Kermetico High Velocity Air-Fuel Thermal Spray

March 2017
Superior hard & tough coatings for new markets

- Gas-tight
- WC-based 1350-1600+ HV$_{300}$
- Cr$_3$C$_2$-based 1050-1100 HV$_{300}$, service up to 900°C
- MoB-based 1200 HV$_{300}$, service up to 1100°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

1200 HV$_{300}$ /$<0.8\%$ porosity WC-coatings, sprayed at 65-70% DE with spray rates 33+ kg/hour (73 lbs./hr.)
Kermetico HVAF Gun Design

Fuel Gas
Air
Powder + carrier gas
Nozzle
Combustion chamber
Ceramic insert

Gas velocity
1100-1500 m/s
850 m/s
40-50 m/s

Gas temperature
<1500°C
~1600°C
1900°C

Acceleration
Heating
Spray particle

March 2, 2017 kermetico.com
averstak@kermetico.com
Combustion Temperature: HVAF vs. HVOF
Adiabatic combustion temperature of fuels in oxygen and air ($\alpha=1$, 20°C, 1 Bar)
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:

<table>
<thead>
<tr>
<th>Model</th>
<th>Power (kW)</th>
<th>Spray Rate (kg/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JP 5000</td>
<td>270</td>
<td>5</td>
</tr>
<tr>
<td>DJ 2600</td>
<td>115</td>
<td>4</td>
</tr>
</tbody>
</table>

Kermetico HVAF:

<table>
<thead>
<tr>
<th>Model</th>
<th>Power (kW)</th>
<th>Spray Rate (kg/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AK6</td>
<td>130</td>
<td>28</td>
</tr>
<tr>
<td>AK5</td>
<td>80</td>
<td>15</td>
</tr>
<tr>
<td>AK-ID</td>
<td>30</td>
<td>5</td>
</tr>
</tbody>
</table>
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 \( L_S = 250 \text{ mm} \). \((p_{cc} = 0.9 \text{ MPa, } d_p = 30 \mu m, L_b = 100 \text{ mm})\)
Particle 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 Coating Properties:
Hardness of HVOF and Kermetico HVAF WC-10Co-4Cr coatings (Schlumberger, UK)

Relative standard deviation, %

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Relative Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>3.9%</td>
</tr>
<tr>
<td>Kermetico</td>
<td>15.7-17.8%</td>
</tr>
<tr>
<td>Supplier C</td>
<td>97</td>
</tr>
<tr>
<td>Supplier D</td>
<td>173</td>
</tr>
<tr>
<td>Supplier E</td>
<td>415</td>
</tr>
<tr>
<td>Supplier F</td>
<td>236</td>
</tr>
</tbody>
</table>

March 2, 2017 kermetico.com averstak@kermetico.com
WC-10Co-4Cr Coating Characterization

Propane
1470 HV₃₀₀
WC-10Co-4Cr Coating Characterization

Propane - 60% Butane
1,500 HV$_{300}$

Propylene
1,650 HV$_{300}$
Kermetico HVAF:

Carbides are hard, but... ductile

WC-12Co
Propane
1,540 HV300

March 2, 2017  kermetico.com
averstak@kermetico.com
Cr$_3$C$_2$-25NiCr Coating Characterization

AK7, Propane
WOKA 7210 (25/5 μm)
1082 HV$_{300}$

AK6, Propane
Amperit 588.059 (30/5 μm)
1068 HV$_{300}$
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>Balanced</td>
<td>Ultra 1</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>
<tr>
<td>Energy density, GJ/m³ = Contact pressure, GPa</td>
<td><strong>3.8</strong></td>
<td><strong>5.6</strong></td>
</tr>
</tbody>
</table>
Mechanical Properties 1/3

Vickers Hardness of WC-10Co-4Cr Coatings

- JP5000 HVOF: 1180HV300, 70HV300
- HVAF Balanced: 1290HV300, 40HV300
- HVAF Ultra 1: 1380HV300, 40HV300
- HVAF Ultra 2: 1473HV300, 40HV300

March 2, 2017  kermetico.com  averstak@kermetico.com
Mechanical Properties 2/3

Fracture Toughness K1C of WC-10Co-4Cr Coatings, MPa*m1/2

![Bar chart showing fracture toughness K1C for different coating methods: JP5000 HVOF, HVAF Economy, HVAF Balanced, HVAF Ultra.](chart.png)

- **JP5000 HVOF**: K1C = 3.86, K1C Standard Deviation = 0.70
- **HVAF Economy**: K1C = 6.33, K1C Standard Deviation = 0.50
- **HVAF Balanced**: K1C = 6.86, K1C Standard Deviation = 0.80
- **HVAF Ultra**: K1C = 5.60, K1C Standard Deviation = 0.15
Mechanical Properties 3/3

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

- **JP5000 HVOF**:
  - Young's Modulus E: 290 GPa
  - Standard Deviation: 21 GPa

- **HVAF Balanced**: Young's Modulus E: 411 GPa, Standard Deviation: 21 GPa

- **HVAF Ultra 1**: Young's Modulus E: 452 GPa, Standard Deviation: 20 GPa

- **HVAF Ultra 2**: Young's Modulus E: 450 GPa, Standard Deviation: 20 GPa
Cavitation Resistance of WC-10Co-4Cr HVOF and HVAF coatings

\[
\frac{dw}{dt} \text{ AF1 (U2)} = 0.23 \text{ mg/h} \\
\frac{dw}{dt} \text{ AF3 (U1)} = 0.71 \text{ mg/h} \\
\frac{dw}{dt} \text{ AF2 (B)} = 0.96 \text{ mg/h} \\
\frac{dw}{dt} \text{ HVOF} = > 3.26 \text{ mg/h} \\
\frac{dw}{dt} \text{ 16Cr-5Ni steel} = 2.0 - 2.5 \text{ mg/h}
\]
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 WC-10Co-4Cr Coatings
During Silt Erosion Test, mg
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

Average Erosion Rate (mg/h)

Coating Supplier

Supplier A 19
Supplier B 6.23
Supplier C 12.75
Supplier D 20.1
Supplier E 59.35
Supplier F 23.1

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

Volume loss (mm$^3$) vs Time (minutes)

- AISI316: $y = 0.0156x - 0.4789$
- DJ Coating: $y = 0.0121x + 0.4744$
- AK Coating: $y = 0.0047x + 0.0922$

March 2, 2017  kermetico.com
averstak@kermetico.com
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

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>1350-1600+</td>
<td>&lt;0.3</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 WC-10Co-4Cr Costs

Comparison of HVAF and HVOF 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

- Operating cost per kg deposited
- Powder cost per kg deposited

WCCoCr Coating Hardness, HV$_{300}$

Spray Rate, kg/hour
- DJ2600 HVOF: 4
- JP5000 HVOF: 5
- HVAF-E: 32
- HVAF-B: 26
- HVAF-U: 26

Deposition Efficiency
- DJ2600 HVOF: 50%
- JP5000 HVOF: 43%
- HVAF-E: 65%
- HVAF-B: 46%
- HVAF-U: 38%

Note: Cost of WC-Co-Cr powder: $81.4 per kg
## 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>
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 CJSC, Russia
Hydro-Power:
Metering Needle Valve and Seat
Application by RenCoat Ltd., China
Sliding Gate of Catalyst Tower

Spraying Upper Sliding Gate
Hydraulic Rods of Dock Cranes

Hard chrome performance: 0.5 year max (pitting)
HVAF WC-Co-Cr coating performance: 5+ years
A Refinery Sulfur Condenser Vessel

Application of Hastelloy C HVAF coating
DIA 1.8 m x L 2.4 m
Refinery: Automated Coating with the Rotating AK5 Gun Inside the 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: ID Spraying Pump Casing
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
Geothermal Power: Turbine Rotor WC-10Co-4Cr
Titanium: HVAF

Titanium: Shrouded HVAF
Spraying Tin 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