# Thermo-Mechanical Properties and Corrosion Analysis of Coated and Uncoated Piston used in CI Engines

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***Abstract***: *The purpose of this paper is to study the thermal, mechanical Properties and corrosion analysis of ceramic coated four-stroke diesel engine piston using plasma coating. Effect of coating thickness on the microstructure, hardness, heat resistance and corrosion resistance is studied at 0.25mm, 0.35mm thickness and the results are compared with uncoated piston material. It is observed from SEM microstructure, porosity is reducing with an increase in coating thickness which results in higher hardness for higher coating thickness, the hardness of coated material is higher compared to uncoated material. The thermal stability is conducted using muffle furnace it is observed that the uncoated material has melted at 600°C, whereas the coated specimen was successfully resisted the heat energy up to 1300°C without any physical deformation. Corrosion test is carried using vanadium pentoxide and sodium sulfate on coated and uncoated material it is observed that the experimental results are not varying much in comparison with uncoated material.*

***Keywords: zirconium dioxide; plasma coating; thermal stability; vanadium pentoxide and sodium sulfate corrosion.***

## I. INTRODUCTION

Internal combustion engines have a wide variety of applications in different sectors like transportation, agriculture, and sports, etc, which attracts the millions of researchers to carry out research on IC engines for obtaining higher performance by improving the properties of engine material by using thermal barrier coatings(TBC). One of the important applications of TBC is to improve the service life of the engine and to reduce the emissions from the IC engines to a certain extent. In TBC we often use the ceramic material such as zirconium dioxide (Zro2), Alumina (Al2o3), Mallite, etc in this research zirconium dioxide is used as a coating material because of higher resistance to corrosion, higher hardness properties, and higher melting point temperature properties, nickel-chromium aluminum yttrium is used as bonding material since it provides the oxidation resistance at the elevated temperature and aids in increasing the adhesion between zirconium dioxide and substrate (aluminum). In IC engines most of the heat energy generated during the combustion process is absorbed by the piston and combustion chamber walls to avoid the degradation of a material due to higher heat energy cooling water is supplied which increases the temperature of cooling water and reducing the efficiency of IC engines. In this research, the IC engine is taken into consideration for improving the properties to resist high heat energy by using the thermal barrier coating. In this study, an aluminum piston is considered and it is coated by zirconium dioxide using plasma spray process up to a thickness of 0.25mm and 0.35mm and following mechanical properties are studied and the results are compared with the uncoated piston material.

- Microstructure analysis
- Hardness test
- Thermal stability
- Corrosion analysis

## II. SAMPLE PREPARATION


**Fig-1:** Uncoated work samples

**Fig.-2:** Coated work samples

Step 1: The aluminum piston taken to Selomac industry, Peenya, Bengaluru for cutting it into 1×1 square inch using a milling machine, shown in fig1.

Step 2: Three work sample of dimension 1x1 square inch is used for the hardness test.

Step 3: Three work sample of dimension 0.5x0.5cm$^2$ is used for microstructure analysis of uncoated and coated

Step 4: Three work samples of dimension 1x1 square inch is used for the corrosion test.

Step 5: Three work sample of dimension 1x1 square inch is used for thermal stability test.

Fig: 1 and Fig 2 shows the work samples of uncoated and coated samples with zirconium dioxide of thickness 0.25mm and 0.35mm.

## III. Microstructure of ZrO2

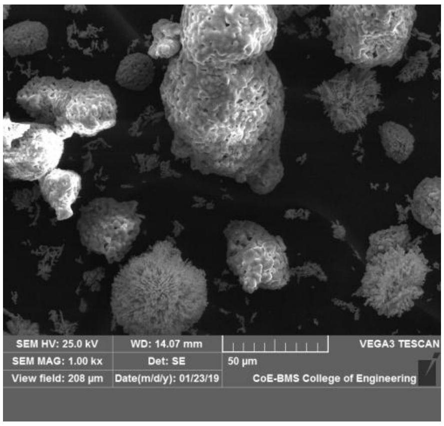


**Fig- 3:** Microstructure of Zro2

Fig. 2: shows, the size of the particles is large and occupies more space resulting in a closely packed structure.

With the help of these SEM images, the average distance between the ZrO2 particles is found out using ImageJ software

**Table -1:** Average Distance between ZRO2 Particles

| Sl.No | Label | Angle | Length |
|---|---|---|---|
| 1 | Average | 45 | 71.72 |
| 2 | distance | 23.076 | 49.642 |
| 3 | between | -44.653 | 31.287 |
| 4 | Zirconium dioxide | 23.199 | 36.747 |
| 5 | | 0 | 72.302 |
| 6 | particles through ImageJ analysis | -118.166 | 38.786 |
| 7 | **Mean** | -11.924 | 50.082 |
| 8 | **SD** | 60.332 | 18.007 |
| 9 | **Min** | -118.166 | 31.287 |
| 10 | **Max** | 45 | 72.302 |

## IV. The Microstructure of Uncoated

Fig. 4: shows SEM Image of the uncoated specimen.

From fig it is found the surface is rough and uneven

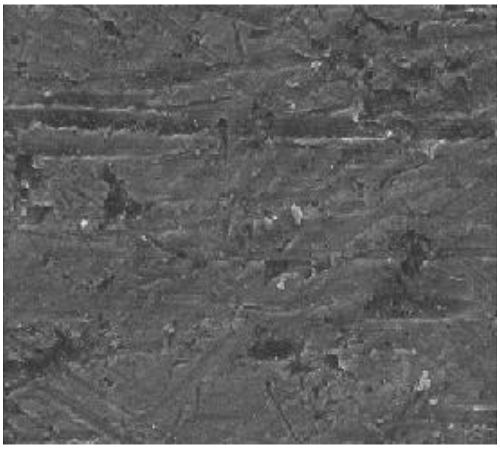

**Fig.-4:** Microstructure of work sample without coating

The solid structure of the surface helps in increasing the strength of the joint, some micro cracks may be seen in the SEM image on the top surface which helps to hold the coated material on to the surface.

## V. Coating Specification

**Table-2:** Coating Specification Details

| Sl. No. | Specifications | Specification Values |
|---|---|---|
| 1 | Current | 500A, 65-70V |
| 2 | Powder Feed | 40-45 grams/minute |
| 3 | Spray Distance | 2 Inches |
| 4 | Cutting thickness | 300μm |
| 5 | Gun | 3Mb spray gun |

- Pla sma spray process is used for coating zirconium di oxide on aluminum piston.
- Three samples are coated on all the surfaces and one sample is coated only on one surface with Zirconium Dioxide using plasma spray process.
- The coating thickness is 0.25mm amd 0.35mm.

Bonding material is NiCrAlY. Nickel chromium aluminum yettrium.

## VI. The Microstructure of Coated

Fig 5 and fig 6 shows the SEM image of the coated specimen of 0.25mm and 0.35mm. From the image, it is evident that the surface porosity is very less and the coating strongly adheres to the surface.

SEM image shows the typical microstructure of the coating produced by plasma coating. Microstructural observations showed that these coatings usually possess less porosity, oxidized, un-melted and semi-melted particles, and inclusions.

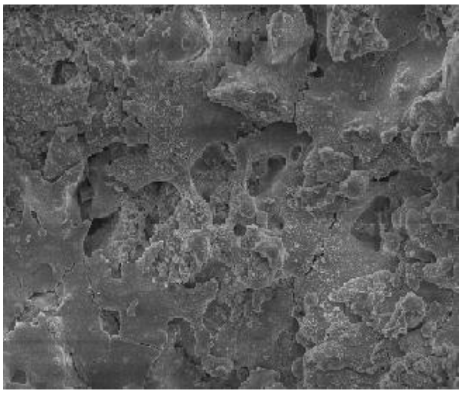

**Fig.-5:** Microstructure of work sample with a coating of 0.25mm

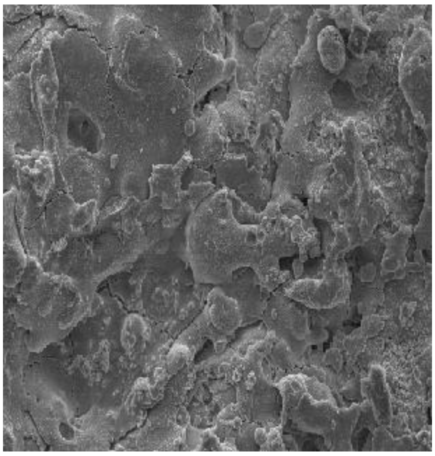

**Fig- 6:** Microstructure of work sample with a coating of 0.35mm

The density of coatings in 0.35mm thick is greater compared to 0.25mm which results in larger hardness and lesser porosity which increases the overall strength of coated material.

## VII. HARDNESS TEST

Hardness values of the coatings on the base material depends on the porosity and oxidised impurities present in the coatings. Due to porosity the hardness values decreases from coating surface to top surface of the bonding material. But NiCrAlY coatings deposited by plasma spray process improves the hardness since coatings show a high density and cohesive strength of the individual splats with bonding material because of the high impact velocity of particles by plasma spray process. Thus, compared to an uncoated aluminum workpiece, the hardness values of the coated workpiece are higher.

Brinell hardness testing equipment is used to determine the hardness of the coatings on the top of aluminium base material because higher strength of zirconium di oxide.

A combined graph of 0.25mm and 0.35mm coated and uncoated specimens is plotted, it is clearly evident that the coated specimen has higher BHN compared to an uncoated specimen. Hardness is directly proportional to the Brinell hardness number (BHN).

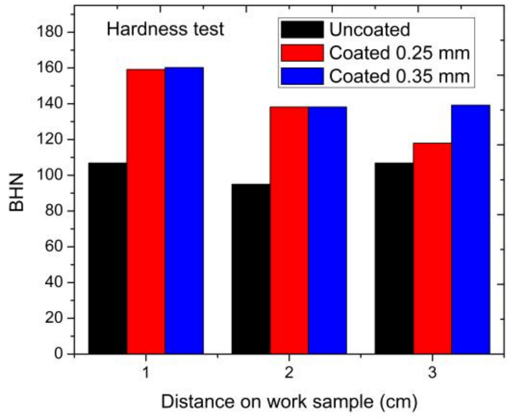


**Fig- 7:**Hardness Test

We conclude that the coated work samples possess a higher hardness than the uncoated work samples and hardness was increased by 26.52%. So, if the BHN is higher, the material will be more resistant to degradation and has higher overall strength. The hardness of the coated specimen increases with increase in coating thickenss and it also increases the resistance to wear, ability to absorb more quantity of heat energy.

## VIII. THERMAL STABILITY

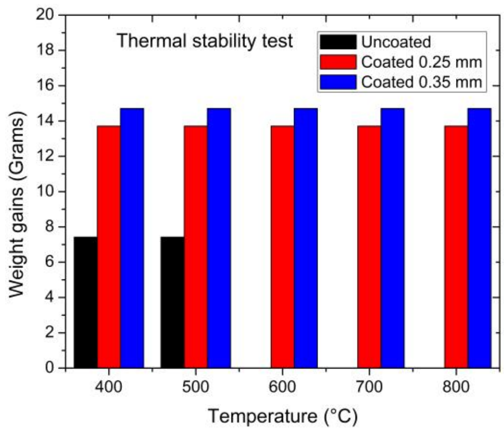


**Fig.-8:** Shows the thermal stability

Fig. 8: shows the thermal stability (ability of material to absorb heat energy) At 400°C, the weight of 0.25mm and 0.35mm coated specimen are 13.7 grams and 14.4 grams respectively and the weight of uncoated specimen is

7.41grams, at 500°C the weight of 0.25mm and 0.35mm coated specimen is 13.7grams and 14.4 grams and the uncoated specimen is 7.41grams, at 600°C the uncoated specimen is melted and the weight of specimen remained same. The test is carried until 900°C and we have stopped at that temperature as the results were beyond our expectations. The ability of material to absorb heat energy at higher temperature using zirconium di oxide is more compared to un coated specimen.

## IX. CORROSION ANALYSIS

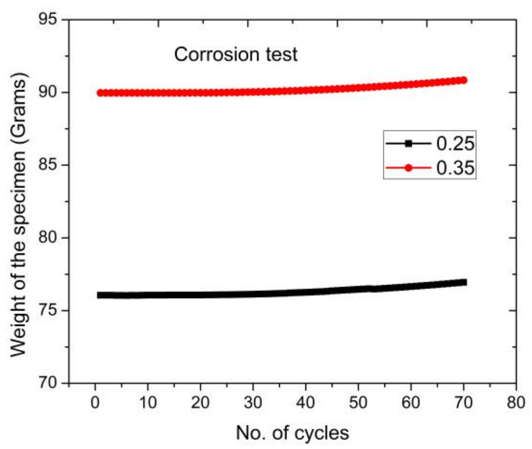


**Fig.-9:** Corrosion Test

Fig. 9: shows the corrosion test of 0.25mm and 0.35mm coated specimen. From the reference, sodium sulfate along with vanadium pentoxide Salts was mixed and used for carrying out the corrosion test. By comparing the fig. 9: we found that the coated specimen was less corroded than the uncoated specimen. From the above trend, we can get to know that the weight of the specimen is increasing. This means that the salts applied are starting to corrode the specimen. We can observe uncoated workpiece that the weight of the specimen at the 20th cycle is 89.5737grams. At the 40th cycle, the weight is 90.1407grams. At the 60th cycle, the weight is 90.5457grams. From the above trend, we can get to know that the weight of the specimen is increasing. This means that the salts applied are starting to corrode the specimen.

We can also observe coated workpiece that the weight of the specimen at the 20$^{th}$ cycle is 76.0855grams. At the 40$^{th}$ cycle, the weight is 76.3402grams. At the 60$^{th}$ cycle, the weight is 76.5662grams. From the above trend, we can come to know that the weight of the specimen is increasing but by a very small value. This means that the salts applied are corroding the specimen in negligible percentage.

## X. CONCLUSIONS

- From the experimental results of SEM analysis, we

- Found that porosity of coated specimen is less and the density of zirconium dioxide molecules is more.

- The hardness of a coated specimen is more when compared to the uncoated specimen. This signifies that the bonding strength between the coated material and base material is significantly more and it can be effectively used in high-temperature applications. This was proved by a thermal stability test.

- During the thermal stability test, it is found that the physical properties of the coated specimen did not deteriorate even at 1200°C.

- Corrosion test was carried out using V2O5 and Na2SO4. The results of a coated specimen were not deviating many forms the uncoated specimen. This indicates that the coated specimen is not corroding under the influence of V2O5 and Na2SO4.

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Mr. Kalyana Kumar M, Assistant Professor at the School of Mechanical Engineering has teaching experience of over 7 years. He has Master degree in thermal power engineering from Visveswaraya Technological University, Belagavi. He has published one technical paper in international journal.

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