Cold Spray Activities in Canada

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Introduction – Overview of Canada

Location of major research and industry activities in cold spray

- University of Alberta
- University of Ottawa
- University of Windsor
- SST Centerline Ltd.
- McGill University
- National Research Council
Introduction – Overview of Thrusts

- Overview of major research thrusts
  - Metal matrix composite coatings (Alberta, Ottawa)
  - Hybrid cold spray-friction stir process (Alberta + Centerline)
  - Modelling cold spray processes (Ottawa, McGill, NRC, Concordia)
  - Additive manufacturing (Ottawa, NRC)
  - Functionalization of polymer structures (McGill)
  - Tribology of composite coatings (McGill)
  - Diagnostics of the cold spray process (Windsor, TECNAR)
  - Low- and medium-pressure cold spray systems (Centerline)
  - Powder development specially for cold spraying (Centerline, NRC)
  - Unique applications – Nuclear Waste Management (NRC)
Activities at University of Ottawa

- The uOttawa Cold Spray Lab was established in 1998.
- Current research team:
  - 5 Professors / 1 Research Assistant
  - 1 Lab technician / machinist
  - 6 Ph.D. students
  - 4 M.A.Sc. students
  - 1 undergraduate student
- 3 spray booths / 1 portable system
- Spray and coating characterization equipment
Fundamental Work

Process Parameters
- Pressure
- Temperature
- Nozzle Design
- Powder Feed Rate
- Powder Type
- Powder Size

Coating Characteristics
- Hardness / Porosity / Thickness
- Adhesion Mechanisms
- Corrosion / Wear properties
- Electrical / Magnetic properties

Particle Velocity

Numerical Model

Particle Diagnostic/ Monitoring
Activities at University of Ottawa
Activities at University of Ottawa

• Examples of recent fundamental work

Nozzle material effect

Adhesion modelling
Activities at University of Ottawa

- Examples of recent development work

Additive Manufacturing of Compact Heat Exchanger Fins
Repair of Damaged Threads
Activities at University of Ottawa

- Examples of recent development work

MCrAlY Protective Coatings
Activities at University of Ottawa

- Examples of recent development work

Repair of Alclad Aircraft Skins by Cold Spray

New Repair Spec Implemented at Everett Facility
Activities at University of Ottawa

- Examples of recent development work

Repair of Cr/Ni plated and HVOF coated parts
Cold spray on CFRP for lightning strike protection (Hanqing Che)

High-pressure spray led to erosion of the CFRP, low pressures: continuous tin coatings deposited;
Component C lightning tests indicate that the cold sprayed tin can provide protection to the CFRP;
Mixing tin with zinc or copper strongly increased DE.

Cold Spray and Biodegradable Stent Design (Chu Frattolin, Barua)

- Dissimilar metallic powders with large potential gap utilized:
  - Anode: Iron
  - Cathode: Stainless steel 316L
  - Accelerated degradation due to galvanic reaction between iron and SS316L
  - Controllable degradation rate
Overview of Cold Spray Research
Prof. Jun Song, Materials Engineering

- **Deposition efficiency prediction**
  - The evolution of $P_E E Q^2$ as a function of impact time is distinct for different particle velocities – specifically: *i)* continuous increase at or above the critical velocity and *ii)* fall into distinct regions beyond critical velocity.
  - The stable rate of $P_E E Q^2$, $R_{EQ}$, thus can be directly correlated with deposition efficiency (DE) as $DE = c_0 \times R_{EQ}$.

- Using the same material constant $c_0$, $R_{EQ}$ can be used to quantitatively predict the experimental DE of metal particles impacting a substrate of similar deformability.

- For **soft particle/hard substrate**, DE is determined by the particle plastic deformation (i.e., $R_{EQ}$ of the particle).

- For **hard particle/soft substrate**, particles’ trapping in substrate, self-interlocking, and plasticity together contribute to its high/fluuctuating DE.

Meng et al., *Scripta Materialia*, 107, 83-87, 2015
Overview of Cold Spray Research
Prof. Jun Song, Materials Engineering

- Coupled DEM-FEA modeling technique for mixed ceramic/metal particle deposition

**Step 1.** Calculate Contact Pressure on the ceramic at maximum crater depth using FEA (Abaqus Software)

**Step 2.** Input this pressure as ceramic bonding criterion in Discrete Element Method (EDEM software) along with the critical velocity for metals.

Prediction of the ceramic retention in composite Cold spray coating.
Overview of Cold Spray Research
Prof. Richard R. Chromik, Materials Engineering

• Areas of Expertise
  • Coatings Tribology
  • Nano- and Micro-mechanical Testing
  • Materials Characterization

• Cold Spray Research Approach

Research on cold sprayed composites - their deposition mechanisms, microstructure and tribological properties.

SPLAT LEVEL
- Single Splat Adhesion Testing
  - Goldbaum, JTST 2012
  - Chromik, S&CT 2010

COATING LEVEL
- Nano- and Micro-scale Mechanical Testing
  - Goldbaum, MS&EA 2011

BULK LEVEL
- Wear Testing of Cold Spray Coatings
  - Video
  - Raman
  - Friction
  - Wear
  - Shockley, Trib. Lett. 2014
  - Shockley, S&CT 2013
Tribology of Composite Coatings

Metal-ceramic coatings: Ni-WC, Ti-TiC and Ti64-TiC
- Research on CS deposition mechanisms and their tribology, including sliding wear, solid particle erosion and abrasion testing.

Metal-solid lubricant coatings: Cu-MoS2
- Compared to a pure Cu coating, the self-lubricating composite has lower friction & reduced wear.
- Tribology performance related to the velocity accommodation and tribofilm formation.

Splat Adhesion Testing

- A wedge shaped tip is used to scratch cold sprayed single splats off of the substrate.
- The tangential forces is used to calculate adhesion strength.

\[
\text{Adhesion Strength} = \frac{F_{T \text{ Peak}} - F_{T \text{ Baseline}}}{\text{Projected Splat Area}}
\]

Current Work

- Adhesion strength of various metals sprayed onto ceramic substrates
- Understand effect of process conditions, material parameters such as ceramic ionicity and roughness.
- High resolution microscopy of metal-ceramic interfaces created by cold spray

Activities at University of Alberta

- Development of Metal Matrix Composites – Low Pressure Cold Spray

- TiC-Ni coating
  75 wt% TiC - 25 wt.% Ni

- B₄C-Ni coating
  75 wt% B₄C - 25 wt.% Ni
Activities at University of Alberta

7 wt% WC, Porosity = 2%

19 wt% WC, Porosity = 0.8%

56 wt% WC, Porosity = 0.1%

66 wt% WC, Porosity = 0.3%
Activities at University of Alberta

WC Content in Coating (vol. %)

WC Content in Powder (wt. %)

WC Coating Content (wt. %)

WC Coating Content (vol. %)
Activities at University of Alberta

ASTM G65 Abrasion Testing

- WC-Ni MMC coating
- Saha and Khan (nano) [8]
- Saha and Khan (micro) [8]
- Guilemany et al. (bimodal) [9]
- Guilemany et al. (nano) [9]
- Guilemany et al. (conv.) [9]
- Dosta et al. [31]

1: 7 wt.% WC (4 vol.% WC)
2: 19 wt.% WC (11 vol.% WC)
3: 56 wt.% WC (42 vol.% WC)
4: 66 wt.% WC (52 vol.% WC)
Activities at University of Alberta

Friction Stir Processing

- Rotating tool
- Substrate secured here
- Motion
Activities at University of Alberta

As-sprayed:
90 wt.% Al₂O₃ + 10 wt.% Al

Friction Stir Process (894 RPM):
90 wt.% Al₂O₃ + 10 wt.% Al

87 ± 24 HV

140 ± 8 HV
Activities at University of Windsor

- In-situ ultrasonic monitoring during cold spray deposition – Thickness and particle deformation mechanism
- In-situ monitoring of particle consolidation in low-pressure cold spraying
- Radial injection gas dynamic spray (RIGDS) technology – Improving deposition of powder mixtures by radial injection; Improved compaction of particles, lower gas consumption.
Activities at SST Centerline

Supersonic Spray Technology Division

• Since 2003
• Design & manufacture of a full range of cold spray systems for the aerospace, defense, and automotive industries.
  • Standard Cold Spray products
  • Custom Cold Spray Integrated Systems
Activities at SST Centerline

Powders

Calibration Kit

UltiLife™

UltiFlow™

Modular Nozzle Assemblies

Powder Feeder

Air Prep Unit

Ventilation
### Corrosion & Strength SST-A0082 Powder Blend (A0071 plus)

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>SST-A0071</th>
<th>SST-A0082</th>
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</thead>
<tbody>
<tr>
<td>Composition:</td>
<td>Al 99.5% min, Al₂O₃ 99% min</td>
<td>Al 99.5% min, Al₂O₃ 99.0% min</td>
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<tr>
<td>Particle Size:</td>
<td>-150 to +5 μm</td>
<td>-75 to +5 μm</td>
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<table>
<thead>
<tr>
<th>Typical Coating Properties</th>
<th>SST-A0071</th>
<th>SST-A0082</th>
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</thead>
<tbody>
<tr>
<td>Bond Strength:</td>
<td>Series P</td>
<td>Series EP</td>
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<tr>
<td></td>
<td>&gt; 8200 psi</td>
<td>&gt; 9200 psi</td>
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<tr>
<td></td>
<td>Up to 9%</td>
<td>Up to 25%</td>
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<tr>
<td>Deposition Efficiency:</td>
<td>58-61</td>
<td>60-62</td>
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<tr>
<td>Deposition Rate:</td>
<td>Series P</td>
<td>Series EP</td>
</tr>
<tr>
<td></td>
<td>&gt; 8200 psi</td>
<td>&gt; 9200 psi</td>
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<tr>
<td></td>
<td>Up to 16%</td>
<td>Up to 36%</td>
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<tr>
<td>Hardness (Brinnel):</td>
<td>Series P</td>
<td>Series EP</td>
</tr>
<tr>
<td></td>
<td>&gt; 58-61</td>
<td>&gt; 60-63</td>
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<tr>
<td>Density:</td>
<td>Series P</td>
<td>Series EP</td>
</tr>
<tr>
<td></td>
<td>&gt; 99.5%</td>
<td>&gt; 99.5%</td>
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</table>

Source: www.engineering.ualberta.ca/mece
Activities at SST Centerline

Series P / N\textsubscript{2} / 14 bar / 400\degree C

Series EP / N\textsubscript{2} / 34 bar / 550\degree C
Activities of Other Stakeholders

- Concordia University on modelling of cold spray gas dynamics and particle impact

- TECNAR Ltee. – Cold spray meter for particle velocity and size distribution

- Polycontrols Technologies Inc. – Helium recycling, powder feeder systems

- Quantum Technology – Gas systems and recovery
Conclusion – Future Directions

- Multi-functional, next generation coatings
  - Metal matrix composites
  - Wear-corrosion resistant coatings
  - Conductive coatings
  - Coatings for structural health and damage detection
  - Coatings for heating
  - Hybrid coatings for unique applications

- A new strategic network for research and commercialization

- Visibility of cold spray activities through TSS, Canadian Cold Spray Alliance

- Special Issues of JTST on Additive Manufacturing and Cold Spraying
Cold Spray Activities in Canada

Questions?

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