International Journal Of Advance Research, Ideas And Innovations In Technology

ISSN: 2454-132X
Impact factor: 4.295
(Volume 4, Issue 3)
Available online at: www.ijariit.com

Finite element analysis and experimental investigation of ceramic coating on automotive piston by high velocity oxygen fuel technique

T. Murali
muralikrishna344@gmail.com
YSR Engineering College of YVU, Proddatur, Andhra Pradesh

Narasimha Prasad .B
say2bnp@gmail.com
Sathyabama University, Chennai, Tamilnadu

ABSTRACT

In the Internal Combustion (IC) engine, there are unburned hydrocarbons due to the improper combustion that takes places during exhaustion which leads to air pollution. These unburned hydrocarbons can be reduced by coating the different ceramic powders on the top of the piston. Here, an automotive piston is modeled and finite element analysis is done with different ceramic powders of 125 µm and 250 µm thicknesses. Different ceramic powders namely Alumina-Titania (60%-40%), Alumina, Titania, and Zirconia are coated on the piston. The coating is done on the piston by High-Velocity Oxygen Fuel (HVOF) technique. The experimental analysis is done on Kirloskar engine with uncoated aluminum piston and Zirconia coated aluminum piston with different loads. The experimental results such as exhaust gas temperature, mechanical efficiency and Carbon monoxide (CO) emissions for both the pistons are compared.

Keywords: *Finite element analysis, Ceramic powders, HVOF technique, Mechanical efficiency, CO emissions*

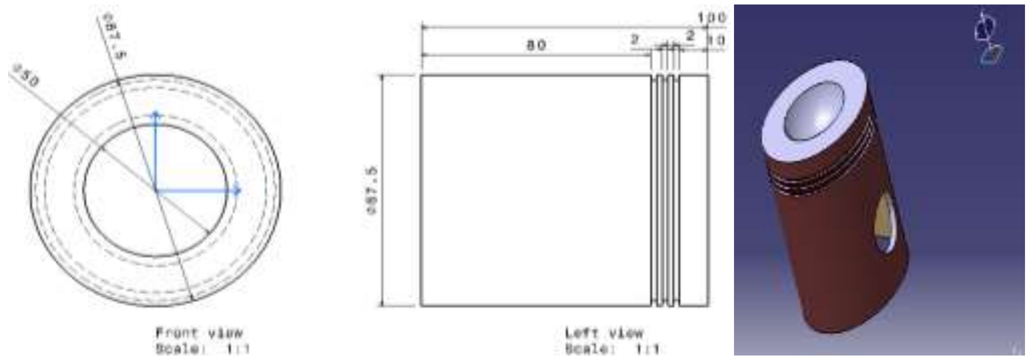
1. INTRODUCTION

The research has been going on the internal combustion engine for developing the efficiency of the engine and also to reduce the harmful emissions coming from the engine. In order to overcome these limitations, the thermal barrier coating is applied to the top of the piston by using HVOF technique. T.K. Chandrashekar et al [1] has done coating on the piston using calcium zirconate ($CaZrO_3$) and concluded that Brake thermal efficiency can be increased by 2% to 3% at low compression ratios and 6% to 8% at higher compression ratios. The thermal efficiency is also increased due to increased compression ratio. In general, the brake thermal efficiency increases by 2% to 4% due to thermal barrier coatings. Farrahi .G.H et al [2], in his project, had used two layers of coating systems; a metallic bond coat and a ceramic coating on the top layer. The bond coat thickness is taken as 50 µm to 250 µm and the top coat thickness is taken as 200 µm to 800 µm. Nitesh Krishnan J et al [3] has stated that numerous coatings and deposition methods have been successfully developed, which are used to reduce friction and also to protect the surfaces. He also states that HVOF coating is very dense, strong and show low residual tensile stress and in some cases compressive stress, which enables up to a very much thicker coating about 3-4 mm. Ilker Turgut Yilmaz et al [4] mentioned that the ceramic material has a high oxygen resistance, low thermal conductivity, high corrosion resistance, high thermal expansion coefficient and high strain tolerance. The HVOF coatings are harder and tougher [5]. Cert. M et al [6], in his project the HC emissions are decreased by 43.2% compared to the standard engine by coating on the piston. Sharma K. R et al [7] has taken the properties of Zirconia coating in thermal shock and thermal punching experiments which gives the best results. Gobind et al [8], shows that the hard, wear resistant and dense microstructured coatings can be provided by using HVOF technique. Few researchers have shown that the zirconia coated material as wear resistance material [9-11]. Bhupendra C et al [12] have shown that the Zirconia and Alumina are most suitable material for ceramic coating and also improved engine performance. Karuppasamy K et al [13], in his study, the thermal barrier materials are alumina-titania (60% – 40%) and nickel - chromium are used.

Taking these aspects into account, ceramic coatings are being used over piston to increase the performance and mechanical efficiency of the engine and also to reduce emissions.

2. NUMERICAL ANALYSIS

The 3D model of both uncoated piston and coated piston are modeled using the commercially available software CATIA V5 R20. The piston is modeled for 125 µm and 250 µm layer thicknesses for different ceramic coatings. The 3D models are converted into compatible step file format and imported to commercially available ANSYS 13 workbench. The 2D drawing and 3D models of the piston are shown in the Fig. 1 (a) and (b).



(a) **(b)**

Fig. 1: CATIA model of piston (a) 2D drawing (b) 3D model

The Finite element analysis for the piston is done using ANSYS Software and parameters are listed below.
Inputs are given for analysis

- Type of Analysis - Steady state thermal analysis
- The temperature on the Top Surface = 873 K
- Convection film Co-efficient = 1500 W/m^2 ºC

2.1 Meshing

The collection of nodes and elements form the finite element mesh. Each element is of simple shape for which the finite element program has information to write the governing equations in the form of stiffness matrix. The meshing plot of the piston is shown in the Fig. 2.

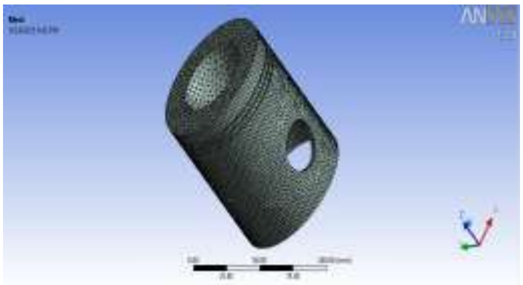


Fig. 2: Meshed model of the piston in ANSYS

- Number of nodes – 141889
- Number of elements – 77566
- Mesh quality Skewness – 0.4567

2.2 Boundary conditions

For structure analysis of the piston, the boundary condition near a pinhole by giving the fixed support. For thermal analysis of piston, the boundary conditions are

- The maximum temperature on the piston head= 600 ºC,
- Heat transfer coefficient on piston skirt = 1.5x10^{-3} W/mm^2 ºC.

Boundary plots of the piston for both structural and thermal analysis are shown in the Fig. 3 and Fig. 4 respectively.

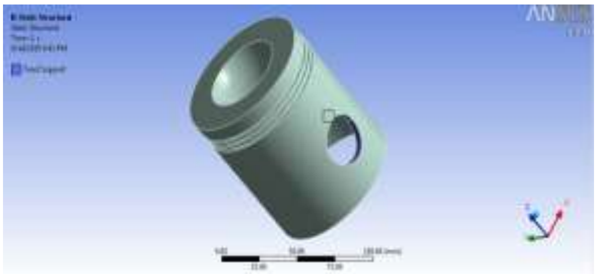


Fig. 3: The boundary condition for structural analysis

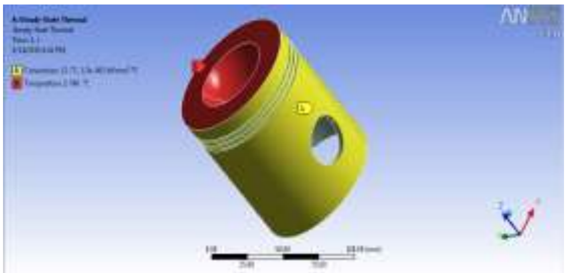
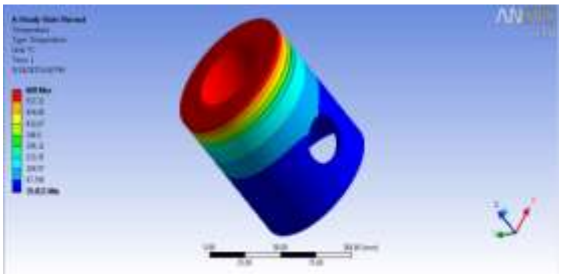


Fig. 4: The boundary condition for thermal analysis

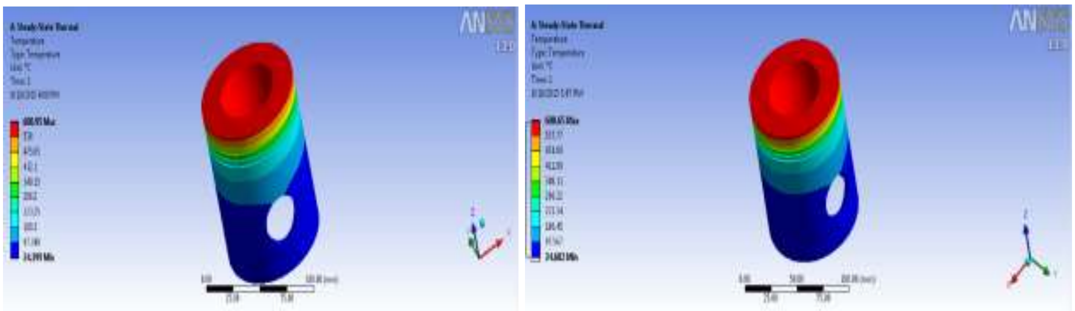
Table 1: Properties of materials

Materials	Density (Kg/m^3)	Young's modulus (Pa	Isotropic thermal conductivity (W/m ºC)
Alumina+Titania ($Al_2O_3 + TiO_2$) (60%-40%)	4004	2.24x10^{11}	19.56
Alumina(Al_2O_3)	3720	3x10^{11}	18
Aluminium	2700	7x10^{10}	205
Titania (TiO_2)	4430	1.1x10^{11}	21.9
Zirconia (ZrO_2)	6050	2.05x10^{11}	2

The properties of both base piston material and coating material used for analysis are tabulated in Table 1. Finite element analysis has been done on the piston by considering different coating materials mentioned in Table 1. The analysis has been conducted by considering two different layer thicknesses such as 125 µm and 250 µm. The ANSYS results are plotted in Fig. 5 for both the thicknesses of different coating materials.

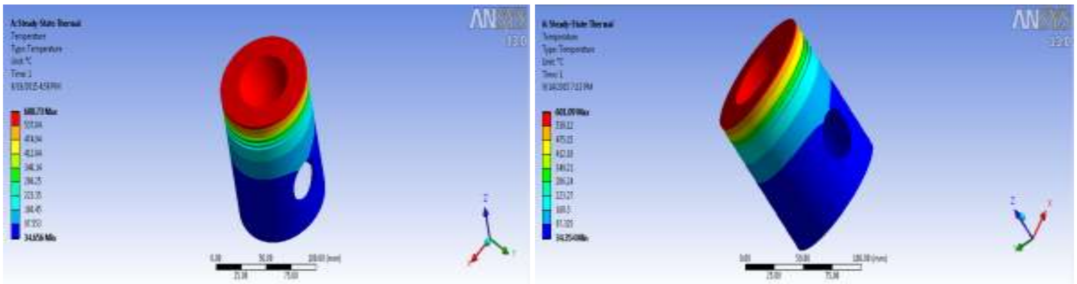


(a)



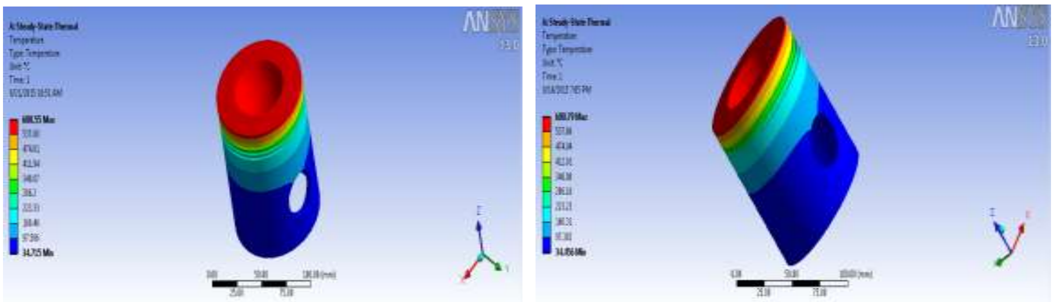
125µm thickness **250 µm thickness**

(b)



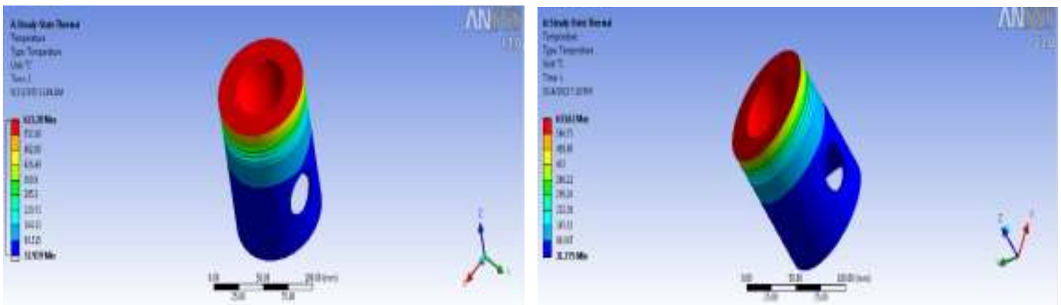
125µm thickness **250 µm thickness**

(c)



125µm thickness **250 µm thickness**

(d)



125µm thickness **250 µm thickness**

(e)

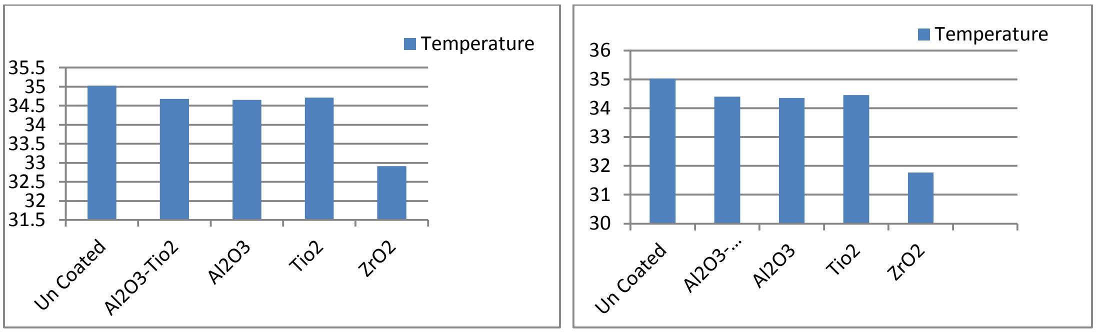
Fig. 5: ANSYS Results for (a) Uncoated (b) Alumina-Titania coated (c) Alumina coated (d) Titania coated (e) Zirconia coated

The minimum temperatures obtained from the numerical analysis for different coating materials are tabulated in Table 2.

Table 2: ANSYS results for all the coating materials

S. No.	Materials	Minimum Temperature (°C)	
		125 µm	250 µm
1	Uncoated Piston	35.021	35.021
2	Alumina-Titania Coated Piston (Al_2O_3 - TiO_2) (60%-40%)	34.682	34.399
3	Alumina Coated Piston(Al_2O_3)	34.656	34.354
4	Titania Coated Piston(TiO_2)	34.715	34.456
5	Zirconia Coated Piston(ZrO_2)	32.919	31.775

The variation of minimum temperatures obtained by using ANSYS for different coating materials with thicknesses 125 µm and 250 µm are shown in the Fig. 6 (a) and (b).



(a) **(b)**

Fig. 6: Minimum temperature distribution for different coatings and thickness of (a) 125 µm (b) 250 µm

From the ANSYS results, the Zirconia coated piston with 250 µm thickness gives the better results compared to other coated pistons. From the Fig. 6(b) it is observed that zirconia is giving the minimum temperature when compared to the remaining ceramic powders. Among all the considerations, the maximum one is an uncoated aluminum piston. This shows that zirconia coating is giving the best performance. The tri-biological property will also be increased in terms of both wear and thermal barrier; the good combustion takes place by coating on the piston and can be improved further overall engine efficiency.

3. EXPERIMENTAL ANALYSIS

Experiments are conducted on a Kirloskar single-cylinder four stroke stationary diesel engine. The experimental set up is shown in the Fig. 7.

Fig. 7: Experimental set-up

For the experimental analysis, uncoated aluminum piston and zirconia coated piston are used, which are shown in the Fig. 8 (a) and (b). The Kirloskar engine is run by using bio-diesel. The engine specifications are shown in Table 3.

(a) **(b)**

Fig. 8: (a) Uncoated piston (b) Zirconia Coated Piston

Table-3: Engine specifications

Item	Specification
Create	Kirloskar engine
Engine Type	Four strokes, Single cylinder, vertical air cooled diesel
Bore Diameter	87.5 mm
Stroke length	110 mm
Compression Ratio	17.5: 1
Rated power	4.4 kW
Rated speed	1500 rpm
Coefficient of discharge	0.6
Calorific value of fuel	42,500 kJ/kg

The zirconia coating for the piston is done by using HVOF technique with a thickness of 250 μm. In HVOF process, the high particle velocity imparts high kinetic energy to the particles which result in high-energy on impact with the substrate. In the experiment, the loads used are 0%, 25%, 50%, 75%, 100%. After the load is applied, the engine reaches a steady condition at a particular point, during this particular point the readings of time taken for 10cc fuel consumption, exhaust gas temperature, and CO emissions are taken.

4. RESULTS AND DISCUSSION

Both uncoated piston and zirconia coated are tested in kirloskar engine by using bio-diesel. From the observed results the mechanical efficiency is calculated using the formula,

Mechanical efficiency (η_m) = $\frac{BP}{IP} X100$

BP - Brake Power,
IP - Indicated Power

4.1 Mechanical Efficiency

The measured Mechanical efficiency by using bio-diesel for uncoated aluminum piston and zirconia coated aluminum piston are tabulated in Table 4.

Table 4: Values of Mechanical efficiency

Load (%)	Uncoated Piston	Zirconia Coated Piston (%)
0	0	0
25	40.19	45.39
50	61.09	61.38
75	61.91	64.95
100	66.6	69.55

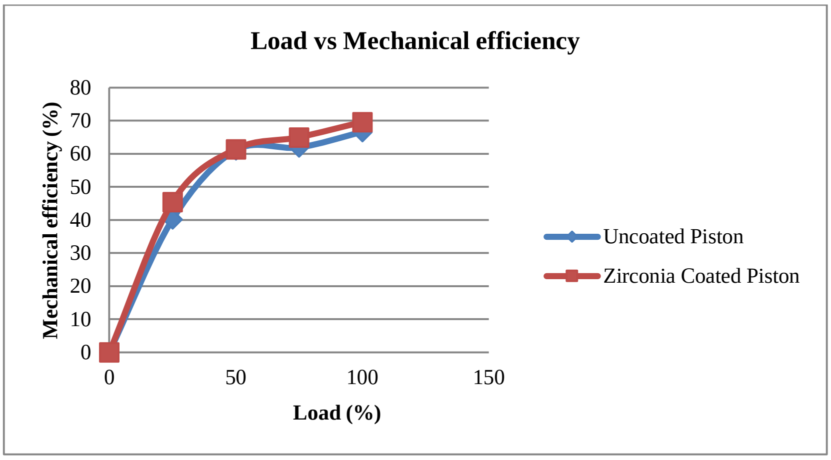


Fig. 9: Comparison of Mechanical efficiency

A graph is plotted between Load (%) and Mechanical efficiency is shown in the Fig. 9. Mechanical efficiency of the engine is increased by 4% by coating the piston with zirconia at full load using the biodiesel.

4.2 Exhaust Temperature

The exhaust temperature for uncoated piston and zirconia coated piston are tabulated in Table 5. The exhaust gas temperature for zirconia coated aluminum piston is high when compared to uncoated aluminum piston under varying load condition. This exhaust gas with high-temperature energy can be recovered by turbo compounding system.

Table 5: Values of Exhaust gas temperature

Load (%)	Uncoated Piston (ºC)	Zirconia Coated Piston (ºC)
0	161	182
25	201	212
50	245	264
75	320	321
100	400	415

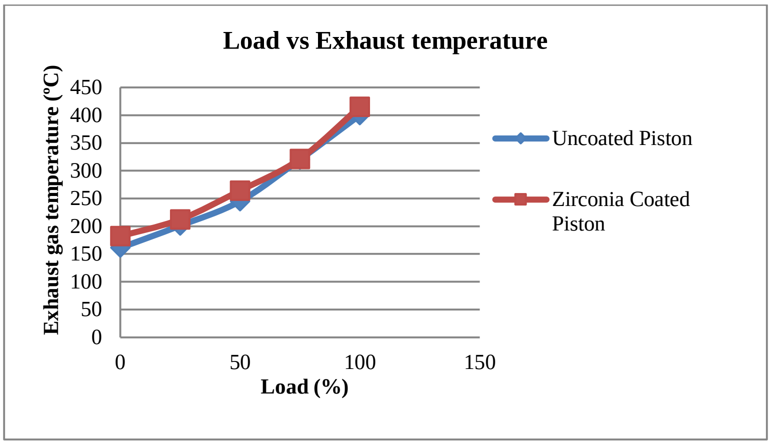


Fig. 10: Comparison of exhaust gas temperatures

The variation of exhaust gas temperature for the uncoated and coated pistons with respect to Load (%) is shown the Fig. 10.

4.3 CO Emission

The Emission indicator set up, which is shown in the Fig. 11 is used to get the information of percentage of CO present in the exhaust gasses. The percentage of CO emissions present in the exhaust gasses for both types of pistons is mentioned in Table 6.

Fig. 11: Emission Indicator Set-up

Table -6: Values of Carbon monoxide (CO) emission

Load (%)	Uncoated Piston (%)	Zirconia Coated Piston (%)
0	0.01	0.01
25	0.02	0.01
50	0.01	0
75	0.01	0
100	0.02	0.02

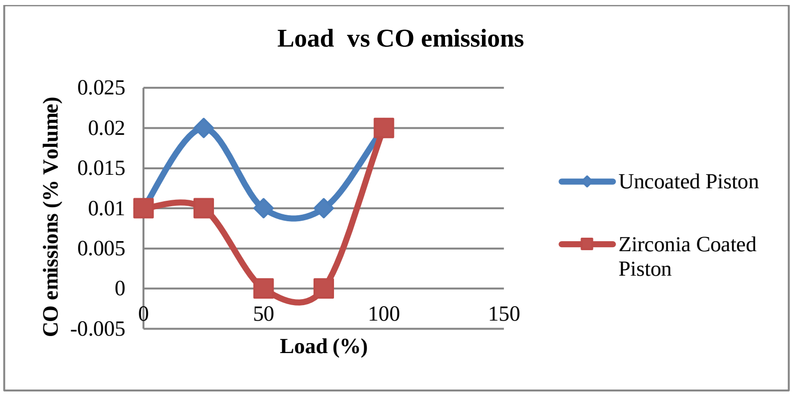


Fig. 12: Comparison of CO emissions

The measured CO emissions for uncoated aluminum piston and zirconia coated aluminum piston using bio-diesel are compared in Fig. 12. The reduction in CO emission is due to complete combustion and CO emission is low for zirconia coated aluminum piston at medium loads.

5. CONCLUSION

Tests are carried out on a Kirloskar engine with bio-diesel for both uncoated aluminum piston and zirconia coated aluminum piston.

1. Mechanical efficiency of the engine can be improved by coating the piston with zirconia. Here, it has been observed that mechanical efficiency of the engine is increased by 4% at full load by coating the piston with ziconia.
2. The Exhaust gas temperature for the zirconia coated piston is increased by 3.75% at full load condition.
3. Carbon monoxide (CO) emission is low for the zirconia coated piston at rated load.

Hence from the above results, we can say that the zirconia coated aluminum piston is better compared to uncoated aluminum piston.

6. REFERENCES

[1] Chandrashekar T.K., Rajshekar C.R., Harish Kumar R. "An experimental study on the effect of the thermal barrier coating on diesel engine performance", *International Journal of Innovative Research in Science, Engineering and Technology,* Vol. 2, Issue 8, August 2013.

[2] G.H. Farrahi1, M. Rezvani Rad, M. Azadi" Coating thickness effect on stress distribution of coated cylinder head considering residual stress", *The Journal of Engine Research*, Vol. 26 (spring 2012), pp. 49-57.

[3] Nitesh Krishnan .J, Hariharan .P," Influence Of Hardness By WC Based Coating On Alsi Alloy And Grey Cast Iron Using HVOF Coating Method", *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, pp. 36-42

[4] Ilker Turgut Yilmaz, Metin Gumus, Mehmet Akçay "Thermal barrier coatings for diesel engines", *International scientific conference*, 19–20 November 2010, Gabrovo.

[5] Yourong Liu, Traugott E. Fischer, Andrew Dent, "Comparison of HVOF and plasma-sprayed alumina-titania coatings-microstructure, mechanical properties and abrasion behavior", *Surface and Coatings Technology*, 167 (2003) ,pp.68–76, July 2002.

[6] M. Cerit, V. Ayhan, A. Parlak, H. Yasar "Thermal analysis of a partially ceramic coated piston: Effect on cold start HC emission in a spark ignition engine", *Applied Thermal Engineering*, Vol. 31, Issues 2–3, February 2011.

[7] K. R. Sharma & Debasish Das, "Integrated Review of Thermo-Physical Properties of Different Ceramic Coatings to make them Suitable for Internal Combustion Engines", *Global Journal of Researches in Engineering*, Vol.13 Issue 10, Version 1.0 the Year 2013.

[8] Gobind, Jwala Parshad & Dr. NeelKanth Grover, "Modern Proficiency in Thermal Spray Coatings to Enhance Wear Resistance of Material", *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Vol.12, Issue 2 Ver. VI (Mar-Apr. 2015), pp. 111-114.

[9] Hannink RHJ, Murray MJ, Scott HG. Friction and wear of partially stabilized zirconia: basic science and practical applications. Wear 1984;100:355–66

[10] Stachowiak GB, Stachowiak GW, Evans P. "Wear and friction characteristics of ion-implanted zirconia ceramics", *Wear 2000*; 241: 220–7.

[11] Sun Y, Li B, Yang D, Wang T, Sasaki Y, Shii KI. "Unlubrication friction and wear behavior of zirconia ceramics", *Wear 1998*; 215: 232–6.

[12] Bhupendra C. Sandhu, Prof. Umesh S. Patil, "Application of ceramic coating for combustion chamber equipment of IC engine", *A Review International Journal of Science, Engineering and Technology Research (IJSETR),* Volume 4, Issue 12, December 2015.

[13] Karuppasamy K., Mageshkumar M.P., Manikandan T.N., Naga Arjun J*, "The Effect of Thermal Barrier Coatings on Diesel Engine Performance", *ARPN Journal of Science and Technology*, Vol.3, No. 4, April 2013 ISSN 2225-7217.

