# HVOF Thermal Spray TiC/$TiB_2$ Coatings for AUSC Boiler/Turbine Components for Enhanced Corrosion Protection

US DOE Project Number: DE-FE0008864
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Southern Illinois University Carbondale

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Southern Illinois University Carbondale

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Gas Technology Institute, Des Plaines

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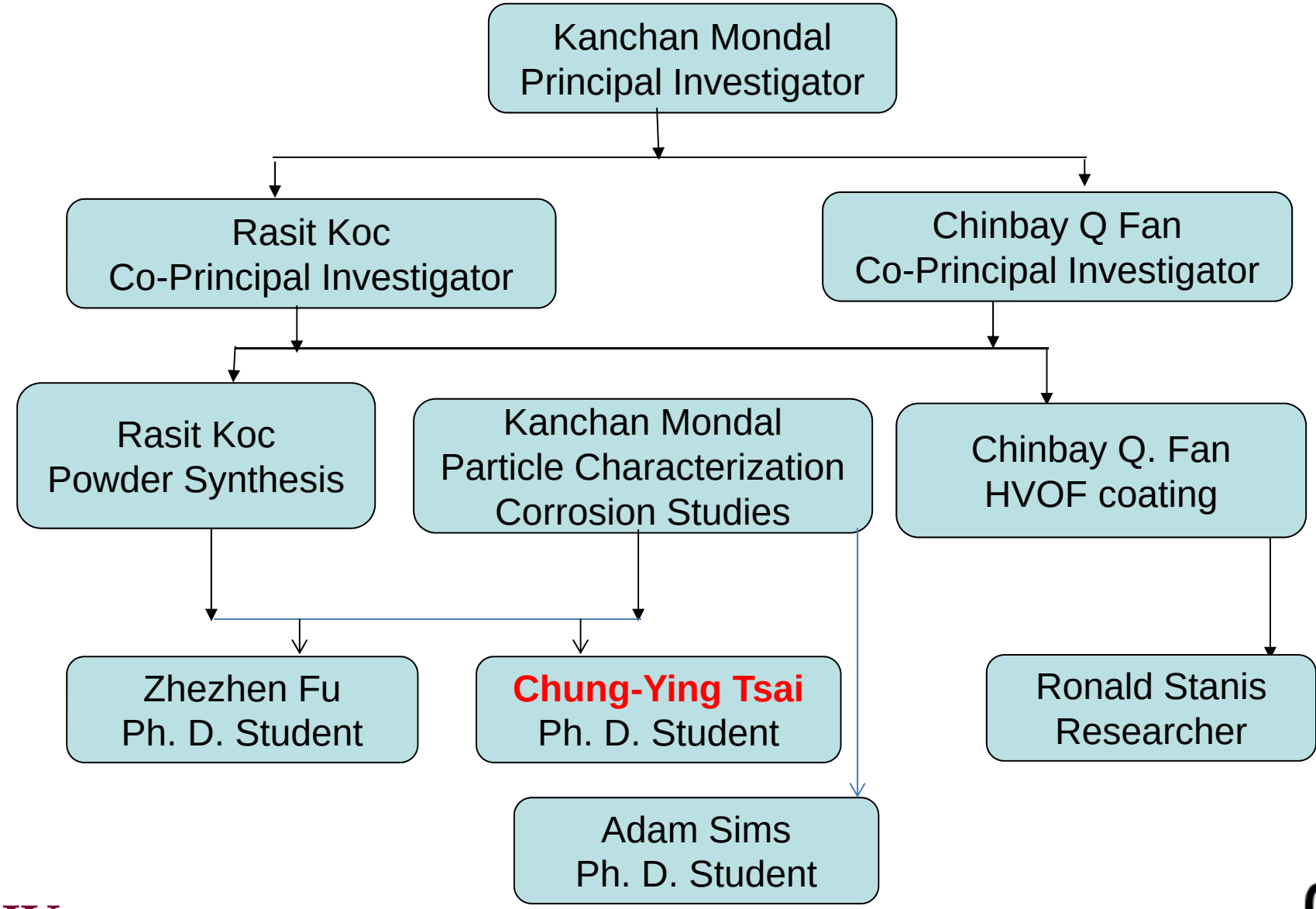
Southern Illinois University Carbondale

**2016 Crosscutting Research & Rare Earth Elements Portfolios Review**
**Apr 18-22, 2016**

SIU CARBONDALE Southern Illinois University

gti

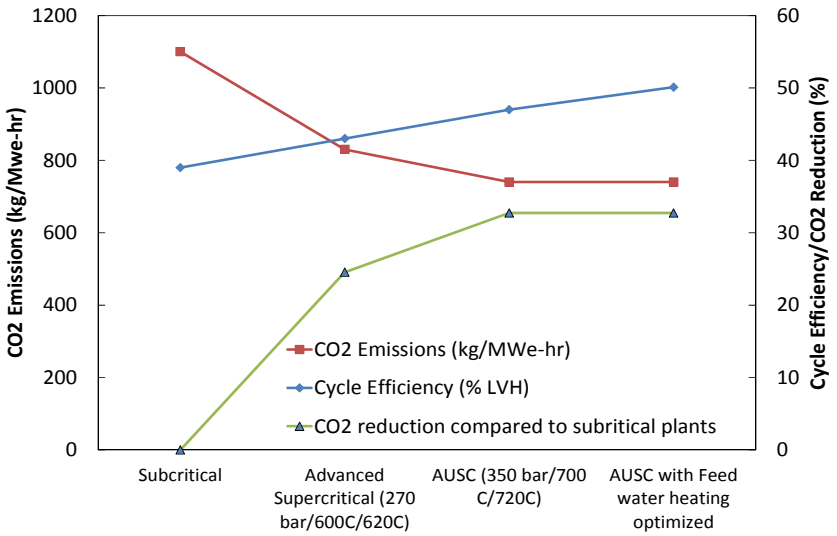
# PROJECT TEAM




# HVOF, Flame Spray Coatings

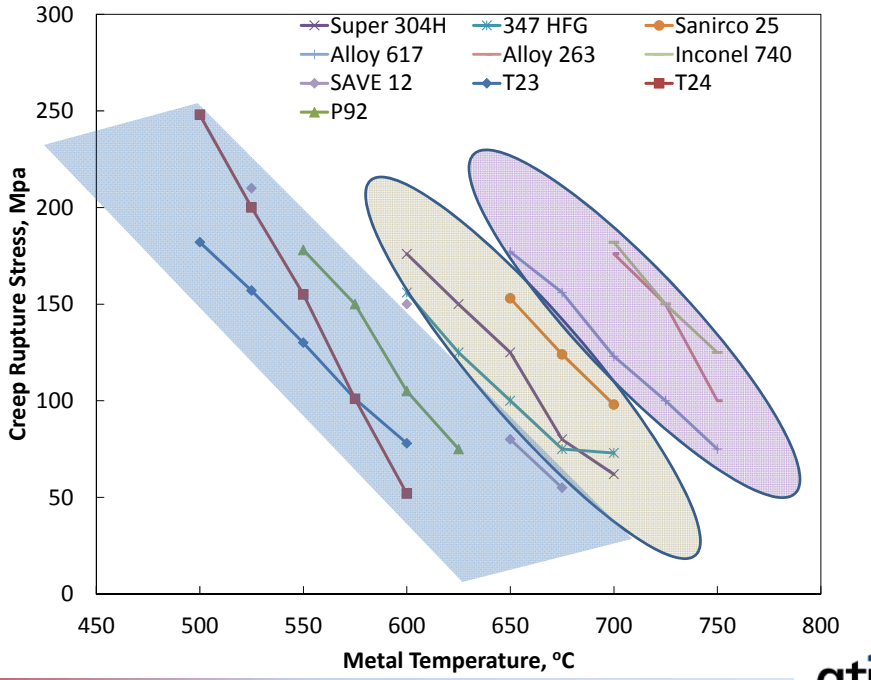
GTI project number 21397
Chinbay Fan and Ronald Stanis

# Background




- High Temperature, High Pressure, Supercritical water
- Mechanical Strength
  - Max Allowable Stress
  - Creep Rupture Stress
  - Fatigue Resistance
- Corrosion Resistance
  - Fireside Corrosion
- Thermal conductivity
- Low coefficient of expansion
- Manufacturing process issues such as weldability and fabricability

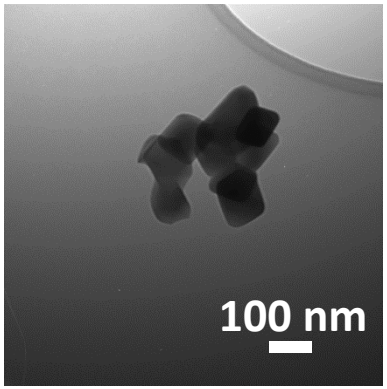
- Fire side corrosion
  - Due to molten Na/K/Fe trisulfates
  - Worst in the region of 600 – 750 °C
  - less than 600 – trisulfates are solid
  - above 750 – trisulfates vaporize
- Resistance increases with Cr content
  - 18-20 % Cr
  - Inconel 870H
  - Inconel 72
  - Inconel 671



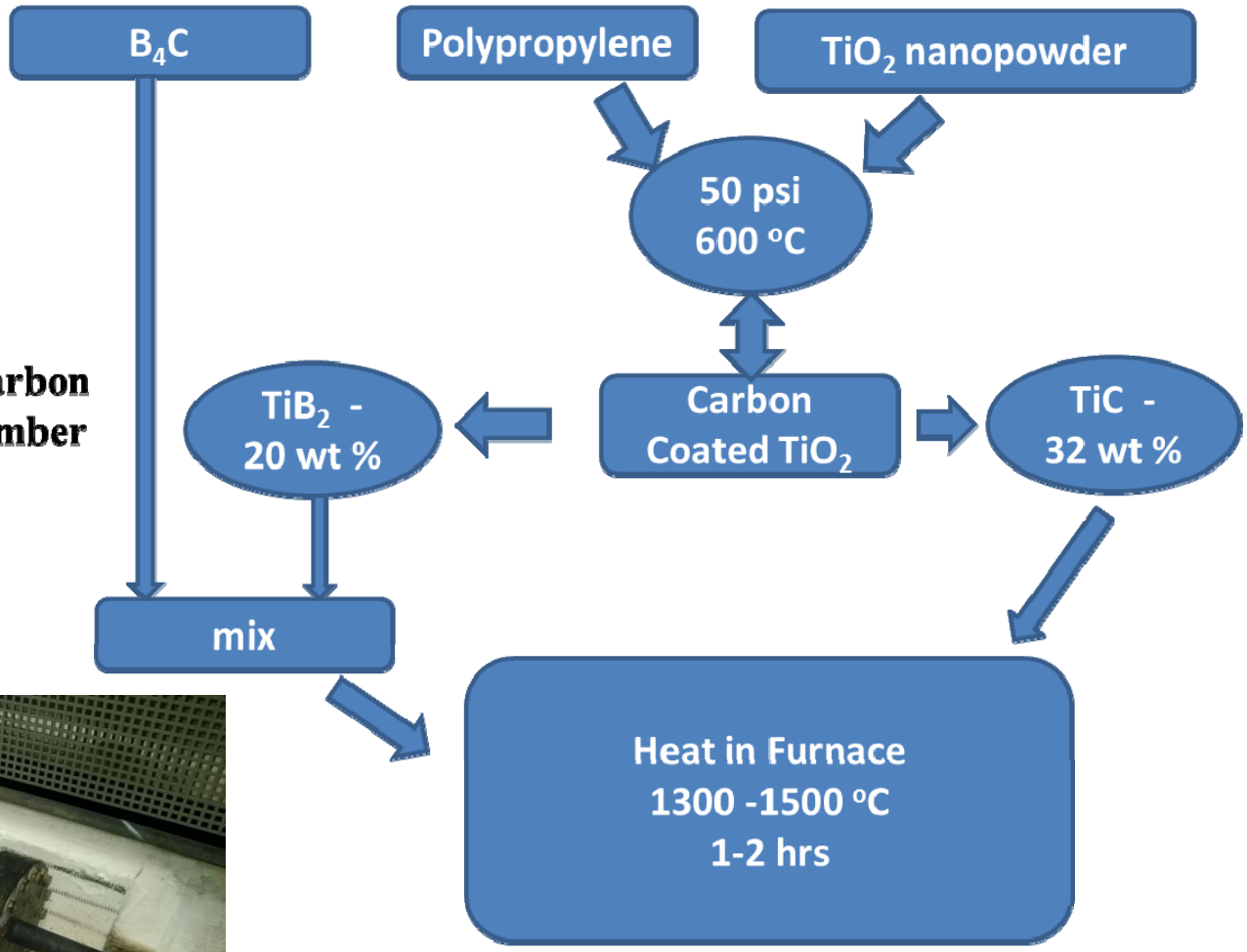
# Substrates of Interest

| | Substrate Material | Class | Applicable Component |
|---|---|---|---|
| **1** | **Super 304H** | **Austenitic** | **SH/RH tubes** |
| 2 | Sarnico 25 | Austenitic | SH/RH tubes |
| 3 | HR3C | Austenitic | SH/RH tubes |
| 4 | STD617/CCA 617 | Nickel Alloy | Tubing, HP turbine-casing, piping, rotor - 700 $^{o}$C |
| 5 | Haynes 230 | Nickel Alloy | SH tubes, HP turbine rotor – 700$^{o}$C |
| 6 | Inconel 740 | Nickel Alloy | SH tubes, HP turbine - casing, piping, rotor- 760 $^{o}$C |
| **7** | **P91/P92** | **Ferritic** | **Low Temp SH/RH** |
| 8 | T91/T92 | Ferritic | Low Temp SH/RH, HP turbine piping – 620$^{o}$C |
| **9** | **430** | **Ferritic** | **Boiler Tubes** |
| 10 | T23/T24 | Ferritic | Furnace Tubes |

# Carbothermal Process for TiC and $TiB_2$ Powder Synthesis




**Weight percent of carbon is determined by number of coating cycles**




**Different temperatures and reaction time were run to get fine particle size and distribution**

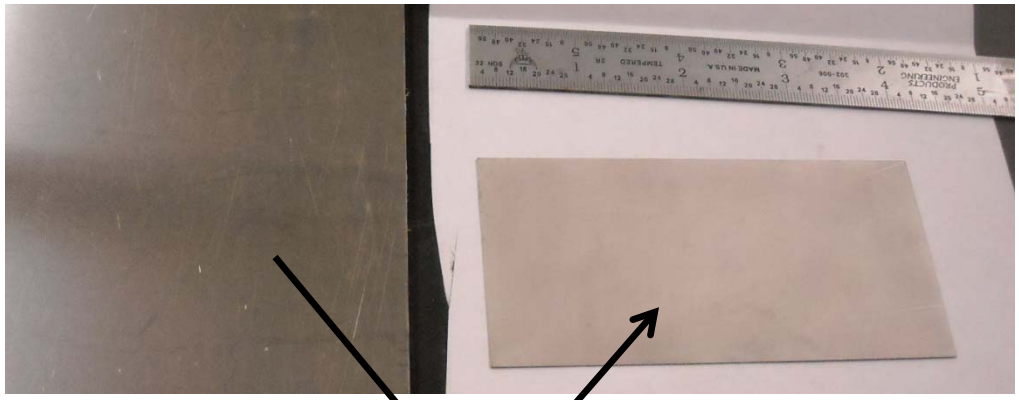
KT3
KT4

# GTI HVOF Flame Spray System

Fuel Flexible: **$H_2$**, Acetylene,Kerosene…
Oxidant Flexible: **$O_2$** or Air


SS 304H As received

After surface roughening



Water honing

**Safety is first priority**

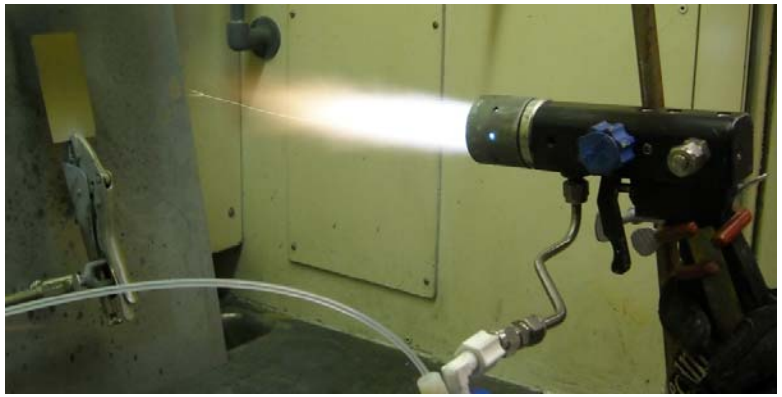
- **Hearing protection**
- **Eye protection (light)**
- **Face Shield**
- **Flame arrestors**
- **Two person operation**
  - **One holding gun**
  - **One operating gas flows**
- **Emergency Stop Button**

**KT3** TiC mp 3260
HVOF- up to 3300 when H2 introduced.
Kyle T, 4/18/2016

**KT4** Hydrogen and oxygen are mixed together and combust causing the powder material to become molten.
Velocity ranges from 600-100 m/s
Kyle T, 4/18/2016

# Spray Deposition

Flame Only

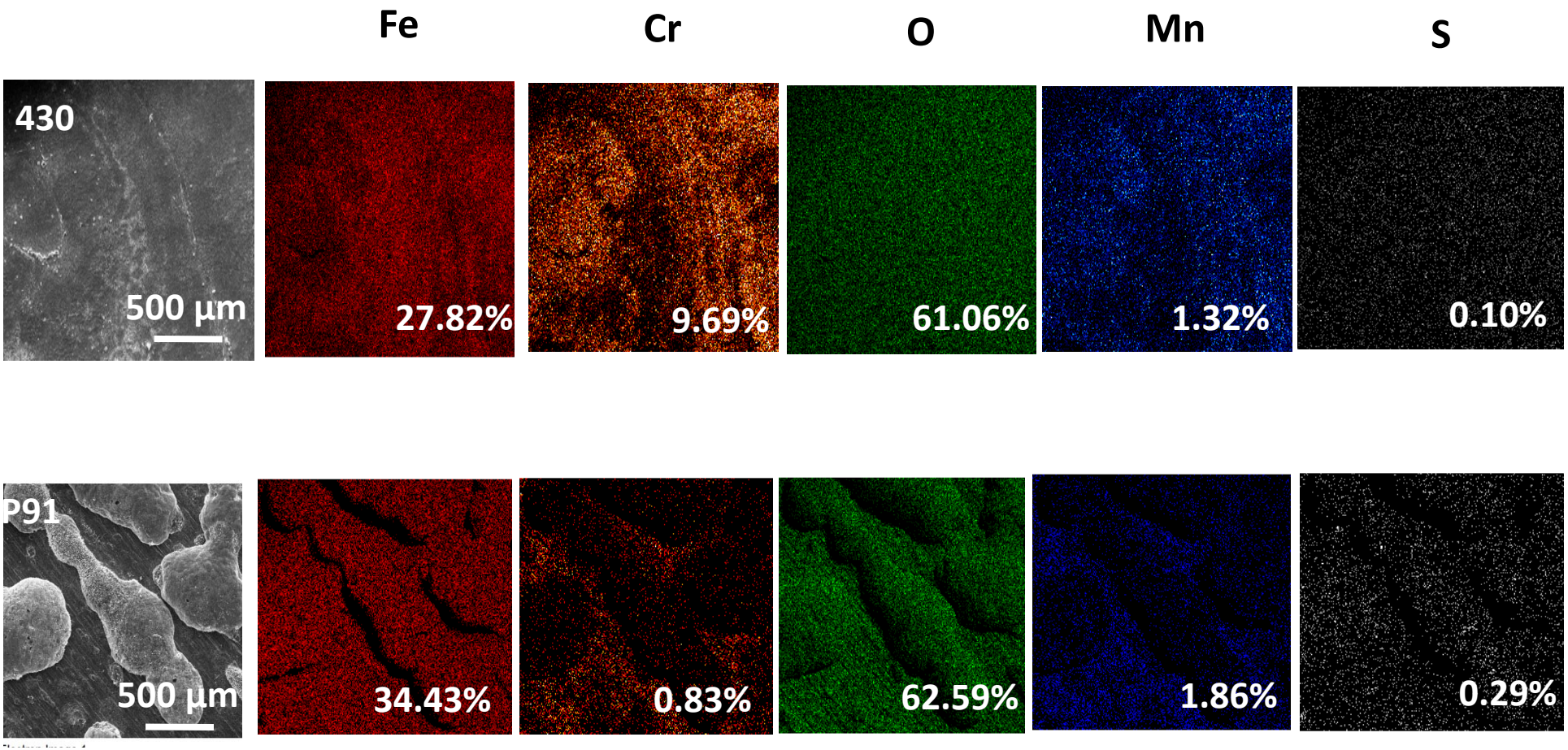


Partially Covered Samples

Flame with Powder

**SS 304H** C(0.04-0.1) Si(0.75) Mn (2) P (0.045) S (0.03) **Cr (18-20) Ni (8-10.5)**
**SS 430** C(0-0.12) Si (0-1) Mn (0-1) **Cr(16-18) Ni(0)**
**P91** C(0.08-0.12) Si(0.2-0.5) Mn (0.3-0.6) Mo (0.8-1.05) **Cr(8-9.5) Ni(0.4 max)**

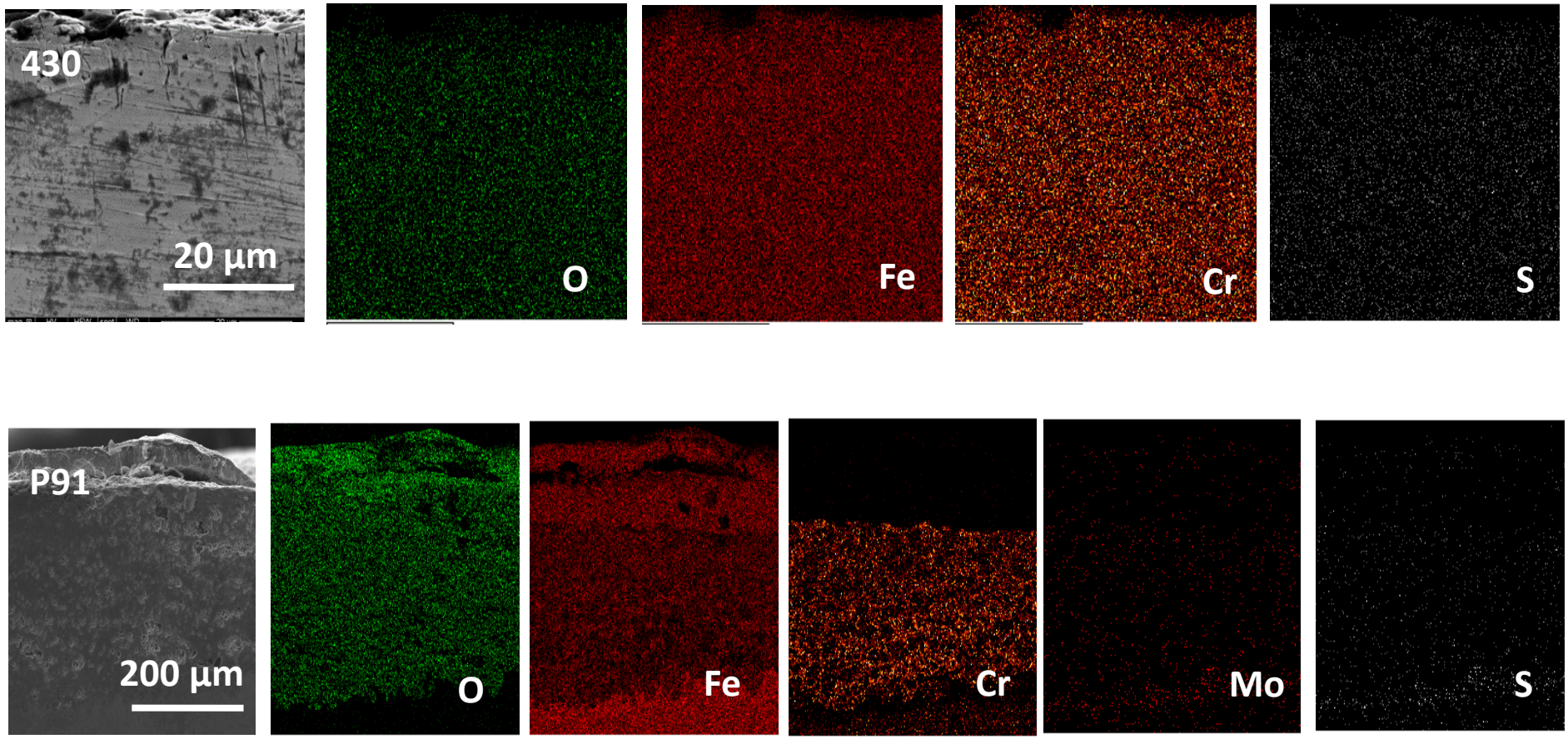
# Pristine 430 and P91 Steels: Corrosion Behavior




7-Days 750 $^{0}$C Simulated Flue Gas Corrosion Test

KT1
KT2

# Pristine 430 and P91 Steels: Corrosion Behavior



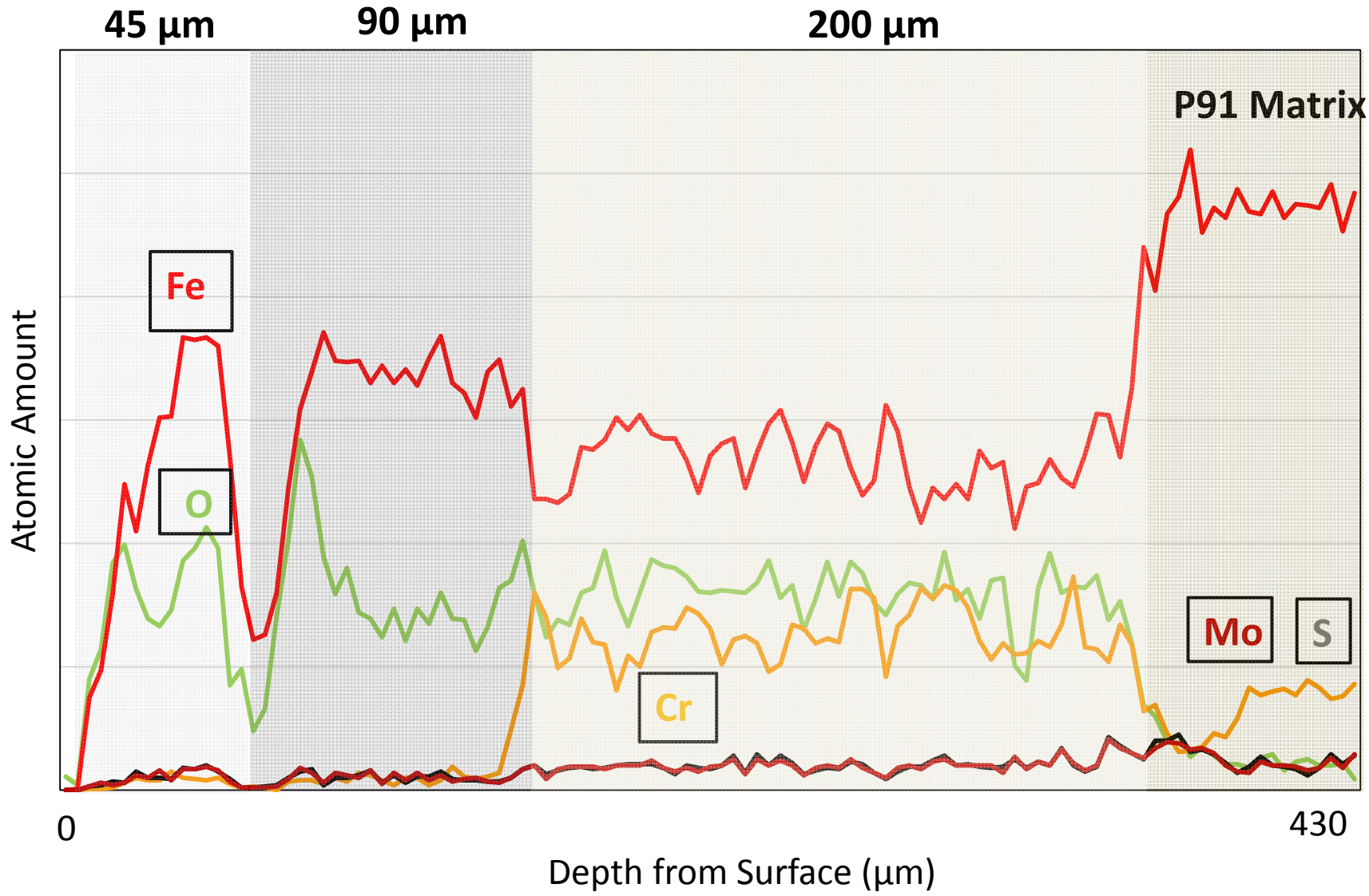

7-Days 750 $^{0}$C Simulated Flue Gas Corrosion Test

**Slide 10**

**KT1** The surface of the steel was initially covered with $Cr_2O_3$, which was then converted to $FeCr_2O_4$, and finally $Fe_3O_4$ and $Fe_2O_3$ formed on it. These results indicated that the reason for the breakaway oxidation in type 430 stainless steel is Cr depletion beneath $Cr_2O_3$ layer and the subsequent ionisation of Fe, not the simple mechanical failure of $Cr_2O_3$.
Kyle T, 4/17/2016

**KT2** Hematite ($Fe_2O_3$) occurs on the inner surface of the tube. Then magnetite ($Fe_3O_4$) appears below hematite. Going deeper into the layer there is a spinel, i.e. a mixture of magnetite and chromite.
Kyle T, 4/17/2016

# 7-Day 750 $^{0}$C Simulated Flue Gas Test: P91 Substrate



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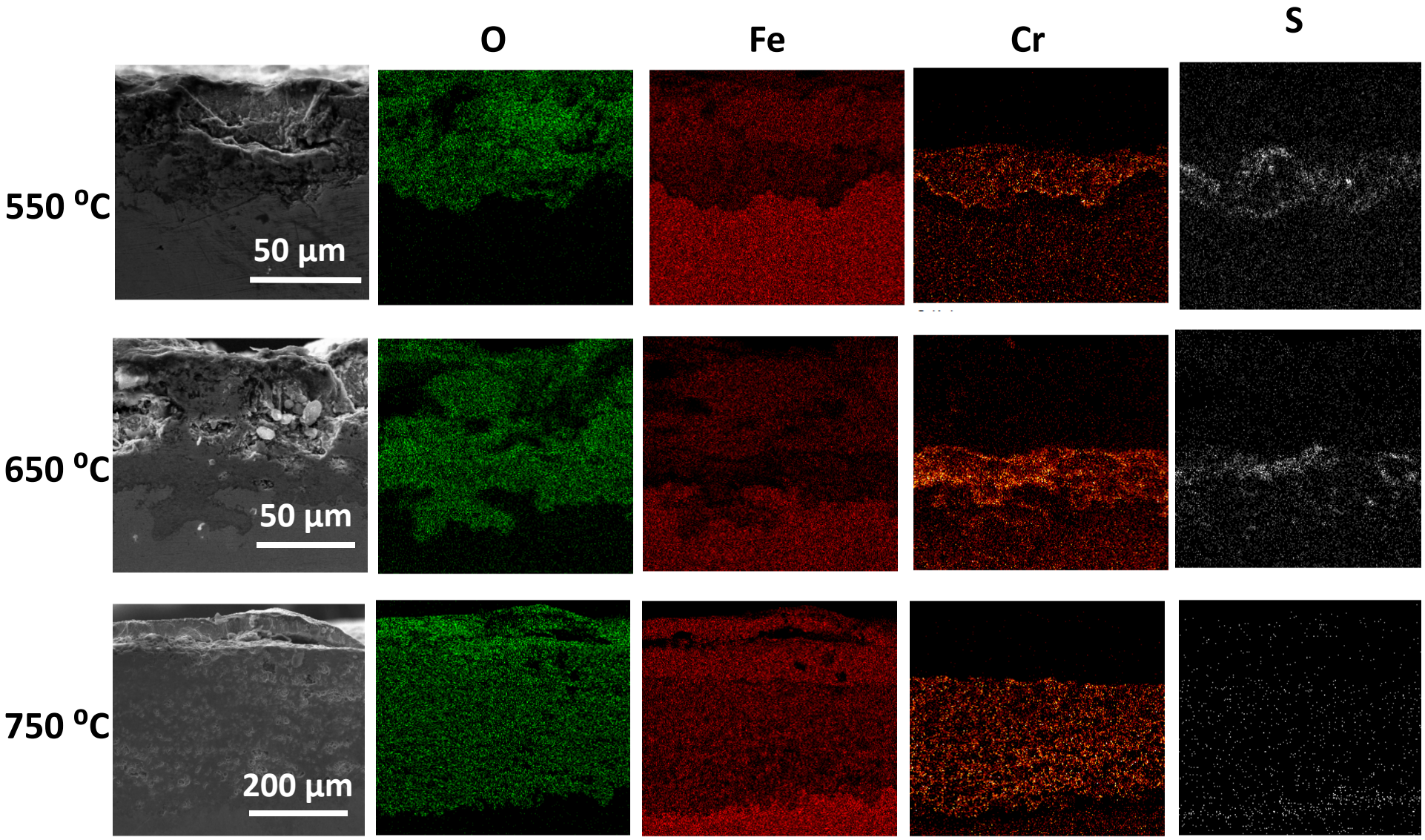
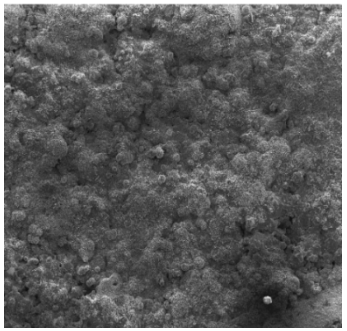
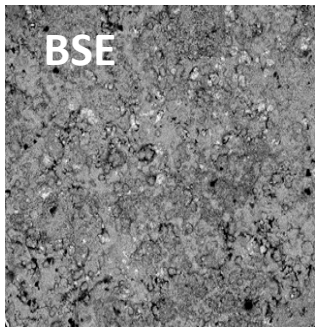
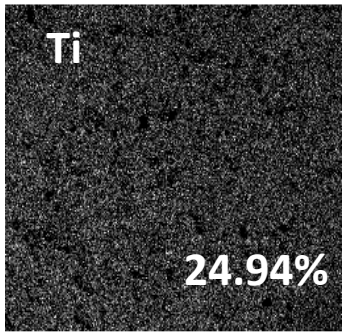


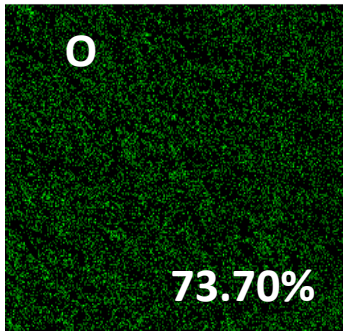
# 7-Day 750 $^{0}$C Simulated Flue Gas Test: Ti Coated P91 Substrate

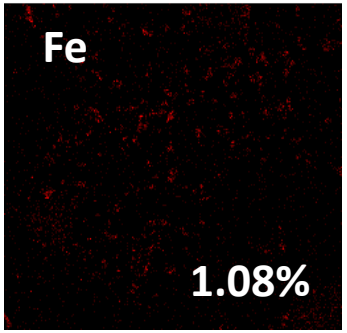


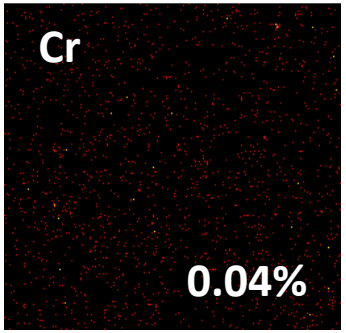


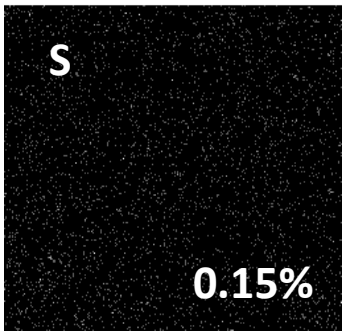




**Ti Coated P91**

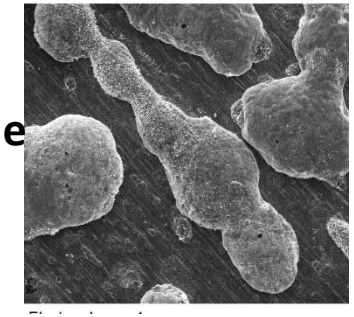


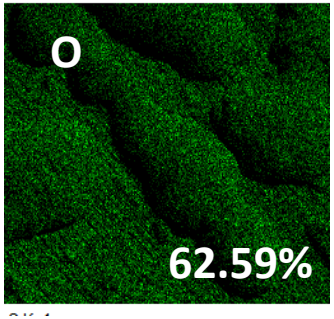



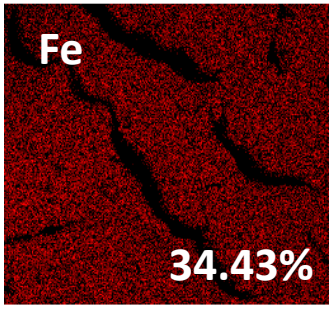



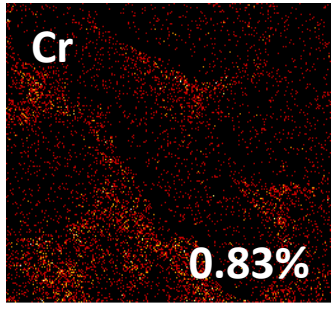



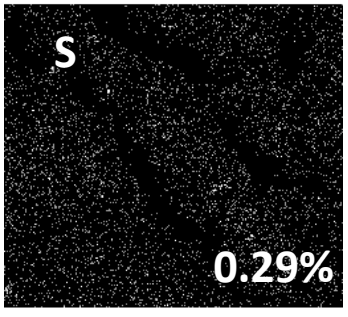

**Pristine P91**





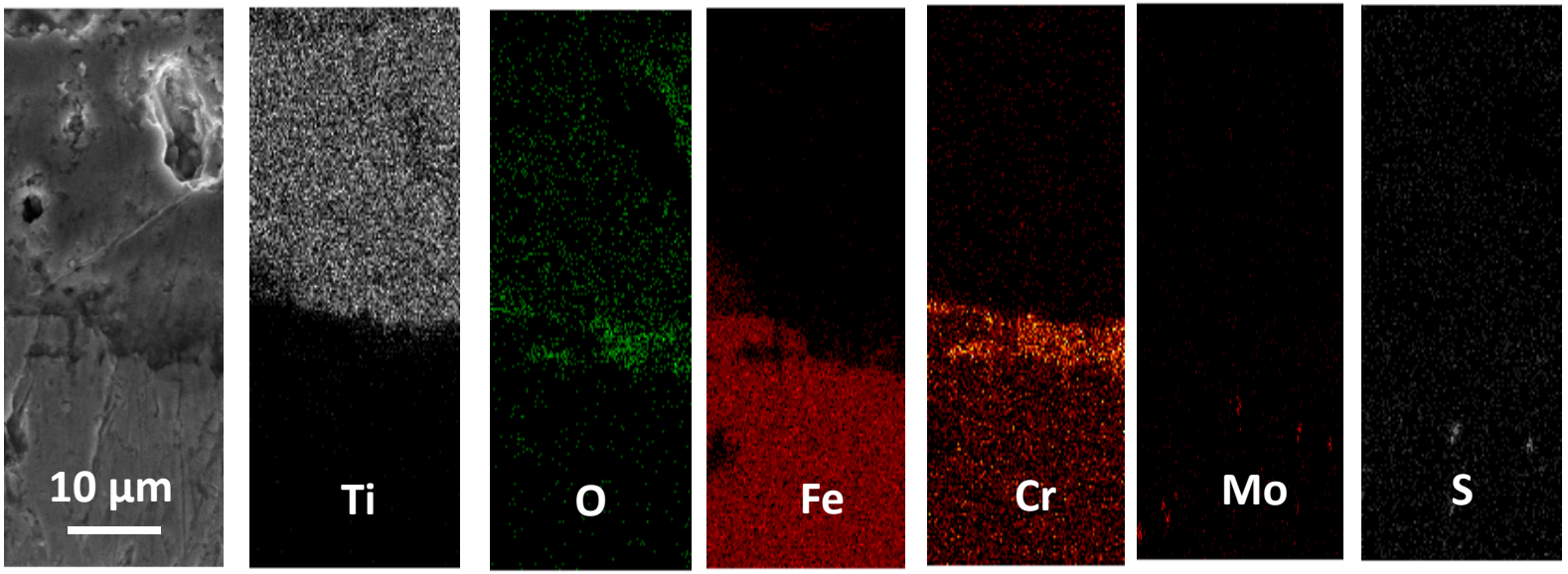



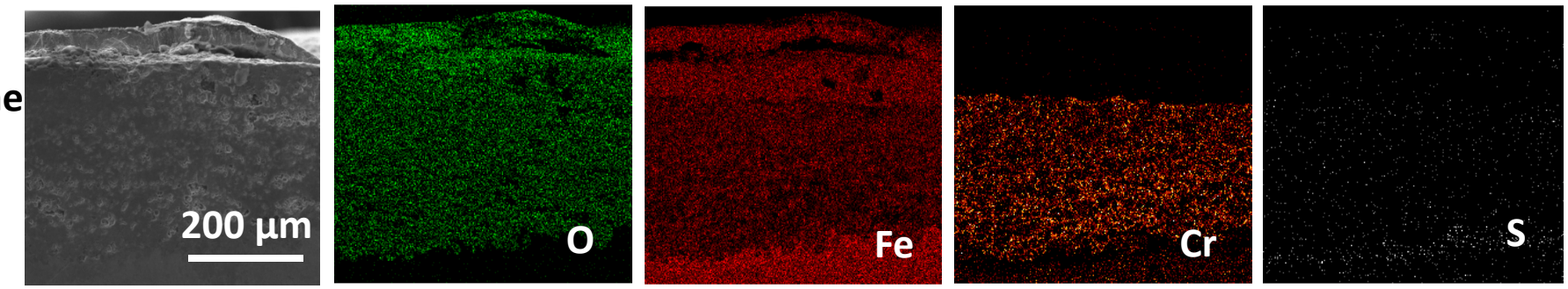



# 7-Day 750 $^{0}$C Simulated Flue Gas Test: Ti Coated P91 Substrate

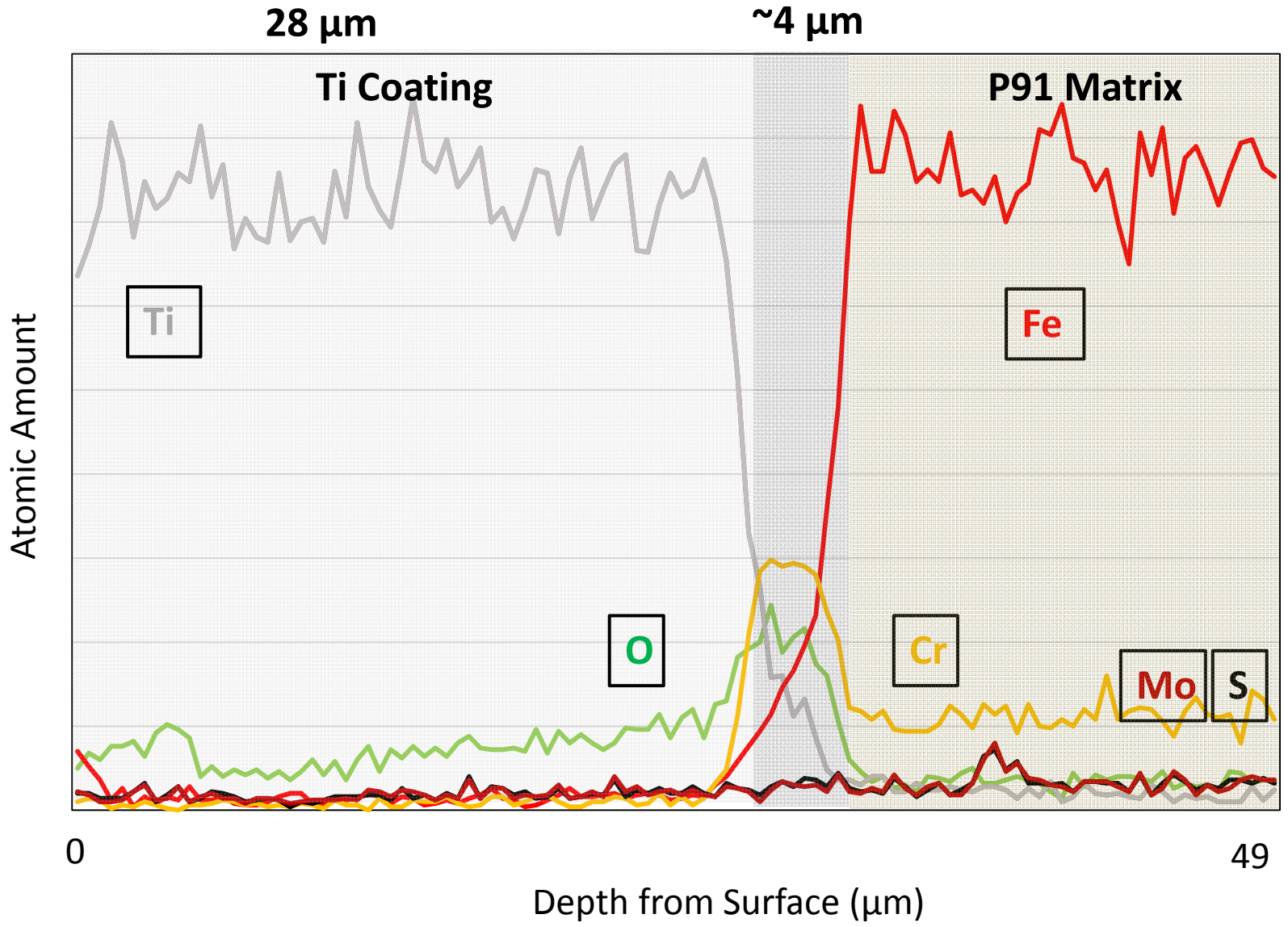
**Ti Coated P91**




**Pristine P91**

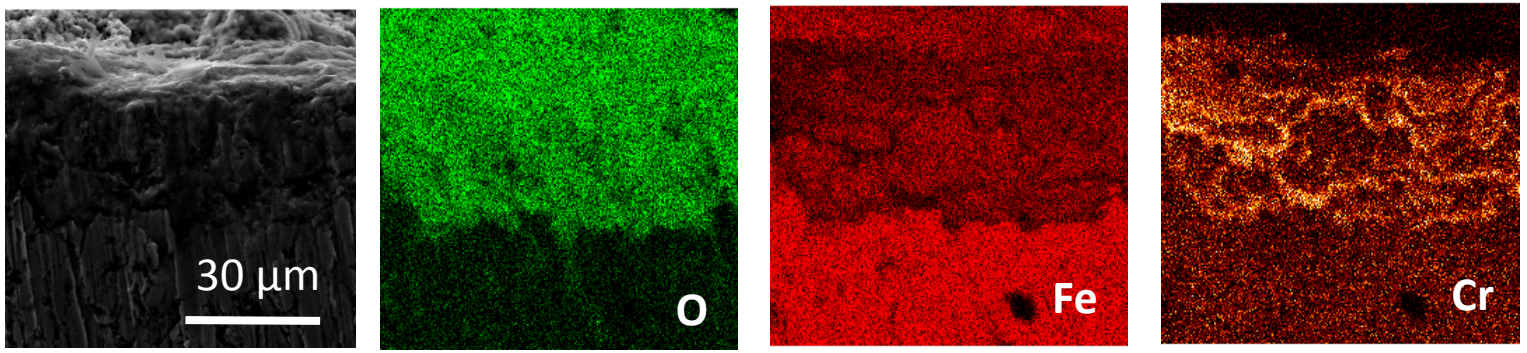


# 7-Day 750 $^{0}$C Simulated Flue Gas Test: Ti Coated P91 Substrate

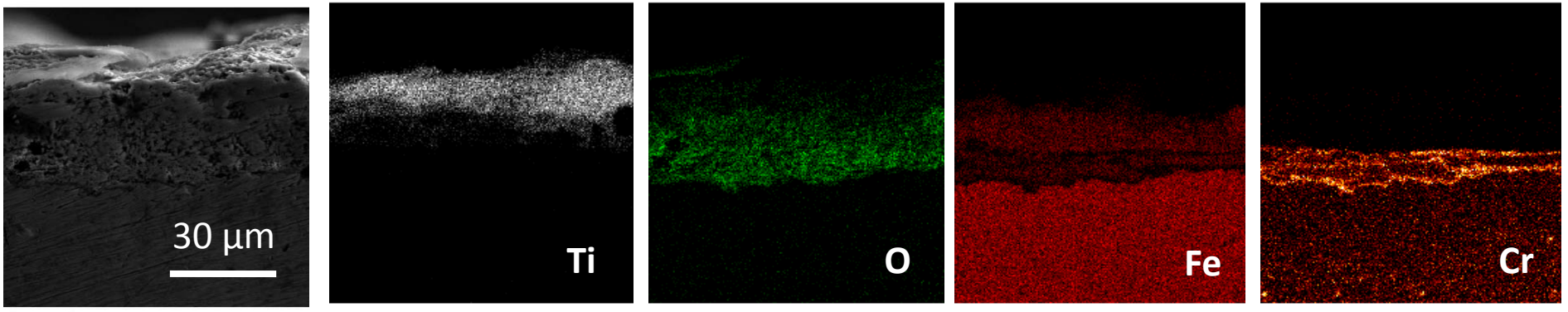


# 7-Day 700 $^{0}$C $H_2O$ + $O_2$ Corrosion Test on P91 Substrates

**Pristine P91**

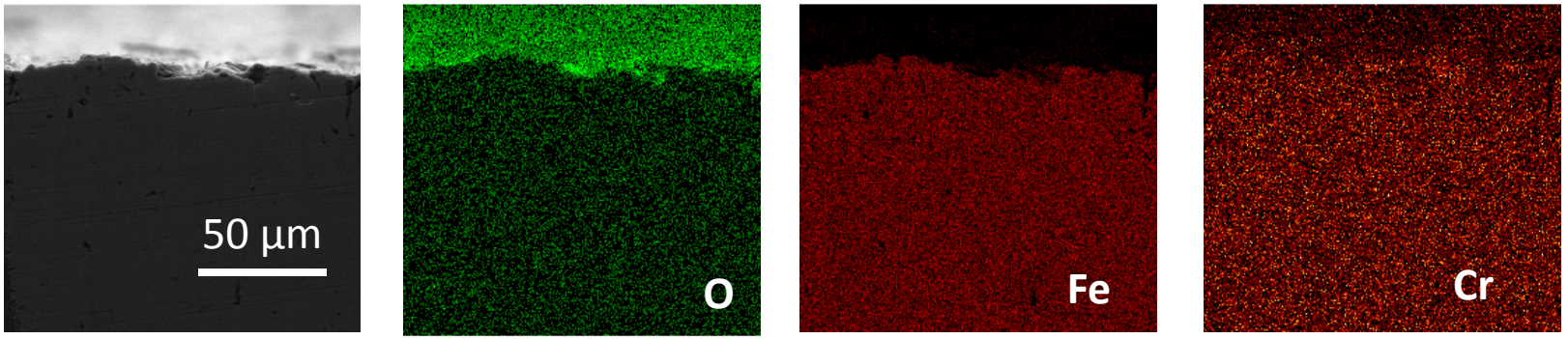



**Ti Coated P91**

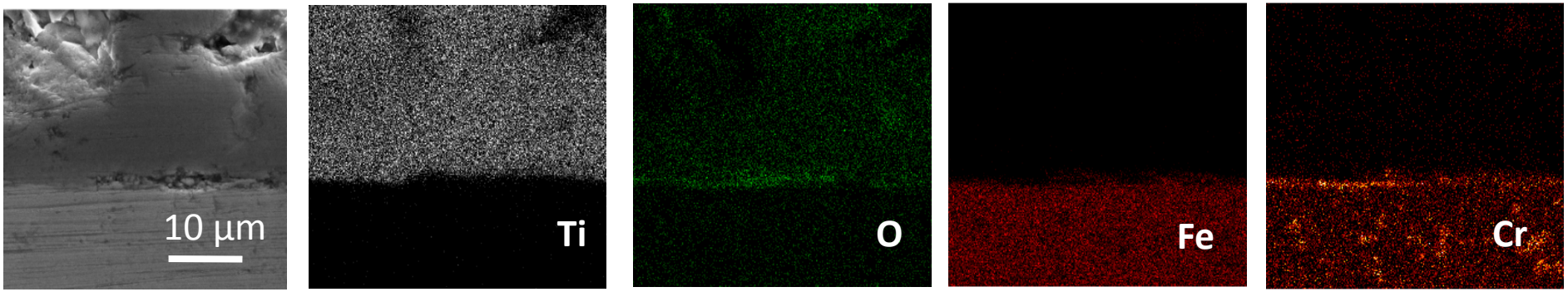


# 7-Day 700 $^{0}$C Air Corrosion Test on P91 Substrates

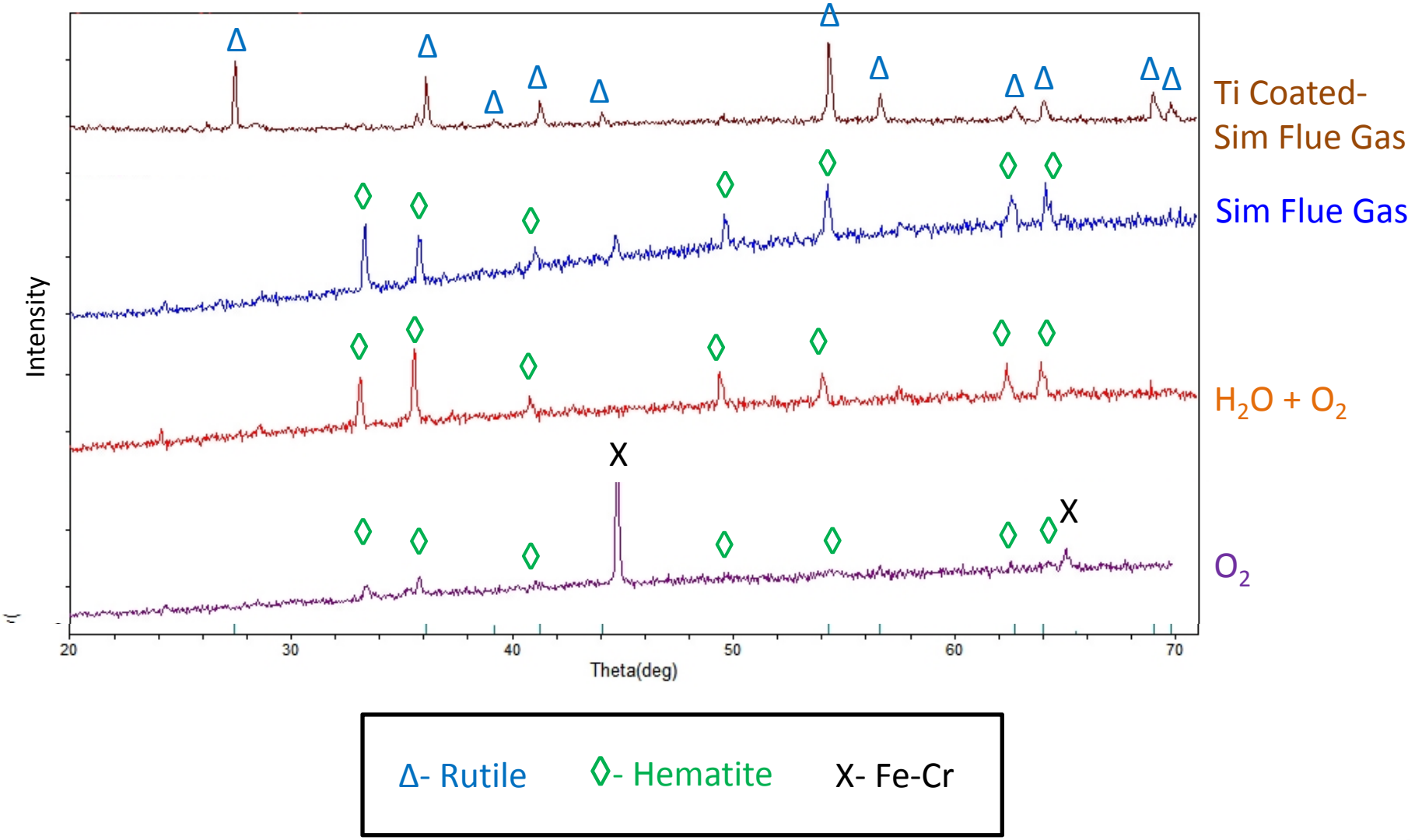
**Pristine P91**




**Ti Coated P91**

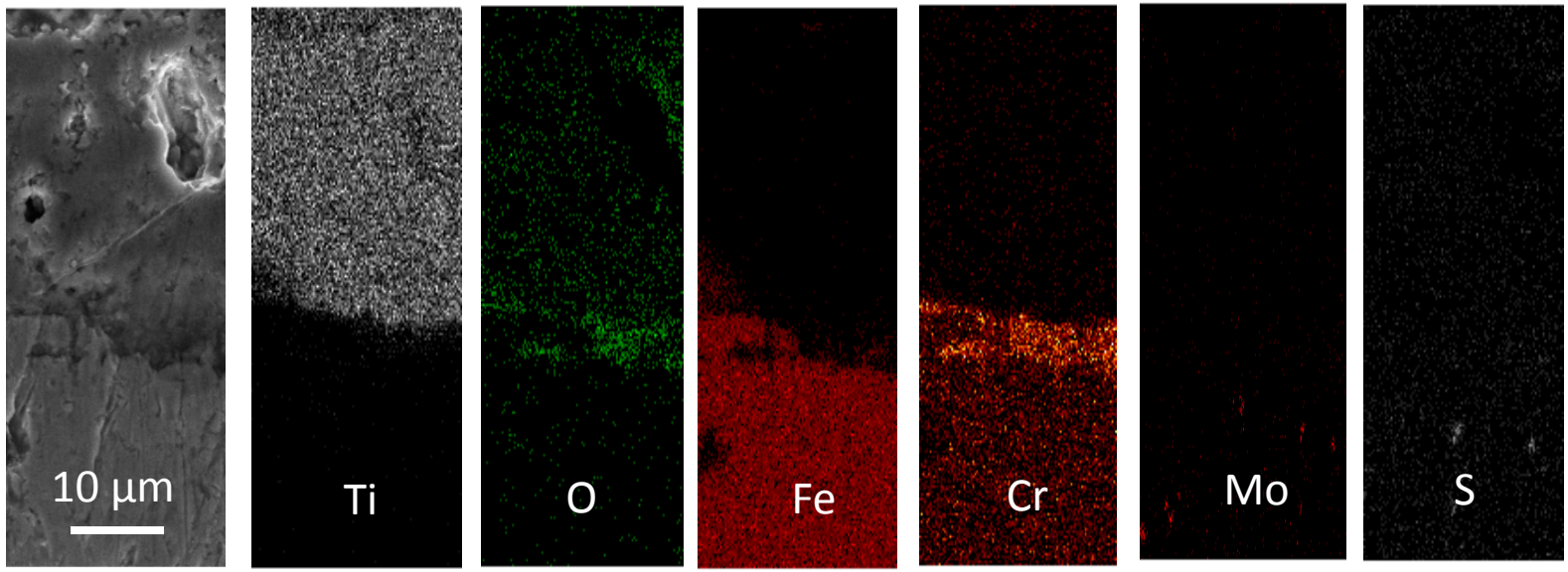


# XRD Results of Ti Coated and Pristine P91 After Corrosion Tests

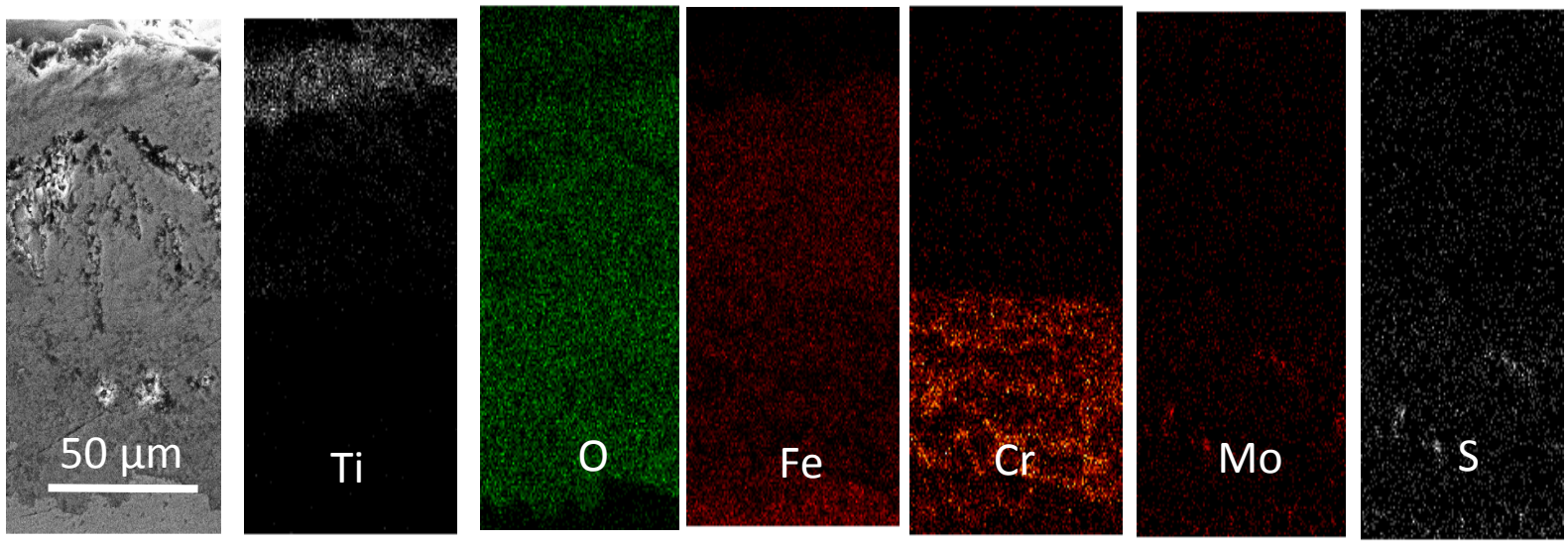


# Impact of Coating Density on Corrosion Resistant

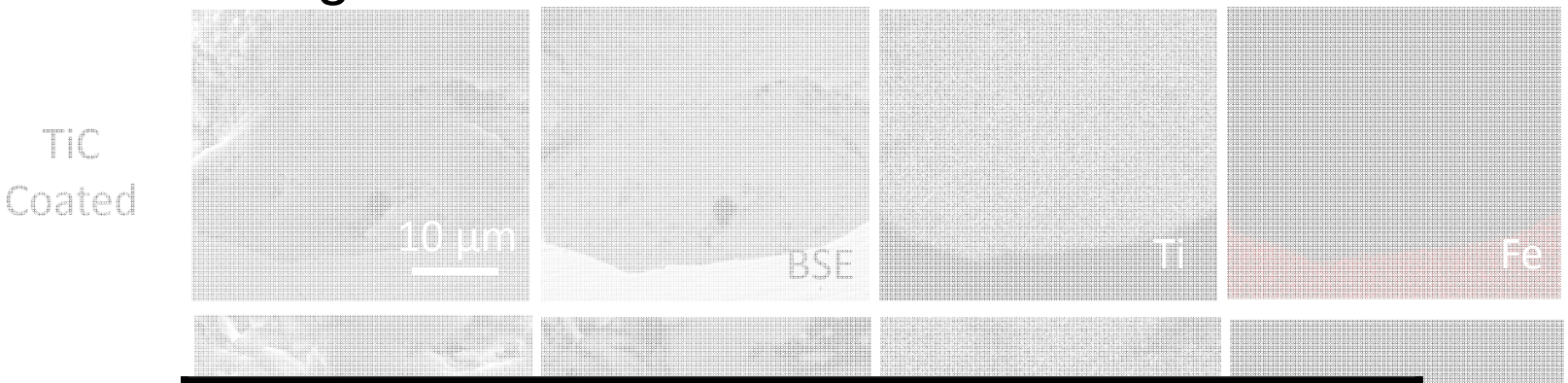
Dense Coating

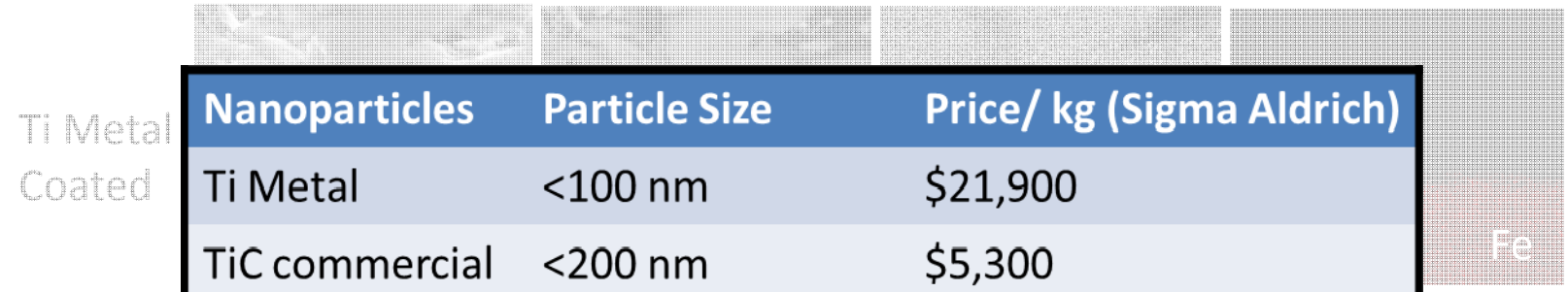



Loose Coating

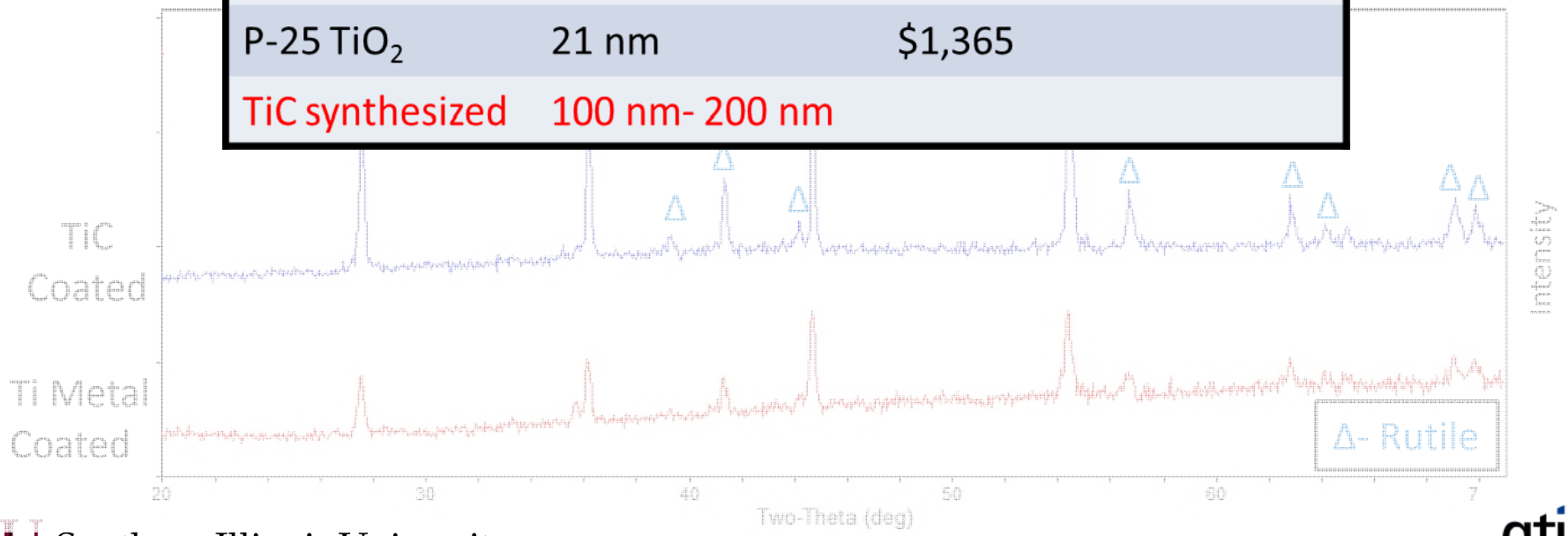


# HVOF Coatings: TiC and Ti Metal




| Nanoparticles | Particle Size | Price/ kg (Sigma Aldrich) |
|---|---|---|
| Ti Metal | <100 nm | $21,900 |
| TiC commercial | <200 nm | $5,300 |
| P-25 $TiO_2$ | 21 nm | $1,365 |
| TiC synthesized | 100 nm- 200 nm | |



# Achievements

- HVOF thermal spray coating of the prepared powders on P91 steel substrates.
- Corrosion characterizations of pristine and coated P91 steels.
- Increased longevity and corrosion resistance of the coated substrates subjected to fireside corrosion in AUSC SH/RH tubes and boiler tubes.

# Acknowledgement

US DOE Project Number: DE-FE0008864
Project Officer: Richard Dunst

# Thank You