Kermetico High Velocity Air-Fuel Thermal Spray

Andrew Verstak
averstak@kermetico.com
www.kermetico.com
HVAF Application Development

1. Superior hard & tough coatings for new markets
   - Gas-tight
   - WC-based 1,500-1,700 HV$_{300}$
   - Cr$_3$C$_2$-based 1,100 HV$_{300}$, service up to 900$^o$C
   - MoB-based 1,200 HV$_{300}$, service up to 1,100$^o$C
   - Thin coatings (40-70 micron) for:
     - High and alternating stress, impact, etc.
     - Economy grades for “flash chrome” replacement
HVAF Application Development

2. Economical “currently specified quality” coatings for existing and new markets

1,200 HV$_{300}$ $<$0.8% porosity WC-coatings, sprayed at 65-70% DE with spray rates 33+ kg/hour
Kermetico HVAF Gun Design

Nozzle  Combustion chamber  Ceramic insert

Fuel Gas

Powder + carrier gas

Air

<table>
<thead>
<tr>
<th></th>
<th>1100-1500 m/s</th>
<th>850 m/s</th>
<th>40-50 m/s</th>
<th>Gas velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas temperature</td>
<td>&lt;1500°C</td>
<td>~1600°C</td>
<td>1900°C</td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td>Heating</td>
<td></td>
<td></td>
<td>Spray particle</td>
</tr>
</tbody>
</table>
Combustion Temperature: HVAF vs. HVOF

Adiabatic combustion temperature of fuels in oxygen and air ($\alpha=1, 20^\circ\text{C}, 1\text{ Bar}$)

- Methane
- Propane
- MAPP
- Hydrogen
- Kerosene

Metals, $T_{\text{melting}}$

Metals, $T_{\text{boiling}}$
Lower Gas Temperature in HVAF:

**HVOF:**
Combustion temperature is higher by more than 1000°C than melting temperature of metals;
Combustion temperature may exceed metal boiling temperature.

**HVAF:**
Combustion temperature only slightly higher than metal melting temperature.
Lower Gas Temperature in HVAF:

- Affects coating properties
  Prevention of oxidation of metals and oxidation/thermal deterioration of carbides
  Note: oxygen activity is 5-times lower in HVAF

- Influences gun design
  HVAF ability to use heating in long/slow-gas combustion chambers = long time for “soft” heating
  High pressure in the chamber = better heat transfer
Combustion Temperature: AF vs OF Design

Ability to use heating in long/ slow-gas combustion chambers =
long time for “soft” heating
High pressure in the chamber =
better heat transfer

Result:
High energy efficiency of HVAF
(same or lower power while higher spray rates than HVOF)
Energy Efficiency = COST

State-of-the-art HVOF:
JP 5000  270 kW  spray rate 5 kg/hour
DJ 2600  115 kW  spray rate 4 kg/hour

Kermetico HVAF:
AK6    130 kW  spray rate 28 kg/hour
AK5    80 kW    spray rate 15 kg/hour
AK-ID  30 kW    spray rate 5 kg/hour
Acceleration of spray particles in the nozzle:
Gas velocity & density
Time (nozzle length)
Particle size

Smaller particles are accelerated to higher velocities.

HVAF uses smaller particle size without material oxidation/ thermal deterioration
Note on nozzle wall influence on particle velocity:

HVOF – dramatic
  (more so – in radial injection)
HVAF – no influence
Particles Acceleration:
Influence of the Nozzle Walls

HVOF (kerosene) per A. Voronetsky et. all, ITSC2004

\[ R_p = \frac{D_{\text{powder jet}}}{D_{\text{nozzle}}} \]

Influence of \( R_p \) on the mean particles velocity
at \( L_s = 250 \text{ mm} \). \( (p_{cc} = 0.9 \text{ MPa}, d_p = 30 \mu m, L_b = 100 \text{ mm}) \)
Particles Acceleration in the Nozzle

Kermetico HVAF:

\[ \frac{D_{\text{powder jet}}}{D_{\text{nozzle}}} = 0.1-0.2 \]

I. There is practically no restriction on the nozzle length to reach necessary acceleration of spray particles

II. Uniform acceleration = uniform coating structure and properties
Uniformity of HVAF Coatings Properties:
Hardness of HVOF and Kermetico HVAF WC-10Co-4Cr coatings (Schlumberger, UK)

Relative standard deviation, %

- HVAF: 3.9 %
- HVOF: 15.7-17.8%

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WC-10Co-4Cr Coating Characterization

Propane
1470 HV\textsubscript{300}

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WC-10Co-4Cr Coating Characterization

Propane- 60% Butane
1500 HV$_{300}$

Propylene
1650 HV$_{300}$
Kermetico HVAF:

Carbides are hard, but... ductile

WC-12Co
Propane
1540 HV300

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averstak@kermetico.com
Data of Central Power Research Institute
Bangalore, India

Comparison of WC-10Co-4Cr coatings, deposited with HVOF (JP5000) and Kermetico HVAF (AK06)

Notes:
HVOF optimized for the best cavitation resistance

HVAF applied in different modes, targeting different particle velocity (coating hardness)
# Spray Parameters: Normalized

<table>
<thead>
<tr>
<th></th>
<th>JP5000 HVOF</th>
<th>Kermetico AK6 HVAF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Nozzle 5L</td>
</tr>
<tr>
<td>Oxidizer flow, SLPM</td>
<td>O2: 873.1</td>
<td>Air: 2,104 (O2: 421.0)</td>
</tr>
<tr>
<td>Fuel, g/sec</td>
<td>5.01</td>
<td>2.65</td>
</tr>
<tr>
<td>O₂/Fuel Ratio vs. Stoichiometric</td>
<td>1.16 (Oxidizing)</td>
<td>1.03 (~Neutral)</td>
</tr>
<tr>
<td>Carrier Nitrogen, SLPM</td>
<td>10.85</td>
<td>21</td>
</tr>
<tr>
<td>Combustion pressure, Bar</td>
<td>7.56</td>
<td>5.25</td>
</tr>
<tr>
<td>Powder feed rate, g/sec</td>
<td>1.50</td>
<td>2.22</td>
</tr>
<tr>
<td>Particle average size, micron</td>
<td>27</td>
<td>18</td>
</tr>
<tr>
<td>Particle velocity, m/s</td>
<td>740</td>
<td>895 +/-2</td>
</tr>
<tr>
<td>Particle temperature, °C</td>
<td>1790-1840</td>
<td>1470 +/-10</td>
</tr>
<tr>
<td>Particle kinetic energy, μJ</td>
<td>29.4</td>
<td>12.7</td>
</tr>
</tbody>
</table>
| Energy density, GJ/m³ =  | 3.8         | 5.6      | 6.4      | 7.1      | Contact pressure, GPa
Mechanical Properties: WC-10Co-4Cr

Vickers Hardness of WC-10Co-4Cr coatings

- AK06-N 5O: 54, 1473
- AK06-N 5E: 58, 1439
- AK06-N 5L: 70, 1308
- JP5000 HVOF: 140, 1180

Hardness, HV300  Standard Deviation, HV300

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Mechanical Properties: WC-10Co-4Cr

Fracture Toughness $K_{1C}$ of coatings, MPa*m$^{1/2}$

- AK06-N 5O: 5.60
- AK06-N 5E: 6.86
- AK06-N 5L: 6.33
- JP5000 HVOF: 3.86

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Mechanical Properties: WC-10Co-4Cr

Young's Modulus E of WC-10Co-4Cr coatings

- AK06-N 5O: 450 GPa
- AK06-N 5E: 452 GPa
- AK06-N 5L: 411 GPa
- JP5000 HVOF: 290 GPa

Young's Modulus E, GPa  | E Standard Deviation, GPa

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Cavitation Resistance
of WC-10Co-4Cr HVOF and HVAF coatings

( \( \frac{dw}{dt} \) ) AF1 (5O) = 0.23 mg/h
( \( \frac{dw}{dt} \) ) AF3 (5E) = 0.71 mg/h
( \( \frac{dw}{dt} \) ) AF2 (5L) = 0.96 mg/h

( \( \frac{dw}{dt} \) ) HVOF = > 3.26 mg/h

( \( \frac{dw}{dt} \) ) 16Cr-5Ni steel = 2.0 - 2.5 mg/h
Surface SEM Micrographs of WC-10Co-4Cr Coatings after Cavitation Testing

Test duration: 1 hour

JP5000 HVOF

AK6 HVAF
Surface SEM Micrographs of WC-10Co-4Cr Coatings after Cavitation Testing

Test duration: 9 hours

JP5000 HVOF

AK6 HVAF
Resistance to Silt Erosion
WC-10Co-4Cr HVOF and HVAF coatings

Cumulative weight loss of coatings during silt erosion test, mg

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>Weight Loss (mg) 1 hr</th>
<th>Weight Loss (mg) 2 hr</th>
<th>Weight Loss (mg) 3 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>JP5000 HVOF</td>
<td>16.3</td>
<td>30.4</td>
<td>47.0</td>
</tr>
<tr>
<td>AK06-N 5L</td>
<td>3.8</td>
<td>6.5</td>
<td>8.6</td>
</tr>
<tr>
<td>AK06-N 5E</td>
<td>3.7</td>
<td>5.4</td>
<td>7.4</td>
</tr>
<tr>
<td>AK06-N 5O</td>
<td>2.4</td>
<td>4.9</td>
<td>7.3</td>
</tr>
</tbody>
</table>

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Other Third-party Data, Comparing Kermetico HVAF WC-10Co-4Cr Coatings to the Best HVOF and Detonation Systems
Test Results

Erosion Rate of Different Coating Types

![Bar chart showing erosion rates for different coating suppliers. Supplier E has the highest erosion rate at 59.35 mg/h, followed by Supplier F at 23.1 mg/h, Supplier D at 20.1 mg/h, Supplier C at 12.75 mg/h, Kermetico at 6.23 mg/h, and Supplier A at 19 mg/h.]

FIGURE 5 - EROSION RATE OF DIFFERENT SUPPLIER COATINGS
WC-10Co-4Cr HVOF & HVAF coatings. Cavitation test

AISI316: $y=0.0156x-0.4789$
DJ Coating: $y=0.0121x+0.4744$
AK Coating: $y=0.0047x+0.0922$
InnoMat GmbH Report on WCCoCr coatings for Stellba AG (2016)

- GTV K2 HVOF
- GTV K2 UHVOF
- Kermetico AK6 HVAF

- ASTM G75-07: Slurry Erosion Test, mg/hour
- ASTM G65-04 (B): Rubber Wheel Test, mg/min
- Ball-On-Disc Test, micron/10,000 cycles
Slat Spray: All WCCoCr Samples Passed 312-Hour Test

K2 HVOF    K2 UHVOF    AK6 HVAF

Before testing

After 312-hours testing

Note: HVAF samples were tested after Pin-On-Disc Wear Test
Economic Aspects of Kermetico HVAF Spraying: Your Choice of Cost and Quality

**HVAF-E** (Economy) – meets HVOF specs

**HVAF-B** (Balanced) – exceeds HVOF specs

**HVAF-U** (Ultra) – substantially exceeds HVOF specs
**Economic Aspects of Kermetico HVAF**

<table>
<thead>
<tr>
<th>Gun Setup</th>
<th>Coating Hardness, HV$_{300}$</th>
<th>Coating Porosity, %</th>
<th>Deposition Efficiency, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy (E)</td>
<td>1050-1250</td>
<td>&lt;0.8</td>
<td>65+</td>
</tr>
<tr>
<td>Balanced (B)</td>
<td>1250-1350</td>
<td>&lt;0.5</td>
<td>48 - 58</td>
</tr>
<tr>
<td>Ultra (U)</td>
<td>1450-1700</td>
<td>&lt;0.1</td>
<td>36 - 42</td>
</tr>
</tbody>
</table>

High spray rates are applicable for large and small parts

**O.D. 38 mm: Rate 25 kg/hour**

**O.D. 330 mm: Rate 32 kg/hour**

Data for WC-10Co-4Cr, agglomerated & sintered powder
Comparison of HVOF and HVAF operating costs, USD per hour (prices in Texas, USA)
Comparison of HVAF and HVOF Cost (prices in Texas, USA)

Cost per WCCoCr kg deposited, USD

<table>
<thead>
<tr>
<th></th>
<th>DJ2600 HVOF</th>
<th>JP5000 HVOF</th>
<th>HVAF-E</th>
<th>HVAF-B</th>
<th>HVAF-U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating cost per kg deposited</td>
<td>Blue</td>
<td>Blue</td>
<td>Blue</td>
<td>Blue</td>
<td>Blue</td>
</tr>
<tr>
<td>Powder cost per kg deposited</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
</tr>
</tbody>
</table>

WCCoCr Coating Hardness, HV\textsubscript{300}

<table>
<thead>
<tr>
<th></th>
<th>DJ2600 HVOF</th>
<th>JP5000 HVOF</th>
<th>HVAF-E</th>
<th>HVAF-B</th>
<th>HVAF-U</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJ2600 HVOF</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>JP5000 HVOF</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>HVAF-E</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
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<tr>
<td>HVAF-B</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>HVAF-U</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
</tbody>
</table>

Note: Cost of WC-Co-Cr powder: $81.4 per kg

<table>
<thead>
<tr>
<th></th>
<th>DJ2600 HVOF</th>
<th>JP5000 HVOF</th>
<th>HVAF-E</th>
<th>HVAF-B</th>
<th>HVAF-U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spray Rate, kg/hour</td>
<td>4</td>
<td>5</td>
<td>32</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Deposition Efficiency</td>
<td>50%</td>
<td>43%</td>
<td>65%</td>
<td>46%</td>
<td>38%</td>
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</tbody>
</table>

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# HVOF vs HVAF WC-10Co-4Cr Costs

<table>
<thead>
<tr>
<th>WC-Co-Cr powder cost: 81.4 USD/kg</th>
<th>DJ2600 HVOF</th>
<th>JP5000 HVOF</th>
<th>AK7 HVAF (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total operating cost, USD/hour</td>
<td>$260</td>
<td>$223</td>
<td>$160</td>
</tr>
<tr>
<td>Spray rate, kg/hour</td>
<td>4</td>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>Deposition efficiency, %</td>
<td>50</td>
<td>43</td>
<td>65</td>
</tr>
<tr>
<td>Deposition rate, kg/hour</td>
<td>2.2</td>
<td>2.2</td>
<td>20.8</td>
</tr>
<tr>
<td>Cost per KG of sprayed coating, USD</td>
<td>$293</td>
<td>$293</td>
<td>$133</td>
</tr>
<tr>
<td>AK7 savings per KG of deposited coating, USD</td>
<td>$160</td>
<td>$160</td>
<td></td>
</tr>
</tbody>
</table>

Changing a HVOF system to Kermetico HVAF saves $160,000 USD per each metric ton of deposited tungsten carbide coating
Examples of Kermetico HVAF Applications
Mud Rotors, Oil Drilling:
WC-20Cr7Ni, WC-10Co-4Cr
Hydro-Power:
Francis Turbine Runner and Head Cover
WCCoCr Application by Plackart Ltd., Russia

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Hydro-Power: a Metering Needle Valve and a Seat Application by RenCoat Ltd., China
A Sliding Gate of a Catalyst Tower

Spraying: Upper slide gate
Hydraulic Rods of Dock Cranes

Hard chrome performance: 0.5 year max (pitting)
HVAF WC-Co-Cr coating performance: 4+ years
A Refinery Sulfur Condenser Vessel

Application of Hastelloy C HVAF coating
DIA 1.8 m x L 2.4 m
Refinery: Automated Coating Application with the Rotating AK5 Gun Inside a Processing Vessel

Diameter: 1.8 m
Length: 11.8 m
Refinery: Heat exchanger vessels
Double-Elbow, Coke Transport Line

12-inch ID,
6-feet long
Double-Elbow, Spraying with rotating AK5 gun
Coke Line Cyclone: Application of WC-10Co-4Cr Coating with the Rotating AK5 Gun
Coke Line Cyclone: Application of WC-10Co-4Cr Coating with the Rotating AK5 Gun
Small ID Transport Pipe Line Components: Application of WC-10Co-4Cr Coating with the Rotating AK-IDR Gun
Oil Refinery: Pump Casing ID Spraying
Oil Drilling:
Fluid-End Pump Casing, 5-inch (125 mm) ID
Application of coating with AK-IDR rotating gun
Wear Rings on HT Pump Housings and Impeller Hubs

AK7 Stellite 6 coating over Stellite weld overlay

HT (400°C) Pump coating solutions:
Housing ring: Stellite 6  
Impeller ring: Stellite 1

→
Housing ring: Stellite 6  
Impeller ring: WCCoCr

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Geothermal Power: Turbine Rotor WCCoCr 86/10/4
Titanium: HVAF

Titanium: Shrouded HVAF

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Tin Spraying with HVAF SL Gun for Low-melting Point Metals
WC-Co-Cr
1 mm thick
Tensiometer Roll:
AK7 HVAF, WC-10Co-4Cr, 1.8 mm thick
AK-HH: hand-held HVAF
Press Pistons, Winemaking