Ceramic Coated Piston Rings for Internal Combustion Engines

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ABSTRACT

This paper reports the development and formulation of a new cost effective means of applying ceramic tribology coatings to sealing rings. This coating, though developed with the support of the U.S. Army Tank Automotive and Armaments Command for use on Low Heat Rejection (LHR) high output diesel engines, can be used on any internal engine compression seal ring. It is not limited for use in LHR diesel engines. Applying ceramic coating, especially on the compression piston ring, reduces the friction losses and wear of sliding contact surfaces. This will result in increased engine efficiency and durability. The work presented examines both laboratory and small bore engine testing of this technology. Laboratory tribometer tests compare the ceramic coating to existing and experimental piston ring tribosurfaces. Friction and wear performance demonstrated in the laboratory is verified for use in LHR diesel engine application. Low raw material cost coupled with ease of application and high deposit efficiency of the ceramic make this coating a viable candidate for commercialization.

INTRODUCTION / BACKGROUND

Many problems must be overcome in developing ceramic coated piston ring coatings. From our research, we find cost is the single deciding factor that prohibits use of ceramic for not only piston ring, but nearly any ceramic component application. Secondly, the application of ceramics is difficult because they typically require very high application temperatures that can distort and anneal the ring substrate [1]. Plasma spray has been the traditional means of applying a hard facing carbide coating rather than a ceramic coating such as Cr2O3 that has a low deposit efficiency [2]. Most methods result in a very hard bi-layer (bond and ceramic) coating that requires expensive diamond grinding and finish diamond polishing. Adiabatics, Inc. had previously developed ceramic coated piston ring technology using a sol-gel technique. This method was all but abandoned as the temperature was high enough to distort and anneal conventional piston ring substrates. The ceramic piston ring coating presented in this paper is based on a low temperature ceramic “sol-gel like” coating that is applied below 250ºC. Its material characteristics show it has the potential to eliminate costly diamond grinding and polishing.

CERAMIC POWDER SELECTION

The key to the success of this coating is the selection of the powder composition. Typically, ceramic powders used for piston rings are hard. In the past, Cr2O3 was used, which was expensive, yet yielded excellent tribological properties. Today, we incorporate two iron based powders (Fe2TiO5 and Fe2O3) to achieve superior tribological properties for application to piston rings. The coating displays the potential to be applied near net shape and may not even require expensive grinding and polishing. An patented organometallic phosphate binder that has a maximum use temperature of 600ºC bonds the coating to the substrate [3]. As the phosphate generates a glass phase once bonded, it is relatively inert.

COMPARISON TO OTHER PISTON RING COATINGS

Coatings and surface treatments to piston ring substrates are compared to the new ceramic coating for both commercial and military applications. Our work has investigated vapor deposited “films” that work well, yet are so thin they do not last over a practical life cycle. We also compare the new ceramic to thermal sprayed ring and plating materials. The mating wear surface is hardened 4140H alloy steel. This was chosen as a possible candidate for future cylinder bores, and proves to be very a challenging wear surface. The ceramic piston ring coating provides a good friction and wear surface as well as a cost effective means of producing it.

This new coating has been compared to others we have worked with such as the following:

1. Chemical (CVD) and Physical (PVD) Vapor Deposited Diamond Like Carbon (DLC) films
3. Plating material such as Hard Chrome Plate

LABORATORY TESTING

Tests were performed on a laboratory pin on roller hot wear tribometer. The configuration for this test apparatus is line on roller contact where operating parameters are described in other technical literature [4, Page 3]. They are presented for
various piston ring coatings and surface films. Other coatings include hard chrome plate (HCP), Plasma Sprayed Molybdenum (PS Moly), and Plasma Sprayed CoCrMo. Tests were run for a period of only 3 to 4 hours as wear due to the incompatibility of the 4140 steel to the mating piston ring coating was typically high. The results are typical for most hardened alloyed steels. Under normal laboratory test conditions, this was a sufficient amount of time to generate measurable wear by weight. Results are provided in Figure 1. The iron based ceramic coating proved superior to all other surface treatments.

![Figure 1: Comparison of Wear Rates for Various Piston Ring Coatings.](image)

**Ring Material** | **Ring Wear (mg/min.)** | **Liner Wear (mg/min.)**
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Plasma Sprayed CoCrMo Alloy | Not Measurable | 0.2708
PVD Diamond Like Carbon | 0.0026 | 0.1231
CVD Diamond Like Carbon | 0.0089 | 0.0897
Plasma Sprayed Moly | 0.0097 | 0.0272
Hard Chrome Plate | 0.0014 | 0.0356
Fe$_2$TiO$_5$ + Fe$_3$O$_3$ | 0.0067 | 0.0111

Small Bore Engine Testing

Small bore LHR engine testing was conducted to assess the performance of the ceramic piston ring coating. In comparison to baseline iron ring, the ceramic coated piston ring proved to be significantly better. Description of the test engine and operating parameters are provided in earlier technical publication [4, Page 7]. A photograph of the LHR engine piston ring pack where the intermediate compression ring is coated with ceramic is shown in Figure 2. After completion of testing at top ring reversal temperatures approached 380ºC, no wear was observed on the piston ring. At this time, we have been working to optimize the ratio of Hematite to Iron Titanate to provide the best friction and wear results for high wear cylinder bore surfaces.

**SUMMARY / CONCLUSIONS**

From previous work in the field of high temperature tribology, we have developed coatings incorporating Iron Titanate and Iron Oxide (Fe$_3$O$_4$) that yield excellent friction and wear properties [5]. The method of using a chemical thermal bonded slurry or sol-gel coating to apply these ceramics has become more attractive now that this method can be performed at such low curing temperatures (250ºC). Our work compares this ceramic coating to conventional and newer exotic coatings for application to piston rings. From this research, we conclude the following:

1. The combination of Iron Titanate and Hematite powders can be applied to ferrous piston ring substrates using an organometallic phosphate binder.
2. Patented binding technology is applied at a temperature low enough (250ºC) that the piston ring substrate will neither lose its tension nor lose hardness or distort.
3. Due to the nature of this “soft” ceramic composition coupled with improved application technique, expensive diamond grinding and polishing can be eliminated.
4. The use of this type of coating for sealing rings, its diversity to bond to ferrous and non-ferrous substrates while having a maximum use temperature of 600ºC make it applicable for use in future powerplants.

**REFERENCES**