International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-3, Issue-5, May 2015

Design and structural analysis of a ceramic coated petrol engine piston using finite element method: A Review

Vinod Kumar Yadav, Yogesh Mishra

***Abstract*— Piston is made of aluminum alloys is a crucial part in internal combustion engine. When the combustion of fuel take place insides the engine cylinder, high pressure and high temperature will be developed as the engine will operate at high load and at high speed. As a result of this high thermal and high structural stresses in the piston is produced inside the engine cylinder and if these stresses exceeds the designed values, the failure of piston take place. To avoid the failure of the piston thermal and structural intensity should be reduced to safe allowable limits. In this paper 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 ANSY .The zirconia-based ceramic coatings are used as thermal barrier coatings owing their low conductivity and their relatively high coefficient of thermal expansion. Firstly the structural and thermal stresses 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 zirconium 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.**

***Index Terms*— Engine piston, FE analysis, structural analysis, thermal analysis.**

I. 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

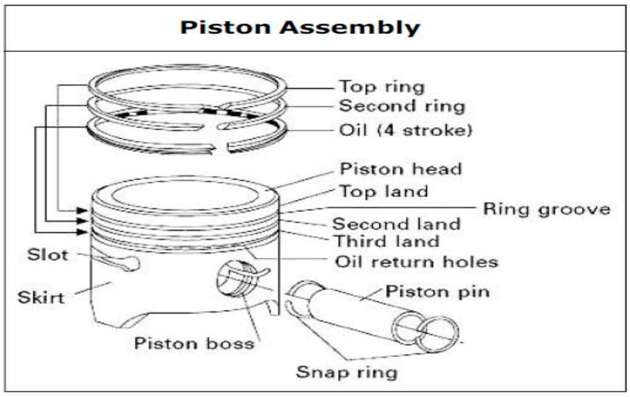

Fig-1.1

II. FUNCTION OF PISTON

- To reciprocate in the cylinder as a gas tight plug causing suction, compression, expansion and exhaust strokes.
- To receive the thrust generated by the explosion of the gas in the cylinder and transmit it to the connecting rod.

Vinod Kumar Yadav, PG student, Department of Mechanical Engineering, NRI Institute of Science and technology, Bhopal, India
Yogesh Mishra, Professor, Department of Mechanical Engineering, NRI Institute of Science and technology, Bhopal, India.

- To form a guide and bearing to the small end of the connecting rod and to take the side thrust due to obliquity of the rod.

III. LITERATURE SURVEY ON PISTON MATERIAL

The properties of the material used for the piston manufacturing plays the important role in withstanding this various stresses and also resist the temperature while working at higher speed and higher loads, the study of the material properties is also very important. The material used for piston is mainly aluminum alloy which can be either casted or forged. Cast iron is also used for the pistons. In early years cast iron was almost universal material for pistons because it possesses excellent wearing qualities, coefficient of expansion and general suitability in manufacturing. But due to the reduction of weight in reciprocating parts, the use the aluminum for pistion was essential.

The result of various authors who studied the various material properties of the piston showed that the various type material used for manufacturing of the piston such as steel is excellent to heat resistance an corrosion resistance and the cast iron is a highly brittle material with good machining ability also the weight of cast iron piston is higher which increases the overall weight of the engine unnecessarily, so the study was carried out by Piotr Szugott on the composite materials to find out the best suitable material for the piston which can handle higher temperature and structural stresses which could not affect the working of piston. The material for the piston should have low hysteresis, the difference of coefficient of thermal expansion which allows the piston resistance to fatigue damage and the thermal shocks. So it was found that the aluminum with 11% silicon is the best material which can be used for handling higher temperature and structural stresses. To obtain equal strength greater thickness of metal is necessary but some advantage of the light metal is lost. Aluminum is inferior to cast iron in strength and wearing qualities and its greater clearance in the cylinder to avoid the risk of seizure or engine jamming. The thermal conductivity of aluminum is about thrice that of cast iron and his combined with various ingredients for strength, mechanical properties and allows aluminum alloy piston to run at much lower temperature than a cast iron this cool running property of aluminum is now recognized as being quite as valuable as its lightness. Indeed pistons are sometimes made thicker than necessary for strength in order to give improved cooling and less weight.

IV. LITERATURE SURVEY ON THERMAL AND STRUCTURAL STRESSES

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 development of high power engine using this material is possible.

V. Discussion

This paper discusses work the significance of thermal and structural stress intensity by coated the piston with other material. Zirconium 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 zirconium 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.

References

[1] Cuddy, M. R. &Wipke, K. B. (1997), Analysis of Fuel Economy Benefit of Drive train. Hybridization http://www.nrel.gov/vechicle fuels/vsa/pdfs/22309.pdf (National Renewable energy laboratory).

[2] F.S. Silva (2006) Fatigue on engine pistons – A compendium of case studies. Engineering Failure Analysis, 13 pp(480–492).

[3] EkremBuyukkaya, MuhammetCerit(2007) Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method. Surface and Coatings Technology 202, 2 pp(398–402).

[4] Dr.NajimA.Saad, Dr. Haitham R. Abed Ali, Dr. Hayder Shakir Abudalla, (2008), numerical analysis of the thermal –stresses of a petrol engine piston with different materials, The Iraqi Journal for Mechanical and Material Engineering, 8, 3 pp (249-256).

[5] Gudimetal P, Gopinath C.V, (2009) Finite Element Analysis of Reverse Engineered Internal Combustion Engine Piston, AIJSTPME, 2, 4 pp (85-92).

[6] Yanxia Wang, YongqiLiu,Haiyan (2010), Simulation and Analysis of Thermo-Mechanical Coupling Load and Mechanical Dynamic Load for a Piston; IEEE, pp (106-110).

[7] Wu, Yi Zeng, Dongjian Feng, Zhiyuan, (2010) Finite Element Analysis for the Thermal Load of Piston in a Dimethyl Ether Fueled Diesel Engine, IEEE.

[8] Piotr Szurgott and TadeaszNiezgoda, " Thermo-mechanical FE analysis of the piston made of composite material with low hyteresis". Journal of kones power train and transport, Vol 18 Nov 2011

[9] Mesut Durat, Murat Kapsiz, Ergun Nart, FeritFicici& Adnan Parlak, (2012), The effects of coating materials in spark ignition engine design; Materials & Design, 36 PP (540-545).

[10] Ajay singh Rai (2014), "Design, analysis and optimization of three aluminum piston alloys using FEA; Journal of engineering research and application. ISSN: 2248-7622 Vol.4 Issue (Version 3, January 201 pp94-102)

[11] R. S. Khurmi, J. K. Gupta (2005); Machine Design; 14th ed.; Eurasia Publishing House (Pvt.)Ltd., Ramnagar, New Delhi.

[12] Ajeet Kumar Rai and Ashish Kumar, "A Review on Phase Change Materials & Their Applications", International Journal of Advanced Research in Engineering & Technology (IJARET), Volume 3, Issue 2, 2012, pp. 214 - 225, ISSN Print: 0976-6480, ISSN Online:0976-6499.

[13] Ajeet Kumar Rai, RichaDubey, Shalini Yadav and Vivek Sachan, "Turning Parameters Optimization for Surface Roughness by Taguchi Method", International Journal of Mechanical Engineering & Technology (IJMET), Volume 4, Issue 3, 2013, pp. 203 - 211, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.

[14] Yuvaraj P. Ballal, Manjit M. Khade and Ajit R. Mane, "Comparison of Performance of Coated Carbide Inserts with Uncoated Carbide Inserts in Turning Gray Cast Iron",

[15] International Journal of Mechanical Engineering & Technology (IJMET), Volume 4, Issue 2, 2013, pp. 392 - 400, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.