The successful use of Plasma Spray Cylinder Coatings in a NASCAR application to achieve friction reduction and cost benefits

Dr. Peter Ernst, Sulzer Metco AG | Charles Jenckes, Consultant
NASCAR Engines: Background

- Displacement: 5.8 liters
- Maximum Bore size: 106.3 mm
- Minimum Stroke: 82.63 mm
- $n_{\text{max}}$: 9800 rpm
- Single 60 mm cam in block
- 2 Valves per cylinder
- Iron cylinder case
- Aluminum cylinder heads

The following major engine components must be submitted by the OEM and approved by NASCAR:

- Cylinder Case
- Cylinder Heads
- Intake Manifold

Source: GM Racing
NASCAR Engines: Background Continued

- Flat tappet (non-roller) cam follower
- 2 plane crankshaft
- Main and rod minimum bearing sizes are regulated
- Power: > 875 BHP
- One engine per race weekend
- Engine life is approximately $2 \times 10^6$ cycles
- Engine materials are regulated
- Piston minimum weight 400 grams
- Connecting rod minimum weight 325 grams
- Piston pin minimum weight 70 grams
- Carburetion is mandated
  - Fuel injection will be introduced 2011

Source: Ford

Source: Ford

Source: TRD
NASCAR Engines: Cylinder cases

- Cylinder cases are either gray iron or CGI.
- Engines are completely rebuilt after each use.
- Typically: engines are honed and the bore size is increased with each rebuild.
  - This procedure requires a large inventory of pistons and rings.
- Once the cylinder case exceeds the maximum bore size than the block may no longer be used in competition.
- Fully machined and prepared cylinder cases can exceed $20,000 US in replacement cost.

Source: GM Racing
NASCAR Engines: Cylinder kit friction development with plasma sprayed bore coatings

- Friction reduction is one of the key areas for improvement of engine performance
- With relatively high engine speeds and a long stroke the cylinder kit is a major target for friction reduction
- SUMEBore® coatings were evaluated as a potential source of friction reduction
  - Low alloyed carbon steel with Molybdenenum
  - Cr$_3$C$_2$ 25 (Ni 20Cr)
  - TiO$_2$
- Appropriate honing techniques were used for each coating
  - Plateau honing is traditionally used with iron bores
  - A smooth honing near mirror finish was used with the coated bores
- Top rings were changed to be compatible with the coated bore surface
  - A CrN-PVD face coated ring was used for the coated bore
- No change was made to the second ring
- Oil ring tension was reduced by 50% with the coated bore without a significant increase in oil consumption
Engine performance comparison with TiO$_2$ cylinder bore coating vs gray cast iron

$\Delta$ engine power from baseline VS engine speed

Trend line:

$y = 2E-07x^2 - 0.002x + 6.235$

$R^2 = 0.952$
Results of testing and observations

- A power gain was observed when the cylinder kit was modified as a system with both the Cr₃C₂ 25 (Ni 20Cr) and the TiO₂ plasma sprayed bore coatings
  - The TiO₂ coating indicates a greater magnitude of friction reduction
- The results are not statistically significant
  - The population was too small
- Additional testing continues
- Piston to bore clearances were increased by 0.013 mm with the coated bores
- The TiO₂ coating is sensitive to oil ring configuration
- The Cr₃C₂ 25 (Ni 20Cr) coating is robust with outstanding wear characteristics but is more difficult to hone optimally
- The key to obtaining friction reduction is to optimize all of the variables in the system
  - Bore coating and honing technique
  - Piston skirt profile and clearances
  - Ring pack
"The blue coating," TiO$_2$ as used in the NASCAR trials (in the "as sprayed" condition)
Cost benefits of plasma sprayed bore coatings in NASCAR applications

- With plasma sprayed bore coatings a cylinder case will only be honed when required from operation such as with debris ingestion
  - The need for a bore hone with each rebuild will be eliminated
  - This significantly reduces labor cost for the rebuild as well as the turn around time
- Most significantly, the number of piston and ring sizes maintained in inventory will be drastically reduced
- Expensive cylinder cases will never be scrapped from reaching the bore limit
- Small imprecations which may otherwise have scrapped the cylinder case may be repaired with the coating
- The inventory of cylinder cases may be reduced
know how transfer into non-race engines
SUMEBore® - the process overview

- Cylinder materials can be cast iron, steel, aluminium or magnesium.

- Feedrates of up to 500g/min are possible, depending on size and material of the cylinder.

- Surface activation can be done by grit blasting, waterjet or mechanical roughening.

- Powder offers the highest flexibility to customize the coating, from metallic to fully ceramic.
Surface activation prior to SUME\textit{Bore} plasma coating application

- All currently applied surface activation techniques work well with the SUME\textit{Bore}\textsuperscript{®} plasma coating process of Sulzer Metco.
- The "as sprayed" surface is very smooth on all differently activated surfaces.
Diamond honed plasma coating – "mirror finished"

Smooth honing (mirror finishing), recommended for the SM plasma coating
Typical topography after honing with diamond tool
Low alloyed carbon steel XPT512 ($H_V_{0.3} = 450$)
# SUMEBore® - our "materials box"

<table>
<thead>
<tr>
<th>Reduced friction</th>
<th>Low alloyed carbon steel</th>
<th>●</th>
<th>●</th>
<th>●</th>
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<tbody>
<tr>
<td>Scuffing</td>
<td>Steel / molybdenum composite for increasing of the scuffing resistance</td>
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<td>●</td>
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<tr>
<td>Corrosion I</td>
<td>Modified base material: Cr-Mo stainless steel for bio-fuel compatibility</td>
<td>●</td>
<td>●</td>
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<tr>
<td>Corrosion II</td>
<td>Highest corrosion resistance with superferrite composition</td>
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<td>●</td>
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<tr>
<td>Wear</td>
<td>Material Matrix Composite MMC with “soft” ceramics to improve wear</td>
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<td>●</td>
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**SUMEBore® Powders**

- XPT 512
- F 4301
- F 2056
- XPT 627
- F 2071
- F 4375
- Ceramics
Automotive Venture – SUME*Bore* cell in Wohlen

- recently moved SUME*Bore* activities into new facility
- ability to coat prototype blocks/liners and small series production
- close to 20,000 engines and 2,000 truck liners coated so far for a large number of clients
Experience Sulzer Metco in Mass Production

Example 1: Cylinder bore coating system for VW

V10-Cylinder Diesel

Capacity: 4000 cylinder bores/d
Experience Sulzer Metco in Mass Production

Example 2: Cylinder bore coating system for outboard

V6-Cylinder Engines
Capacity:
300 cylinder bores/d

- grit blasting
- cleaning
- plasma coating
Experience Sulzer Metco in Mass Production

Example 3: Scaleable production cell for truck liners

Cylinder liners for trucks

Capacity single cell:
250’000 liners / year (bottom left)
500’000 liners / year (bottom right)
Concept Sulzer Metco for mass production
Example 4: Production cell for large liners
Conclusions

- In a limited trial an optimized cylinder kit showed a performance increase with the SUME Bore® plasma sprayed bore coatings in a NASCAR engine application.

- While the population size was not large enough to provide statistically significant results, the trend continues to show that the system is directionally correct for the reduction of cylinder kit friction.

- The SUME Bore® plasma sprayed bore coatings also offer operational benefits:
  - Elimination of routine honing operations (Reduced labor costs & Improved turnaround)
  - Reduction in cylinder case, piston and ring inventory.

- The results can be transferred into the non-racing engine business with similar advantages and:
  - Emission reduction
  - Reduction in oil and fuel consumption
  - Capability for engine remanufacturing

- Additional performance gains are likely with continued development.