EXPERIMENTAL ANALYSIS & MICRO STRUCTURAL INVESTIGATION OF CERAMIC-COATED IC ENGINE CYLINDER LINER

Darapu Kiran Sagar Reddy
Department of Mechanical Engineering, Shri Jagdish Prasad Jhabarmal Tibrewala University (SJJTU), Jhunjhunu, Rajasthan.
kiransagarreddy1@gmail.com

Praveen Barmavatu
Department of Mechanical Engineering, Shri Jagdish Prasad Jhabarmal Tibrewala University (SJJTU), Jhunjhunu, Rajasthan.
praveen205.bps@gmail.com

Venkat Reddy Ragireddy
Department of Mechanical Engineering, Anurag University, Venkatapur, Medchal, Hyderabad, Telangana.
ragireddyvenkatreddy@gmail.com

Abstract:
The main goals in the automotive sector are to increase power and decrease fuel consumption. Because of its incredibly high compression ratio, the diesel engine provides the best performance of any traditional internal combustion engine. Even when the performance of the two engines is equal, gasoline engines use more fuel per unit of power than diesel ones. An engine's power output is often only used for productive purposes to the extent of 40%. Thirty percent of the remaining heat is lost through the exhaust, and another thirty percent is dissipated as heat losses by the cooling system. Ceramic and YSZ Coatings are applied to the cylinder liners and the piston head to transform the heat generated by the combustion process into meaningful mechanical work. As a result, the engine's heat transmission will be reduced, increasing efficiency. The higher gas temperature is expected to minimize the concentration of incomplete combustion products at the expense of an increase in nitrogen oxides (NOx). Scanning Electron Microscopy (SEM) and optical microscopy studied an engine cylinder liner's top-ring reversal point surface texture. Experiments were done on a single spark ignition engine during the break-in stage. It is the texture of the cylinder liner and this temperature distribution was used to conduct the liner's ANSYS Fluent®. The tension and distortion are greatest at a midway close to top dead centre. The gas pressure is initially stronger at top dead centre, but as the piston moves towards bottom dead centre, the pressure force diminishes and an expanding region is gradually affected by the piston's action.

Key words: *Cylinder liners; Ceramic and YSZ Coatings, Scanning electron microscopy; Ansys Fluent*

I. INTRODUCTION

Sleeves or cylinder liners are cylindrical components that fit within the engine block to form a cylinder. They are frequently called sleeves. One important engine part guards the piston and its rings against wear. The cylinder wall of a machine experiences pressure and heat when a piston and piston ring glide past it quickly [1]. Cast iron cylinders with high wear resistance are necessary for big vehicle engines since they need to last longer. Additionally, aluminium alloy engine blocks have taken the role of cast-iron engine blocks as lighter engines have grown more prevalent [2]. Al-alloys, when employed as the inner cylinder's sliding surface, have drawbacks in terms of deformation and wear resistance. Therefore, the majority of individuals use cast-iron cylinder liners.

The better performance and decreased cost of these components drive the increase in supply because of the rise in popularity of automobiles; there is a high need for auto parts. New products should be launched as quickly as possible by developing crucial elements as soon as possible by R&D and testing engineers. This needs an awareness of new technologies and integrating them into creating new products quickly. Cylindrical reciprocating IC engines require a piston. A piston receives an exploding gas impulse and is transmits to a connecting rod in an internal combustion engine. Cylinder and piston rings keep this moving part sealed against leakage [3]. An engine's combustion chamber generates a significant amount of heat, and the piston must transfer this heat to the cylinder walls, where it can be absorbed by cooling water or air. With today's latest IC engines, the inertia force generated can be controlled by using a lightweight piston. An engine uses a piston rod or connecting rod to convey the expanding gas to the crankshaft through the crankshaft. Due to this working state, cyclic gas pressure and inertial force can cause cylinder fatigue damage, such as piston side wear, cylinder head/crown cracks, and so on. In the trial, maximum stress was found to be a common cause of fatigue failure [4]. Piston overheating can only lead to overheating and seizure if this oil film is destroyed or scraped away. Internal combustion engines, rotary pumps, and gas converters all use cylinders as a moving element that is contained in a cylinder and sealed by piston rings. An engine's control valve and connecting rod convey the cylinder's expanding gas power to the crankshaft. As the piston compresses the cylinder's discharge fluid, crankshaft force is transferred to piston. Thermal Barrier Coatings can improve gas engines' fuel economy, power density, and ability to run on many types of fuels. The use of thermal Barrier Coatings can enhance fuel-efficient vehicles, reduce specific fuel consumption, and raise exhaust gas temperatures.

II. LITERATURE REVIEW

Khor K., A., and Chan S., H. [5] used nickel-chromium and alumina-titanium alloys in research on thermal barrier materials. To reduce the quantity of heat lost via the engine, these materials are used. The coating is applied using a plasma spraying procedure. Taymaz I discussed ENC composite coatings in his paper [6]. NCC coatings have been proven to have a number of benefits when used in two-stroke bikes and diesel engines. Better fuel efficiency and lower emissions have been observed. The main goal of Chan S., H's paper [7] was to lessen heat transfer to the surroundings. The top surfaces of the engine piston, cylinder head, and valves are coated with thermal barrier coating materials to lessen heat transfer through the components. B.B. Goash [8] aimed to highlight the energy balance and emission characteristics of low heat rejection (LHR) engines with and without turbochargers as well as normal engines (uncoated). Under various load situations, the conventional and standard heat rejection engines with and without turbochargers were put to the test. Thermal barrier coating impacts, advantages, and disadvantages were demonstrated by Palaniswamy E. and Manoharan N [9]. This article examines how the TBC system affects the efficiency of diesel engines and the durability of their components. Researchers Yao, Z.-M., and Qian [10] looked at how a ceramic combustion chamber covering affected the output and emissions of turbodiesel engines. The higher exhaust system temperatures caused by turbocharged engines' enhanced power can result in decreased soot and carbon monoxide emissions. They are striving to increase combustion by raising the temperature of the coolant's walls and accelerating ignition timings in addition to lowering cooling load and improving mechanical force.

III. RESEARCH METHODOLOGY

In addition to the break-in stage, gradual and catastrophic wear are all stages of cylinder liner erosion. For each phase, there are a variety of wear mechanisms. The cyclical changes in-cylinder gas pressure, gas temperature, and piston ring sliding speed on the cylinder liner may also produce diverse wear mechanisms on different surface points. Adding alkaline earth elements like calcium oxide (CaO), magnesium oxide (MgO), YSZ and rare metal oxides to zirconia prevents this from developing and keeps zirconia stable in the cubic structure at room temperature. Zirconia-based ceramic materials stabilized with yttria are superior to zirconia-based ceramic materials stabilized with magnesia and calcium oxide) Cubic zirconia's mechanical properties are prone to wear and tear. Zirconia's mechanical qualities and relevance of the martensitic transition have led to PSZ, which contains monolithic and tetragonal sediments chosen because of its better mechanical properties.

Experimental setup and cylinder wear probe:

An engine with a single cylinder and four strokes is used in the tests. It has an air-cooled, spark-ignition engine. The 10W-30 engine oil is put to use. The pressure of the cylinder gas was measured using a piezo quartz crystal pressure transducer (PQCP). Instantaneous angular velocity was calculated using an optical shaft meter an inertia meter and a torque meter were employed to measure the engine's load torque. The cylinders are lined with cast iron, which is the basic material. Chromium is deposited on the top piston ring as an additional layer of protection.

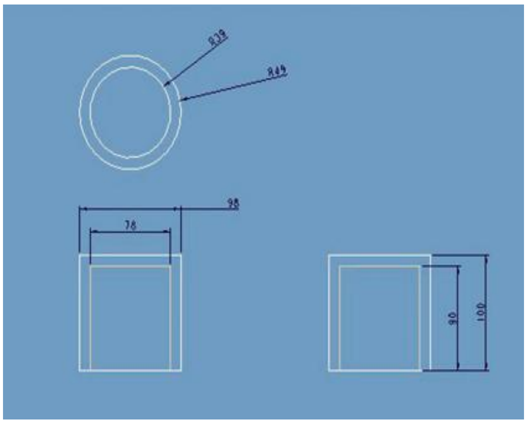

Figure.1: Dimensions of the cylinder head and liner

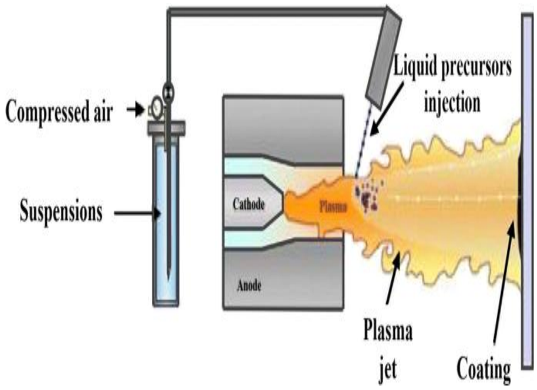

Figure.2: Schematic diagram of plasma spray gun

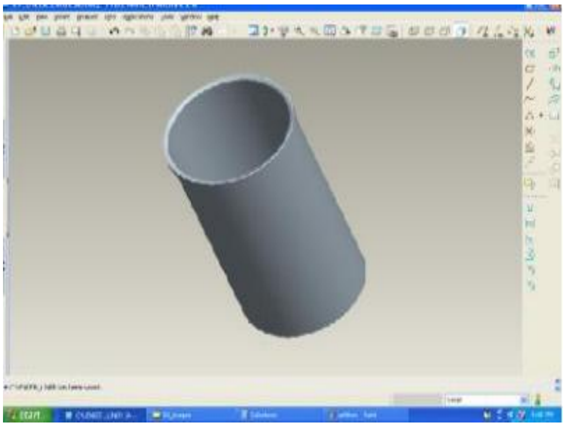

Figure.3: Design model

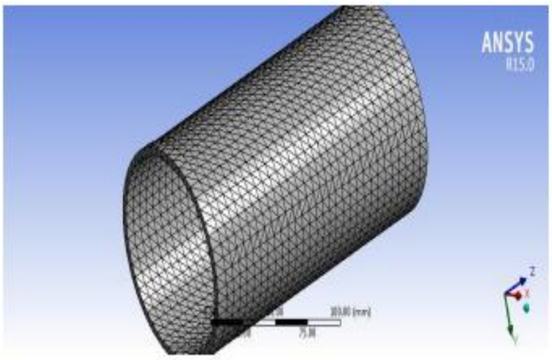

Figure.4: Meshed model

Table.1: Physical properties

Density Kg/m^3	Poisson's Ratio	Young's Modulus Mpa	Ultimate Tensile Strength Mpa
7200	0.28	110000	240

Table.2: Thermal Properties

Thermal Conductivity W/m-k	Melting Point °C	Specific Heat J/gm°C
56.8	1024	0.490

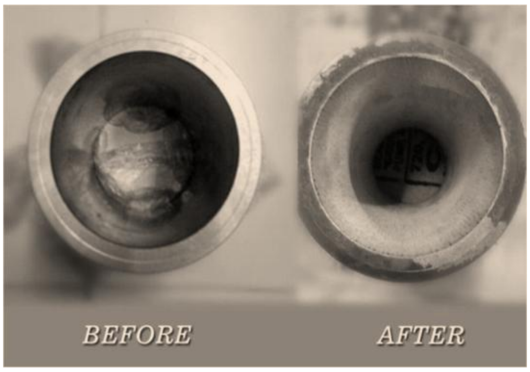

Figure.5: Cylinder liner before and after coating

The porosity in SPS coatings comes from delicate pores, underscoring the relevance of analyzing at different magnifications and the substantial concentration of small-scale porosity in SPS coatings. FOR EXAMPLE, THE SPS YSZ P-M sample demonstrated that coarse porosity could influence total porosity. The coarse porosity in this sample accounted for twice as much as the fine porosity in this specimen. The metallic sealing layer impacted in considerations of fine, rough, and overall porosity. Metallic sealing layer samples had lower porosity than samples without a metallic sealing layer. However, porosity should be equivalent when compared without a metallic sealing layer. The ceramic sealing layer had a lower influence on overall porosity than the metallic sealing layer, which resulted in porosities in the same range as the sample without a sealing layer.

The coating thickness (100 µm, 200 µm) was measured by ASM standard with magnification 100X27 on the cross-section of the optimized specimen as shown in Figure. Surface area and amount of ceramic coating are the primary factors that influence the thickness of the coating. Furthermore, Ozkan Sarikaya discovered that even at a lesser coating thickness of 30 m, hardness, decreased porosity, and a lower surface roughness may be attained. It is obvious that the specified coating thickness was attained under the previously described circumstances.

The ceramic layer in the Cylinder liner's insulating material is the highest in all areas. As with the TBC Cylinder liner, the TBC ceramic layer reaches its greatest operational temperatures in its combustion chamber throat at 498.39°C, which is within the usual operating temperature range of ceramic material. A high temperature load is also maintained by the bond layer.

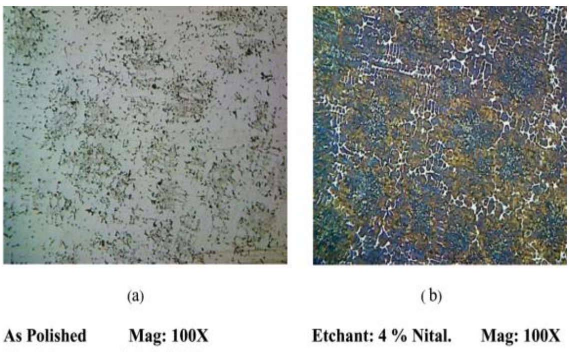

Figure.6: Microstructure analysis of cylinder liner.

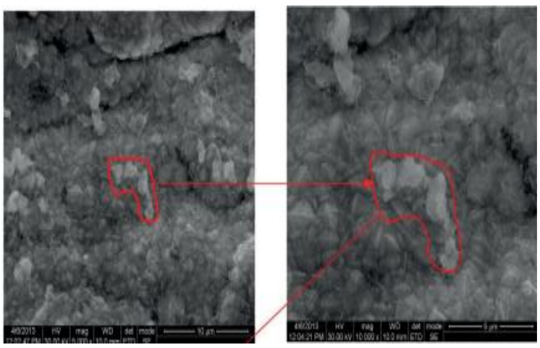

Figure.7: Scanning electron microscopy analysis of ceramic coatings of optimized cast iron cylinder liner 100,200 microns.

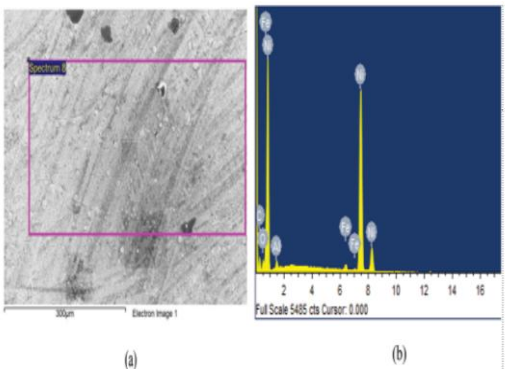

Figure.8: EDX spectrum of the Ceramic composites of cylinder liner.

The particular method of proving, investigating, and illustrating the structure of an example is known as morphology. Scanning Electron Microscope is used to examine the surface structure of a plasma spray-coated sample under different magnification. This is essentially a study of the sample's surface using imaging technology. The two unique surface morphologies of the plasma sprayed coatings may be noticed in the images. Particles in the pores exhibit an unmolten or semi-molten state. The porosity ranges in size from 0.25 micrometers to 1 micrometers.

To demonstrate the accuracy of the coating thickness on the example, two different coating thicknesses (100 and 200 microns, respectively) are applied to the sample (Ceramic, YSZ). Coating was applied to this sample as seen in the image. The thickness of the coating generated by plasma spraying is confirmed using SEM cross - section.

From X-Ray Diffraction, Investigating the example's contents or its constituents can be done using this method. Encased in an X-Ray device, the example is exposed to ionizing radiation. Graphical information is gathered through a logical programming process that is matched to the available technology. In order to conduct XRD analysis on the tests and their scales following oxidation, they were evacuated from the vessel. Because of its large temperature difference, the ceramic layer proves it to be an effective thermal conductivity. The temperature of the bond layer's top surface is near to that of the substrate, and the temperature gradient in the bond layer is quite tiny. This further demonstrates that the ceramic layer of the ceramic coatings is the primary high - temperature material.

- SEM images clearly show that the YSZ composites are distributed equally over the optimum specimen.
- The optimized specimen attained a coating thickness of 100 µm, 200 µm. It can be seen in this XRD image that the 111 (200) plane is oriented in a similar manner.

The use of Y-PSZ/Al_2O_3 TBC greatly reduces the amount of heat that is lost from the hot working media into the substrate, resulting in higher thermal efficiency or reduced cooling load for the system, and lower substrate temperatures. Figure 9 shows the deformation in liners and Figure 10 shows the stress without temperature gradient.

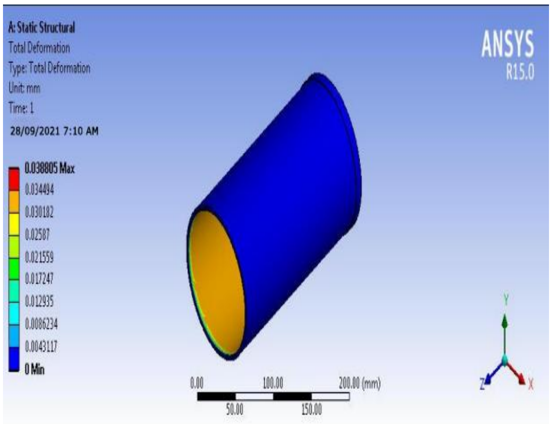

Figure.9: Deformation in liner

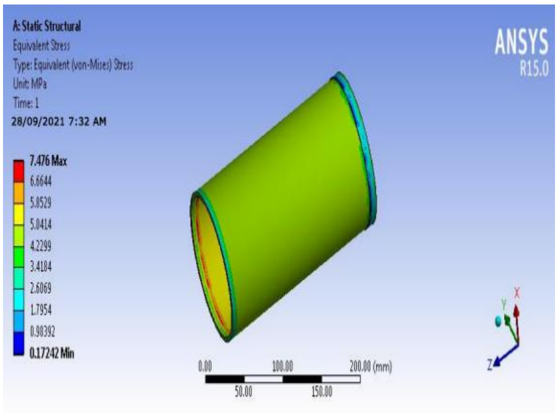

Figure.10: Stress without temperature gradient

Table.3: Comparison of different coating materials

Coating materials	Maximum deformation	Minimum deformation
Al_2O_3 Coating	809.25	0
	1860.8	42.394
YSZ Coating	838.05	0
	74.76	172.42

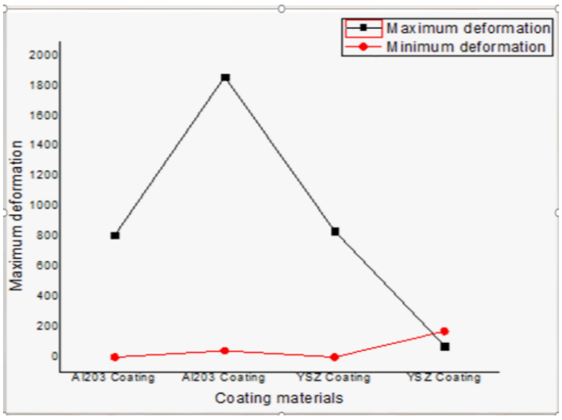

Figure.11: Comparison of different coating materials variations

Conclusion:

In this work, cast iron substrates were coated with ceramic and yttria-stabilized zirconia (YSZ) powders. Various bond coatings will be applied utilising plasma spray techniques. For each sample, APS is tasked with producing ceramic top layers.

Our research shows that coating adherence and hardness ratings go better with higher temperature and longer exposure times. X-ray diffraction may be seen in the sprayed zirconia layer (XRD). The high current of yttria ceramic and the quick temperature increase rate of plasma spraying combine to form the tetragonal stage zirconia that makes up the plasma-sprayed zirconia coating. A constant maximum temperature of about 1200 °C exists. The engine's exterior surface loses a significant amount of heat. Criteria like reducing and repurposing this waste heat into productive labor should be implemented. However, a cylinder coated with a 1 mm layer of zirconium oxide and heated to 1200°C was found to have an outside surface temperature of only 10°C. Approximately 90°C of heat is converted to practical work. According to Liner's study, the breakdown is typically clear-cut. The band from the top to the bottom of the cylinder liner on the thrust side is where it mostly appears, but it can also occasionally be seen there. Pitting can enter the combustion chamber through the liner wall and completely shut down the engine. After comparing the results, the best-coated cylinder dry Liner for this type of diesel engine can be suggested. The cylinder liners in this car were coated with YSZ coating, which is Al2O3.

REFERENCES:

1. *Rejowski, E.D., Mordente, P., Sr.; Pillis, M.F., Casserly, T. "Application of DLC Coating in Cylinder Liners for Friction Reduction", Technical Paper, SAE: Warrendale, PA, USA, doi:10.4271/2012-01-1329, 2012.*
2. *Dhinagar, S.J., Nagalingam, B. and Gopalakkrishnan, K.V., 1997, "Use of Ceramics in Internal Combustion Engines", Proceedings of 10th National Conference on IC Engines and Combustion, India.*
3. *Tadeusz Hejwowski, 2010, "Comparative study of thermal barrier coatings for internal combustion engine", Vacuum 85.*
4. *T. Morrel, P.N. Blumberg and E.F. Fort, 1985, "Examination of key issues in LHR engines", SAE 850356. 6. R. Kamo, N.S. Mavinahally, L. Kamo, Bryzik, and E.E. Schwartz, 1997, "Injection Characteristics that improve performance of ceramic coated diesel engines", SAE 1997-01-0972.*
5. *Chan S., H. and Khor K., A. "The effect of thermal barrier coated piston crown on engine characteristics", Journal of Materials Engineering and Performance, 2000, 9(1), pp.103-109.*
6. *Taymaz I., Çakır K., Mimaroğlu A., "Experimental study of effective efficiency in a ceramic coated diesel engine", Surface and Coatings Technology, 2005, 200(1-4), pp.1182-1185.*
7. *Chan S., H. "Performance and emissions characteristics of a partially insulated gasoline engine", International Journal of Thermal Sciences, 2001, 40(3), pp.255-261.*
8. *B.B. Goash., T.K. Banerjee., "Experimental investigations on some performance parameters of a diesel engine using ceramic coatings on the top of the piston", Technical Paper, SAE, paper No. 970207, 1997.*
9. *Palaniswamy E, Manoharan N. "Ceramic coated combustion chamber for improving ic engine performance", International Journal on Design and Manufacturing Technologies, 2008, 2(1), pp.22-25.*
10. *Yao, Z. M., Qian Z. Q., Li R., Hu E., "Energy efficiency analysis of marine high-powered medium-speed diesel engine base on energy balance and exergy", Energy, 2019, 176, pp.991–1006.*
11. *Y. Miyairi, T. Matsuhisa, T. Ozawa, and N. Nakashima, 1998, "Selective heat insulation of combustion chamber walls for a DI Diesel engine with Monolithic Ceramics", SAE 980186.*
12. *J.Rajasekaran, B.M.Gnanasekaran, T.Senthilkumar, B.Kumaragurubaran, M.Chandrasekar, Effect Of Thermal*

Barrier Coating For The Improvement Of Si Engine Performance & Emission Characteristics, International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308.

13. *C.S. Ramesh, Suresh Kumar, D.S. Devaraj, R. Keshavamurthy, Slurry Erosive Wear Behavior of Plasma Sprayed Inconel-718 Coatings on Al6061 Alloy, Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.5, pp.445-453, 2011.*
14. *D.M. Kennedy, M.S.J. Hashmi, Methods of wear testing for advanced surface coatings and bulk Materials, Journal of Materials Processing Technology 77 (1998) 246–253.*
15. *Adriana Benitez-Rico, Mario F. Gracia Sanchez, High ionic conduction in nanocrystalline ytterbium stabilized zirconia grown by ultrasonic spray pyrolysis, International Journal of Engineering Science and Innovative Technology, volume 3, issue 3, (May 2014) 156-165*
16. *Kavaliauskas, K. Brinkiene, J. Cesniene, and R. Kezelis, Influence Of Plasma Jet Temperature On The Synthesis And Structure Of Ysz Coatings, Lithuanian Journal of Physics, Vol. 49, No. 1, pp. 85.90 (2009).*
17. *Mareike Hahn and Alfons Fischer Characterization of thermal spray coatings for cylinder running surfaces of Diesel engines Journal of Thermal Spray Technology, Vol 19(5) Sept 2010, and pp 866-872.*
18. *Murat Ciniviz, Mustafa Sahir Salman, Eyüb Canlı, Hüseyin Köse and Özgür Solmaz, Ceramic Coating Applications and ResearchFields for Internal Combustion Engines, ISBN: 978- 953-51-0083-6, 286 pages, In Tech, 24, February, 2012.*