Supersonic Particle Deposition (SPD)

Applications and R&D at ARL

Victor Champagne
US Army Research Laboratory
Weapons & Materials Research Directorate

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**Applications and R&D at ARL**

**U. S. Army Research Laboratory, Weapons & Materials Research Directorate, Aberdeen Proving Ground, MD, 21005**

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**25th Replacement of Hard Chrome and Cadmium Plating Program Review Meeting, March 15-17, 2005, Greensboro, NC. Sponsored by SERDP/ESTCP.**

**Standard Form 298 (Rev. 8-98) Prescribed by ANSI Std Z39-18**
### SPD Applications At ARL

1. **EMI Coatings for HMMWV Shelter**  
   General Dynamics
2. **Aluminum Coatings for Mg Housings**  
   Sikorsky Aircraft
3. **Advanced Med. Cal. Munitions**  
   ARL R&D
4. **Fuel Cells**  
   ARL R&D
5. **Heat Exchangers**  
   ARL R&D, U of Maryland
6. **Armor Tile Encapsulation**  
   ARL R&D, PennState
7. **W-Cu Coatings (Classified)**  
   ARL-R&D
<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Phone Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victor Champagne</td>
<td>Materials Engineer</td>
<td>(410) 306-0822</td>
</tr>
<tr>
<td>Dr. Christopher Norfolk</td>
<td>Materials Engineer</td>
<td>(410) 306-0818</td>
</tr>
<tr>
<td>Dr. Dennis Helfritch</td>
<td>Scientist</td>
<td>(410) 306-1928</td>
</tr>
<tr>
<td>Phillip Leyman</td>
<td>Process Engineer</td>
<td>(410) 306-0818</td>
</tr>
<tr>
<td>Robert Lempicki</td>
<td>Process Engineer</td>
<td>(410) 306-0808</td>
</tr>
<tr>
<td>Dr. William DeRosset</td>
<td>Modeling/Simulation</td>
<td>(410) 306-0816</td>
</tr>
</tbody>
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Army Research Laboratory
SPD System
Portable SPD

Downstream Powder Feed
Portability/Field Repair
Slightly Lower Particle Velocity
Special Powder Formulation
ARL Has Two Portable Systems
SPD Advantages

- **Low temperature**
  - Solid State Process
  - Low residual stresses
  - Minimal grain growth

- **Little oxidation**
  - good electrical/thermal conductivity
  - electrical conductivity: 80% of OFHC Copper

- **High deposition rates and efficiencies**
  - rates - up to 20 kg/hr.
  - efficiencies generally 50 - 80%

- **Wide variety of coating materials and substrates**
  - Al, Zn, Sn, Cu, Ni, Ti, Ta, Co, Fe, Nb, Mo, W.
Particle/Substrate Interaction* 

*from H. Assadi, www.modares.ac.ir/eng/ha10003/CGS.htm
EMI Shielding for HMMWV Shelter and Al Coating for Helicopter Mg Housings-FY05 Effort

Supersonic Particle Deposition

AL EMI Coating on lap joint seam

The main rotor transmission gearbox in the UH60 Blackhawk.

6061-T6 Al Cross-section Composite Lap joint
HMMWV-mounted Lightweight Shelter
Metallographic Cross-Sections of EMI Coatings

Supersonic Particle Deposition

High Velocity Oxy Fuel

Aluminum Lap Joint

Al Coating

Hand-held portable SPD System

Automated HVOF System

.072 in

.085 in

.031 in

.031 in

.031 in
Flame Spray vs. Supersonic Particle Deposition

Flame Spray Sn and Steel Coating

- ~12.2% Porosity

SPD Sprayed Sn Coating

- ~1.18% Porosity
Flame Spray vs. Supersonic Particle Deposition

Flame Spray Sn and Steel Coating

~12.2% Porosity

SPD Sprayed Al Coating

~0.83% Porosity
Portable SPD Application
Cost to operate Portable SPD System

Utilizes regular air at no cost.

Aluminum powder cost is $9.70/lb.

One quarter pound of powder was used to coat the test piece

It took 1.5 min. to spray a 1ft section which equates to ~$2.43/ft.
This only includes gasses and powder. It does not include cost to run the equipment (operator, gun parts and overhead).

$2.43/ft. for .031 in coating or $.60/ft. for .008 in coating
Cost to operate Metco Diamond Jet HVOF System

Hydrogen - $8.17 per bottle $50/hr. Oxygen - $5.25 per bottle $15/hr.

Aluminum powder cost is $13.27/lb. @30 grams/min. $53/hr.

Traverse rate 600 mm/sec or 23.6 inches/sec.

40 passes is what was used to spray the test piece.

It took 1 min. to spray a 2ft section which equates to $2.05 or ~$1.00/ft. This only includes gases and powder. It does not include cost to run the equipment (operator, gun parts and overhead).

$1.00/ft. for .031 in coating or $.25/ft. for .008 in coating
Conclusions SPD for HMMWV

- SPD can provide EMI Coatings for the HMMWV superior to Thermal Spray in terms of porosity and conductivity (fewer oxides).
- SPD can easily deposit onto lap joints.
- TAS could be used in conjunction with SPD for butt joints.
- SPD recommended for field repair and for production.
Copper Deposited On Aluminum Rod
Advanced Medium Caliber Munitions
Magnified Interface
Super Plastic Agglomerated Mixing (SPAM)
EDS X-ray Mapping of SPAM

Forced mixing of copper and aluminum.

Copper SPD Coating

Aluminum Substrate

BEI

SEI
Triple Lug Shear Test Fixture

MIL-J-24445A
Triple Lug Shear Test Sample
Copper on Aluminum

Shear Test Bond Strength = 11,650 psi
Shear Test Results
(Triple Lug Shear Test)

<table>
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<th>Trial</th>
<th>Pressure psi</th>
<th>Temperature degree C</th>
<th>Stand-off mm</th>
<th>Speed mm/sec</th>
<th>Feed rate gm/min</th>
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Failure Mode = Cohesive
Particle Velocity Distribution

- Measured by DPV 2000

- 20 micron copper particles
- 25 mm downstream
- 400 psi, 400 C  N₂ gas
SPD and DYMET
Velocity and Particle Flux Profiles
Nozzle flow equations are used to calculate gas velocity and temperature within the nozzle.

The resulting particle velocity and temperature are then calculated by gas-particle drag and heat transfer.

An empirical relationship between critical velocity and particle material characteristics is used to determine deposition efficiency.
Typical Calculation

Velocity & Temperature, m/s & degree K

Nozzle Axis, meters

- blue: particle velocity
- red: particle temp
- green: nozzle throat
- cyan: gas velocity
- purple: gas temp
Effect of Particle Diameter on Deposition Efficiency

Deposition Efficiency

Particle Mass Mean Diameter, microns
SPD Fuel Cell Concept

O₂ + 4e⁻ → 2O²⁻

BY-PRODUCTS OUT

POROUS CATHODE

DENSE ELECTROLYTE

POROUS ANODE

FUEL IN

2CO + 2O²⁻ → 2CO₂ + 4e⁻

2H₂ + 2O²⁻ → 2H₂O + 4e⁻
SOFC Anode Construction

Conventional Method

• Tape cast YSZ with organic filler
• Bake out organic
• Deposit NiO
• Reduce to Ni with hydrogen

SPD Deposition

• Mix YSZ and nickel powders
• Deposit mixture with SPD
Improved Heat Exchanger

Copper on SiC

Al-SiC heat exchanger

Other ceramics include alumina & aluminum nitride
Develop SPD Parameters

As-received 4x4x.55in Al₂O₃ ceramic tile prior to Cold Spray. Initial test runs using sponge Ti displayed ‘orange peel’ surface (465). Encapsulated tile (Tile #1).
8 Al$_2$O$_3$ tiles encapsulated with .25in of Ti.
Complete coating characterization studies:
* adhesion, density, hardness, microstructure

Ballistically test encapsulated tiles:
* perform hot isostatic pressing if required

Establish process parameters to encapsulate SiC tiles:
* conduct cold spray simulation studies for Ti6Al4V
* investigate alternative coating materials
* encapsulate additional tiles with best candidate