Microstructure, Processing, Performance Relationships for High Temperature Coatings

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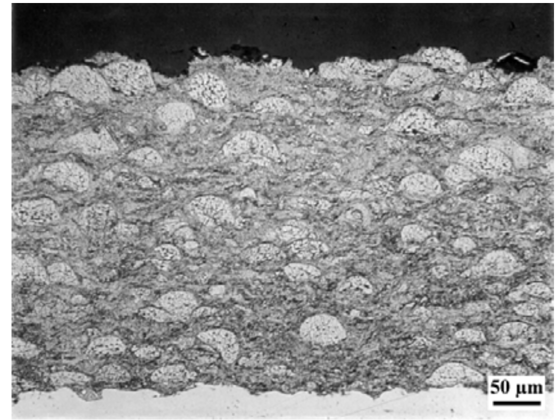
INL

Introduction

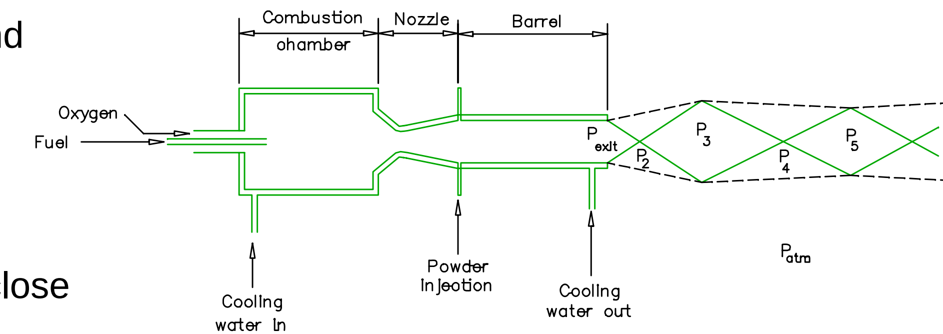
- **Research goal: understand relationships between *coating processes*, *coating characteristics*, and *coating performance***
- **Coating types:**
  - HVOF Fe_3Al, (alumina former)
  - HVOF 316SS (model alloy)
- **Substrates:**
  - Low-alloy ferritic steels
  - Advanced ferritic-martensitic steels (e.g. Grade 91)
  - Austenitic stainless steels
  - Ni-base alloys (e.g. alloy 600 or 617)

Past Results

- Thermal spray parameters can be used to generate highly dense coating with varying levels of residual stress
- Residual stresses in coating arise from three sources
  - CTE mismatch between coating and substrate
  - Quench stresses
  - “Peening” stress
- Corrosion resistance of coating is very close to wrought material
- Coating failure governed by cracking and delamination



Fe_3Al Coating



High-Velocity Oxy-Fuel (HVOF) thermal spray

- Equivalence ratio (phi)- $\Phi = \frac{Fuel/Oxygen}{(Fuel/Oxygen)_{Stoich}}$
- Combustion chamber pressure

  P_C – *Determined by total mass flow of* O_2 *and fuel*

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Current Project Focus

Goal:

Determine factors affecting the mechanical stability of HVOF thermal spray coatings

Tasks:

- Refine methods for detecting cracking in coatings
- Characterize the influence of thermal spray parameters on the mechanical stability of coatings
- Determine the influence of substrate properties on coating durability
- Define coating failure

Parameters of Interest

Objective: Identify parameters that result in adherent, high-durability coatings

- Materials parameters
  - CTE difference between coating and substrate
  - Microstructure stability
- High-Velocity Oxy-Fuel (HVOF) thermal spray parameters
  - Chamber pressure – particle velocity
  - Fuel/oxygen ratio – particle temperature
  - Substrate temperature during spraying – standoff distance, traverse speed, preheat/active cooling
  - Coating thickness - # of passes

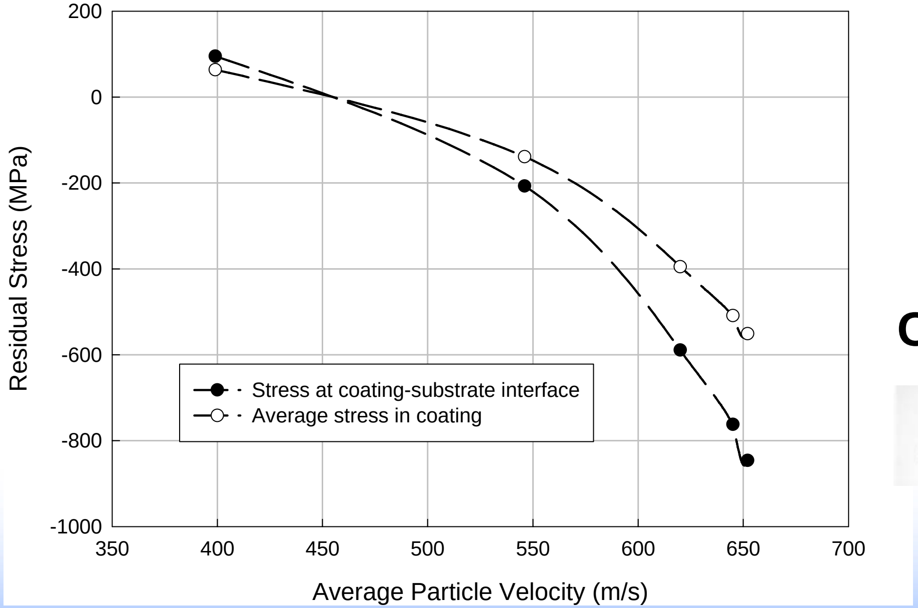
Control of Residual Stress

Total = Quench + CTE + Peening

Quench	CTE	Peening
- Substrate temp. - Particle temp. - CTE of particle	- Coating CTE - Substrate CTE - Processing temp.	- Particle hardness - Particle velocity - Particle mass

TENSILE

NEUTRAL



COMPRESSIVE

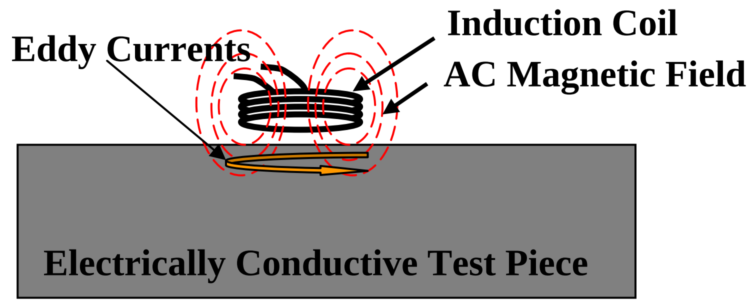
Materials Systems of Interest

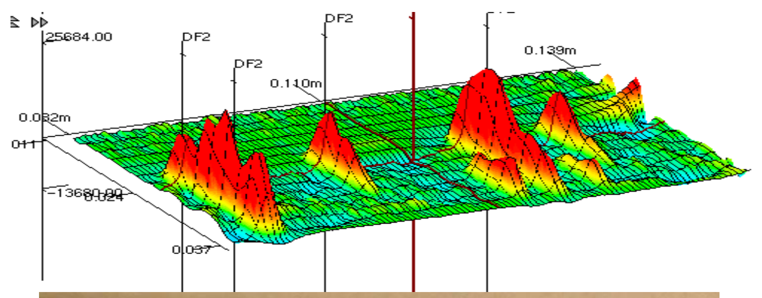
- Coating materials – alumina formers
  - Fe_3Al
  - FeAl

- Substrate materials
  - Carbon Steel
  - Low-alloy ferritic steels
  - Advanced ferritic-martensitic steels (e.g. Grade 91)
  - Austenitic stainless steels
  - Ni-base alloys (e.g. alloy 600 or 617)

Coating Durability Tests

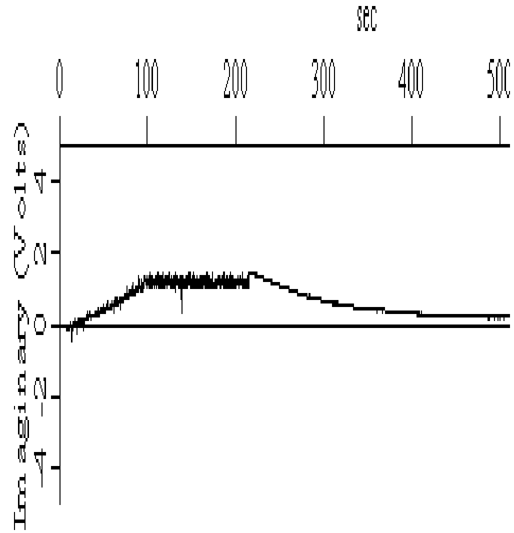
- Coating failure resulting from thermal cycling
  - Optical methods
    - Visual – dye penetrant examinations
    - Metallographic methods
  - Real time crack detection using eddy current methods
- Room temperature coating strength/ductility – tensile testing
  - Acoustic emission
  - Eddy current methods

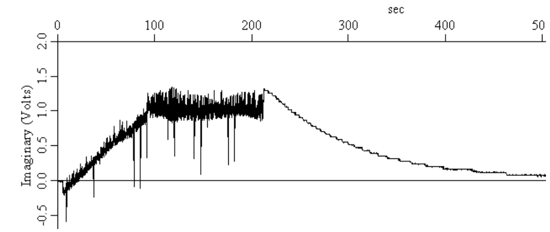


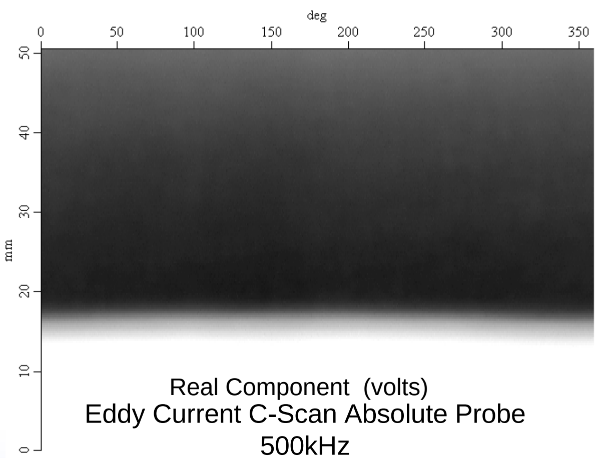


Eddy Current Response During Thermal Cycling

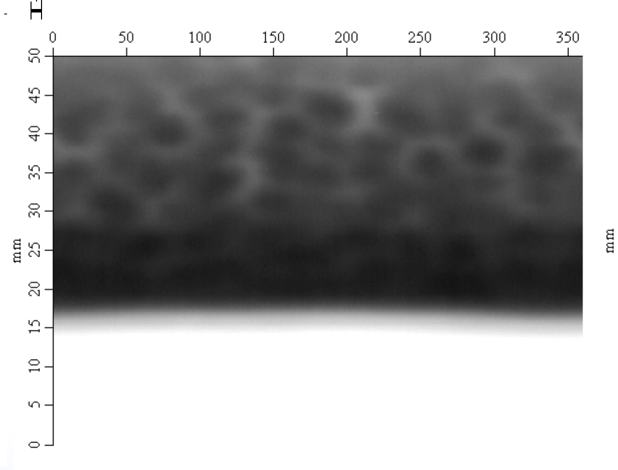
FeAl Coating on Carbon Steel - Thermal Cycle (Room Temp. - 700º C)



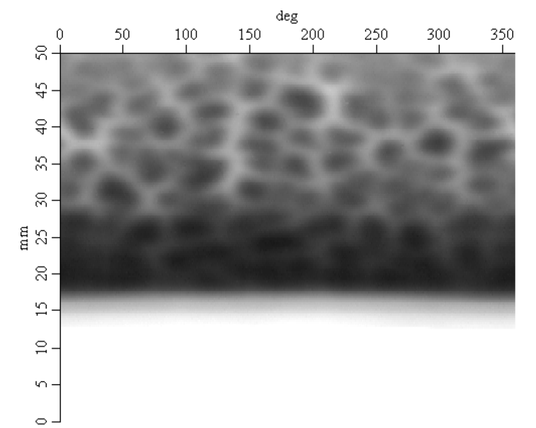




As-sprayed

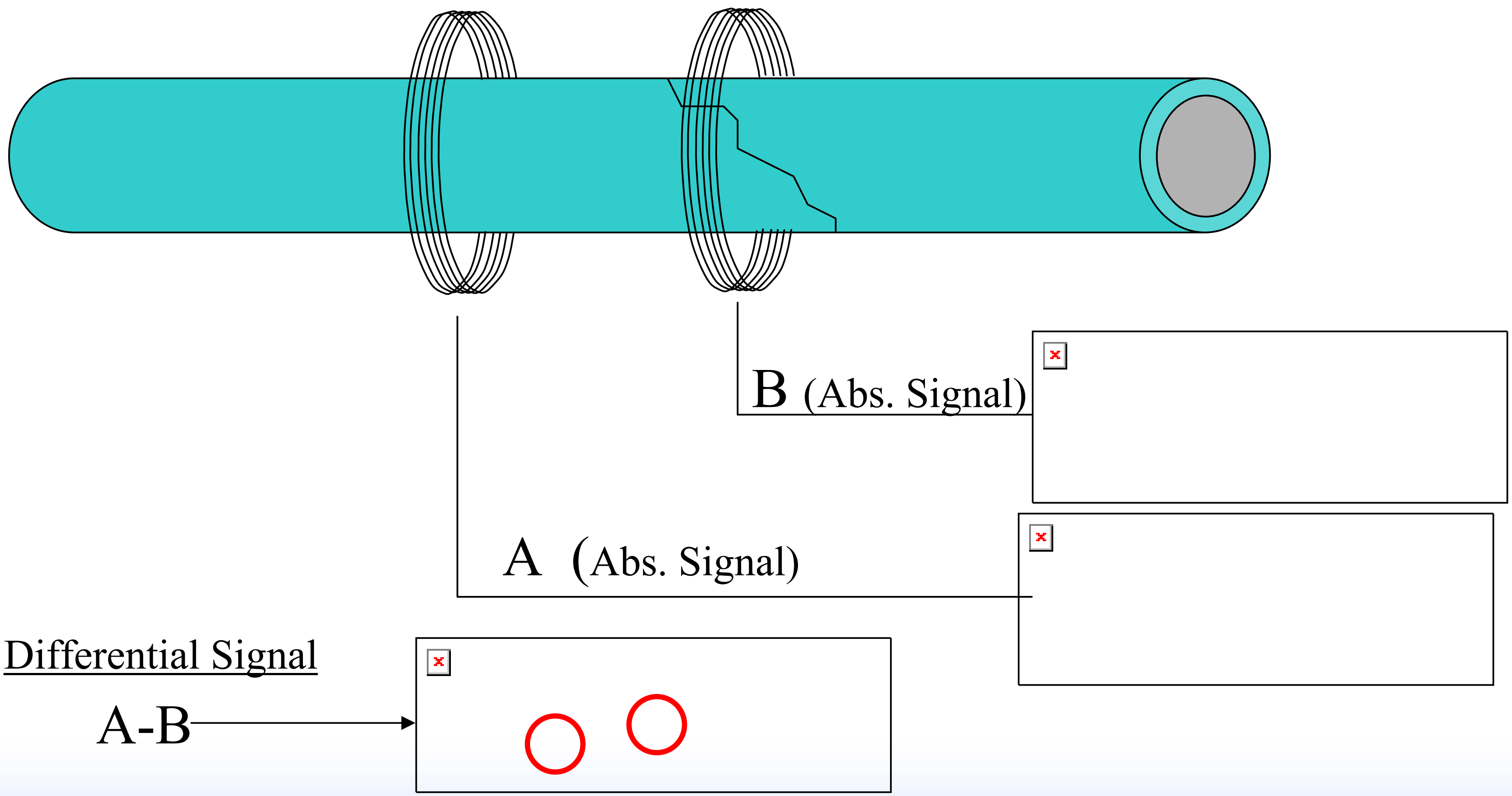


1 Thermal Cycle

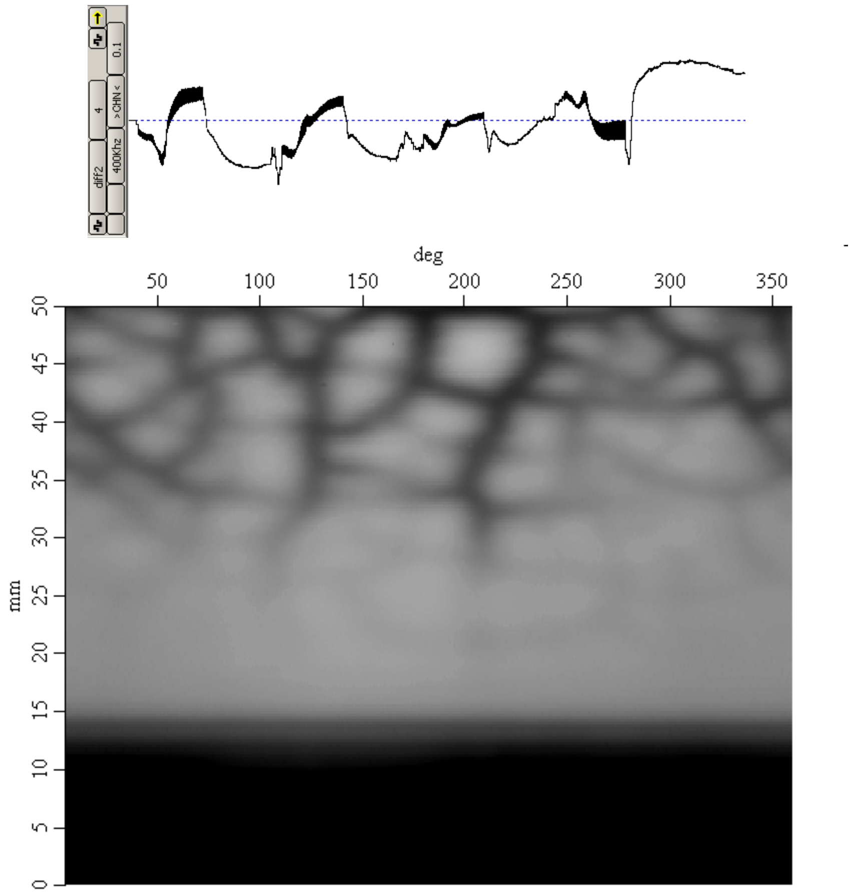


2 Thermal Cycles

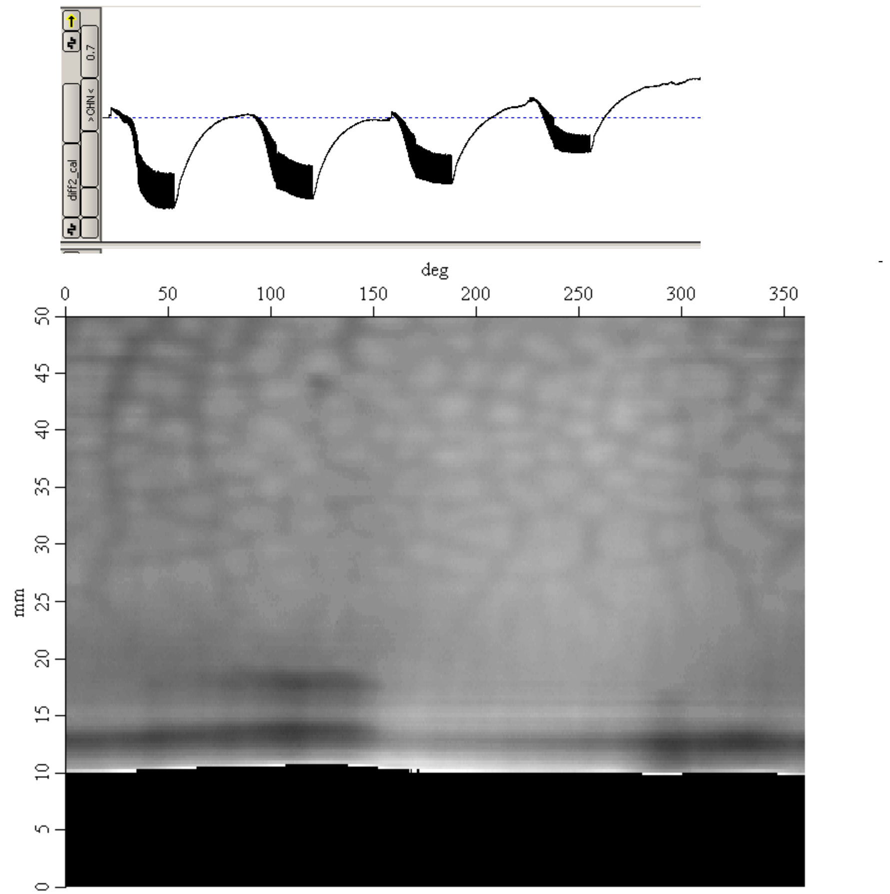
Dual Eddy Current Coils



Fracture Behavior – FeAl Coatings on CS



Thick Coating- 250 μm



Thin Coating- 160 μm

Cycle Temperature = 700^{o}C

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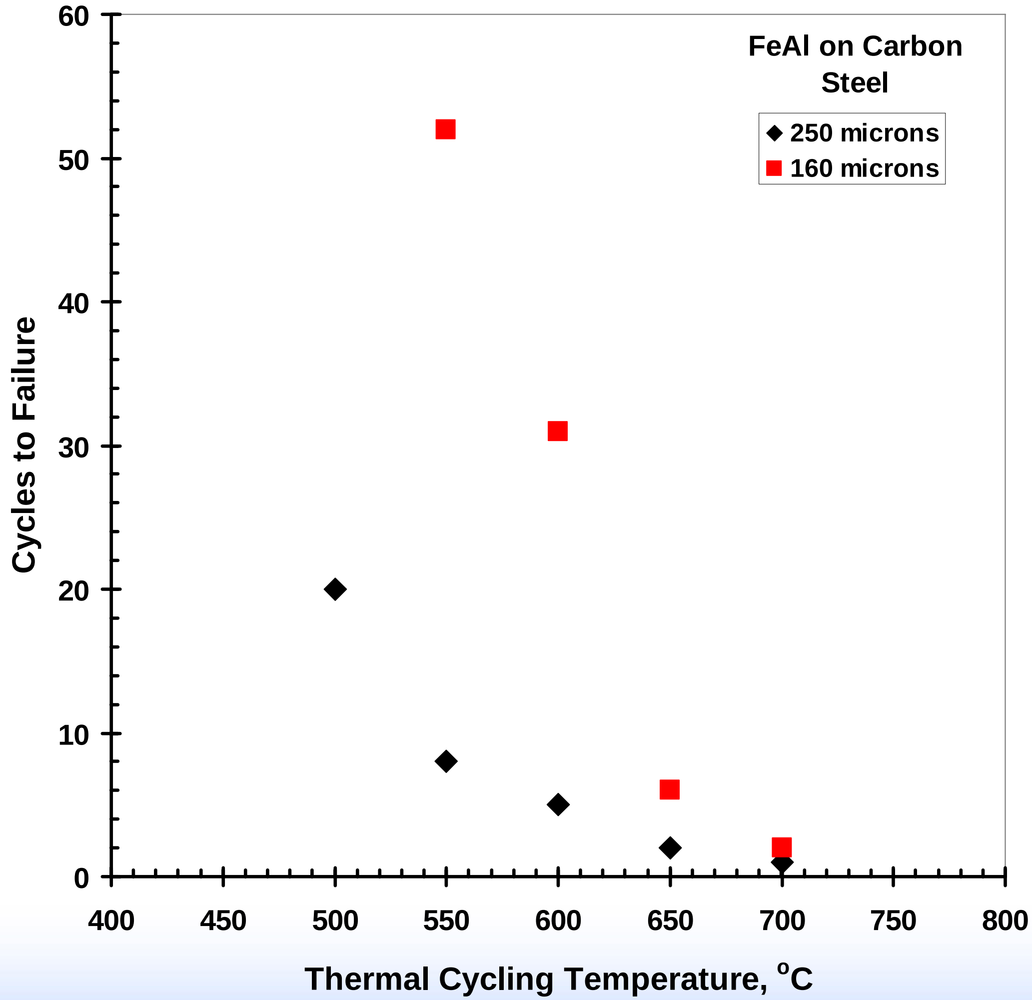
Effect of Cycle Temperature on Coating Failure

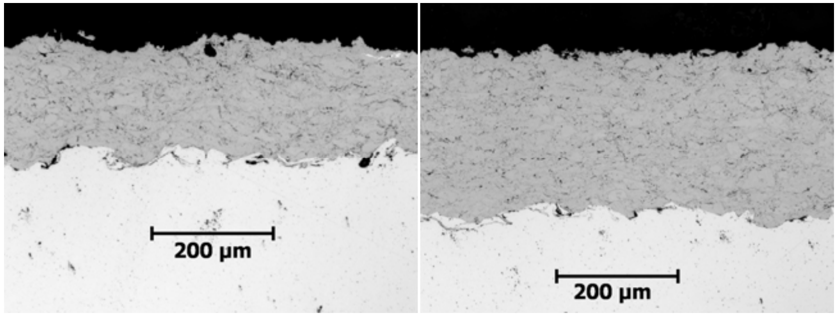


<u>Possible explanations</u>

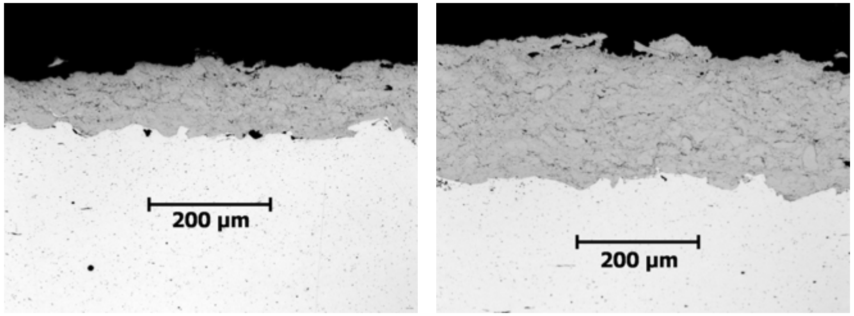
- More defects in thick coatings
- Higher stresses in thick coatings
- Different substrate temperature during deposition – more passes higher temperature

Thermal Cycling – Dye Penetrant Exams

- HVOF coatings (FeAl) on thick plate
  - Grade 91 steel, ¾” thick
  - Carbon Steel (1018), ½” thick
- EDM cylinders ($^{5}/_{8}$” diameter) from the coated plates
- Thermal cycle in CM Rapid Temperature Furnace
- Periodically examine coatings using dye penetrant
- Multiple samples under identical conditions



Grade 91 Steel

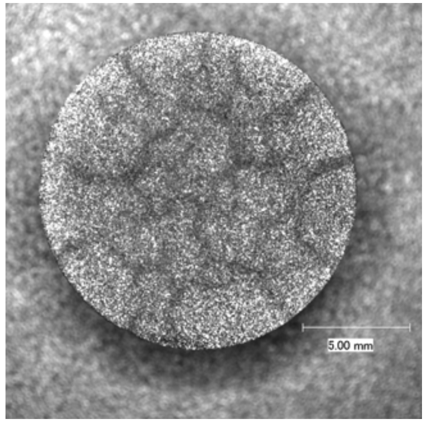


Carbon Steel (1018)

Furnace Cycling – Preliminary Results

Grade 91 – 250 µm

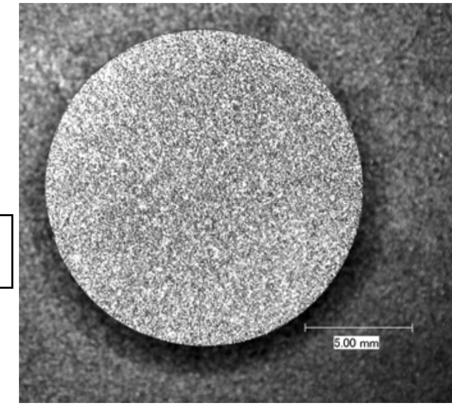
CTE – 11 µm/m°C



4 cycles

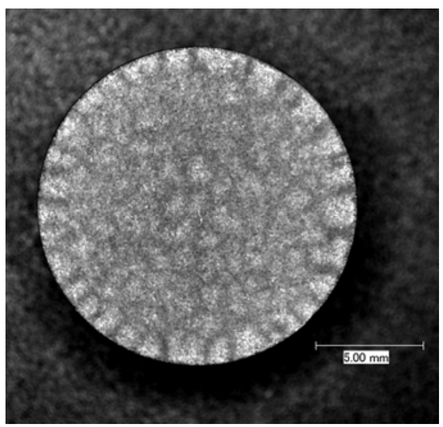
Carbon Steel – 250 µm

CTE – 14 µm/m°C



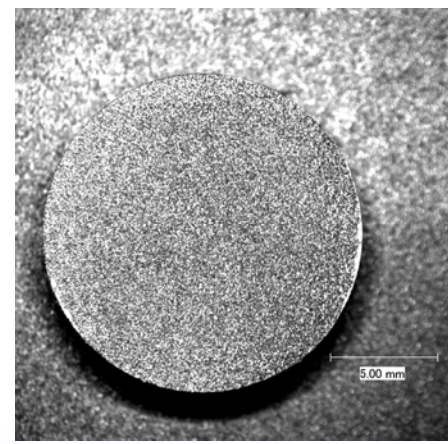
42 cycles

Grade 91 – 160 µm



10 cycles

Carbon Steel – 160 µm



42 cycles

FeAl Coating

CTE – 23 µm/m°C

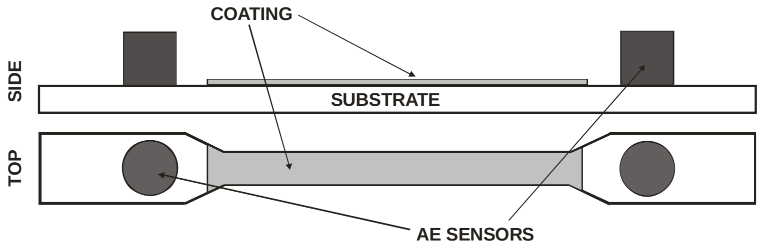
Cycle Temperature = 480°C

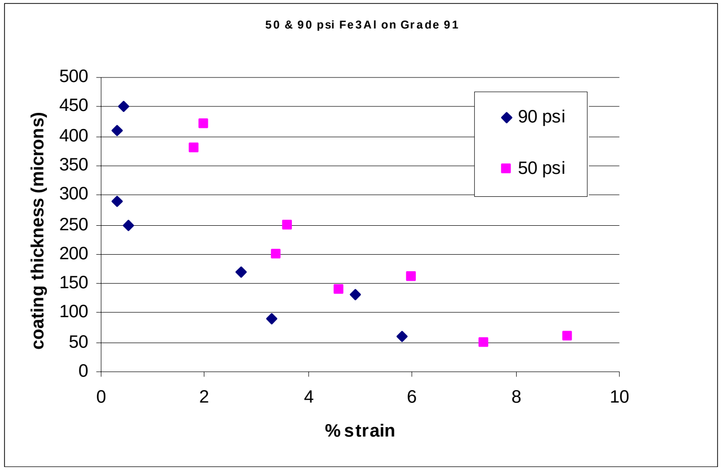
Issues of Interest

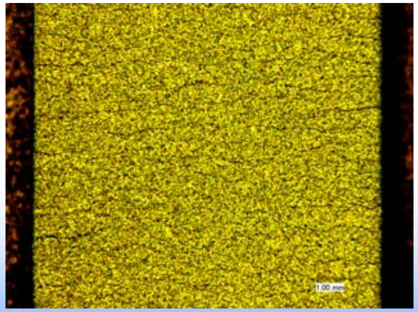
- Substrate temperature during deposition - affects stress state during thermal cycling
- HVOF parameters that affect CTE of coating – can we tailor the coating CTE to match the substrate?
- Model cracking patterns, coating thickness and defect population – relate to HVOF parameters

Previous Coating Fracture Tensile Testing

- Coating strain to fracture measured using acoustic emission monitoring
- 500 µm coatings applied to dogbone-shaped tensile specimen substrates
- Two AE sensors attached to each end of substrate near grips
  - Used to locate events within coated gage section
- Coating cracking produces clear AE signals for thick coatings
- Crack initiation appears to be at stress concentrator at 90° edge







Current Direction in Coating Fracture Tensile Testing

- Round tensile samples
  - Uniform diameter
  - Reduced diameter gage section
- Crack detection using eddy current –
  - Dual coil method – differential signal
  - Need to detect hoop cracks

Project Status/Milestones

By the end of FY09 we will:

- **Complete the study on the influence of HVOF parameters on cracking resistance**
  - √ **Developed techniques to identify cracking of coatings**
  - – **Currently investigating FeAl coatings on carbon steel and grade 91 steel substrates**
  - – **Applying HVOF coatings of Fe_3Al to CS, grade 91, 316 SS and Inconel 600**
- **Complete the study of HVOF parameters on coating adhesion**
  - √ **Applied HVOF coatings to test rods**
  - √ **Designing eddy current coils**
  - – **Fabricate and test coils**
  - – **Additional HVOF coating parameters and substrates**
- **Add more conventional weld overlay coating to the testing matrix**