Kinetic Metallization™

Interior Diameter (ID) Bores

AeroMat 2011 Session 1 - Emerging Materials & Processes - Spray Processes
24 May, 2011
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Overview

- Kinetic Metallization (KM) Process and Equipment
- WC-Co for Actuator Sleeve
- NiCrAlY for Thrust Chamber
- Dimensional Restoration of Aluminum Landing Gear Bores
Kinetic Metallization (KM) Process and Equipment
Introduction to Kinetic Metallization™ (KM)

- Metal deposition through particle impact
- Low-temperature << melting point
- **Sonic Mach 1 Nozzle**
  - High particle velocity > 750 m/s
  - Pressure < 1 MPa (150 psig)
  - Temperatures to 450°C
  - Powder preheater & mixer
  - Powder injection at nozzle inlet
  - Low noise < 75 dBA @ 1 m
  - High quality coatings
Kinetic Metallization™ Difference

Potential Energy → Powder → Heat → Kinetic Energy

Mass Loading ~ 100% gas mass flow
Kinetic Metallization™ Difference

Gas Storage System

2.5 kW Thermal Conditioning Unit < 150 psig

Ultra-fine Powder Fluidizing Unit

Sonic Deposition Nozzle with Powder Preheater & Mixer

Mass Loading ~ 100% gas mass flow
KM-Production Coating System (KM-PCS with Robot)

- Robotic KM Spray Gun
  - Repairs of large surfaces
  - Uniform coating thickness
  - Gas blending (He, GN2 or Air)

- Applicable Coatings
  - Air/GN2 (Al-Trans®, Cu, Zn, Ni)
  - He/GN2 (WC-Co, Ni alloys, Nb, Ta)
  - Composite polymers (PEEK, PTFE)

- Powder Loading
  - ~100% gas mass flow

⚠️ Cold Spray limited to 5% gas mass flow
KM-Guns

- **KM-Standard Gun**
  - Robotic rastering & translation
  - Uniform & large area coating repairs

- **KM-Handheld Gun**
  - Lightweight (< 5 lbs)
  - Round or oval nozzles (< 75 dBa)
  - Preheated powder chamber
  - Gas blending (He, GN2 or Air)

- **KM-ID Gun**
  - Bore internal diameters 3-inches (80-mm)
  - Bore Depths ~ 48-inches

So, what can KM do?
<table>
<thead>
<tr>
<th>Material</th>
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</tr>
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<tbody>
<tr>
<td>Ag</td>
<td>C103 (Nb/Hf)</td>
<td>Co</td>
<td>Reactive Intermetallic Compounds</td>
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<tr>
<td>Al/Zn</td>
<td>Co</td>
<td>CoCr</td>
<td>Sn</td>
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<td>Al-4047 -Al/Si</td>
<td>CoNiCrAlY</td>
<td>CoNiCrAlY/CBN</td>
<td>SnAg</td>
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<tr>
<td>Al-6061</td>
<td>Cr</td>
<td>CrC/NiCr</td>
<td>SnAgSb</td>
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<tr>
<td>Al-7075</td>
<td>Cu</td>
<td>Cu/SiC</td>
<td>SS</td>
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<tr>
<td>Al-CP</td>
<td>CuAlFe</td>
<td>CuCr</td>
<td>Ti/HA</td>
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<td>Al-Trans -Al₂O₃</td>
<td>CuCrAl</td>
<td>CuCrAl</td>
<td>Ti/TiC</td>
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<tr>
<td>Al-Trans- Co</td>
<td>In</td>
<td>In718</td>
<td>Ti/TiN</td>
</tr>
<tr>
<td>Al-Trans- Cr</td>
<td>Mo</td>
<td>Mo</td>
<td>Ti6-4</td>
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<td>Al-Trans-Mo</td>
<td>Nb</td>
<td>Nb</td>
<td>Ti-CP</td>
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<tr>
<td>Al-Trans-Ni</td>
<td>Ni</td>
<td>Ni</td>
<td>WC-Co</td>
</tr>
<tr>
<td>Al-Trans-SiC</td>
<td>Ni/CBN</td>
<td>Ni-braze</td>
<td>Teflon PTFE</td>
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<tr>
<td>Al-Trans-SS</td>
<td>NiCrAl</td>
<td>NiCrAl</td>
<td>Ultem Polyetherimide</td>
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<tr>
<td>Al-Trans-Ti</td>
<td>Ni</td>
<td>Ni</td>
<td>Nylon polyamides</td>
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<td>Al-Trans-TiC</td>
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<td>Ni</td>
<td>Polymer+</td>
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<td>Al-Trans-V</td>
<td>NiCrAlY</td>
<td>NiCrAlY</td>
<td>Al₂O₃</td>
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<tr>
<td>6061Al-Trans</td>
<td>Re</td>
<td>Re</td>
<td>BaTiO₃</td>
</tr>
<tr>
<td>7075Al-Trans</td>
<td>Amorphous Al</td>
<td>Amorphous Al</td>
<td>Fused Silica</td>
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<tr>
<td>Amorphous Fe</td>
<td>Amorphous Ni</td>
<td>Amorphous Ni</td>
<td>Quartz</td>
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<tr>
<td>Amorphous Ni</td>
<td>Au braze alloy</td>
<td>Au braze alloy</td>
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WC-Co for Actuator Sleeve
3.75” ID x 16” deep bore
WC-Co Microstructure
KM800 WC-Co Microhardness

- Vickers hardness - 300g load
- No indent cracks
ASTM C633 Adhesion Testing

In718

Sample 1
Sample 2
Sample 3
Sample 4

KM800 WC-Co

Ti 6-4

0
3250
6500
9750
13000

Sample 1
Sample 2
Sample 3
Sample 4
NiCrAlY for Thrust Chamber
3.5” Throat Thrust Chamber
NiCrAlY on Cu Alloy
Dimensional Restoration of Aluminum Landing Gear Bores
Process Requirements for LG Dimensional Restoration

- Deposition thickness of up to 0.025-inches
- Coating applied while maintaining a maximum part surface temperature of 225 F
- Overspray (dust) generated during the spray process must be adequately removed from the bores, which may include blind holes
Material Requirements for LG Dimensional Restoration

- Coating hardness must be equitable to 7075-T6
- Compatible with the Type III sulfuric-acid anodize process
- Fully dense and cohesive
- Adherence to base alloy to prevent delamination and spalling under loads
## Screening Tests for Powder Formulations

<table>
<thead>
<tr>
<th>Screening Test</th>
<th>Acceptance Criteria</th>
<th>Test Method References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating Thickness</td>
<td>0.025-inches minimum buildup</td>
<td>Metallographic Analysis</td>
</tr>
<tr>
<td>Coating Density</td>
<td>Fully dense</td>
<td>Metallographic Analysis</td>
</tr>
<tr>
<td>Adhesion – Machining of Coated Coupons</td>
<td>Machining coated coupons to ensure sufficient adhesion and ductility to permit final machining of LG components.</td>
<td>MIL-DTL-83488D, April, 1999</td>
</tr>
<tr>
<td>Hardness</td>
<td>&gt; 150 HB (7075-T6)</td>
<td>ASTM E92</td>
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<td>ASTM E384</td>
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</table>
7075-Al
7075Al-Trans
Coating Hardness

<table>
<thead>
<tr>
<th>Coating Formulation</th>
<th>Measured Rockwell F (HRF)</th>
<th>Calculated Brinell Hardness (HB)</th>
<th>Calculated Rockwell B (HRB)</th>
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<tbody>
<tr>
<td>6061</td>
<td>77.9</td>
<td>86</td>
<td>36</td>
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<tr>
<td>6061/Al-Trans</td>
<td>93.5</td>
<td>126</td>
<td>64</td>
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<tr>
<td>7075</td>
<td>104.6</td>
<td>173</td>
<td>83</td>
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<tr>
<td>7075/Al-Trans</td>
<td>110.2</td>
<td>205</td>
<td>93</td>
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## Screening Tests Results

<table>
<thead>
<tr>
<th>Coating Formulation</th>
<th>Thickness</th>
<th>Coating Density*</th>
<th>Type III anodize compatibility</th>
<th>Hardness</th>
<th>Machinability</th>
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</thead>
<tbody>
<tr>
<td>6061</td>
<td>Pass (&gt;0.025”)</td>
<td>Pass</td>
<td>Pass</td>
<td>Fail (&lt;150HB)</td>
<td>Pass</td>
</tr>
<tr>
<td>6061Al-trans</td>
<td>Pass (&gt;0.025”)</td>
<td>Pass</td>
<td>Pass</td>
<td>Fail (&lt;150HB)</td>
<td>Pass</td>
</tr>
<tr>
<td>7075</td>
<td>Pass (&gt;0.025”)</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass (&gt;150HB)</td>
<td>Pass</td>
</tr>
<tr>
<td>7075Al-Trans</td>
<td>Pass (&gt;0.025”)</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass (&gt;150HB)</td>
<td>Pass</td>
</tr>
</tbody>
</table>

* at 200x per MIL-STD-3021
ID Coating System - Qualification Tubes

- Coating applied to lower 10” of 36” deep tube
- Closed-end bonnet used to simulate closed-end bore of LG cylinder
- Coated tube section cross-section to assess coating quality
- Machinability assessment
- Type-III anodize post-process
Optical Micrographs of 7075Al-Trans Coated Tube ID at 50x (left) and 100x (right) from lowest end of coated tube section
KM Coated ID Section being Machined (left) and After Machining
Demonstrated Integrity During Machining
36” Length of Tube Showing Lower 10” After Anodizing
0.002” Nominal Anodized Thickness

Fully Dense (>99%) After Anodizing

KM Coating After Anodizing
OEM Landing Gear
Process Requirements for LG Dimensional Restoration

- Deposition thickness of up to 0.025-inches
  - PASS – >0.030” capable

- Coating applied while maintaining a maximum part surface temperature of 225 F
  - PASS – Temperature did not exceed 200F

- Overspray (dust) generated during the spray process must be adequately removed from the bores, which may include blind holes
  - PASS – no loss of coating quality at bottom of closed-end bore
Material Requirements for LG Dimensional Restoration

- Coating hardness must be equitable to 7075-T6
  - PASS – Coating hardness >150HB
- Compatible with the Type III sulfuric-acid anodize process
  - PASS – 0.002” nominal anodized layer, KM coating remains fully dense
- Fully dense and cohesive
  - PASS – >99.5% dense at 200x per MIL-STD-3021, August 2009, section 5.2.3