Supersonic Particle Deposition (SPD)

Applications and R&D at ARL

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## Applications and R&D at ARL

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**Abstract:**

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

**Subject Terms:**

- Unclassified
- Unclassified
- Unclassified
## 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
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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

6061-T6 Al

Cross-section

Composite

Lap joint

AL EMI Coating on lap joint seam

The main rotor transmission gearbox in the UH60 Blackhawk.
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
Flame Spray vs. Supersonic Particle Deposition

Flame Spray Sn and Steel Coating

- ~12.2% Porosity

SPD Sprayed Sn Coating

- ~.18% Porosity
Flame Spray vs. Supersonic Particle Deposition

Flame Spray Sn and Steel Coating

- ~12.2% Porosity

Supersonic Particle Deposition (SPD) Sprayed Aluminum Coating

- ~.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 \(~$2.43/\text{ft.}\) This only includes gasses and powder. It does not include cost to run the equipment (operator, gun parts and overhead).

$2.43/\text{ft. for .031 in coating or .60/ft. for .008 in coating}$
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 gasses 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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<tr>
<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>
<th>Shear strength psi</th>
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Failure Mode = Cohesive
Particle Velocity Distribution

20 micron copper particles
25 mm downstream
400 psi, 400 C N₂ gas

Millimeters

Millimeters

500 m/sec
600 m/sec
700 m/sec
800 m/sec
900 m/sec
SPD and DYMERT
Velocity and Particle Flux Profiles
Modeling Efforts

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

Nozzle Axis, meters

Velocity & Temperature, m/s & degree K

- Particle velocity
- Particle temp
- Nozzle throat
- Gas velocity
- Gas temp
Effect of Particle Diameter on Deposition Efficiency
SPD Fuel Cell Concept

Diagram showing a fuel cell with the following components:
- LSGM + YSZ
- YSZ
- Ni + YSZ

Chemical reactions:
- $2\text{CO} + 2\text{O}_2 \rightarrow 2\text{CO}_2 + 4\text{e}^-$
- $2\text{H}_2 + 2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + 4\text{e}^-$

Oxygen flow:
- $\text{O}_2 + 4\text{e}^- \rightarrow 2\text{O}^2-$
- BY-PRODUCTS OUT

Materials:
- POROUS CATHODE
- DENSE ELECTROLYTE
- POROUS ANODE

Fuel flow:
- FUEL IN
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
As-received 4x4x.55in Al$_2$O$_3$ ceramic tile prior to Cold Spray.
Initial test runs using sponge Ti displayed ‘orange peel’ surface (465).
Encapsulated tile (Tile #1).
8 Al₂O₃ 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