Cold Spray (CS) Coatings for Cr and Ni Plating Replacement

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Performers

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Problem Statement

- Cr and Ni electroplating operations must comply with environmental regulations (i.e. AERTA PP-2-02-04) and Executive Orders (i.e. 13148) to eliminate Chromic Acid. The EO requires the usage reduction of hexavalent chromium by 50%.

- Plating operations must also conform to the DoD Emerging Contaminates Directorate in the Memorandum from John Young, USD (ALT), to Secretaries of Military Departments, Minimizing the Use of Hexavalent Chromium.

- OSHA has proposed a reduction in the current Permissible Exposure Limit (PEL) established for water soluble chrome VI compounds from the current 5 µg/m³ to less than 1 µg/m³.

- Eliminate $5M/yr waste disposal costs collected from Watervleit and Rock Island Arsenals, Corpus Christi and Anniston Army Depot (CCAD). Based upon yearly production numbers from NDCEE Toxic Metal Waste Study.
Technical Objective

- This work will advance the state-of-the-art for CS by providing a better understanding of the particle/substrate interaction and bonding mechanism and result in novel CS coating powders/materials that can be used by DoD and industry to replace Cr and Ni electroplating.

- This will be accomplished by a ‘Materials by Design” approach through proven modeling/simulation, innovative nozzle design, the synthesis and development of CS powders and process parameters that can produce protective coatings with properties comparable to those of Cr and Ni plating for production and/or field relevant performance characteristics.
The Cold Spray Process

- CS developed in Russia in mid 1980’s but has yet to realize potential
- Cr plating replacement material not developed to date

Background

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- Cr plating replacement material not developed to date

Basic Process is known – but the technology must be ‘enabled’ to allow development of new materials/coatings.

“Materials by Design” Approach-Materials Science-Modeling-Hardware/Software

ARL Cold Spray Center has led R&D and applications development since 2000’s
CS Materials (bulk/coatings)

- titanium
- nickel
- stainless steel
- tantalum
- aluminum
- copper – SiC/diamond/W

Low Oxide Ta

High strength/ductility Al

5056 Al (58ksi-UTS & 22% EI)

Encapsulation (SBIR)
Background

ARL Cold Spray Research From Concept to Transition

TRL 9
POWDER SYNTHESIS
Nano, High Strength Al, Ta, CrC-NiCr, Encapsulation Process, Low Oxide Powder

TRL 8
PROCESS SCALE-UP
UH-60 Sump Repair
MEO T7631
Flexible Robot Environment

TRL 7
CHARACTERIZATION & TESTING
Reactive Materials Shaped Charge Liners
UTS > than Wrought

TRL 6
PRODUCTION SCALE-UP
TD-63 Actuator
First Approved Army-Navy & Air Force Applications

TRL 5
FEB Panels & Hydro Tubes

TRL 4
PROCESS DEVELOPMENT

TRL 3
MODELING & SIMULATION
Multi-Particle Interaction Model

TRL 2

TRL 1

Industry
AF & Army
RIF
OSD & Army
Mantech
TMR
NAVAIR
AFRL
ESTCP
DLA
SBIR
SERDP
ARL, ONR
RIF
MEO T7631
Reactive Materials Shaped Charge Liners
Flexible Robot Environment
First Approved Army-Navy & Air Force Applications
TD-63 Actuator
FEB Panels & Hydro Tubes
Multi-Particle Interaction Model

Background

UTS, ksi
YS, ksi
%EL
annealed
T4-T451
T6-T651
cold
sprayed
Holistic Approach to Coating Development

- Environmental Regulations
- Composition
- Manufacturing process
- Compatibility
- Health Hazards

**Particle size distribution**

- **Impact Modeling:** Actual copper CS deposit
- **CFD: Nozzle and Process Modeling**
  - Validation: Velocity calculations calibrated with Laser Doppler Velocimeter

**CS Process Conditions**
- Pressure
- Temperature
- Accelerating gas

**Cold Spray System Design**
- Temperature capability
- Powder heating
- Gun heating

**Nozzle Design**
- Conventional nozzles with varying aspect ratios
- Specialty ID nozzles

**CS : Relative Critical Velocity Ratio Calculations**

**Post-Processing Characterization**

- Porosity
- Microstructure
- Bond-line

**Analytical Tools**

- Powder / Material Characterization
- Powder / Material Selection
- Chemical Clad
- Mechanical Clad

- In-situ mechanical tests in SEM

- Impact Tests
- Microstructure

- Chemical Analysis
- Mechanical Testing

**Cold Spray Process**

- Analytical Tools

- Powder / Material Characterization
- Chemical Clad
The goal of this project is therefore to:

a. Identify the appropriate types of soft and hard phases
b. Identify the best configuration of these phases within the powder particle
c. Identify the appropriate particle size
d. Develop the spray process parameters required to consolidate this material

### Materials by Design

- **Hard Phases**
  - Tungsten Carbide
  - Chrome Carbide
  - Iron-based hard powders

- **Soft Phases**
  - Nickel
  - Stainless Steel
  - Cobalt
  - Chrome
  - Tantalum
  - Niobium
  - Bronze
  - Copper-Nickel

### Methods of Combinations

- Blending
- High Energy Milling
- Powder Plating
- Small-Large Powder Granulation
- Spray Drying / Agglomeration
Results

Blending

- Blending of powders can achieve high quality deposits with a variety of combinations of hard and soft phases.
- Blending achieves harness limited to approximately 350-500 HV making it a potential solution for nickel plating replacement.
- Several potential combinations of hard and soft phases have been successful.

Chrome Carbide Nickel-Chrome

Iron hard face with Nickel

Iron hard face with Stainless Steel
High Energy Milling

- Milling of powder has had limited success to date
- Lack of transfer from soft powder to hard powder during the milling process
- Potential for improvements through the use of finer powders

Powder Plating

- Powders have been encapsulated by nickel plating process
  - Chrome Carbide
  - Tungsten Carbide
- First batch of plated powders received

Results
Small-Large Powder Granulation

- Large core powders have been granulated with fine metal powders using aqueous PVP solutions
- Powders are then heat treated to sinter the fine powder to the hard core powder
- Fine powders create a coating around the core powder
- Potential for low cost high volume production
Spray drying / Agglomeration

- Improvement in performance by using smaller carbides and smaller particle sizes
- Deposits greater than 850 HV to 1600 HV have been achieved
- Both chrome carbide and tungsten carbide-based powders were sprayed successfully
- **The following powder characteristics lead to improved outcomes:**
  - Sphericity of agglomerates
  - Homogeneity of agglomerates
  - Finer constituents in agglomerates <2 microns
  - Small agglomerate size <20 microns lower preferred (related to density)
- **Chrome carbide powders were sprayed showing similar trends:**
  - chrome carbide is lower density and therefore particle size is not as critical

Tungsten Carbide (powder and deposit)  Chrome Carbide (powder and deposit)

Deposits hardness are >850 HV
Project Deliverables & Timeline

1. Select and procure powder for Cr & Ni replacement
2. Optimize Cold Spray process conditions for Cr & Ni replacement
3. Perform materials characterization and requirements
4. Recommended CS nozzle and hardware for demo/validation in a follow-on ESTP Program
Future Steps

- Nano-grained chromium alloy powder (MIT)
  - Increased hardness

- Improve spray dried deposit quality
  - Lower particle size distribution
  - Modified chemical composition
  - Use of sub-micron carbides

- Complete screening tests of preferred candidates
  - Hardness
    - Ni replacement > 450HV
    - Cr replacement > 850HV
  - Microstructure
  - Bond strength
  - Wear (ASTM G133, ASTM F1978)

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