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Characterization of thermal barrier coating on piston crown for high temperature internal combustion engine

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ABSTRACT – High temperature and pressure produced in an internal combustion engine may lead to high thermal stresses. A piston may need to be coated to avoid fails operation due to insufficient heat transfer. Common material that used as a material for Thermal Barrier Coating (TBC) is Yttria Partially Stabilized Zirconia (YPSZ) and a ceramic based material called Mullite which has very good properties against high temperature application. In this work, the usage of Mullite and YPSZ were compared to improve the performance of TBC and were plasma sprayed on piston crown (AC8A aluminium alloys) in order to reduce thermal stresses. Those samples were deposited with NiCrAl bonding layers prior to coating of Mullite and YPSZ some samples is remained uncoated for comparison purpose. Detailed analyses (microstructure and hardness) on the deposited coating were examined and studied.

1. INTRODUCTION

Internal combustion engine runs in very high operating temperature especially when the fuel used is compressed natural gas (CNG) due to higher octane level [1]. Hence, the durability of parts especially the piston crown in IC engine is highly affected by exposure to high temperature and pressure because the crown is the most critical part been exposed to the combustion in IC engine [1, 2]. Therefore a layer of surface coating may be applied to minimize the thermal stress by forming the temperature gradient between the exposed top surface and the bond/topcoat interface [1, 3]. Ceramic based coatings are possible surface coatings because they possess low thermal conductivity, high melting point, good oxidation resistance and high resistance against corrosion [3, 4].

Most study only focused on the application of YPSZ as a topcoat for TBC. Hence, an initiative was taken to study the performance of Mullite to be used as top coat for TBC replacing the top coat material, YPSZ.

2. METHODOLOGY

2.1 Starting Material and Coating Process

A set of Proton CamPro piston consist of three samples were selected. The deposition work was started when the samples were sand-blasted to 6 μm surface roughness to increase the interlocking and adhesion between the substrate and the TBCs. It may also allow the surface of the sample to have larger area to be coated with ceramics powder.

Figure 1 Actual plasma sprayed Mullite coated piston crown.

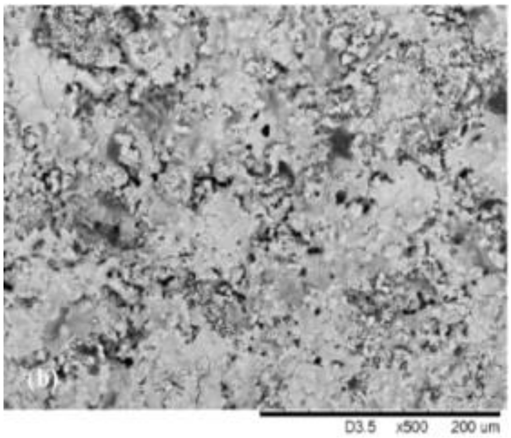
Mullite and YPSZ powder with particle size between 20 μm to 100 μm were selected as the top coat on the sample. Both of them possess low thermal conductivity, high corrosion resistance and high thermal expansion coefficient that could reduce the interfacial stress [1]. Plasma spray was chosen in this work because of its low thermal stress and high deposition per unit time [1, 2]. Before deposited the samples, a 150mm thickness of NiCrAl layer was first sprayed on the crown to improve the mechanical interlocking and it will also act as oxygen diffusion barrier thus delaying the oxidation to occur on the substrate.

The samples were sent for micro-structural observation on their top surface. All samples were tested using Vicker's hardness tester with load of 1 kg for 20s.

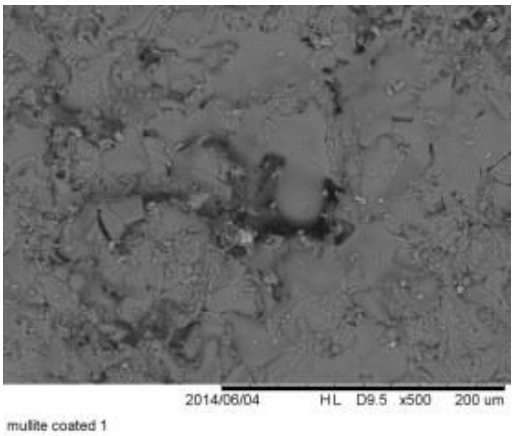
3. RESULTS AND DISCUSSION

3.1 Microstructural Observation

Actual surface coated of Mullite is shown in Figure 1 where as in Figure 2(a) shows the microstructure of Mullite coated and Figure 2(b) shows the microstructure of YPSZ top coat in high magnification. Both of Figure 2(a) and (b) shows the presence of the hairline cracks and voids that was mainly formed by the stress upon cooling. This stress was developed when the powder particles cooled from their melting temperature after plasma spray process [1, 2]. After the spraying process is done, the specimen was cooled by the aid of air. This technique could contribute this stress to develop thus producing this hairline cracks.



(a)



(b)

Figure 2 (a) SEM photograph of YPSZ coated [3, 4] and (b) SEM photograph of top coat Mullite surface.

The top coat layer with the thickness about 350μm consists of tremendous amount of void and quite porous throughout the layer. The microcracks are also developed in this layer that cause by the plasma spray process. Apart from that, the sample preparation for cross-sectional observation is very difficult process because those particles in every layer could easily pull out

3.2 Hardness Profile

Figure 4 shows the value of Vicker's hardness for uncoated, Mullite coated and YPSZ coated piston crown. From the chart below, YPSZ coated possess the highest value of hardness which is 760Hv that was slightly higher than the hardness value of Mullite which is 661 Hv. The uncoated piston has the lowest hardness value that is 151 Hv. From the previous work by Chan and Khor, they obtained only 417Hv for their YSZ-coated [5]. It shows that YPSZ have the best properties in term of hardness followed by Mullite and YSZ. Hard properties of YPSZ and Mullite may give an additional protection to the piston especially when the engine runs and require high combustion pressure.

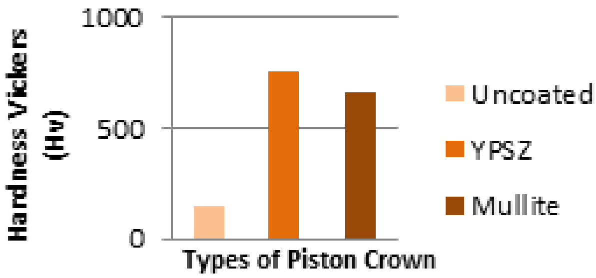


Figure 4 Hardness profile of several types of piston crowns.

4. CONCLUSIONS

Based on all the experiment conducted, both Mullite and YPSZ coated piston crown show a great properties compared to the uncoated piston crown. With the hardness value of 760Hv, YPSZ exhibits the best condition to prevent the crown from thermal stress that could lead to crack who can develop from the high temperature and pressure during the combustion. From the observation of microstructure, it can be concluded that plasma spray process also must be done with a proper technique to stop the crack propagation mainly cause by the primary cooling stress. Future studies can focus burner rig test and a run in real engine tests based on the current values and parameters of deposition.

5. ACKNOWLEDGEMENT

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