Study of Ceramic Adiabatic Engines: A Review

[1]Chaitanya Bidave, [2]Prof. Mr. Yogesh Sonawane

Mechanical Engineering, RMD Sinhgad School of Engineering, Pune.

Abstract- *An internal combustion engine (ICE) is defined as a device which converts chemical energy of fuel into thermal energy by means of combustion process which takes place in presence of an oxidizer (usually air), and later this very thermal energy gets converted into mechanical energy, which is the required output. But the problem is that, only one third of the total energy given out by fuel gets converted into useful work, whereas the rest two third of the total energy is wasted through exhaust gas, cooling system and lubricating system. So we can infer that in a conventional engine, a large percentage of energy is wasted unused.*

To overcome these losses, combustion chamber parts like cylinder head, piston crown, inlet and exhaust valves are coated with ceramic materials, without modifying any of the original dimensions. Experiments performed by various researchers have shown that there are drastic changes in overall performance of the engines those are coated with ceramics. Results revealed that heat loss to cooling water gets reduced, thermal efficiency increases, specific fuel consumption reduces, and other emission characteristics also get altered. Zirconia is considered to be the most perfect ceramic to be coated for engines.

Keywords: *Ceramic coating, emission characteristics, combustion chamber, engine performance.*

I. INTRODUCTION

An engine is a machine used to convert chemical energy of fuel into mechanical energy. These, burn a fuel to generate heat, which is then used to create a force on pistons. An engine is considered to be the prime mover of the whole world. It plays a dominating role in transportation as well as agriculture industry. It is considered to be the backbone of the industrial revolution. It is responsible in forming the benchmark of the today's modern society. It is so famous due to its higher fuel economy and low operating and maintenance costs. Mostly engines have four, six or eight cylinders. A cylinder is like a tin can in which a round piston slides up and down. For continuous operation, an engine has four support systems. These systems are: fuel, ignition, lubrication and cooling systems. Typical engine applications include generators, off-highway and construction equipment, farming equipment and automotive.

However only one third of the total energy given out by fuel gets converted into useful work, whereas the rest two third which is a considerable amount of the total energy is wasted through lubricating system, exhaust gas and cooling system. The engine cooling system dissipates combustion and friction generated heat energy to the surrounding to ensure that the engine operates under the safe defined temperature. Also the lubrication and exhaust gases play to be other sources which carry away the generated heat from the combustion chamber. So in short, these systems are necessary evils.

This can be reduced, only if by some means, operating temperature of the engine is raised. This is because the hotter an engine runs; the higher will be its efficiency. But simply raising the operating temperature will not work since metal parts would melt or fail. Hence, by application of thermal insulation on the combustion chamber parts like cylinder head, piston crown, inlet and exhaust valves with ceramic materials would improve the combustion process and would reduce energy losses. This allows the engine to operate at a much higher temperature. Then more of the energy in the fuel generates power.

Ceramic materials are seen to be the alternatives for naked metallic parts of the combustion chamber because of the following properties of them:

- High strength.
- High fracture toughness.
- Good Frictional behavior.
- Corrosion resistance in acids and alkalis.
- Excellent surface finish.
- Resistant to high temperatures.
- High chemical stability.
- High hardness value.
- Excellent wear resistance.
- Low heat conduction coefficient.
- High compression strength.

Following are the ceramic coating materials which are widely used:

- Yttria.

- Magnesia.
- Alumina.
- Beryllia.
- Silicon Nitride.
- Silicon Carbide.
- Zirconia.

Zirconium dioxide also known as zirconia is a white crystalline oxide of zirconium. It's commonly found form is the mineral baddeleyite, which has a crystalline monoclinic structure. Zirconia is produced by calcination of zirconium compounds. Crystal structure of zirconia is shown in the fig. 1.

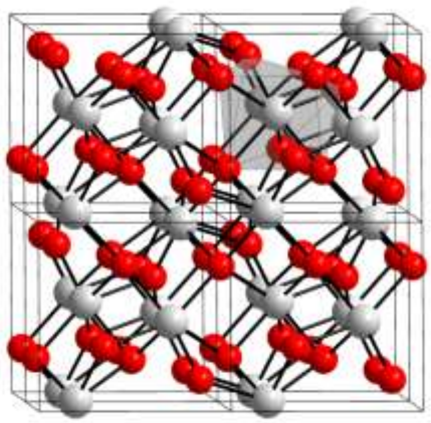

Fig. 1. Crystal structure of zirconia.

Mostly zirconia is used for ceramic coating applications due to following properties of it:

- It has relatively good mechanical strength.
- Zirconia ceramic does not suffer from thermal degradation which plagues several other ceramics.
- Being an oxide, zirconia is unlikely to be further oxidized.
- Taking into consideration that many so fuels contain chemically-active and corrosive substances, resistance against hydrothermal degradation and resistance against oxidation are highly desirable attributes of a ceramic material for an internal combustion engine which zirconia possesses.

Zirconia is generally blended with some other oxides for enhancement of its properties. Most common is yttrium oxide.

Ceramic coating applied to inlet and exhaust valves in a four cylinder engine is shown in fig. 2. Ceramic coating applied to piston crown is shown in fig. 3.

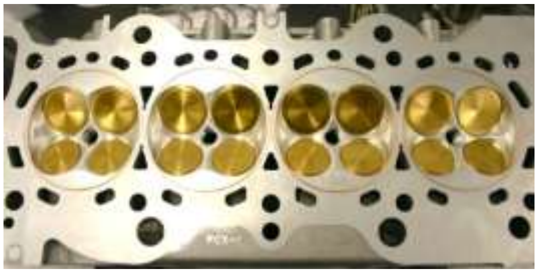

Fig. 2. Ceramic coating applied to inlet and exhaust valves.

Fig. 3. Ceramic coating applied to piston crown.

II. HISTORY

Thermal barrier coatings are been used for aero- propulsion operation since the 1960s. These thermal barrier coatings (TBC) are composed of an oxidation resistant metallic base layer and a thermally resistant ceramic top layer which is very thin. The evolution of it includes performance and durability improvements, process advancements, and understanding and evolution of failure modes of these coatings. More recent efforts are focused on future challenges for thermal barrier coatings to meet ever increasing operating temperature demands of the future applications. There is a wide scope in this field in near future.

III. LITERATURE REVIEW

G. Sivakumar et al. [1] carried out experimental investigation under different loading conditions in a three cylinder diesel engine with its piston crown coated with Yttria Stabilized Zirconia (YSZ) to understand the influence of the thermal barrier coating (TBC) on the performance and emission characteristics in comparison with baseline engine characteristics. He used plasma spray coating method which is shown in fig. 4.

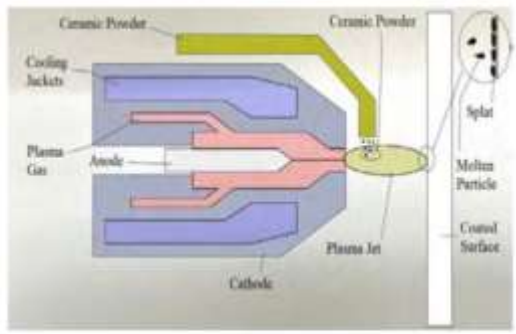

Fig. 4. Plasma spray technique used for thermal barrier coating. [1]

Mesut Durat et al. [2] performed steady state thermal analysis to evaluate the temperature gradients in the standard and two different partially stabilized ceramic coated pistons by using Abacus finite element (FE) software. He observed a sharp increase in the temperature of the coated area of the piston as a result of FE simulations. He also used plasma spray technique for coating.

M. Cerit et al. [3] investigated effect of partially thermal barrier coating on piston temperature distribution and cold start HC emissions of an engine, numerically and experimentally.

Nitesh Mittal et al. [4] conducted an experimental investigation on a partially insulated single cylinder engine to study the performance and emission characteristics when fueled with two different blends of butanol and gasoline.

Shanhong Wan et al. [5] experimented and found out that the presence of hard amorphous graphite like carbon (GLC) not only reduces the scuffing damage and running instability effectively for conventional chromium-based coatings, but also improves the reliability and robustness of the piston rings.

X. Q. Cao et al. [6] studied and found out that ceramic materials, in contrast to metals, are often more resistant to oxidation, corrosion and wear, as well as better thermal insulators. Other than yttria stabilized zirconia, other materials such as lanthanum zirconate and rare earth oxides are also promising materials for thermal barrier coatings.

Hideo Kawamura [7] studied different design methods of the parts and triborogical features for producing ceramics engines. In order to use ceramic materials, with suitable strength and fracture toughness, he investigated the correlation of strength and pore or flaw size. Also designing methods were studied by using calculation results of F. E. M. on practical engine and the strength of ceramics. Isuzu adiabatic engine developed by him is shown in fig. 5.

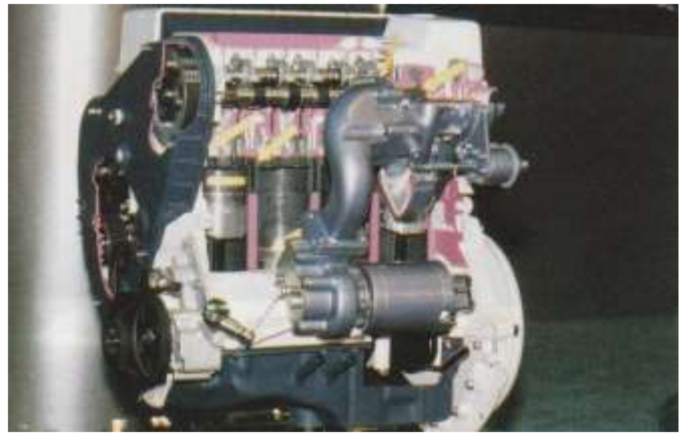

Fig. 5. Isuzu adiabatic engine. [7]

IV. METHODOLOGY

If yttria stabilized zirconia (YSZ) is used as a candidate material for coating the piston crown because of its desirable physical properties such as high coefficient of thermal expansion, low thermal conductivity, high Poisson’s ratio, and stable phase structure at high temperature conditions and for the measurement of emission characteristics, ISO 8178-4 “CI” 8 Mode testing cycle is followed, expected results are that there would be reduction in heat rejection to the cooling medium which would result in an increase in exhaust energy. Also there would an increase in volumetric efficiency of the engine, as the hotter combustion chamber walls and residual gas decrease the density of inducted air. Even brake specific fuel consumption (BSFC) would reduce due to reduction in the fuel consumption and improved energy conversion rate. Also brake thermal efficiency improvement would be notable, due to the fact that the reduction in fuel consumption for the same power output helps in increasing the brake thermal efficiency. Also there would be an increase in the heat energy available at the exhaust. Even carbon monoxide (CO) and hydrocarbon (HC) emissions would reduce, as there would be a decrease in the heat losses going to the cooling system and subsequent increase in the after combustion temperature. Carbon monoxide emissions would also reduce and carbon dioxide emissions would increase due to complete combustion (oxidation).

Yttria-Partially Stabilized Zirconia (Y-PSZ) coating may contribute better, as compared to Mg-PSZ, to decrease the cold start and steady state HC emissions without auto ignition. An engine with partially thermal barrier coatings has a great potential to improve performance and to reduce unburned emissions at idle as well as partially loaded conditions.

By performing a thermal analysis for both standard and coated pistons by using a commercial code, namely ANSYS, and conducting engine tests on a single cylinder, water cooled engine for both standard and coated cases, one would analyze that the surface temperature of the coated piston part would increase up to 100°C, which would lead to an increase in air-fuel mixture temperature in the wall quenching regions. Due to this cold start HC emissions would decrease as compared to the standard engine without any degradation in engine performance. This would be due to the fact that the surface temperature on the coated section of the piston increases leading to an increase in air-fuel mixture temperature. Also it would be found that there would be an increase in engine torque at all engine speeds and also in combustion efficiency.

Coated cylinder head surface and valves with a ceramic material consisting of Zirconium dioxide (ZrO2) with 8% by weight of Yttrium Oxide (Y2O3) to a thickness of 0.3 mm by plasma spray method and by testing two different fuel blends containing 10% and 15% by volume of butanol in gasoline on an engine dynamometer using the uncoated and ceramic coated engines, the results that would be obtained strongly indicate that combination of ceramic coated engine and butanol gasoline blended fuel has potential to improve the engine performance including all the efficiencies. Also the peak cylinder pressure of ceramic coated engine would be higher than baseline engine, as heat rejection reduces. Also specific fuel consumption (SFC) would decrease in coated conditions. Results also would indicate an increase in exhaust gas temperature in ceramic coated engine. Also there would be a decrease in CO emissions due to an increase in combustion temperature as a result of decrease in the heat losses going to cooling system. Also a decreasing trend of unburned HC emission level would be seen as the brake power (BP) increases. Also it would be found out that the ceramic coating protects the combustion chamber components from negative effects such as irregular thermal tension and thermal shock.

It would be achieved to produce the ceramics engine with a satisfactory durability and a lower friction through very severe tests. Also it would be found out that when ceramic piston ring and cylinder linear with optimum combination after investigations of triborogical factors in ceramic materials are used, there would be a reduction in engine friction. Also the possibility to make a heat insulated engine without a cooling system by using engine constructions produced by the gasket with low thermal conductivity and combustion chamber walls made up of a ceramic material is high.

V. CONCLUSION

Due to ceramic coatings on engine, following effects can be observed:

- Heat loss to cooling water reduces.
- Heat energy available at exhaust increases which is boosts turbocharging.
- Increase in air-fuel mixture temperature.
- Increase in engine torque at all engine speeds and also in combustion efficiency.
- Brake specific fuel consumption (BSFC) reduces.
- Brake power increases.
- Brake thermal efficiency increases.
- Volumetric efficiency increases.
- Fuel consumption reduces.
- Hydrocarbon emission reduces.
- Carbon monoxide emission reduces.
- Carbon dioxide emission increases.
- Cold starting HC emissions reduce.
- Scuffing behavior gets reduced.
- Engine performance improves.
- For increasing engine efficiency.
- For reducing HC emissions which cause pollution.
- For efficient and maximum usage of fuel (natural resources).
- Improvement the engine performance
- Reliability and robustness increases.

VI. FUTURE SCOPE

Ceramic coating is seen as a boon for future engines for improvement of performance. This would even give better fuel economy which would be a solution for non-renewable fuel crises. It is even assumed that this would be helpful to tackle problem of air pollution caused by automobile emissions. In short, there is a wide scope of research in this field.

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