Microstructure, Processing, Performance Relationships for High Temperature Coatings

High Temperature Corrosion Behavior of HVOF, Fe_3Al Coatings

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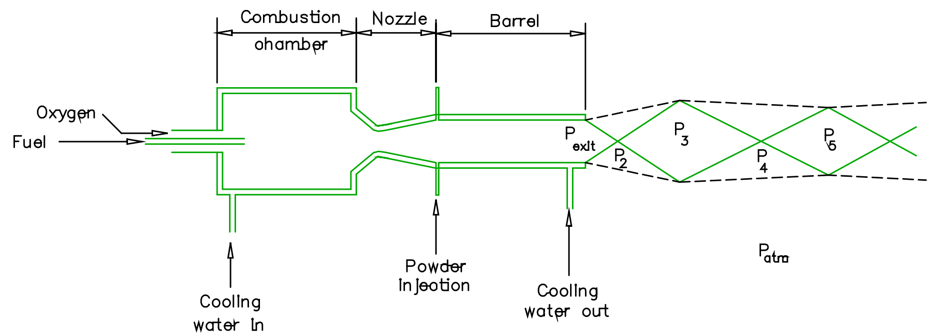
Goals of the Program

Develop Fe_3Al coatings for high temperature service in fossil fuel environments

- Develop High Velocity Oxy-Fuel (HVOF) thermal spray techniques for applying the coating
- Understand factors and thermal spray parameters that affect the reliability of this coating
- Verify the corrosion resistance of the HVOF coatings in simulated, fossil fuel, combustion environments:
  - High temperature, gaseous corrosion behavior
  - Corrosion behavior in the presence of simulated ash
- Demonstrate repair of HVOF, Fe_3Al coatings

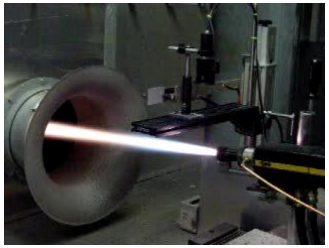
Past Results

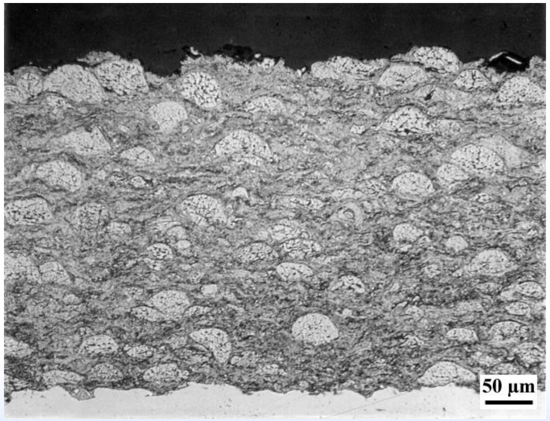


High-Velocity Oxy-Fuel (HVOF) thermal spray

- 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
- Substrate surface preparation is critical in coating adherence
- Higher HVOF combustion chamber pressures result in better resistance to thermal cycling

- Equivalence ratio (phi)- $\Phi = \dfrac{Fuel/Oxygen}{(Fuel/Oxygen)_{Stoich}}$
- Combustion chamber pressure
  P_C – *Determined by total mass flow of* O_2 *and fuel*





Fe_3Al Coating

Current Project Focus

Goal:

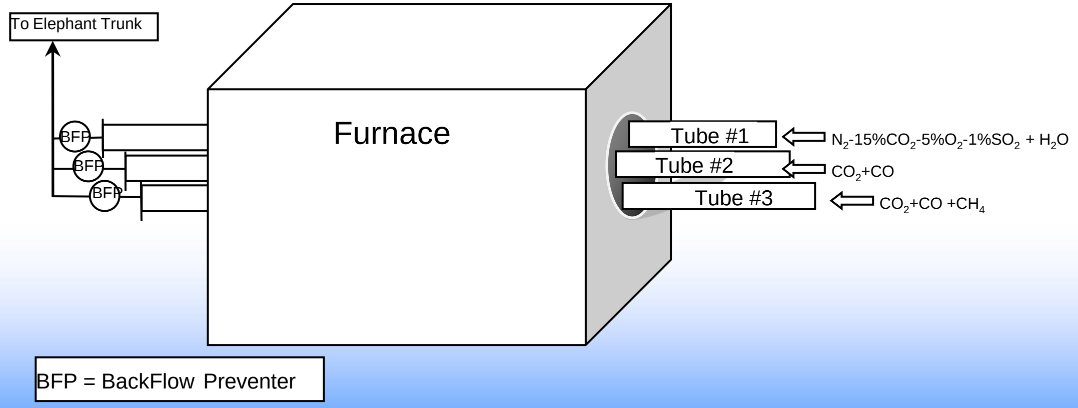
Determine the corrosion/oxidation behavior of HVOF thermal spray coatings

Tasks:

- Oxidation behavior of free standing HVOF coatings in dry and "wet" air
- Corrosion behavior of free standing coatings in simulated fossil fuel combustion atmospheres (N_2-15CO_2-5O_2-1SO_2 + 10-20% H_2O)
- Degradation behavior in carbon-containing atmospheres – CO_2/CO and CO_2/CO/CH_4 mixtures
- Long term aging to assess interdiffusion potential and coating degradation
- Comparison of HVOF, Fe_3Al coatings to weld overlay coatings.

Coating Degradation Testing in Various Atmospheres

- Air – dry and "wet"
- Simulated fossil fuel, combustion atmospheres –
  - Dynamic / once through gas flow
  - N_2-15CO_2-5O_2-1SO_2 + 10-20% H_2O
- Oxidizing – control of p_{O_2} through the CO/CO_2 ratio
- Carburizing - CO_2/CO/CH_4 mixtures to control the carburization potential



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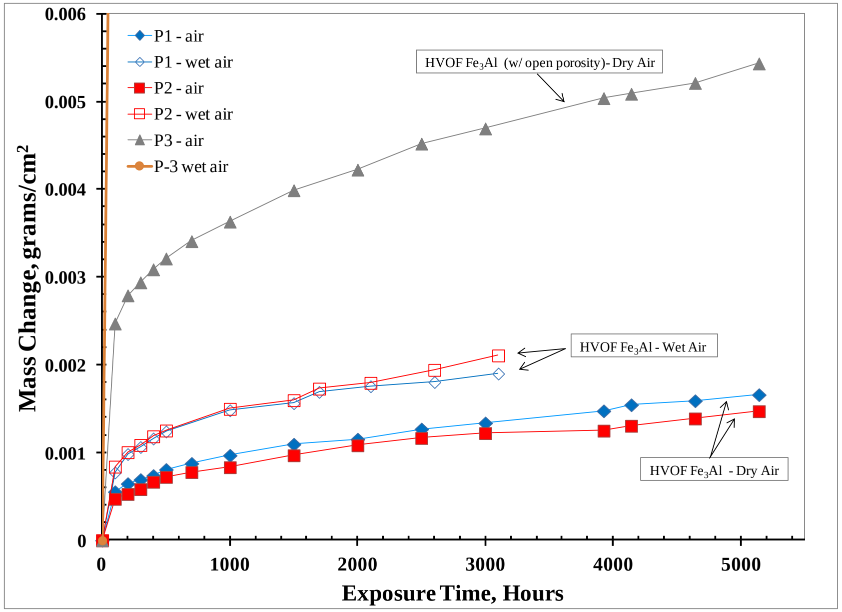
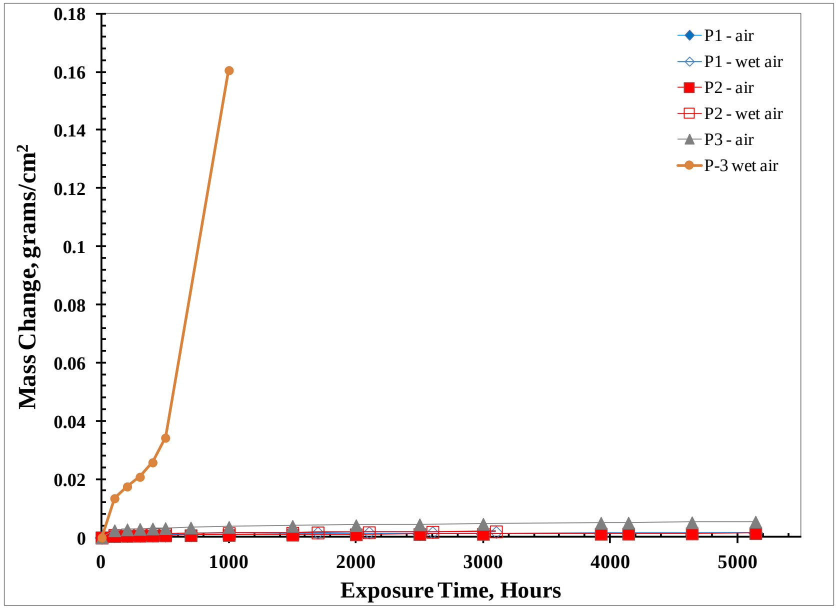
Oxidation of Free Standing HVOF, Fe_3Al Coatings – 1000°C





- Dense HVOF coatings exhibit very low corrosion rates in both dry and “wet” air at 1000°C
- Oxidation rate in “wet” air is higher than in dry air.
- P-3 exhibited high oxidation rates and contained open porosity – P-1 and P-2 did not contain open porosity.

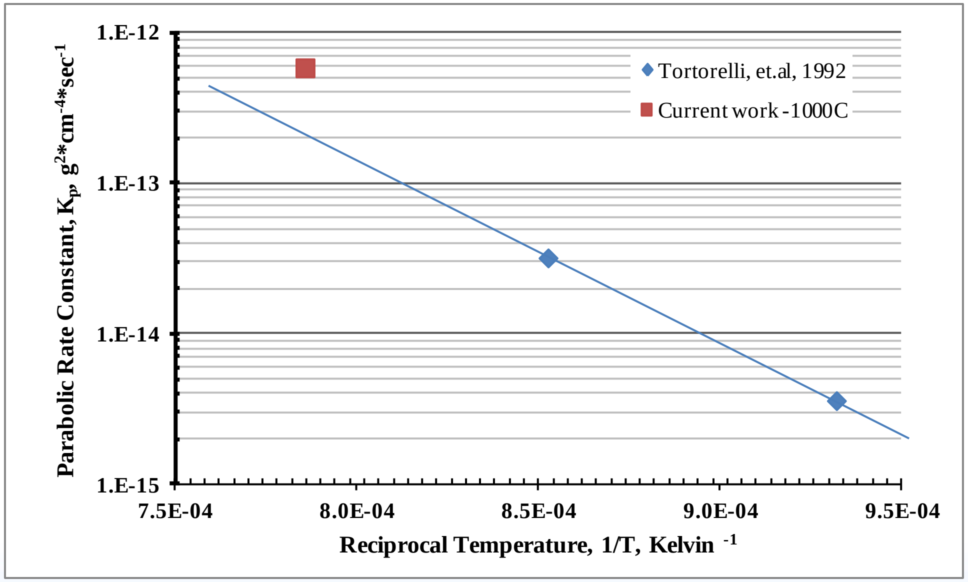
P-1: P_c=0.6 MPa	P-2: P_c=0.7 MPa	P-3: P_c=0.3 MPa

Parabolic Rate Constant for Oxidation

Temperature = 1000°C	Parabolic Rate Constant*, g^2/cm^4s			
Atmosphere	HVOF Fe_3Al – P_c=0.6 MPa	HVOF Fe_3Al – P_c=0.7 MPa	HVOF Fe_3Al – P_c=0.3 MPa	I-600 base metal
Dry air	$1x10^{-13}$	$1x10^{-13}$	$1x10^{-12}$	Not evaluated
Wet air	$3x10^{-13}$	$3x10^{-13}$	$4x10^{-10}$	$2x10^{-11}$

*Parabolic rate constants determined from plots of mass $(change/area)^2$ versus time

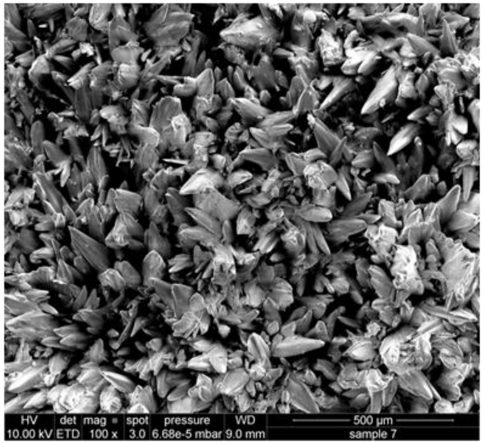
- Oxidation of HVOF, Fe_3Al coatings in dry air are comparable to literature
- Activation energy for oxidation is close to that for alumina formation



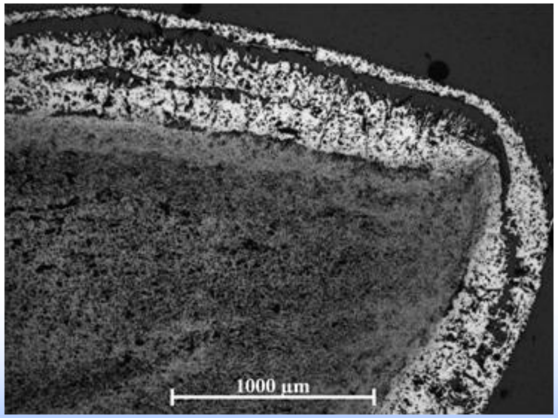
Calculated by the method of Tortorelli, et. al, 1992 at 200 hrs of exposure – dry air, bulk Fe_3Al.

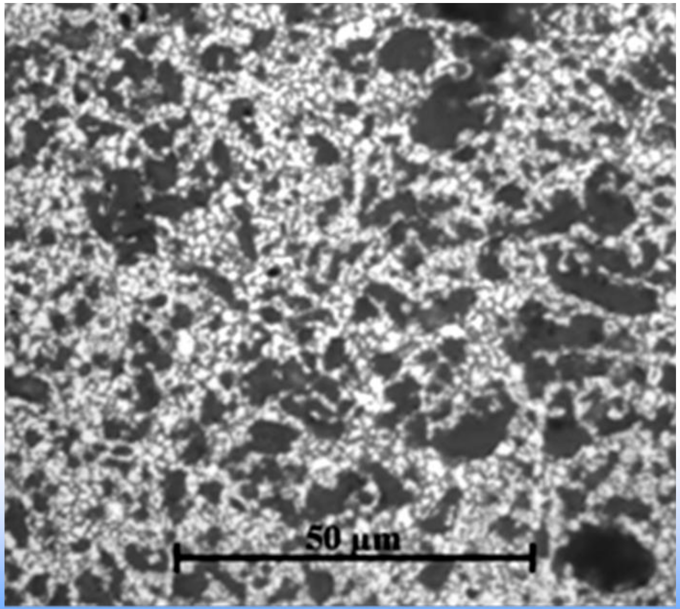
Breakaway Oxidation in P-3

- Surface reaction product is iron oxide
- Coating interior is highly fractured
- Oxidation of open porosity resulted in volume change and fracturing of coating, resulting in further oxidation



Element	Wt %	At %
O K	14.33	36.67
AlK	00.65	00.99
CrK	00.52	00.41
FeK	84.49	61.93





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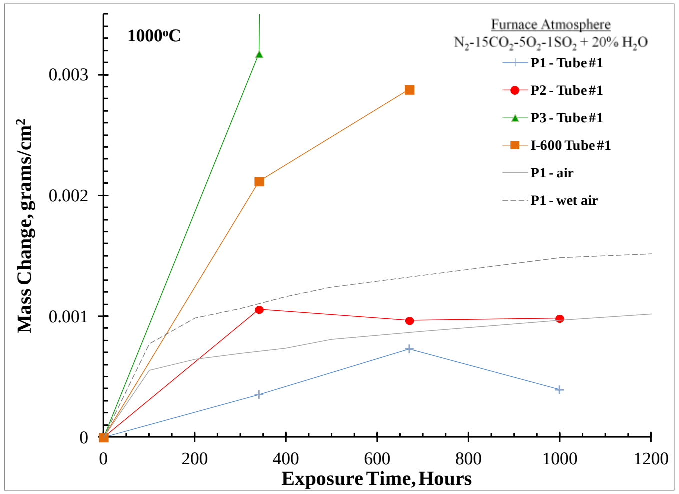
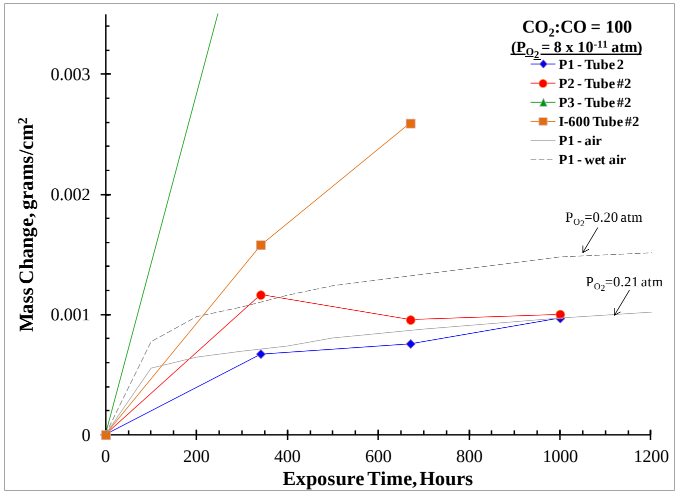
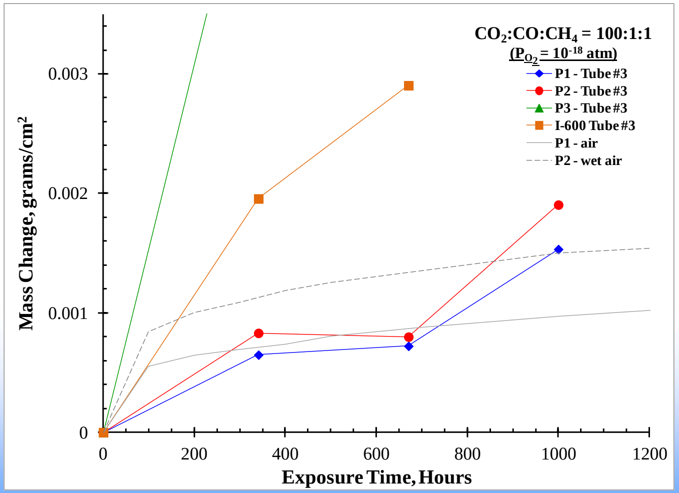
Simulated Combustion, Oxidizing and Carburizing Atmospheres – 1000°C







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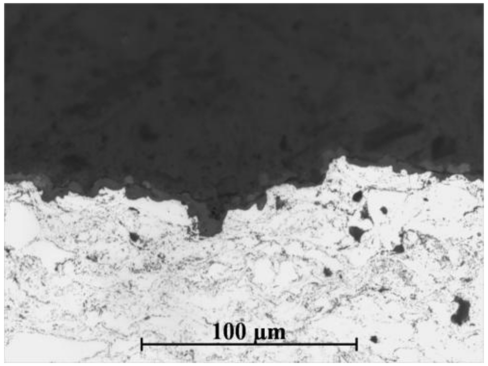
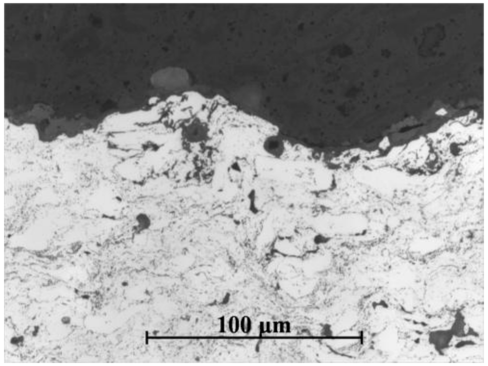
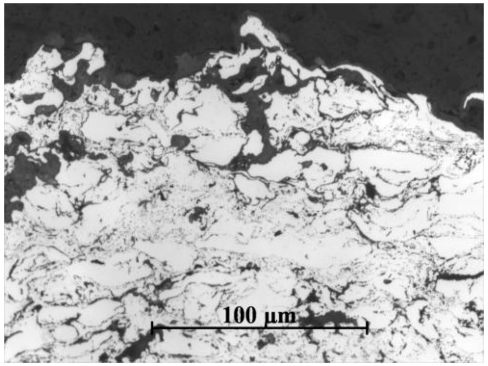
Corrosion in Simulated Fossil Fuel Combustion Atmosphere - 1000ºC, 341 hrs



P-1



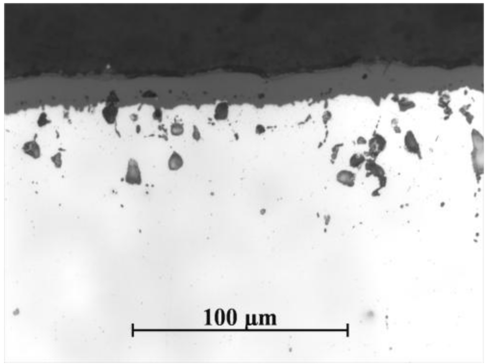
P-2



P-3

Furnace Atmosphere

N_2-15CO_2-5O_2-1SO_2 + 20% H_2O



Inconel Alloy 600

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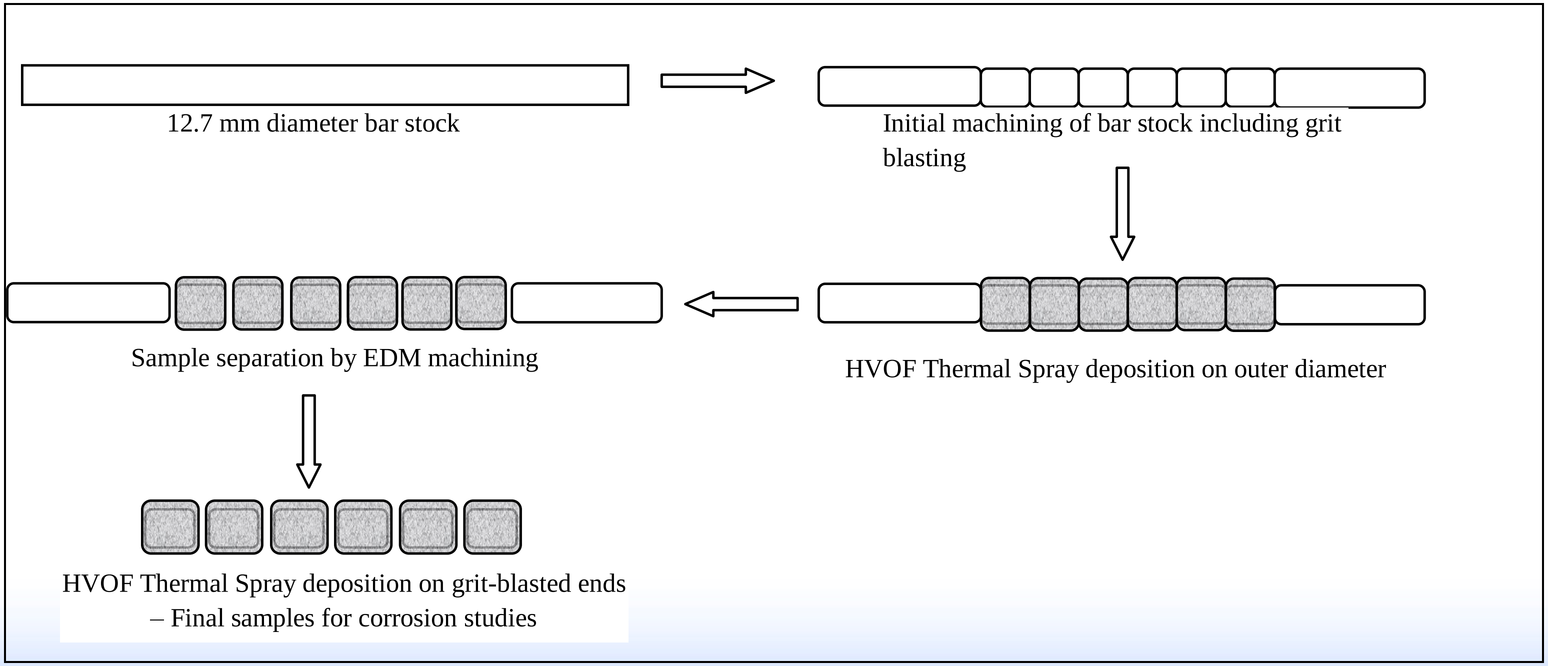
Substrate Effects – Sample Fabrication

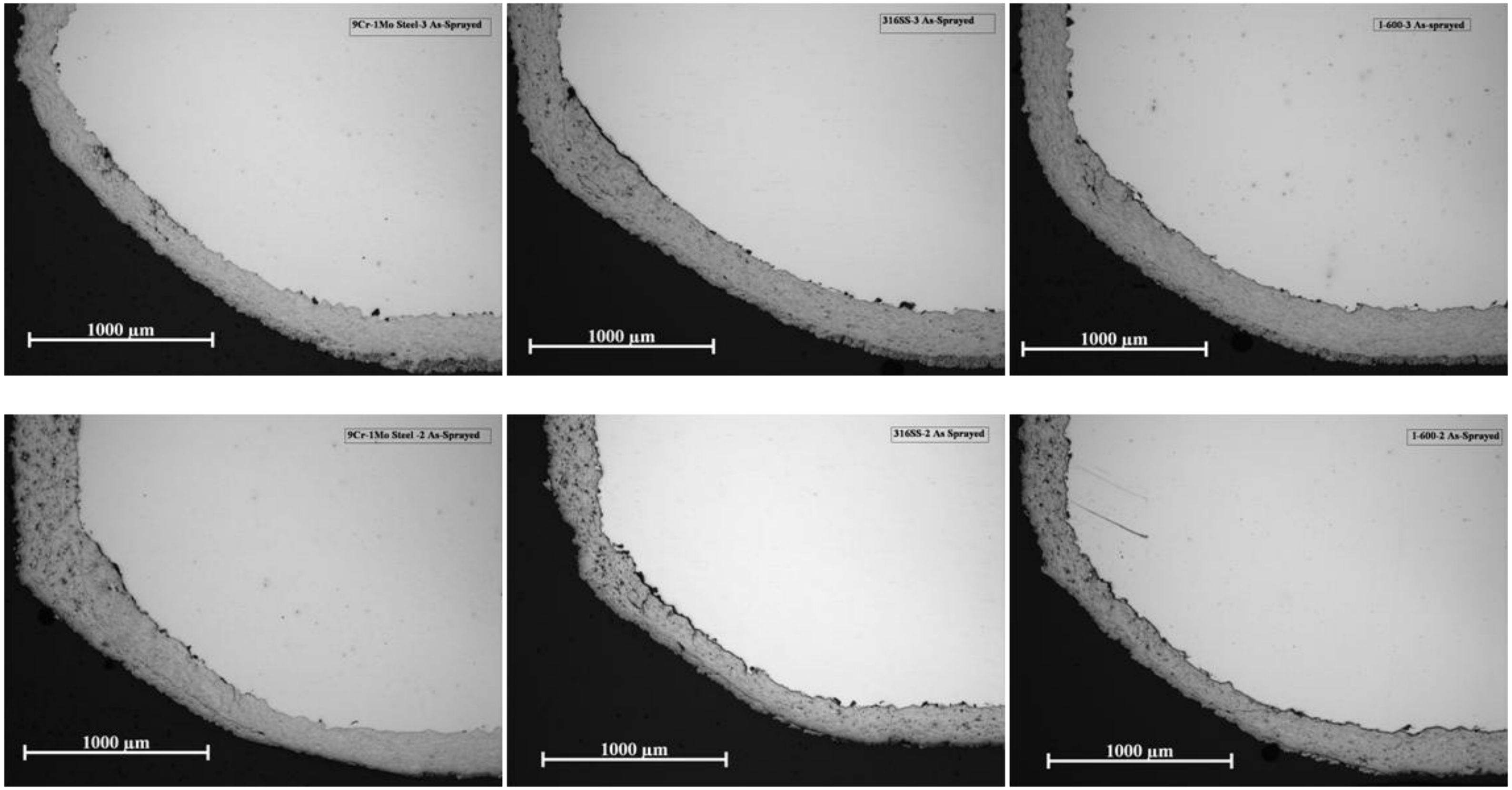
- Fully coating-encapsulated samples to assess the effects of CTE differences
- Fabrication method cannot involve harsh machining of the coating
- Sample geometry must not have sharp corners



HVOF, Fe_3Al-Encapsulated Samples - Microstructure

P_c=0.6 MPa

P_c=0.4 MPa



9Cr- 1Mo steel

316 SS

Inconel Alloy 600

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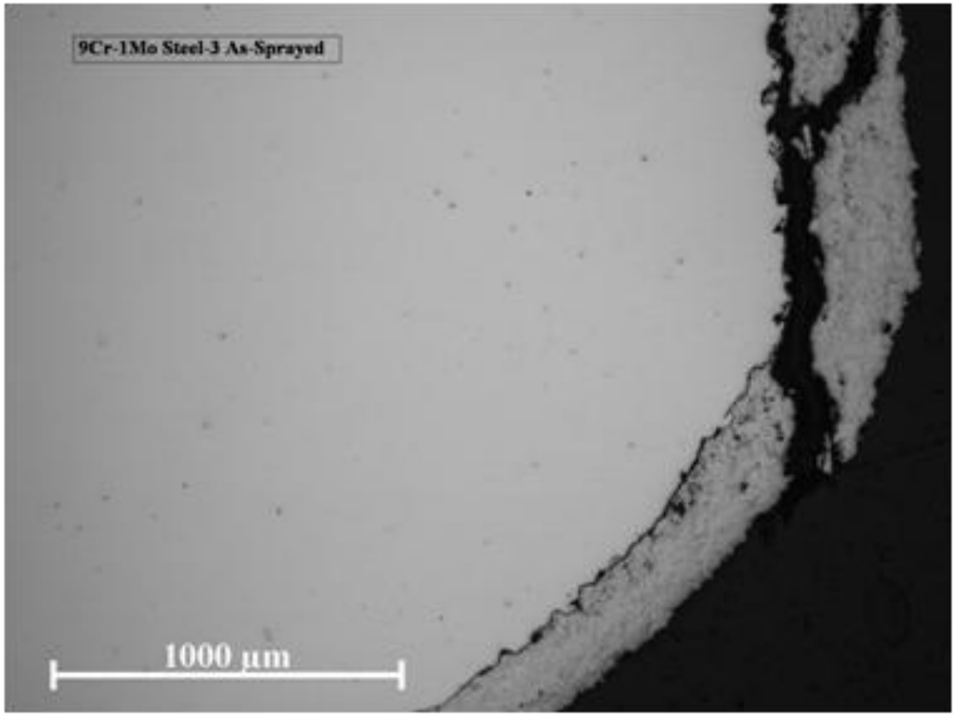
HVOF, Fe_3Al-Encapsulated Samples – Potential Defects

- Delamination and cracking of the coating occurs occasionally on the parting surface
- Possible metallography artifact



Exposure Tests for HVOF, Fe3Al-Encapsulated Samples

- Started exposure tests using encapsulated samples, uncoated base metal samples and free standing coatings
- Long term aging tests (w/ periodic mass change data) in air to assess interdiffusion – 650^{o}C for 9Cr-1Mo steel substrate and 800^{o}C for 316 SS and Alloy 600 substrates – 5000 hrs tests
- Thermal cycling in air – 800^{o}C, 4 hrs plus 500^{o}C, 15 minutes – total time at 800^{o}C to be 1000 hrs

Summary & Conclusions

- Oxidation of free standing HVOF Fe_3Al coatings is similar to oxidation of bulk Fe_3Al
- Open porosity in HVOF Fe_3Al coatings results in breakaway oxidation
- Corrosion of HVOF Fe_3Al coatings in simulated fossil fuel combustion atmospheres is similar to oxidation in air
- Corrosion/oxidation of HVOF Fe_3Al coatings is lower than Inconel Alloy 600 in the environments studied
- Currently performing long term aging tests and thermal cycling tests in air on Fe_3Al-encapsulated substrates to assess the effect of CTE mismatch on corrosion/oxidation behavior.