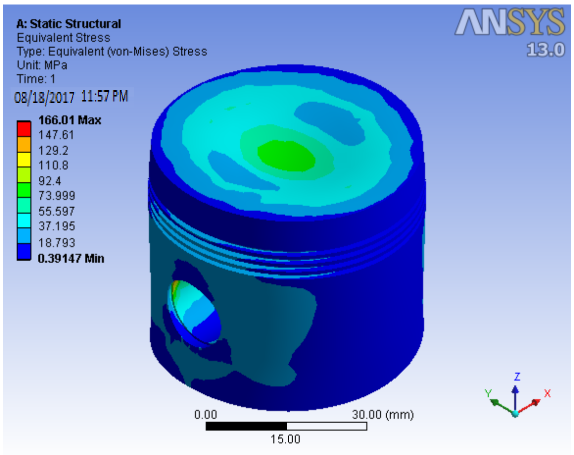

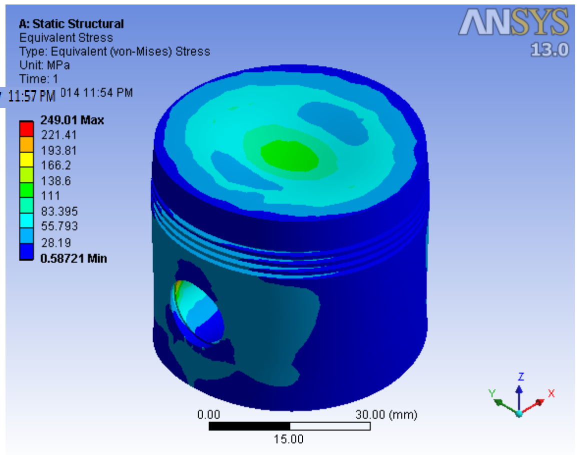

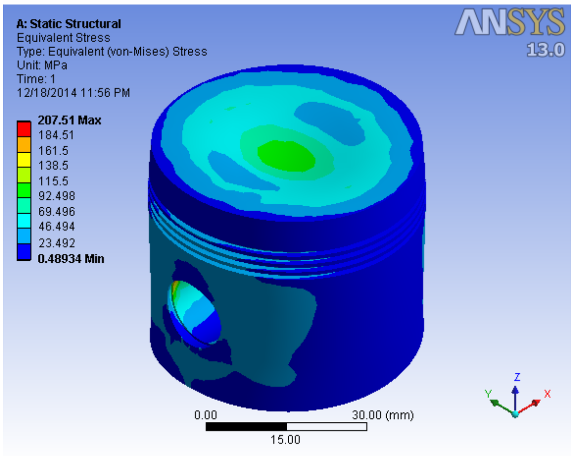

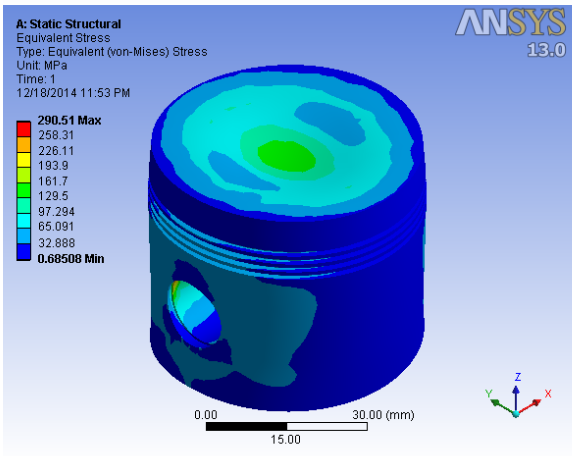

Fig.5.1 Equivalent stress at100% load
Fig.5.2Equivalent stress at125% load

Fig.5.3 Equivalent stress at 150% load
Fig.5.4 Equivalent stress at 175% load

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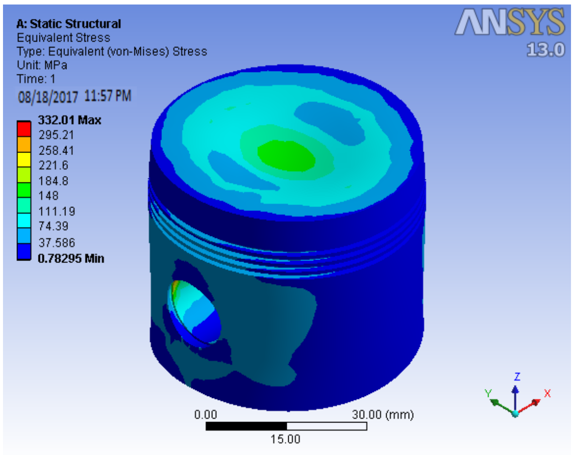

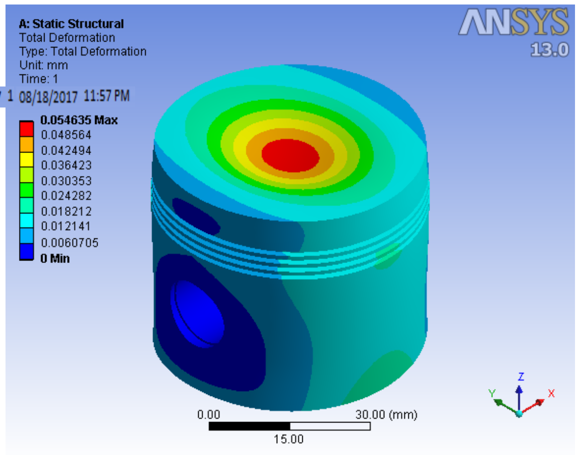

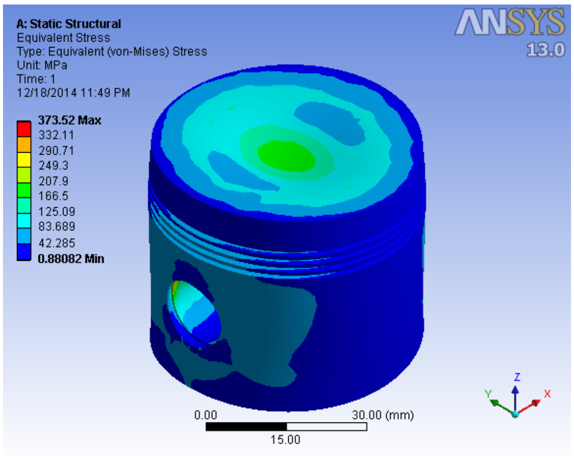

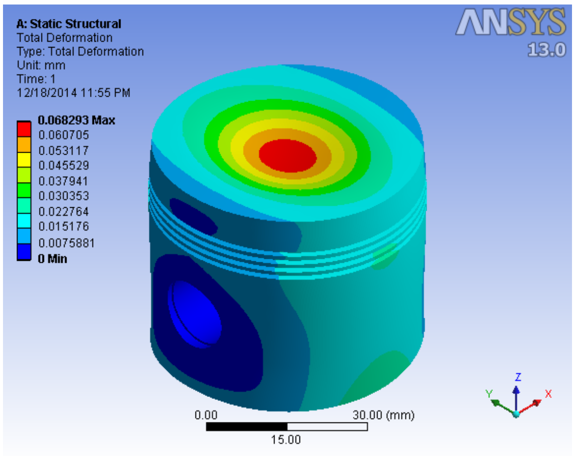

Fig.5.5 Equivalent stress at 200% load

Fig.5.6 Equivalent stress at 225% load

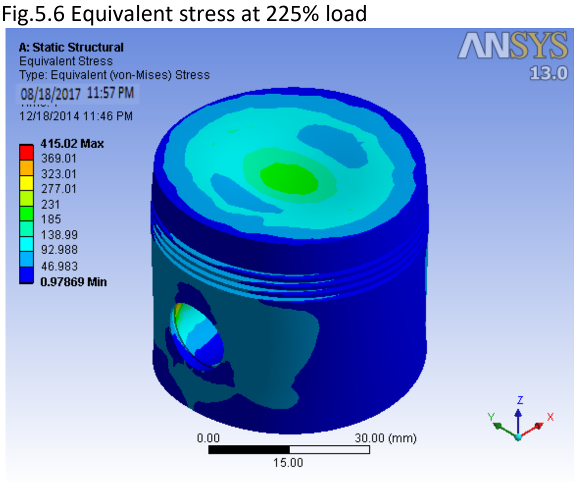

Fig.5.7 Equivalent stress at 250% load

Fig.5.8 Total deformation at 100% load

Fig.5.9Total deformation at 125% load

5.2 Result of Total deformation before coating of piston

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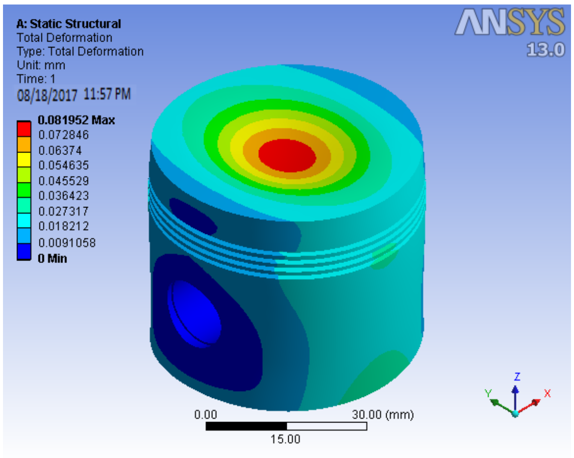
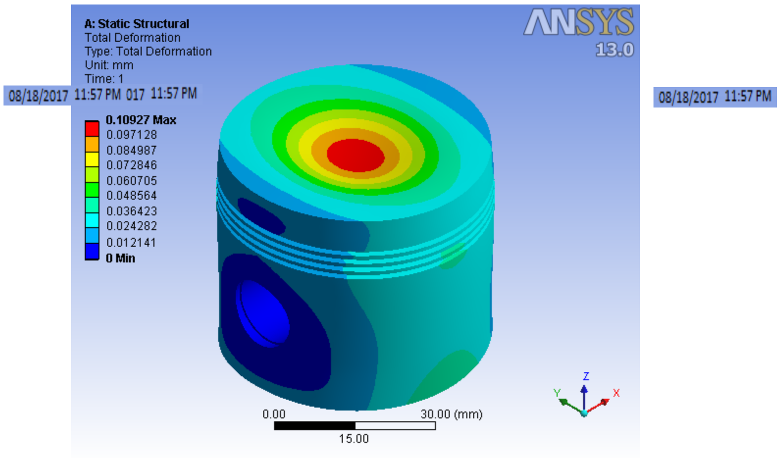
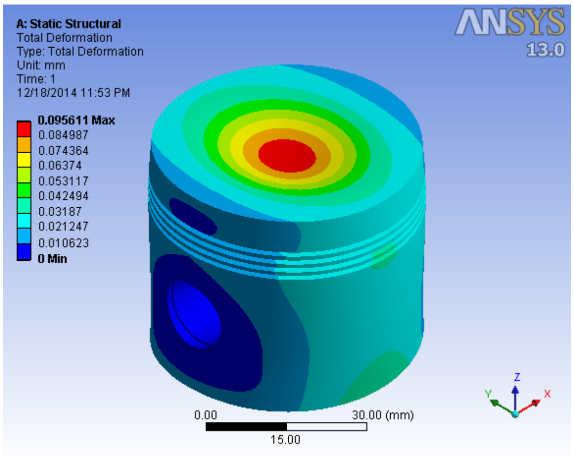






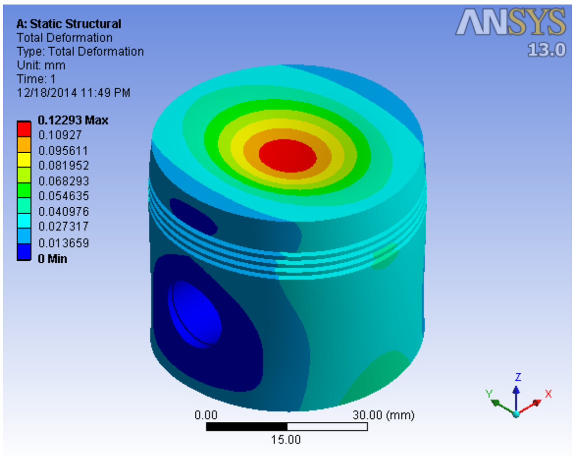


Fig.5.10Total deformation at 150% load
Fig.5.11Total deformation at 175% load

Fig.5.12Total deformation at 200% load
Fig.5.13Total deformation at 225% load

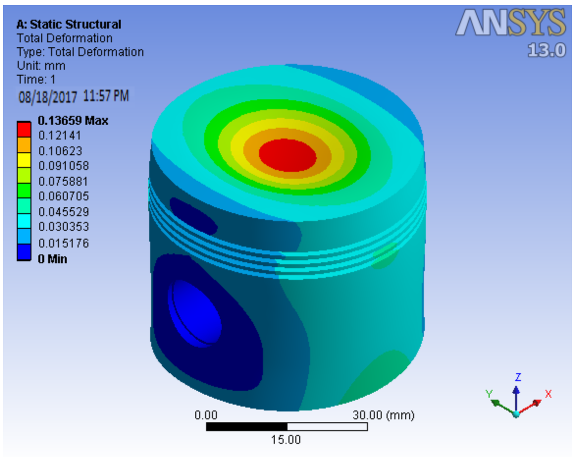


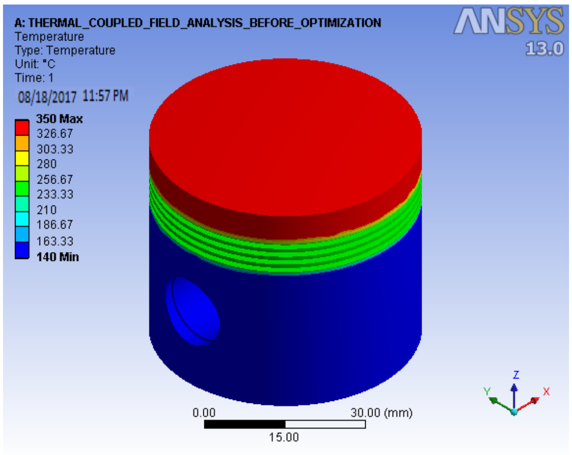
Fig.5.14Total deformation at 250% load

Figure 5.1 to figure 5.14 shows the stress map and total deformation when the piston under static load .The largest stress produces on the top of the piston pin boss and the value observed during the analysis is below the yield stress of material. Below table shows the minimum and maximum stress and total deformation at different loading condition.

Table 5.1 Static structural analysis result

S/no.	Pressure/Load (Mpa)	Equivalent stress(MPa)		Total deformation(mm)	
		Min	Max	Min	Max
1	12.08 (100%)	0.39147	168.01	0	0.054635
2	15.10 (125%)	0.40934	207.51	0	0.068293
3	18.12 (150%)	0.5872	249.01	0	0.081952
4	21.14 (175%)	0.68508	290.51	0	0.095611
5	24.16 (200%)	0.78295	332.01	0	0.190927
6	27.18 (225%)	0.8808	373.52	0	0.12293
7	30.70 (250%)	0.9789	415.82	0	0.136559

5.3 Result of Temperature distribution and heat flux (coupled field) before coating of piston the thermal loads the thermal loads



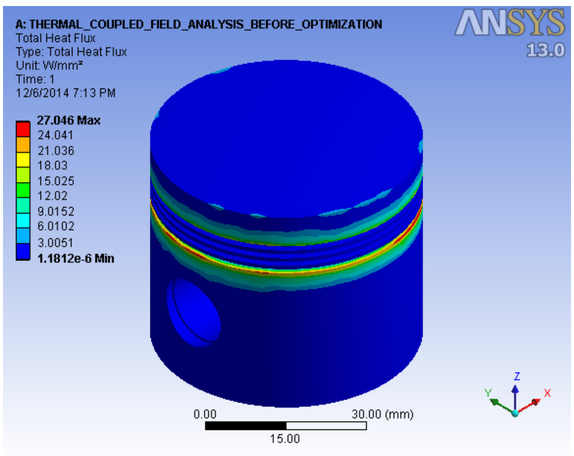


Fig.5.15 Temperature field of piston in
Fig.5.16 Total Heat flux of piston in

The temperature distribution of the piston is uneven with the maximum value of 350 °C and the minimum value of 140 °C. There is large range of temperature distribution on the top surface of the piston area. The temperature is higher at the combustion chamber side of the deviation from the center of the piston.

5.4 Result of stress distribution and total deformation (coupled field) before coating due to thermal and mechanical loads

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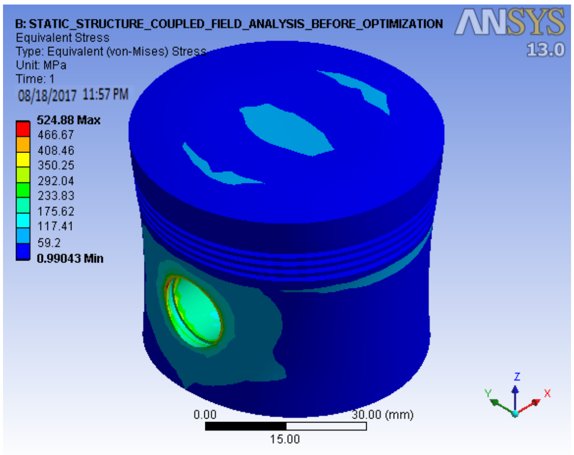

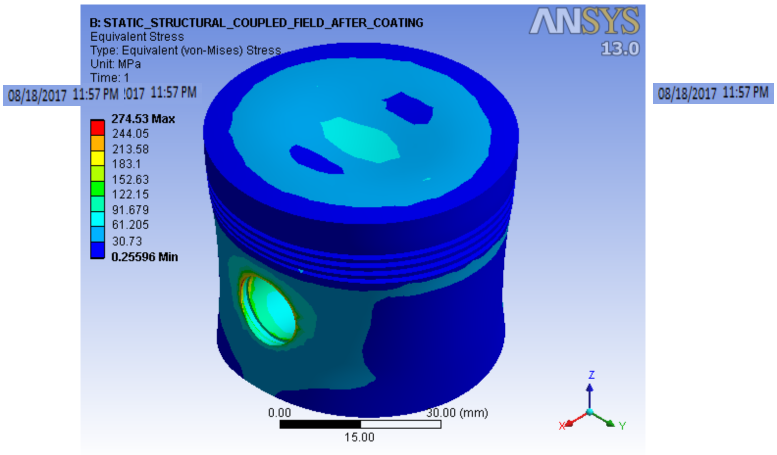

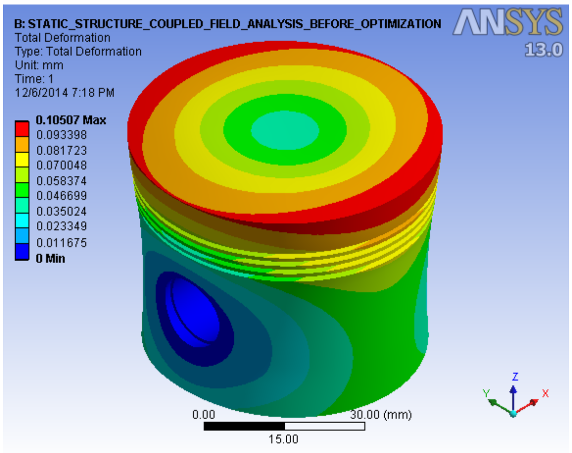

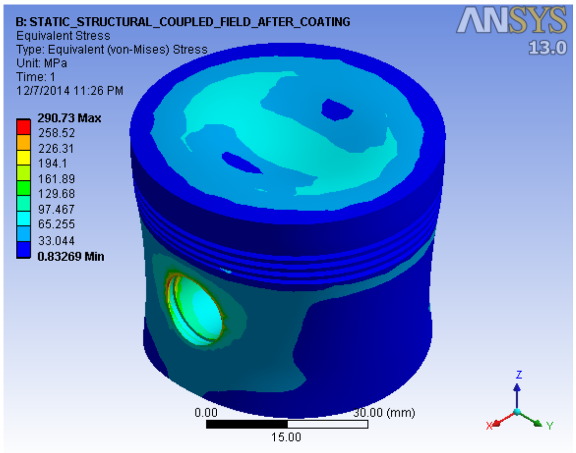

Fig.5.17 Equivalent stress of piston due
Fig.5.18 Total deformation of piston
the thermal and mechanical
due to the thermal and
loadsmechanical load

Fig.5.19 Equivalent stress at 100% load
Fig.5.20 Equivalent stress at 125% load

Figure 5.17 show the equivalent stress map, when the piston under the joint action of the temperature and the gas pressure. The largest stress produces on the top of the piston pin boss and the value observed during the analysis is above the yield stress of material. Figure5.18 shows the deformation contour of the piston under the mechanical and thermal loads. From the figure it is obvious to see that the center of top of the piston have largest deformation. For the overall analysis of the piston shows from top to bottom of the piston geometry deformation decreases gradually and then gradually increase.

5.4 Result of stress distribution (coupled field) after coating of piston due to thermal and mechanical loads

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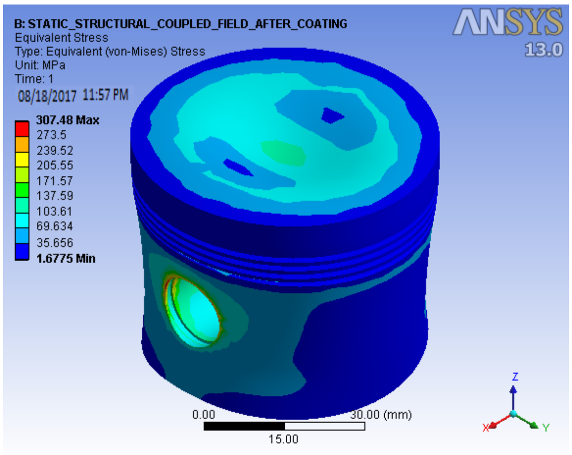

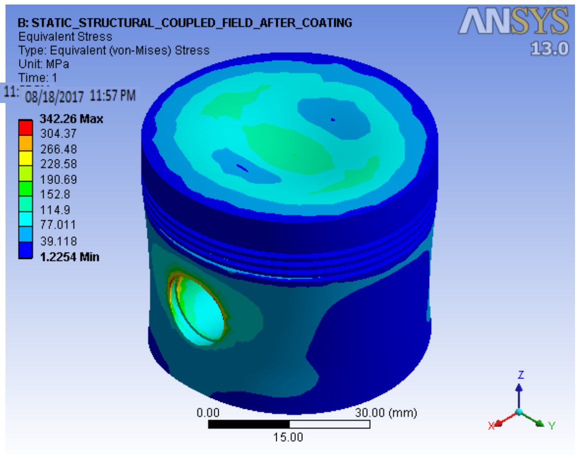

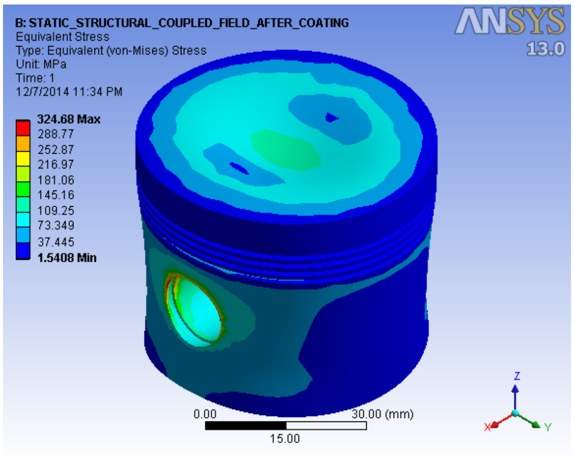

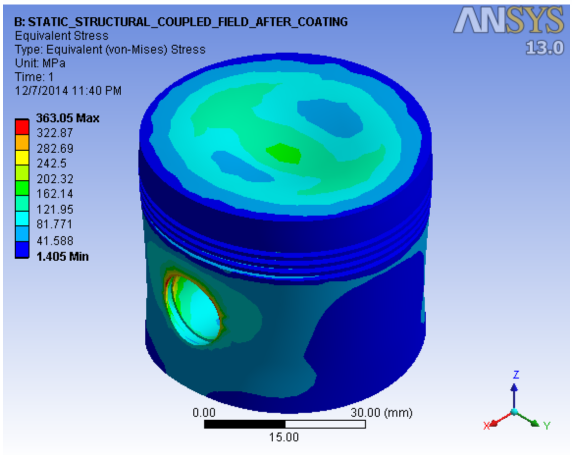

Fig.5.23 Equivalent stress at 200% load
Fig.5.24 Equivalent stress at 225% load

Fig.5.21 Equivalent stress at 150% load
Fig.5.22 Equivalent stress at 175% load

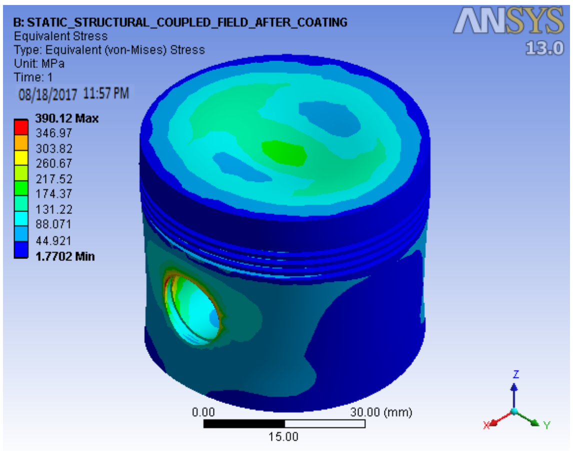

Fig.5.25 Equivalent stress at 250% load

5.4 Result of total deformation (coupled field) after coating in thermal and mechanical loads

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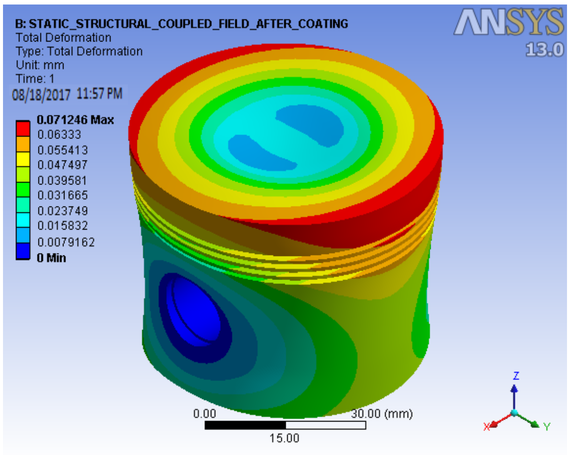

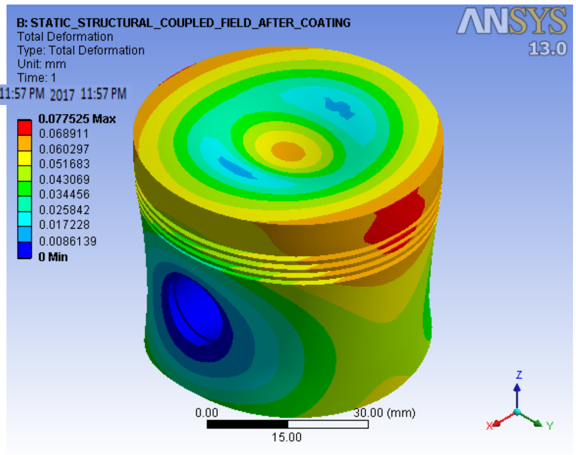

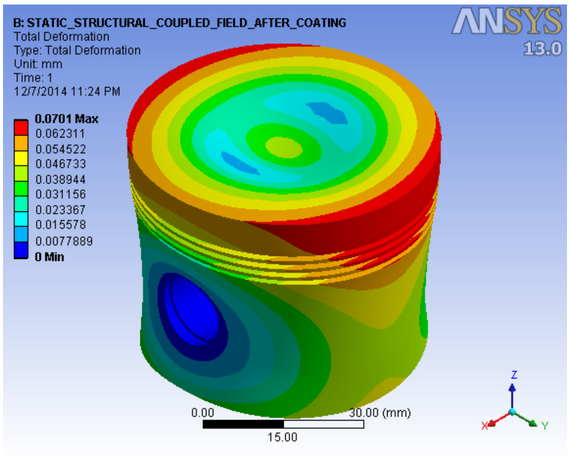

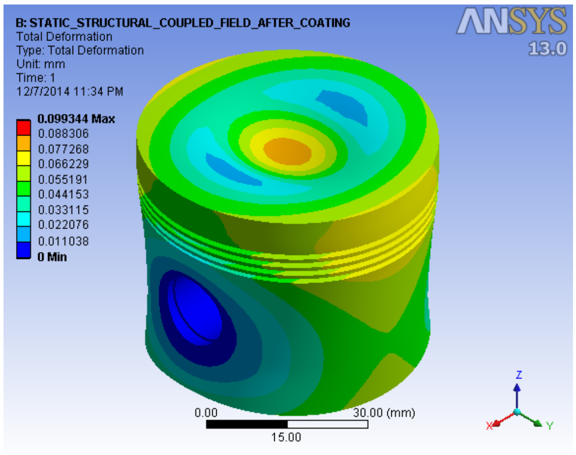

Fig.5.26 Total deformation at 100% load
Fig.5.27Total deformation at 125% load

Fig.5.28 Total deformation at 150% load
Fig.5.29Total deformation at 175% load

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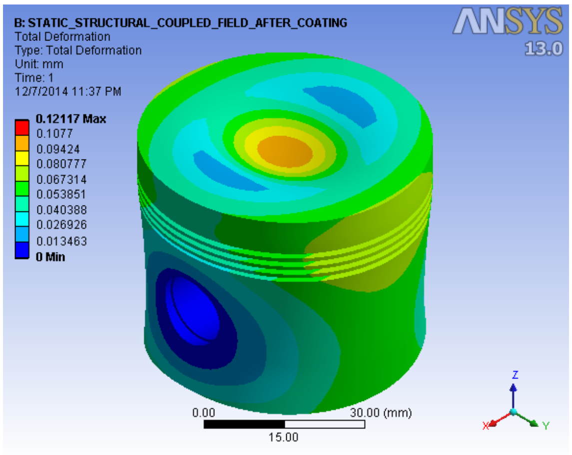

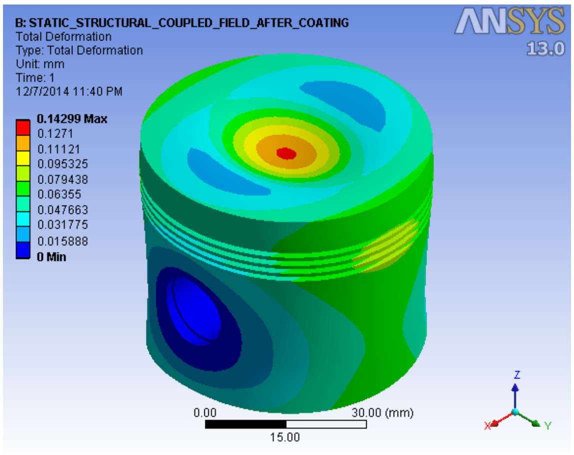

Fig.5.30 Total deformation at 200% load
Fig.5.31Total deformation at 225% load

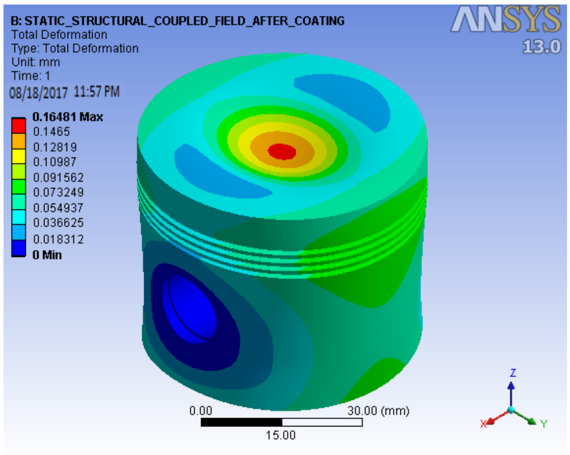

Fig.5.32 Total deformation at 250% load

Figure 5.19 to figure 5.25 show the equivalent stress map, when the piston under the joint action of the temperature and the gas pressure. The largest stress produces on the top of the piston pin boss and the value observed during the analysis is below the yield stress of material. The result shows that the temperature contributed a great deal on the piston stress. The values of equivalent stress at most of the section of the piston are under 100 MPa. Figure5.26 to figure 5.32 is the deformation contour of the piston under the mechanical and thermal loads. From the figure it is obvious to see that the center of top of the piston have largest deformation. For the overall analysis of the piston shows from top to bottom of the piston geometry deformation decreases gradually and then gradually increase.

Table 5.2 Static structural analysis result of uncoated piston under thermal and mechanical loads

S/no.	Pressure/Load (Mpa)	Equivalent stress(MPa)		Total deformation(mm)	
		Min	Max	Min	Max
1	12.08 (100%)	0.99043	524.88	0	0.10507

Table 5.3 Static structural analysis result of coated piston under thermal and mechanical loads

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S/no.	Pressure/Load (Mpa)	Equivalent stress(MPa)		Total deformation(mm)	
		Min	Max	Min	Max
1	12.08 (100%)	0.25596	274.453	0	0.071246
2	15.10 (125%)	0.83	290.73	0	0.0701
3	18.12 (150%)	1.6775	307.48	0	0.07525
4	21.14 (175%)	1.5408	324.68	0	0.099344
5	24.16 (200%)	1.2254	342.26	0	0.12117
6	27.18 (225%)	1.405	363.05	0	0.14299
7	30.70 (250%)	1.7702	390.12	0	0.16481

Conclusion: The result showed that coated piston with ceramic material has better performance in stress and deformation in comparison with the aluminum alloy named A2618 under the joint action of the thermal and mechanical loads.

The preliminary thermo-mechanical FE analysis was presented in the thesis. Its main purpose was to compare behavior of the piston made of different type of materials under thermal load. The new composite material was primarily considered due to low hysteresis of the coefficient of thermal expansion for heating and cooling. The obtained results shows that the new composite piston has around 2.5 times lower radial displacements than the actual one. Therefore, a dimensional stability of the piston is strongly improved. The radial component of the stress is also much lower for the new composite piston as well.
Combined CAD and ANSYS, get the results of stress and deformation and temperature when the piston under the mechanical loads, thermal loads and assembly the mechanical and thermal load. And get the discussion as below:

1) The temperature is higher at the combustion chamber side of the deviation from the center of the piston. Highest temperature appears in the throat of the exhaust port of the combustion chamber adjacent side, the temperature reached 350°C. The temperature of the piston ring area is extremely important for the reliability of the engine, if the temperature of the ring zone is too high, it will make the lubrication oil to be deterioration even carbonization. It causes the piston ring bonded, loss of activity to make the piston rapid wear, deformation.

2) The stress under the mechanical action, the maximum stress value of the piston is 390 Mpa, and the most stress of other parts below 100Mpa. For the tensile strength of the piston, it's having an enough strength margin.

3) When under the assembly of mechanical and thermal loads, the value of the largest displacement is 0.16mm, causing at the center of the piston top. The stress of the top of the piston is mainly caused by the temperature load and the deformation of the piston is caused by the thermal expansion.

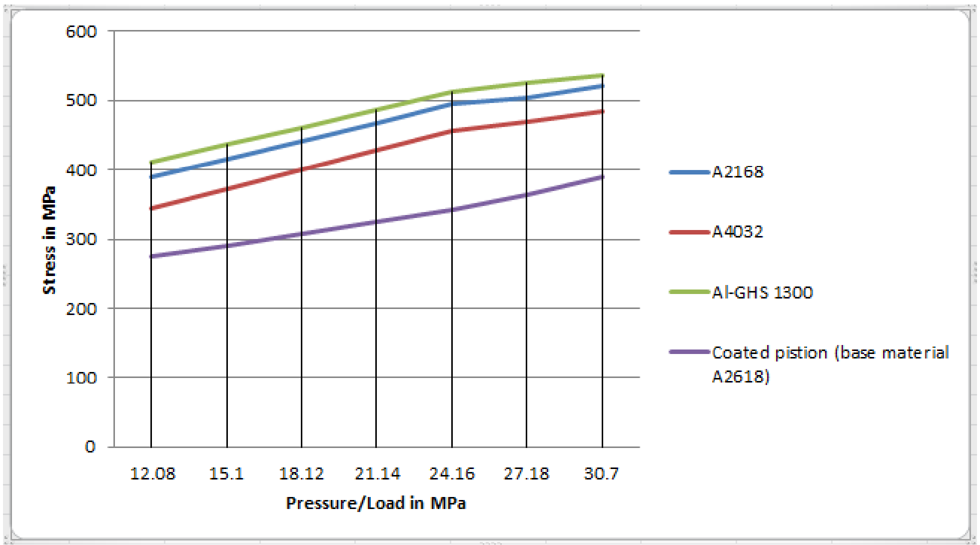

Fig.6.1 Graph between Stress(Mpa)Vs Pressure/load (Mpa)

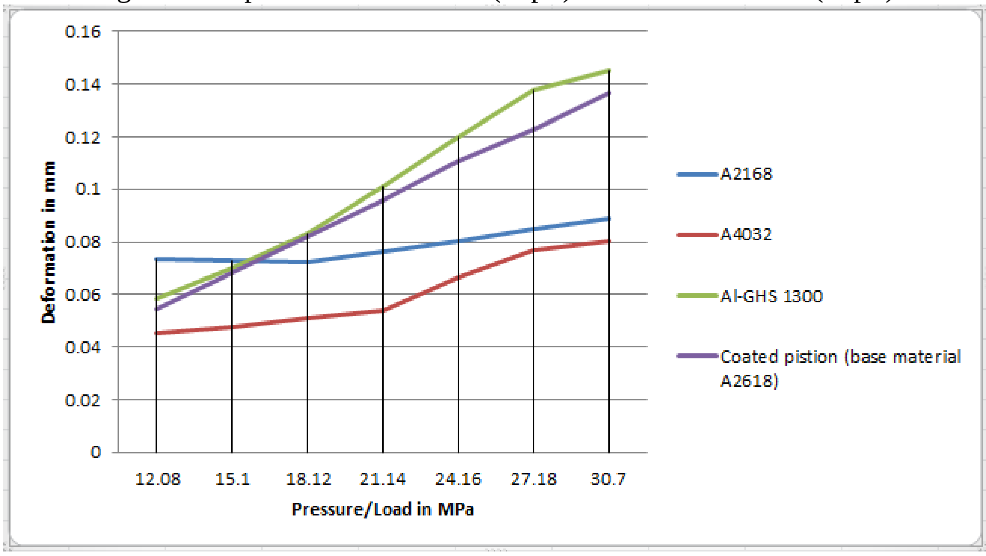

Fig.6.2 Graph between Deformation(mm)Vs Pressure/load (Mpa)

Future Scope of Work: Further more research is required to select the base material and coating material which has less weight and higher strength with high thermal coefficient of thermal expansion. Piston design models are simulated on iteration based and it required more number of iterations to further optimized the design.

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