Influence of Post-treatment on the Tribo-mechanical properties of Cermet Coatings

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HIPing Post-treatment — Previous Investigations


Al₂O₃, ZrO₂ and TiC plasma spray coatings HIPed (Capsulated) at 1100 to 1300°C for 1hour at 100MPa - Remarkable improvements in hardness and tensile strength.


WC-Co plasma spray coatings HIPed (Capsulated) at 500 to 1000 °C for 30 minutes at about 5MPa – Remarkable improvements in hardness and abrasive wear resistance. Lamellar to granular transformation.


Numerous studies on Capsulated and uncapsulated HIPing of plasma sprayed NiCrAl and ZrO₂-Y₂O₃ coatings – Improvement in hardness and modulus, reduction in porosity.
### Project Background


**Project Background (WC-Co coatings)**

<table>
<thead>
<tr>
<th>HIP Code</th>
<th>HC-1</th>
<th>HC-2</th>
<th>HC-3</th>
<th>HC-4</th>
<th>HC-5</th>
<th>AS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capsulation</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>850</td>
<td>850</td>
<td>900</td>
<td>900</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Pressure (MPa)</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Holding Time (minutes)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>120</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

**Project Background (WC-Co coatings)**

- **As-Sprayed Coating**
- **Holding Time ~ 1 hour**
- **Holding Time ~ 1 hour**
- **Holding Time ~ 1 hour**
- **Holding Time ~ 2 hour**
- **Holding Time ~ 1 hour**

**Project Background (WC-Co coatings)**

- **HIPed @800°C (Capsulated)**
- **HIPed @800°C (Not Capsulated)**
- **HIPed @900°C (Capsulated)**
- **HIPed @900°C (Capsulated)**
- **HIPed @1000°C (Capsulated)**
Aims of Current Investigation

• Consider Economical and Design Factors
• Higher Temperatures?
• Influence of pressure? (HIPing vs. VHT)
• Develop structure property relationship for tribo-mechanical applications

Methodology of Investigation

POWDER MANUFACTURE (WC-12%Co) Agg. & Sint. 

HVOF SPRAYING (JP5000)

POST-TREATMENT
HIPed (850 & 1200°C @ 150MPa for 1 hour) (Uncapsulated)
Vacuum Heating @1200°C for 1 hour

• Coating Microstructure (SEM, XRD)
• Mechanical Strength (Modulus, Hardness)
• Residual Stress using Neutron Diffraction
• Sliding Wear Resistance (Ceramic and Metallic couples)
• Rolling Contact Fatigue Testing
Hot Isostatic Pressing Unit

**HIPping Conditions**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>850 °C, 1200 °C</td>
</tr>
<tr>
<td>Pressure</td>
<td>150 MPa</td>
</tr>
<tr>
<td>Environment</td>
<td>Argon</td>
</tr>
<tr>
<td>Heating/Cooling rate</td>
<td>4 °C/minute</td>
</tr>
<tr>
<td>Encapsulation</td>
<td>No</td>
</tr>
</tbody>
</table>

**SEM – As-sprayed vs. HIPed@850°C**

- **As-Sprayed**
- **HIPed @850°C**
XRD – As-sprayed vs. HIPed @850°C

As-sprayed

HIPed@850°C

SEM – As-sprayed vs. HIPed or VHT @1200°C

As-Sprayed

HIPed or VHT
**Microstructural Changes - Summary**

- **As-sprayed**
  - Coating: Co, WC
  - Substrate: Fe, Cr

- **HIPed @1200°C**
  - Co-W6C & C
  - Kirkendall voids

- **Changes**
  - Diffusion of Fe and Cr from substrate
  - Carbide dissolution to form prismatic faces
  - Free Carbon & eta-phases
  - Carbon diffusion towards the substrate
  - Formation of Kirkendall voids
  - Diffusion layer

**At%**
- W 21%
- C 48%
- Co 5%
- Fe 19%
- Cr 7%
Residual Strain – Neutron Diffraction

ISIS Facility Set-up, UK

Hardness Comparison
Indentation Modulus = $E(1-\nu^2)$

![Graph showing indentation modulus for different treatments](image)

**Sliding Wear Tests**

**Test conditions**

<table>
<thead>
<tr>
<th>Counter Body (balls)</th>
<th>440C Steel Si$_3$N$_4$ ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>12 and 22 N</td>
</tr>
<tr>
<td>Sliding Speed</td>
<td>0.012m/s</td>
</tr>
<tr>
<td>Lubrication</td>
<td>Dry</td>
</tr>
</tbody>
</table>

Reciprocating ball on plate apparatus
Wear Performance - system

<table>
<thead>
<tr>
<th>Wear resistance (Nm/mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-sprayed</td>
</tr>
<tr>
<td>HIPed at 850°C</td>
</tr>
<tr>
<td>HIPed at 1200°C</td>
</tr>
<tr>
<td>Heat-treated</td>
</tr>
</tbody>
</table>

- steel - 12N
- steel - 22N
- ceramic - 12N
- ceramic - 22N

Rolling Contact Fatigue Tests

Drive shaft connected via belt to motor
rotates coated disc at 4000 rpm

- Hertzian Contact Width
  - 2a

- Coating
  - 0.5a

- Substrate
  - Maximum shear stress
  - 45°

Air pressure from bellows generates required contact load between balls and disc.
## RCF Test Conditions

<table>
<thead>
<tr>
<th>Planetary Balls</th>
<th>Steel / Ceramic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>25 °C</td>
</tr>
<tr>
<td>Hertzian Contact Stress</td>
<td>2.7 GPa</td>
</tr>
<tr>
<td>Lubricant Boundary Regime</td>
<td>Full Film</td>
</tr>
</tbody>
</table>

## RCF Test Results

![Graph showing RCF test results for different conditions](image-url)
RCF Failure Modes

- HIPed@1200°C
  - Progressive and Predictable Failure

- Vacuum heated@1200°C
  - Catastrophic Failure

Post RCF Test Analysis

- as-sprayed
  - 200 (µm)

- HIP 1200°C
  - 200 (µm)
  - 40µm
  - 20µm
Conclusions

1. Microstructural changes associated with the post-treatment of WC-Co coatings can significantly improve tribo-mechanical performance of components by improving the hardness (phase changes), cohesive strength (interlamellar bonding) and adhesive strength (diffusion zone) of coatings.

2. Improvement in RCF performance was attributed to the diffusion at the coating substrate interface resulting in metallurgical bonding.

3. Sliding wear test results indicate that the overall wear resistance improves with the post-treatment, and best results were obtained for coatings HIPed at 850°C for ceramic and at 1200°C for steel counterbody.

4. Residual stress investigations confirmed that not only the post-treated coatings have lower and more uniform compressive strain, but also the strain gradient at the coating substrate interface is minimised after the post-treatment.

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