Aluminum Engine Paper:

INTRODUCTION

Fuel economy improvement is one of the major challenges of the future automotive industry. Two major factors impacting the fuel economy are vehicle weight and frictional loss (1). In addition to structural components, engine itself contributes significantly to the vehicle weight, and replacement of cast iron engine blocks by aluminum engines can appreciably improve fuel efficiency. Nearly half of the engine blocks to be manufactured worldwide in the current decade are anticipated to be made of aluminum (2).

In engine systems, friction accounts for a loss of over 40% of the total vehicle power (3). Majority of the power loss, about 50%, can be attributed to frictional loss between piston rings and cylinder bores (3, 4, 5). Compared to conventional cast iron, the surfaces of aluminum cylinder bores have relatively poor friction and wear characteristics and require cast iron liners. Cast iron liners, however, adversely affect weight and heat transfer and cylinder wall temperature. Elimination of cast iron liners also offers the flexibility of reduced engine components length with further weight reduction and increased engine displacement for greater power (1). Hence, the automotive industry is now moving to sleeveless aluminum cylinder blocks to achieve both lightweight and compact design requirements (6). Several alternative approaches have been evaluated or are now being pursued to eliminate cast iron liners and improve tribological characteristics of aluminum cylinder bores. Different approaches are summarized as follows.

High Silicon Hypereutectic Aluminum Alloys: Hypereutectic 390 series aluminum alloys have excellent wear characteristics and were introduced by General Motors in the Chevrolet 2.31L4 Vega engine in 1970 (7). However, they suffer from poor castability and machinability compared to low silicon hypoeutectic aluminum alloys. Also, tribological characteristics are determined by the distribution of primary silicon particles in the as-cast condition, which is difficult to control (3).

Fiber or Particle Reinforced Aluminum Alloys: Al2O3-SiO2 fiber reinforced aluminum represented the first such technology for production. A number of candidate fiber reinforced metal composites (FRM) are being evaluated primarily by the Japanese engine manufacturers, such as FRM pistons for diesel engines by Toyota (8) and cast-in FRM engine bores by Honda (9). The FRM technology has not yet been adopted for a large-scale mass production.

Thermal Spray Coatings: This is one of the most promising surface modification technologies for hypoeutectic aluminum alloys potentially suitable for mass production. Recent development in rotating plasma spray guns using plasma-powder spray process offers a cost-effective versatile high throughput surface engineering tool for cylinder bore applications (10). The plasma spray process is also suitable for high volume and compact die-cast cylinders which contain surface porosity and allow the flexibility to incorporate solid lubricants and low-cost iron-base powder to reduce friction, wear and oil consumption (11 and 12).

Two other thermal spray processes also being evaluated are Plasma Transfer Arc (PTA) and High Velocity Oxy Fuel (HVOF) and Table 1 compares all three thermal spray processes (10).

Table I: Comparison of Thermal Spray Processes for Aluminum Cylinder Bore Applications (10)

Criteria	**Plasma Transfer (Wire Arc)**	**HVOF (Wire or Powder)**	**Rotating Plasma (Powder)**
Versatility in material choice	Low	Medium	High
Heat transfer to engine block	Medium	High	Low
Reliability of the melting process	Medium	High (powder) Medium (wire)	High
Coating properties of cylinder bore	Medium	High	High
Process cost	Low	High	Low

The rotating plasma powder process is emerging as the most promising prototype manufacturing method, which is now being evaluated for large volume production worldwide (10,13).

Electrolytic processes: Two major electrolytic coating processes are either currently being used or evaluated for aluminum engine bores. These are nickelceramic electrocomposite coatings (1, 3) and Micro-Arc Oxidation (13) or Plasma Electrolytic Oxidation (14) coatings.

Presently, nickel/SiC electrocomposite coatings are being made for Honda motorcycles, BMW, Jaguar, Mercedes-Benz and Formula-1 engine cylinder bores (1,3). In addition to SiC, other ceramic particles including Si3N4 and hexagonal BN are being evaluated for 2-stroke motorcycle, marine and snowmobile engines (1). Nickel-ceramic electrocomposites have been successful primarily in high performance low volume automotive engines because of their superior performance and lower deposition rate compared to those of thermal spray technologies (15).

Micro Arc Oxidation (MAO) or Plasma Electrolytic Oxidation (PEO) coatings are being evaluated by both tribological and engine tests (13,16).

Preliminary friction and wear tests yielded a lower friction coefficient compared to that of cast iron (13). The process is also suitable for both hypoeutectic and hypereutectic aluminum alloys.

The significance of frictional loss in automotive engines is mentioned before. Only 12% of the available energy in the fuel is transmitted to the wheels and about 15% of the available energy is dissipated mainly as frictional losses (4). The rest of the energy is lost as cooling and exhaust. The majority of the frictional loss, ~40%, is dissipated in the piston ring/cylinder linings. "A 10% reduction in frictional losses would lead to a 1.5% reduction in fuel consumption"(4). Therefore, the basic characterization of friction and wear behavior of candidate piston ring and cylinder lining tribo-pairs using a simulated bench test is an important screening test prior to fired engine dynamometer tests.

A number of studies (11, 13,17) have attempted to characterize friction and wear behavior of various cylinder bore and piston ring segments using some form of a linearly reciprocating wear test. A good correlation was demonstrated between the piston ring/cylinder lining reciprocating bench test results with those of fired engine dynamometer tests (7).

The present study is directed primarily toward bench test characterization of high performance electrolytic coatings using a modified ASTM test G133-95 for “Linearly Reciprocating Sliding Wear” (8) with piston ring and cylinder bore segments as tribo pairs. Several commercially available electrolytic coatings used for aluminum alloys, a hard anodized coating, a nickel-SiC electrocomposite coating (19) and a PEO coating (14) are selected for detailed characterization and comparison with cast iron cylinder liners. The experimental conditions are chosen to simulate lubrication starved conditions and produce a detectable wear rate during a reasonably short test but not harsh enough toinitiate “scuffing” or gross material transfer between tribo pairs. In the future, these results will be correlated with fired engine dynamometer tests.

References

(1) Funatani, K. et al., “Engine Performance Improvements”, Automotive Engineering, January 1995, pp. 15-20.

(2) Automotive News Market Data Book, 1990.

(3) Funatani, K. et al., “Improved Engine Performance Via Use of Nickel Ceramic Composite Coatings (NCC Coat)”, SAE International Congress & Exposition, February 1994, pp. 82-96.

(4) Priest, M. and Taylor, C.M., “Automobile engine tribology-approaching thesurface”, Wear, Vol. 241, pp. 193-203.

(5) Parker, D.A. et al., “Friction losses in reciprocating internal combustion engine”, IMech E, C5/82, 1982, pp. 31-33.

(6) Kunioka, S., “Development of plasma spray-coated cylinders”, Society of Automotive Engineers of Korea, 2000 FISITA Word Automotive Congress, June 2000, pp. 1-6.

(7) Wang, Y. and Tung, S.C., “Scuffing and wear behavior of aluminum piston skirt coatings against aluminum cylinder bore”, Wear, Vol. 225-229, 1999, pp. 1100-1108.

(8) Kubo, M. et al., “Development of New Fiber Reinforced Aluminum Alloy for High Performance Diesel Engine Pistons”, SAE paper 830252, 1983.

(9) Hayaski, T. et al., “the Properties of Hybrid Fiber Reinforced Metal and It’s Application for Engine Block”, SAE paper 89057, 1989.

(10) Wuest, G. et al., “The Key Advantages of the Plasma-Powder Spray Process for the Thermal Spray Coating of Cylinder Bores in Automotive Industry”, SAE International Congress & Exposition, February 1997, pp. 33-43.

(11) Rao, V.D.N., et al., “ Material Systems for Cylinder Bore Applications- Plasma Spray Technology”, SAE International Congress & Exposition, February 1997, pp. 107-132.

(12) Rao, V.D.N., et al., “Performance of Plasmaspray coated Bore 4.6L-V8 Aluminum Block Engines in Dynamometer and Fleet Vehicle Durability Tests”, SAE International Congress & Exposition, February 1997, pp. 57-67.

(13) Rao, V.D.N., et al., “Friction and Wear Characteristics of Micro-Arc Oxidation Coating for Light Weight, Wear Resistant, Powertrain Component Application”, SAE International Congress & Exposition, February 1997, pp. 91-105.

(14) KERONITE Advanced Surface Technology News, May 2001, Cambridge, UK.

(15) Marantz, D.R., et al., “Lightweight Engine Bore Coating”, 29th International Symposium on Automotive Technology and Automation, Vol. 1, 1996, pp. 723-729.

(16) Dearnley, P.A.,”The Tribological Application of Surface Engineered Aluminum Based Materials”, Heat Treatment and Surface Engineering of Light Alloys, Proc. 7th International Seminar IFHT; Budapest, Hungary, September 1999, pp. 131-136.

(17) Bin, F. and Cole, G.S., “Scuffing Resistance of Selected Materials as Protection for Bores in Aluminum Engine Blocks”, SAE International Congress & Exposition, February 1992.

(18) Friction and Wear Testing Source Book of Selected References from ASTM Standards and ASM Handbooks, ASM International, 1997, pp. 153-160.

(19) Nicom Product Literature, US Chrome Corporation, Stratford, CT.

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