High Velocity Oxy-Fuel Thermal Spray technique for Durable Coating

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Introduction - HVOF
Thermal Spraying Techniques

- Coating processes in which melted (or heated) materials are sprayed onto a surface
- Can provide thick coatings (20 micrometers to several mm)
- Available materials include metals, alloys, ceramics, plastics, composites
- Fed in powder form, heated to a molten or semi-molten state and accelerated towards substrates in the form of micrometer-size particles
Project Objectives

- To develop a modular HVOF Thermal Spray hardware to systematically study combustion chamber design, injector configurations, nozzle design, mixture ratio, gas flow rate, combustion chamber pressure, particle size, and position of substrate on the quality of Inconel and Fe-Al coatings.
  - LO$_2$/CH$_4$ Heritage Rocket Engine Technology
  - High-temperature tolerance, thermo-mechanical, thermo-chemical, and fracture toughness of the coatings
- Possibly Extend the operation to cryogenic and storable liquid fuel and oxidizers.
Student Team

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Project plan

Year 1: Design analysis Hardware development (Completed)
Year 2: Parameter testing Initial Coating (Completed)
Year 3: Coating optimization characterization (Ongoing)
Requirement Overview

- Deep throttle capability (4:1)
- Maximum exit Mach number: 1.4
- Exit temperature: 2000-3000 K
Requirement Overview

- **Five Modular** Sections:
  - Injection system
  - Combustion chamber section
  - Converging-Diverging Nozzle
  - Barrel section
  - Cooling jacket
Technical Approach - Injector

Shear coaxial injection configuration
Technical Approach – Nozzle

- De Laval conical nozzle accelerates gases to supersonic speeds
- Addition of barrel section allows for smooth particle integration into the flow
Ethylene glycol combination fluid allows for effective heat removal.

- Design allows coolant flows of up to 33 LPM.
- Configuration acts as a heat sink when testing for short durations.
Technical Approach - Products

Vent enclosure ensures proper disposal of products/particles

Fire blankets are placed around setup exhaust for added protection
System Layout
System Layout

- Cooling
- Particles
- Oxidizer
- Fuel
Operational Optimization

- Low output velocities presented stable flame in all ignition configurations
- High velocity approach required additional experimentation
- Outside torch ignition yielded instabilities
- Spark ignition configuration was optimized to avoid hard starts
Test Conditions

- CH₄+O₂ mixture
- Oxidizer to fuel ratio = 3.5
- Distance to substrate = 50-150 mm
- Test Duration = 2-5 seconds
- Inconel 718, FeAl particles tested
- Exit Temperatures = 2980 K – 3020 K
- Exit Velocities = 938-1400 m/s

Premixed flame in supersonic conditions
Coatings

Fe-Al samples generated at a distance of 100 mm

Substrate positioning/holding in experimental setup

Mach 1.2

Mach 1
Coatings

Unoxidized  600 C  700 C  900 C
Coatings

- Operational Parameters
  - Studied
    - Exit velocity
    - Distance to substrate
    - Coating material
  - To be studied
    - Propellant composition
    - O/F ratio

- Testing Methods
  - Exposure - Furnace thermal treatment, high pressure combustion
  - Imaging – Scanning Electron Microscopy
  - Composition – X-Ray Diffraction
  - Mechanical Testing – Nanoindentation
SEM imaging (Inconel 718, 100 mm to substrate)

UNOXIDIZED

600 C

900 C
SEM imaging (900°C)
High crystallization shown at increased oxidation states where amorphous structure is shown as initial.

- Grain growth at high temperatures implies evaporation and restructuring of coating components.
- Nanoindentation preliminary testing shows decrease in hardness, Young’s modulus in oxidized samples.
- Additional analysis will be performed to compare operational parameters, coating materials.
Year 3 plan

- Sample testing completion
- Test matrix refinement and testing
- Development of liquid-fuelled system
Publications


Thank You

Questions?