Requirements on Al crankcases for thermally sprayed bore coatings

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Motivation for linerless crankcases in Aluminum

History of linerless crankcases

Casting requirements for coatable crankcases and realization in sand castings (core package process, CPS®)

Thermally sprayed cylinder bores

The Nemak Coating Center
Motivation
Increasing power with decreasing engine weight

Spec. Power / Engine Weight

Al-ZKG
GG ZKG

4-Cylinder-Diesel
8-Cylinder-Diesel
6-Cylinder-Diesel

4-Cyl.-Diesel-GI-Motor: 55,2 kW/l → 181 kg
4-Cyl.-Diesel-AI-Motor: 80 kW/l → 161 kg
Heat dissipation during operation

- Aluminum alloys have a higher heat conductivity than GCI-liners, factor 2.5
- Due to their thickness coatings do not deteriorate this heat transfer
- Additional cooling in the interbore bridge may be realised by cooling channels
Heat dissipation during operation

Possibility of a interbore bridge cooling:

Potential with TS-Coating:

Bore bridge + 2,7 mm

Additional wall thickness in the interbore bridge gives more durability and higher mechanical stability in this area.
Tribology and Corrosion Protection

- Less friction due to smoother honing of cylinder bore
- Higher wear resistance due to embedded carbides and oxides

TS-coatings offer a wide choice of coating material for increasing certain characteristics such as chemical resistance for e.g.:

- Plug-In-Hybrids
- High EGR rates
- Alternative fuels
History of linerless crankcases
Monolitic crankcase

- Crankcase made of grey cast iron
  - Economic production
  - Good tribological properties
  - High weight
  - Poor heat dissipation

- Alusil® AlSi17Cu4Mg
  - Semi permanent mold casting
  - Good tribological properties
  - Coated pistons needed
  - Not suitable for Diesel engines
Aluminum crankcase with cast in liner

- Liner made of grey cast iron
  - Cast in or pressed in
  - Good tribological properties
  - Increase of engine weight and size
- Lokasil®
  - Cast in liner made of silicon or ceramic fibers
  - Thinner interbore bridge than iron liner
  - Better heat dissipation than iron liner
  - Can only be realised in high pressure die casting due to needed infiltration of the porous pre-form
Coated aluminum crankcase

- Ni-SiC-coatings
  - Ni-matrix with embedded SiC-particles
  - Good tribological properties
  - Environmental concerns
  - Not suitable for fuels with Ester-content

- Thermally sprayed coatings
  - Very good tribological properties
  - Very good heat dissipation
  - Good cold start properties
## Market for TS bore coatings

<table>
<thead>
<tr>
<th>Product</th>
<th>SOP</th>
<th>CC/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nissan V6 3.8l</td>
<td>2007</td>
<td>~10.000</td>
</tr>
<tr>
<td>Mercedes AMG V8 6.3l</td>
<td>2008</td>
<td>~10.000</td>
</tr>
<tr>
<td>Ford Shelby V8 5.4l</td>
<td>2010</td>
<td>~5.000</td>
</tr>
<tr>
<td>BMW I4 2.0l</td>
<td>2011</td>
<td>~100.000</td>
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<tr>
<td>BMW I4 2.0l</td>
<td>2012</td>
<td>&gt;1.000.000</td>
</tr>
</tbody>
</table>

- Growing demand for coated crankcases (CC)
- Mercedes Benz and BMW are operating own LDS processes each
Casting requirements
Good properties in bores and bulk heads

Tensile strength: alloy and local engineering

feeding
Good properties in bores and bulk heads

Tensile strength: alloy and local engineering

Same properties in the bore and in the bulk head:

Highest tensile strength:
- \( R_m \) 350 MPa ✓
- \( R_{p0.2} \) 290 Mpa ✓
- A 3% ✓
- Dyn. 95 MPa ✓
- Hardness: 115 HB ✓

(secondary alloy A 319, T6)
Required surface quality

- Requirement to the surface of the substrate material prior coating:
  - Prior roughening the surfaces must be nearly free from pores

360°-view of a bore after water jet roughening
Thermally sprayed cylinder bores
Growth of a TS coating

Multiple Impact of Nickel Particles on 0.5×0.5 mm Stainless Steel
Diameter = 40-80 μm, Velocity = 40-80 m/s, Impact time interval = 2 μs

\[ T_{di}=1600-2000^\circ C, \ T_{wi}=20^\circ C, \ R_w=10^{-7} \text{ m}^2 \text{K/W} \]

Quelle: Advanced Coating Centre, University of Toronto
Structure of TS coatings

1. Sectioned oxide layer
2. Liquid metal droplet
3. Impact and splat
4. Oxide layer formed during impact
5. Clamping of molten metal droplet
6. Partial welding of splat
7. Droplet, solidified prior impact
8. Micro porosity
9. Substrate material

Typical coating defects

- Contamination from shot blast material
- Interface oxidation
- Pores
- Micro cracks due to intrinsic stresses
- Embedding of re-solidified particles
TS coating systems for cylinder bores

- Atmospheric Plasma Spraying (APS; Sulzer Metco Rotaplasma®)
- Plasma Transferred Wire Arc-Spraying (PTWA; FSI and GTV Automotive)
- Lichtbogendrahtspritzen (LDS; Daimler and BMW own variants each)

**APS**

- Plasmatemp.: max. 20.000°C
- \( V_{\text{max particle}}: 400 \text{ m/s} \)
- Deposition rate: up to 10 kg/h
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![Diagram of LDS process]

**LDS**

- Arc-temp.: approx. 4000°C
- Vmax particle: 150 m/s
- Deposition rate: 8 – 20 kg/h
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**PTWA**

- Plasmatemp.: max. 10,000°C
- Vmax particle: 200 m/s
- Deposition rate: up to 15 kg/h
Cylinder bore coatings

as-sprayed

cross section polish

100 µm

top view

100 µm

honored
The Nemak Coating Center
Process flow for cylinder bore coatings

- Linerless Casting
- Cubing
- Precision machining
- Roughening
- Coating
- Chamfer and hone overtravel
- Rough honing
- Cleaning Overspray
- Quality control with special camera
- Adhesive tensile strength / porosity
- Delivery to Customer
Roughening of bore

- Bore surfaces have to be roughened prior coating

- Quality of roughening has a very high impact to the adhesive tensile strength of the coating and thus to the coating performance during engine lifetime

- The two mostly recognized roughening technologies within the automotive industry are:
  
  ![High Power Fluid Jet Roughening](image1)
  
  ![Mechanical Roughening](image2)
**PTWA in Dillingen**

- Plasma process with high melting temperatures (10.000°C)
- Processing of filled wires with ceramic content possible
- No pre-heating necessary due to favorable distribution of intrinsic stresses
Daimler-LDS® in Dillingen

- Process in licence of Daimler AG
- Higher material throughput than PTWA
- Nearly oxide free coatings due to the use of nitrogen as atomizing gas
- Crankcases must be pre-heated prior to coating
Conclusion

- Al-crankcases have a growing market share among passenger car engines
- New engine concepts and new emission regulations require continuous improvement and development of the tribological system „bore-piston-pistonring“
- For TS bore coatings new process chains for engine block manufacturing must be established.
- Nemak is able to cast blocks that fulfill all requirements for coatability
- The variety of coating materials allows tailor made solutions for the worldwide use of passenger car engines.
- For future developments Nemak is operating a coating center at the Nemak Dillingen facility with two different thermal spray technologies.