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

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

Principal Investigator: Kanchan Mondal
Southern Illinois University Carbondale

Co-Principal Investigator: Rasit Koc
Southern Illinois University Carbondale

Co-Principal Investigator: Chinbay Fan
Gas Technology Institute, Des Plaines

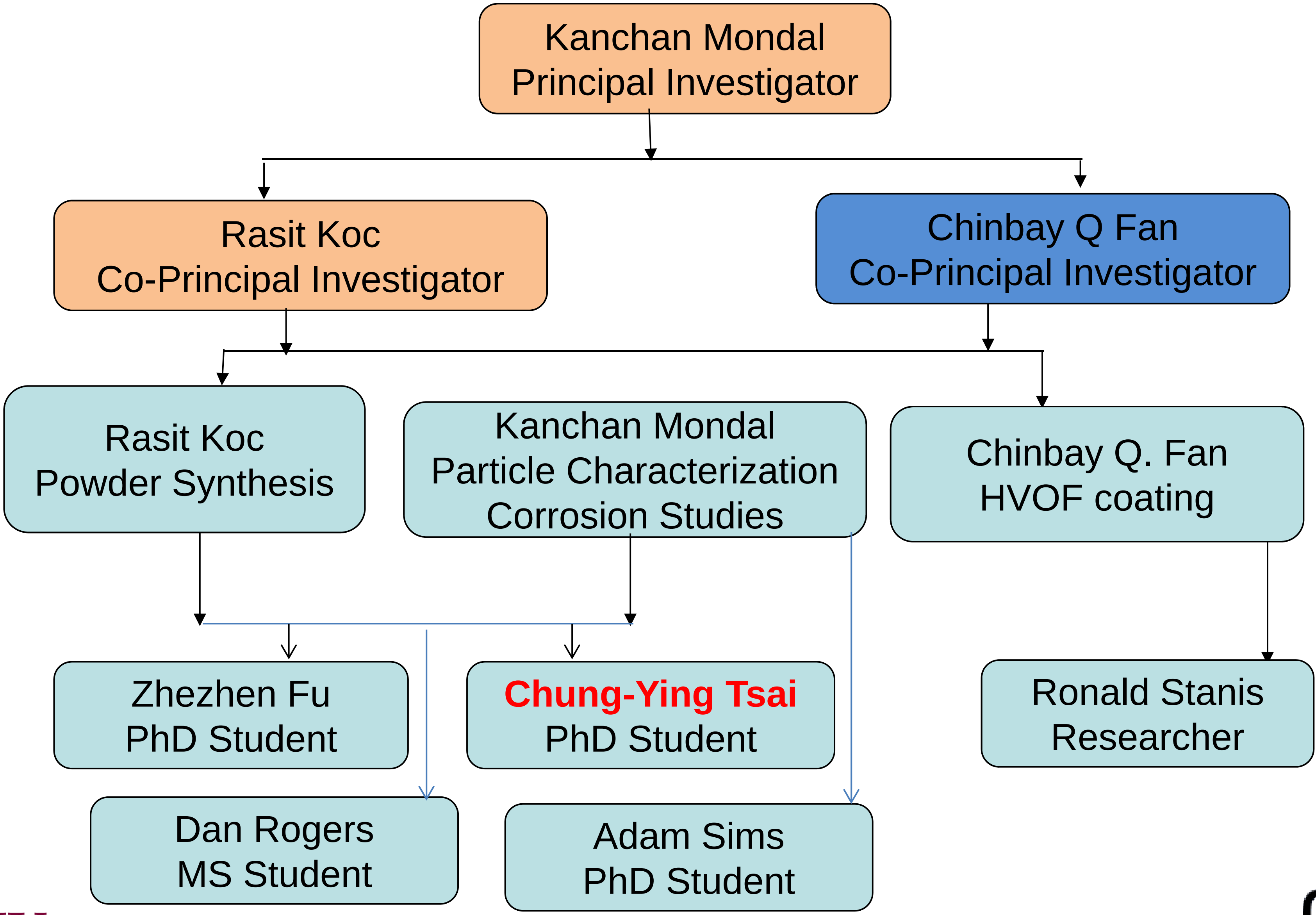
Presenter: Chung-Ying Tsai
Southern Illinois University Carbondale

2015 NETL Crosscutting Research Review Meeting
Apr 27-30, 2015

SIU Southern Illinois University CARBONDALE

gti

PROJECT TEAM



the Energy to Lead

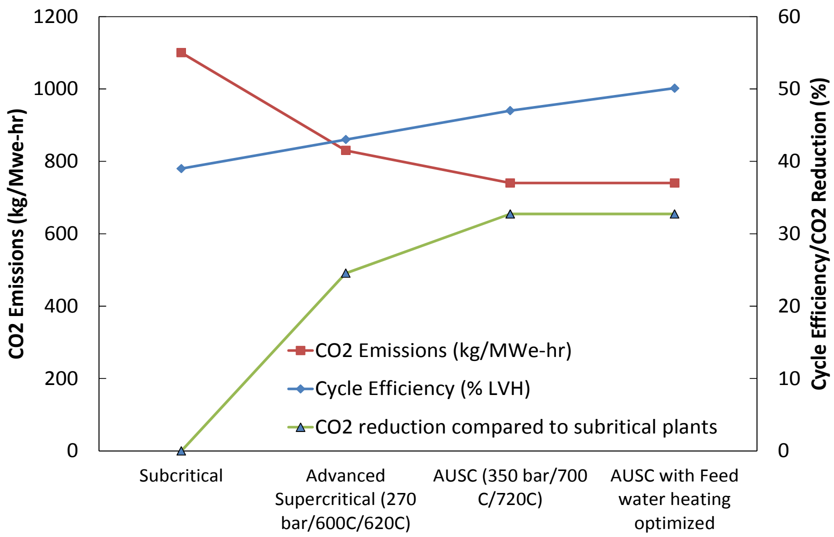
HVOF, Flame Spray Coatings

GTI project number 21397

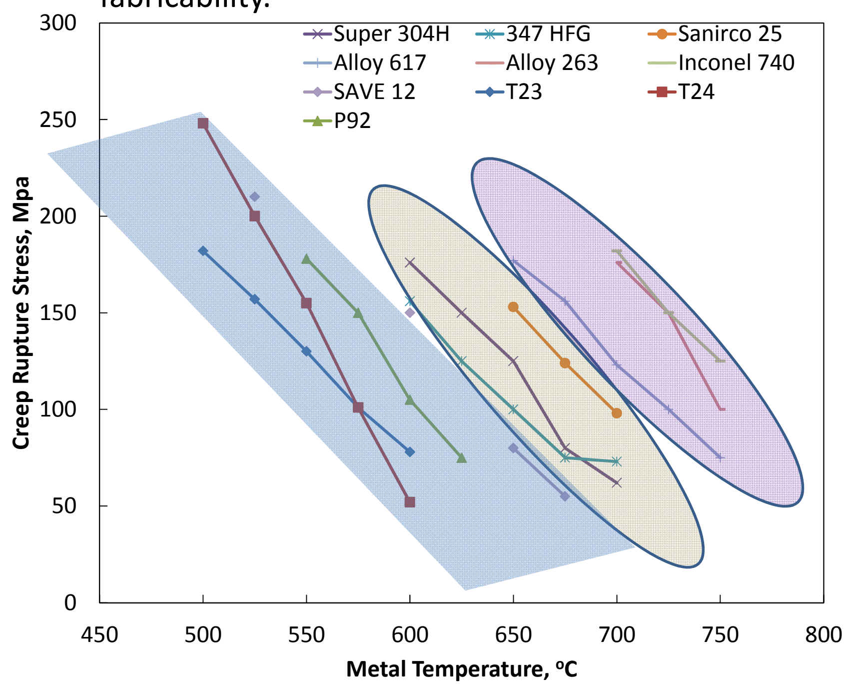
Chinbay Fan and Ronald Stanis

gti

Background

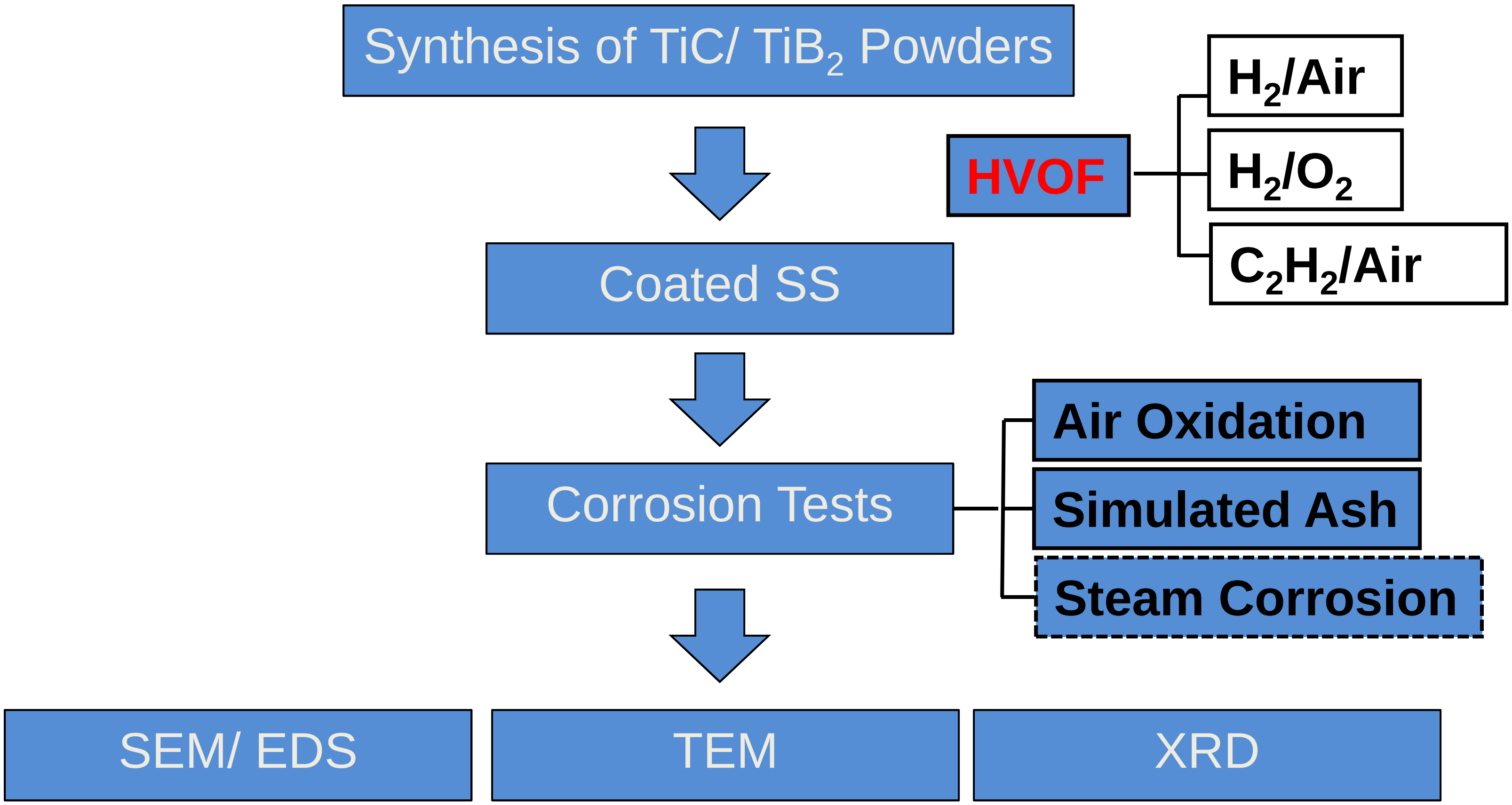


- High Temperature, High Pressure, Supercritical water
- Mechanical Strength
  - Max Allowable Stress
  - Creep Rupture Stress
  - Fatigue Resistance
- Corrosion Resistance
  - Fireside Corrosion
  - Steamside Oxidation
- Thermal conductivity,
- Low coefficient of expansion, and
- Manufacturing process 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

Research Approach

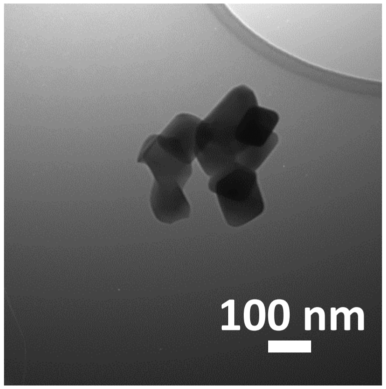


Powder Physical Properties

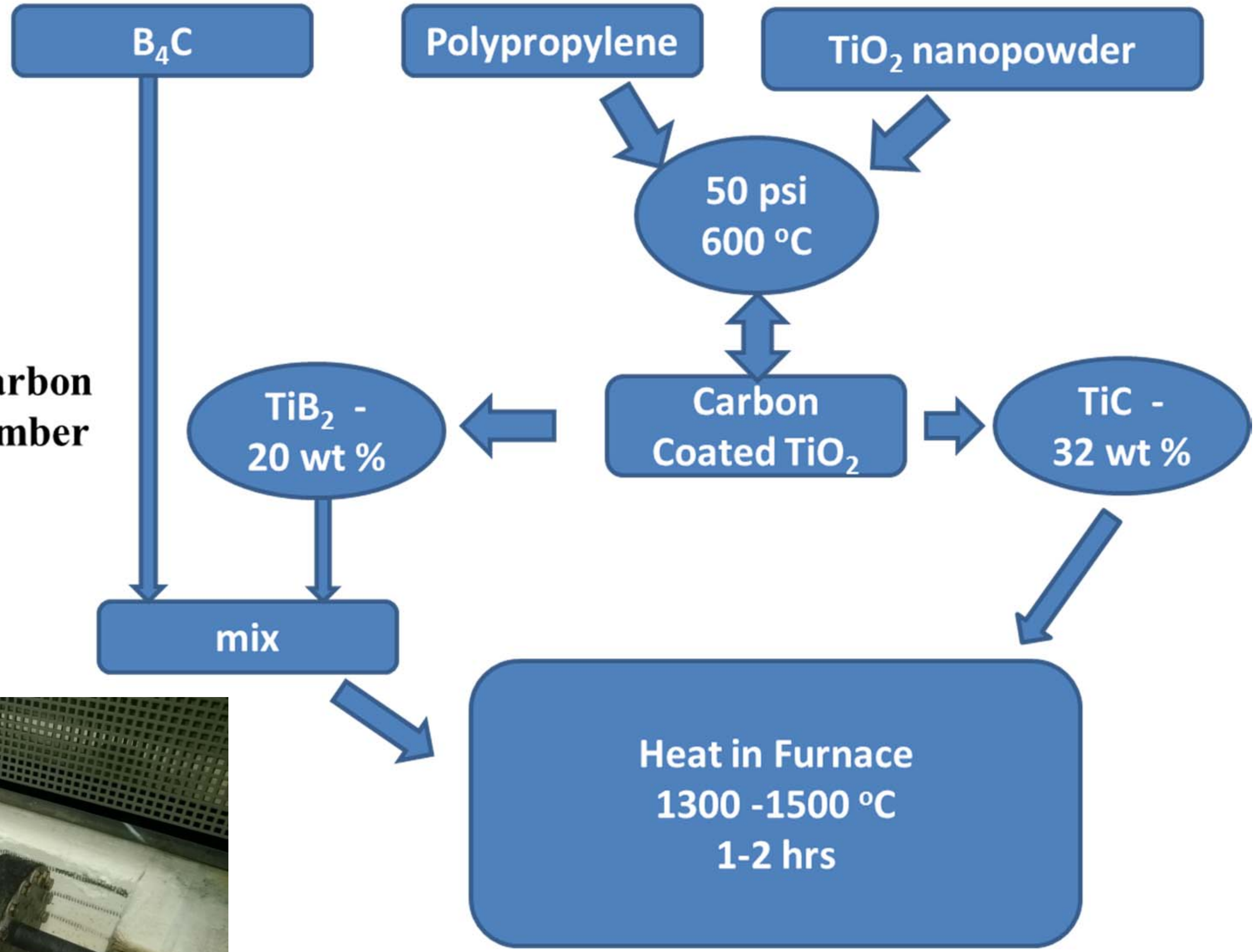
- High temperature strength retention
- Low thermal expansion coefficient
- High wear resistance
- High melting point
- Light weight

	Melting Temp	Density	Hardness	Young's
	^{o}C	g/cm^3	GPa	GPa
TiC	3070	4.65	28	456
TiB_2	2900	4.5	34	570
B_4C	2500	2.52	38	450

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

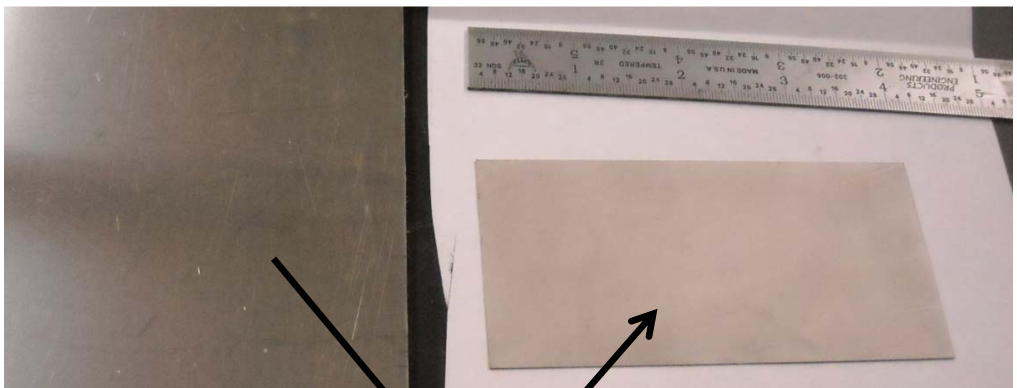
Substrates of Interest

	Substrate Material	Class	Applicable Component
1	Super 304H	Austenitic	SH/RH tubes
2	347HFG	Austenitic	SH/RH tubes
3	Sarnico 25	Austenitic	SH/RH tubes
4	HR3C	Austenitic	SH/RH tubes
5	STD617/CCA 617	Nickel Alloy	Tubing, HP turbine-casing, piping, rotor - 700 ^oC
6	Haynes 230	Nickel Alloy	SH tubes, HP turbine rotor – 700^oC
7	Inconel 740	Nickel Alloy	SH tubes, HP turbine - casing, piping, rotor- 760 ^oC
8	Haynes 263	Nickel Alloy	HP turbine casing – 700 ^oC
9	P91/P92	Ferritic	Low Temp SH/RH
10	T91/T92	Ferritic	Low Temp SH/RH, HP turbine piping – 620^oC
11	430	Ferritic	Boiler Tubes
12	T23/T24	Ferritic	Furnace Tubes

GTI Flame Spray System

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

Stainless Steel As received   After surface roughening



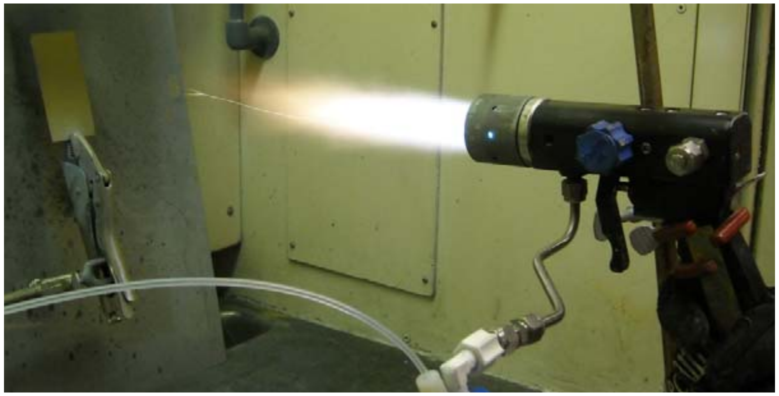
Water honing

<u>Safety is first priority</u>

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

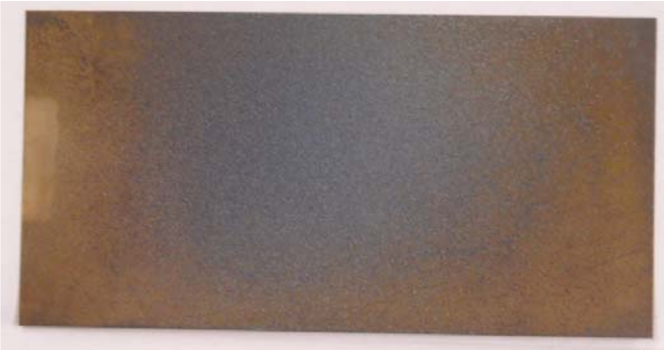
Spray Deposition

Just Flame



Partially Covered Samples

Flame with Powder

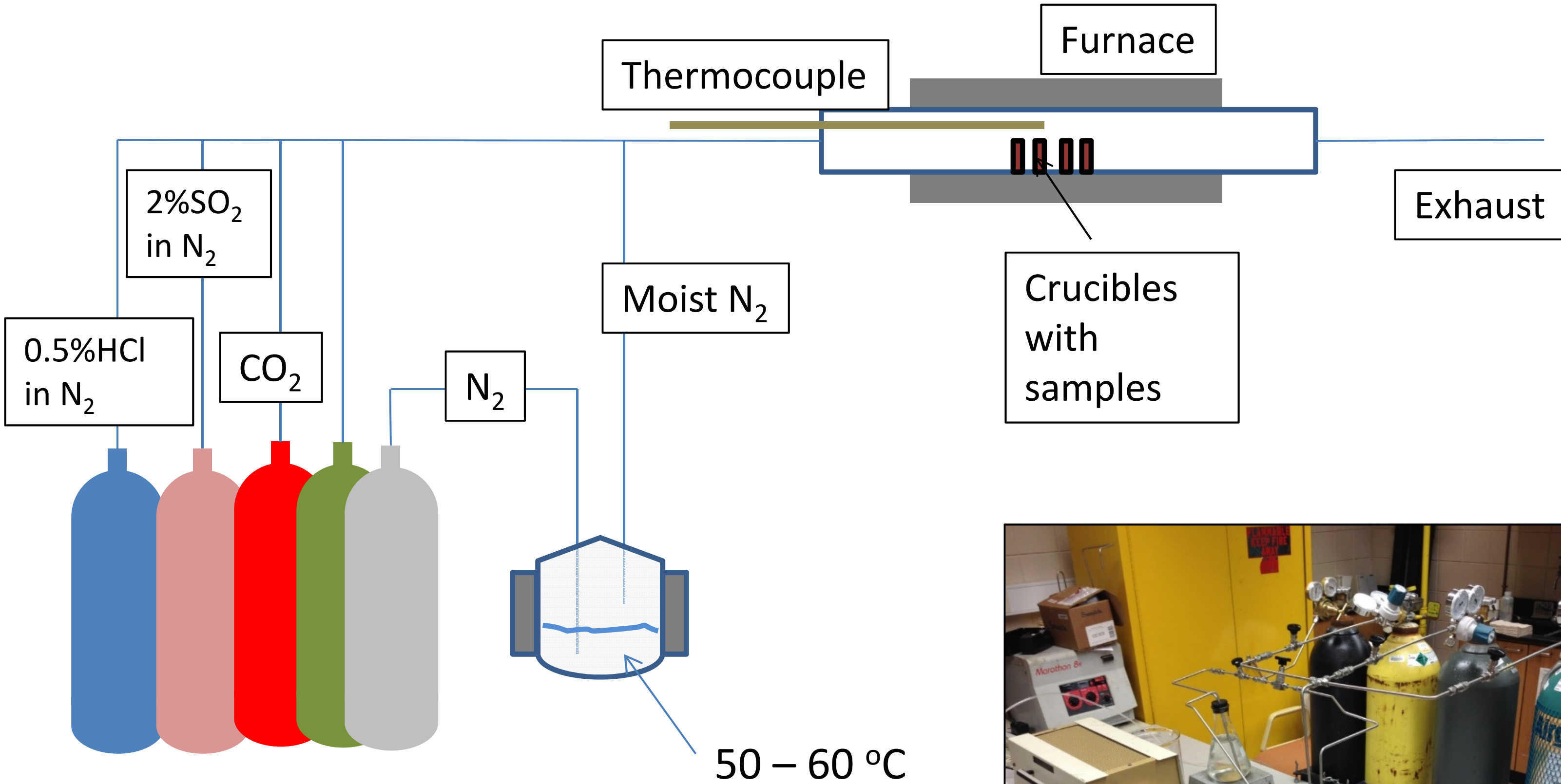


SS 304H C(0.04-0.1) Si(0.75) Mn (2) P (0.045) S (0.03) **Cr (18-20) Ni (8-10.5)**

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) **Cr(8-9.5) Ni(0.4 max)**

Corrosion Test Setup



Summary of Coated 304H Samples after Simulated Flue Gas Tests

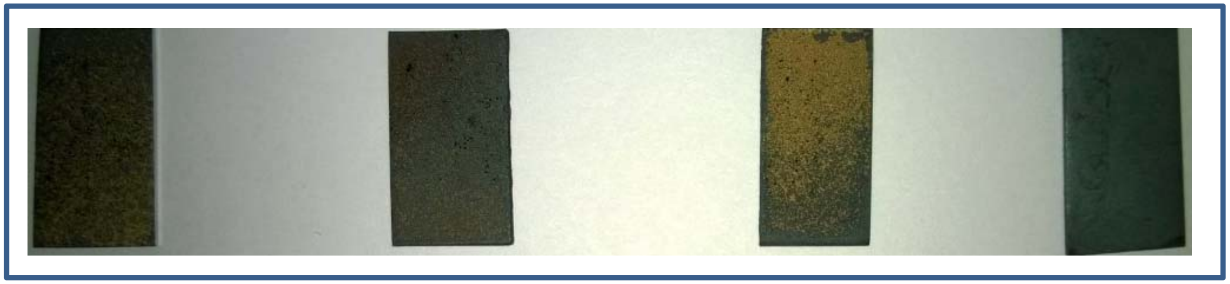
	500°C	600°C	650°C	700°C
Titanium	No noticeable oxidation or sulfurization (coated)	**S** - Less (coated)	**S, O** – Less (coated)	**O** -Less (coated)
TiB_2		**S - Significantly** less (coated) **O** -slightly less (coated)	**S - Significantly** less (coated) **S, O** – concentrated (around coated)	**O** -Less (coated)
TiC		**S - Significantly** less (coated) **O- Significantly** less (coated) **S, O** – concentrated (around coated)		**S - Significantly** less (coated) **O** -slightly less (coated)

Coated 430 Substrates: Simulated Flue Gas Test- 750 ^{0}C

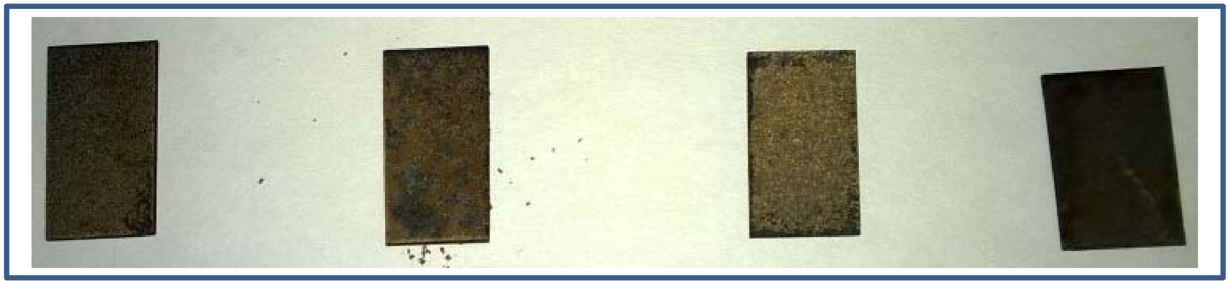
TiC (32%) | TiC (33%) | TiB_2 | 430

As Received

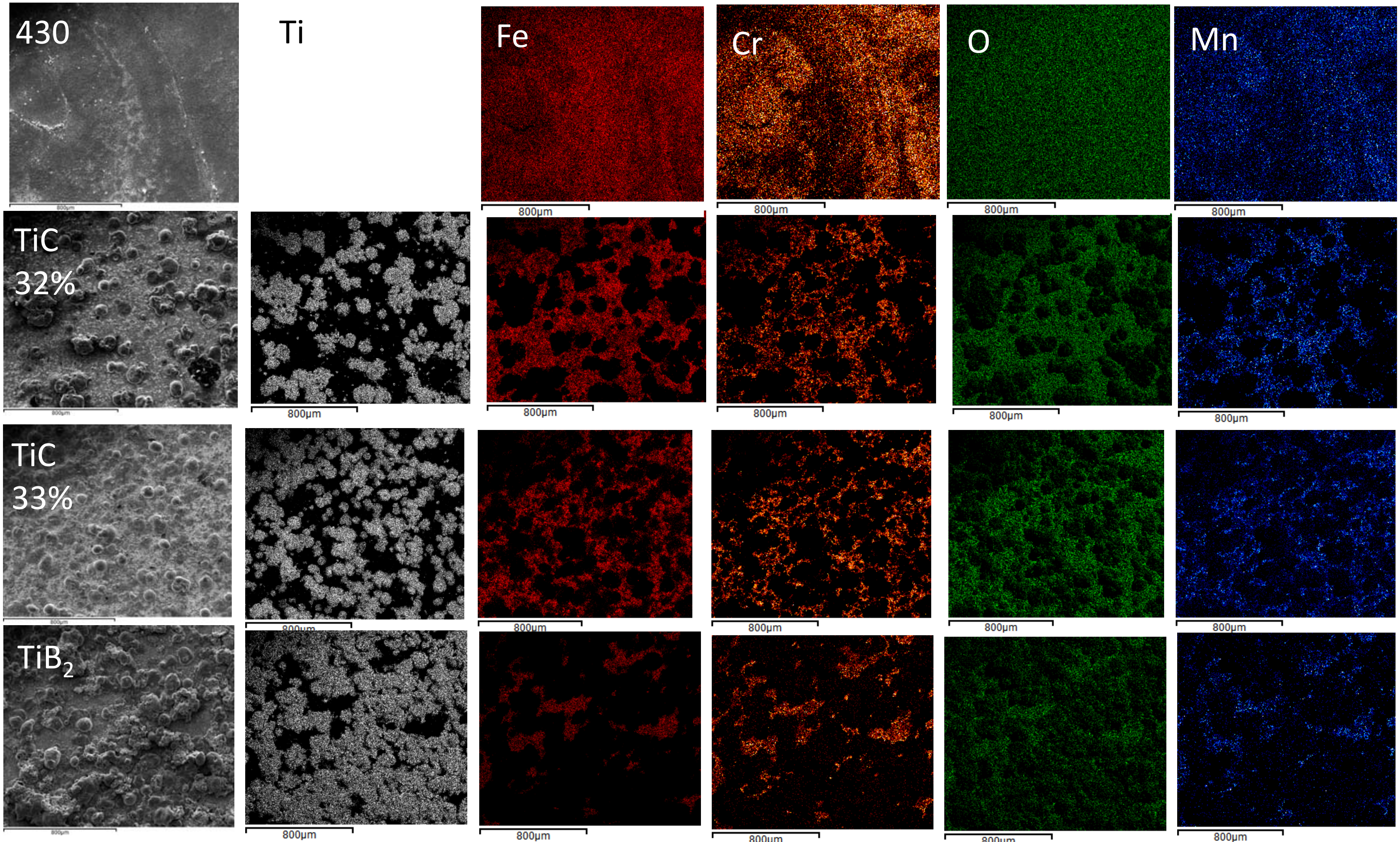
7 Days



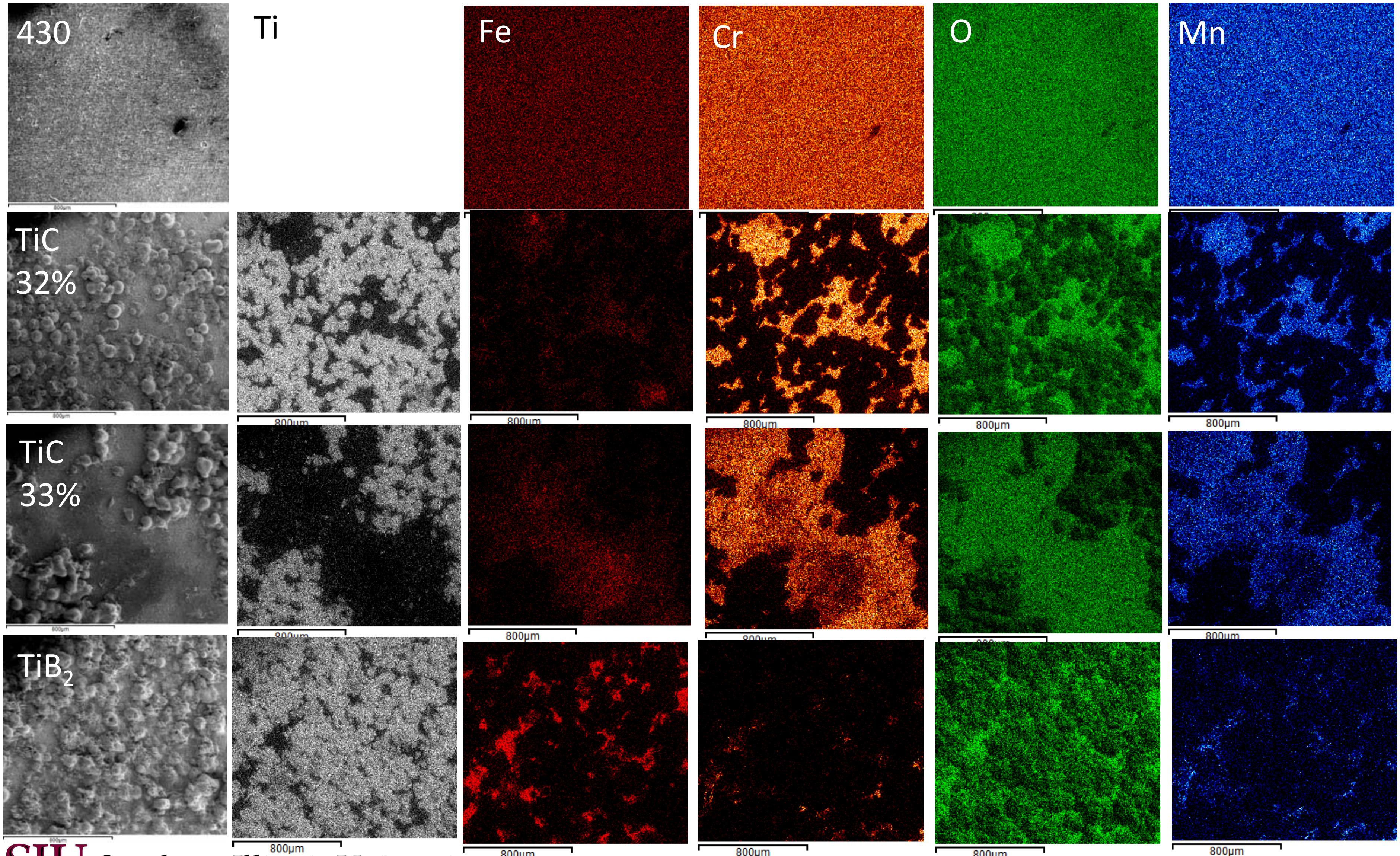
30 Days



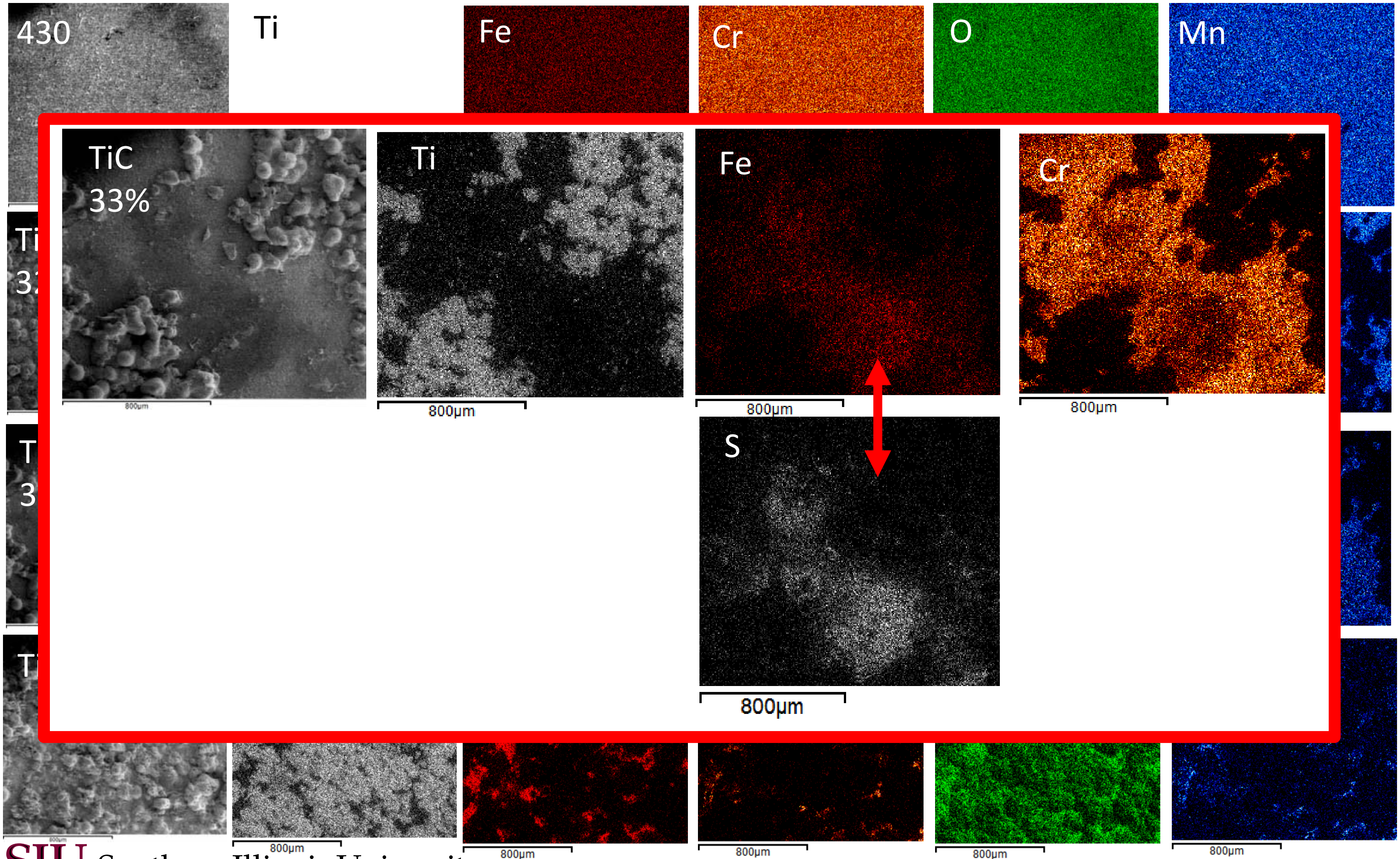
Simulated Flue Gas Test: 7 Days



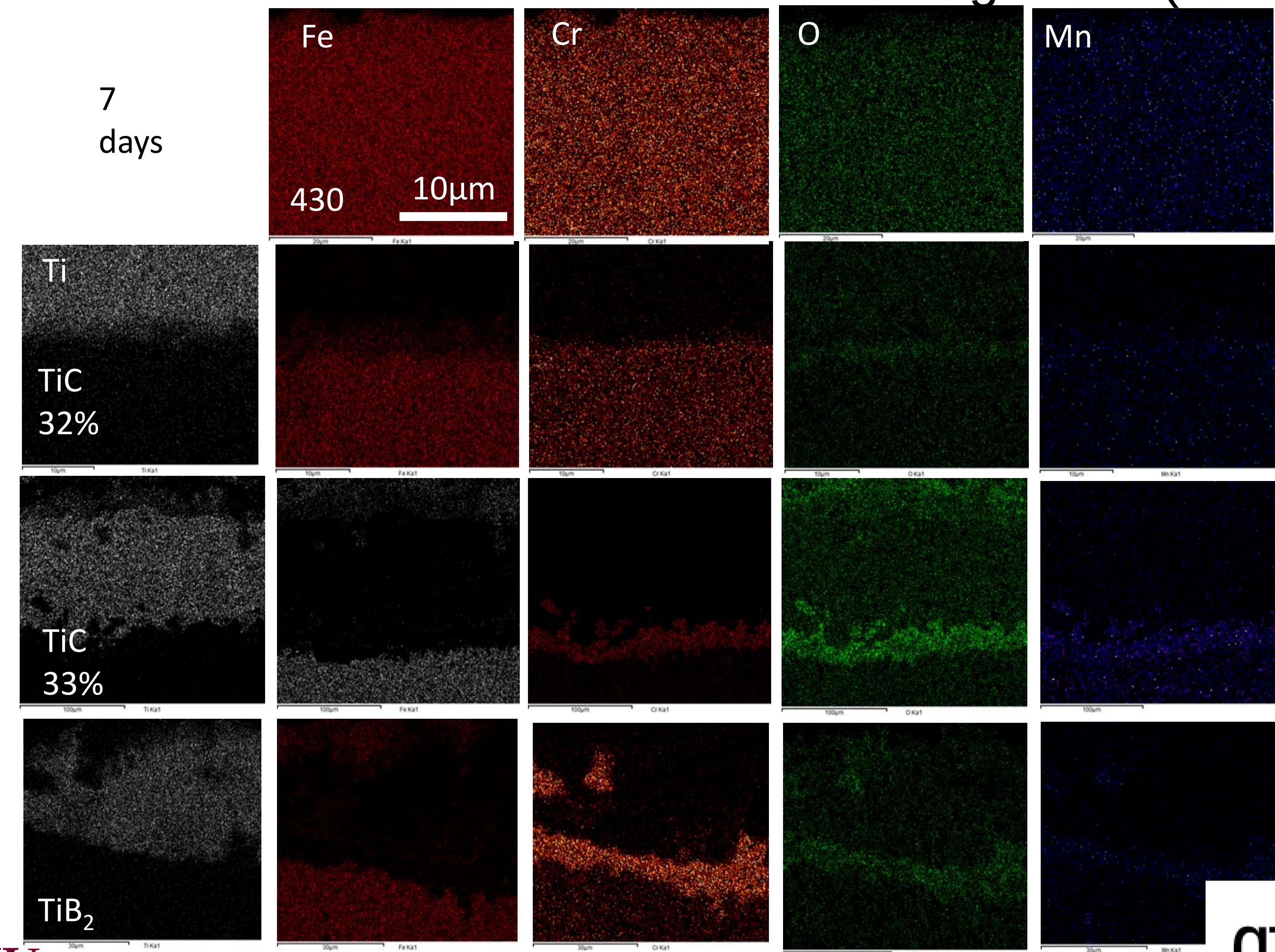
Simulated Flue Gas Test: 30 Days



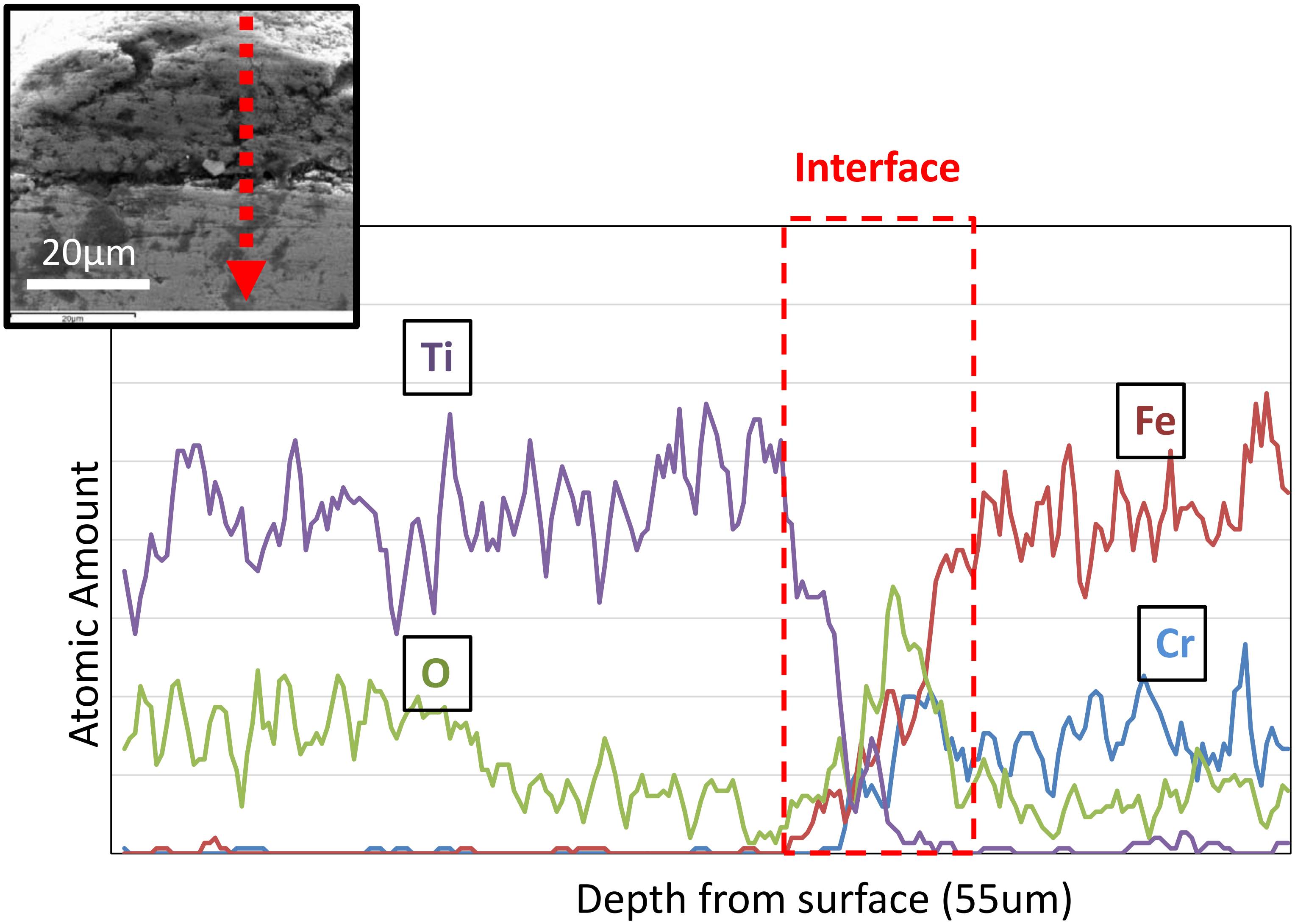
Simulated Flue Gas Test: 30 Days



Oxidation resistance from coating: TiC (32%)



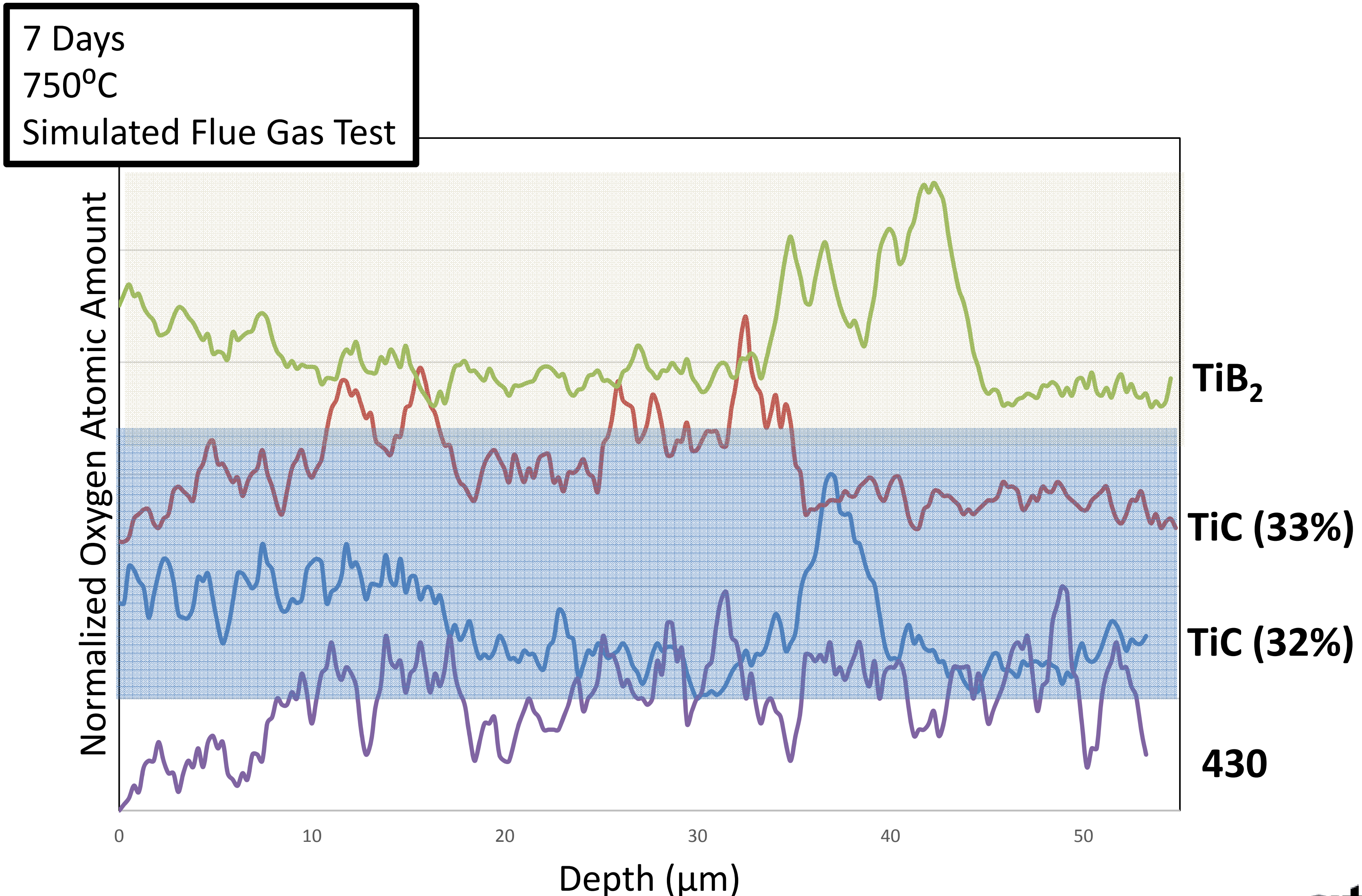
Oxidation resistance from coating: TiC (32%)

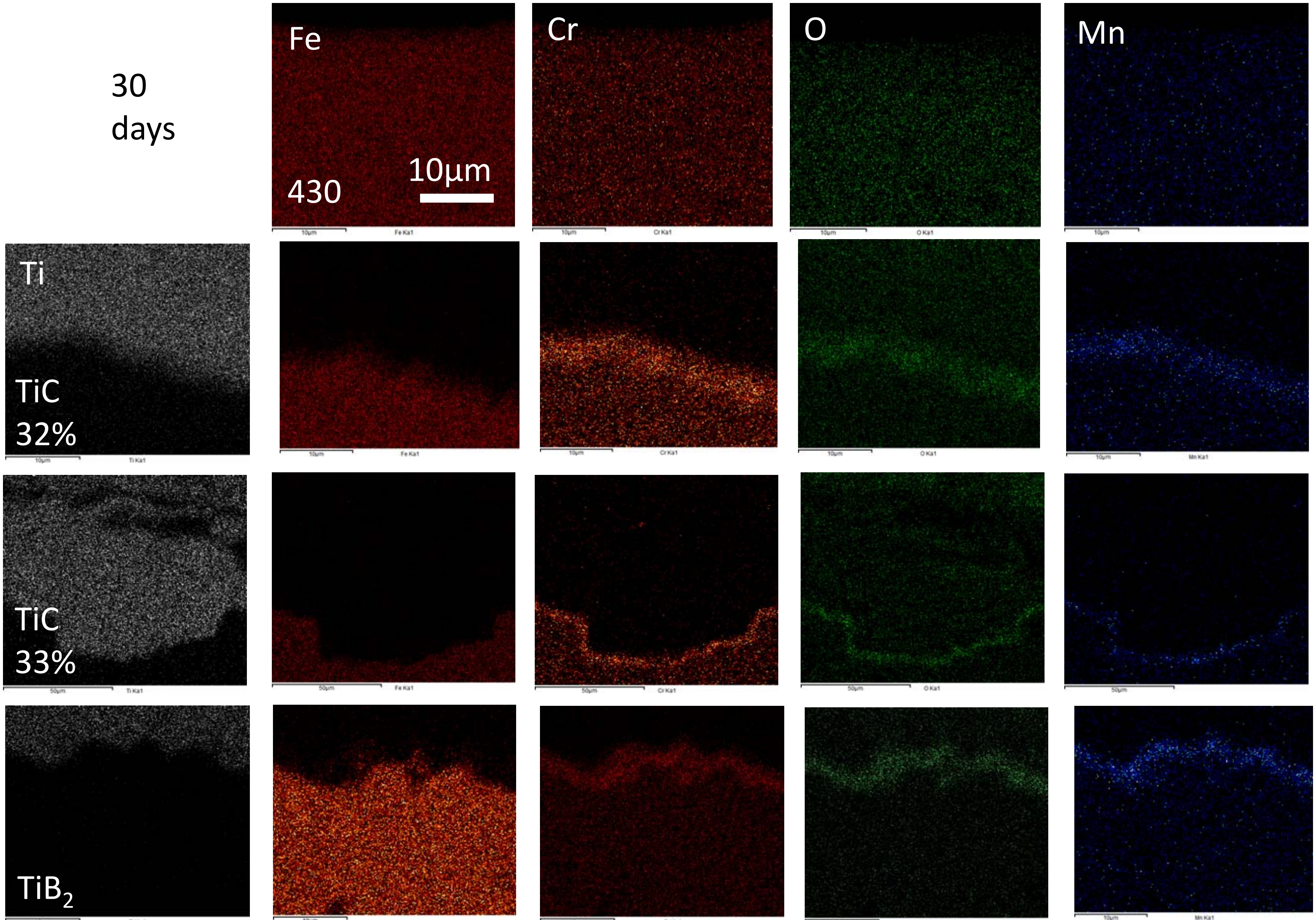


SIU Southern Illinois University
CARBONDALE

gti

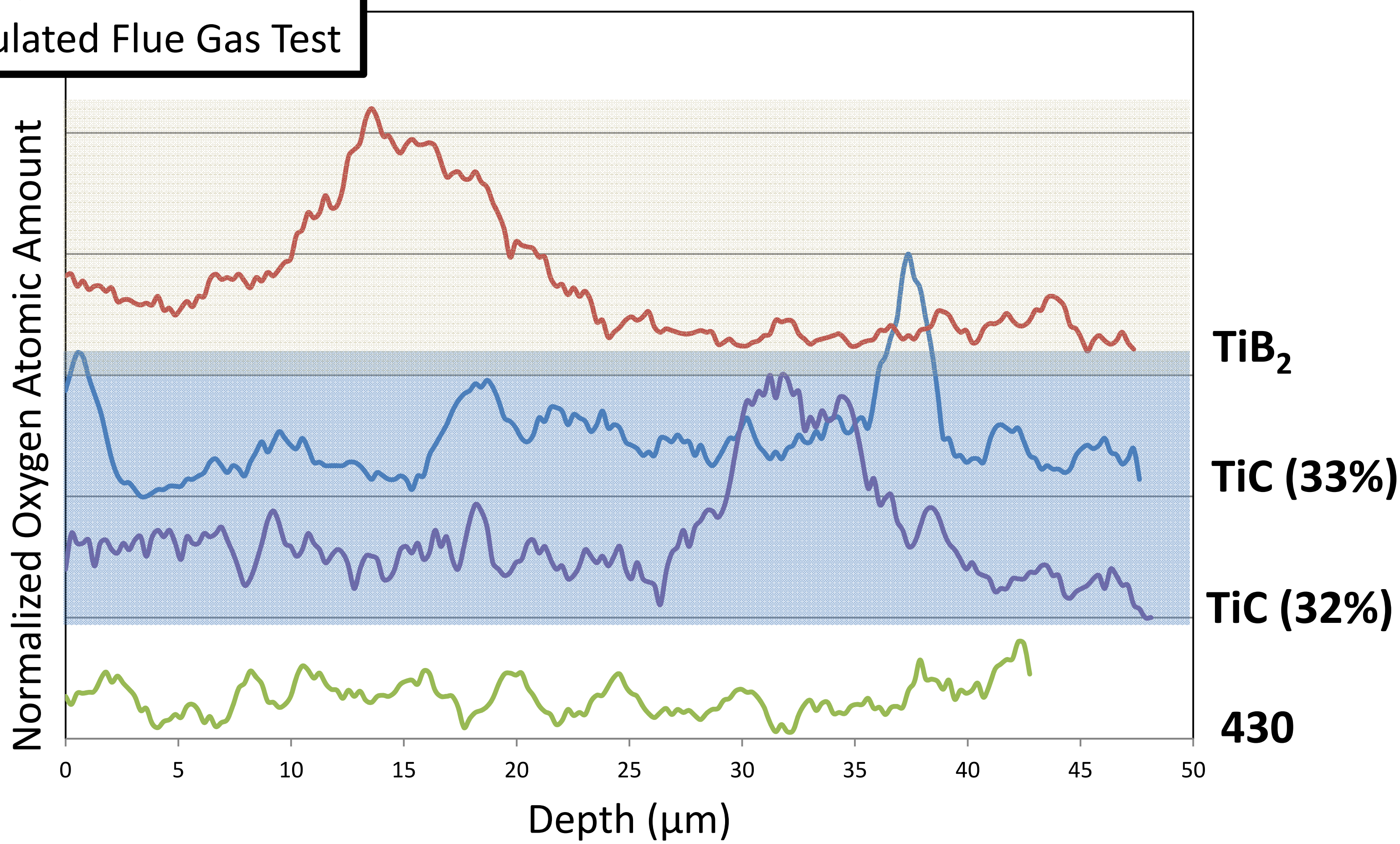
Oxidation Resistance: Oxygen Penetration



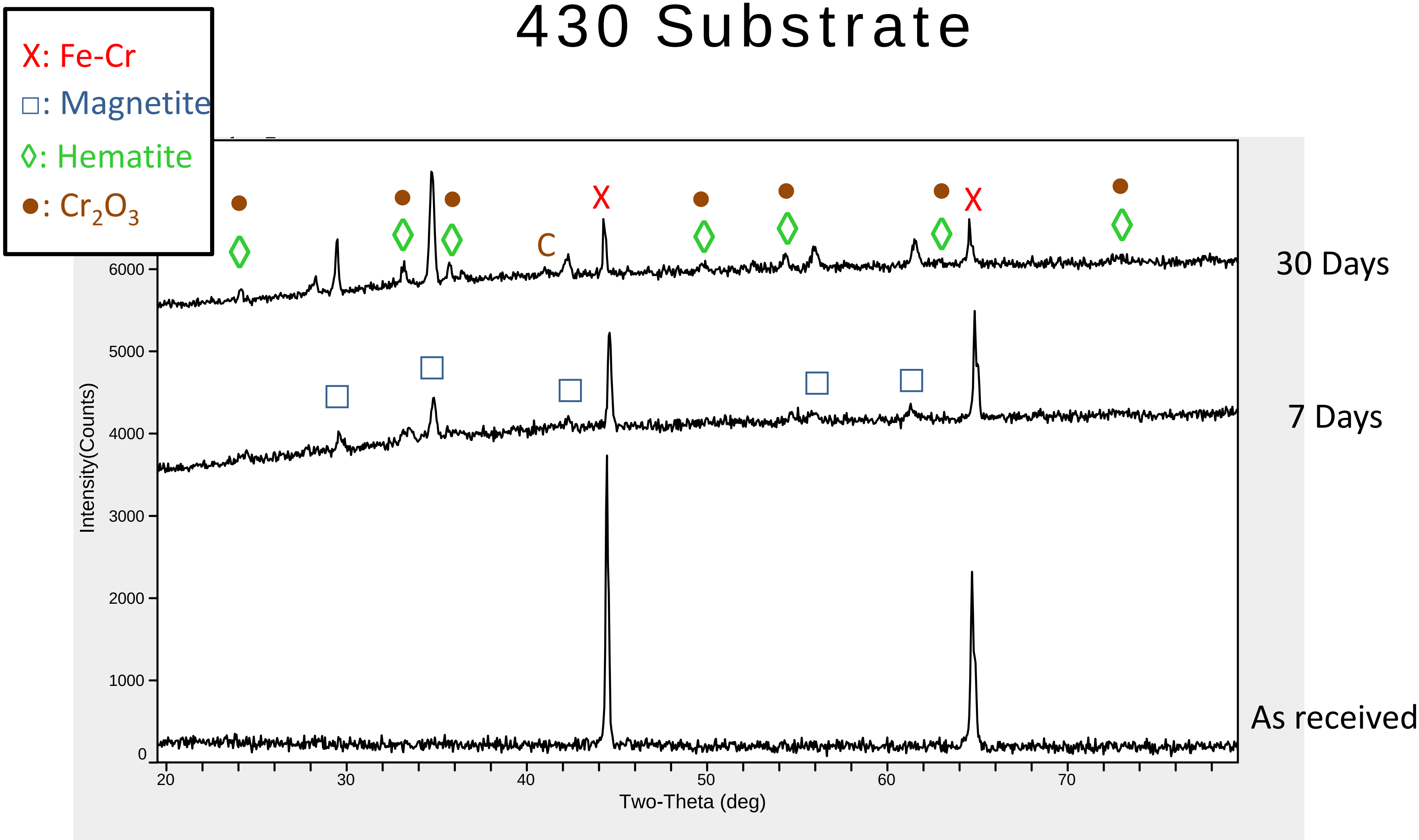

30 days
Fe
Cr
O
Mn
430
10µm
Ti
TiC 32%
TiC 33%
TiB_2

Oxidation Resistance: Oxygen Penetration

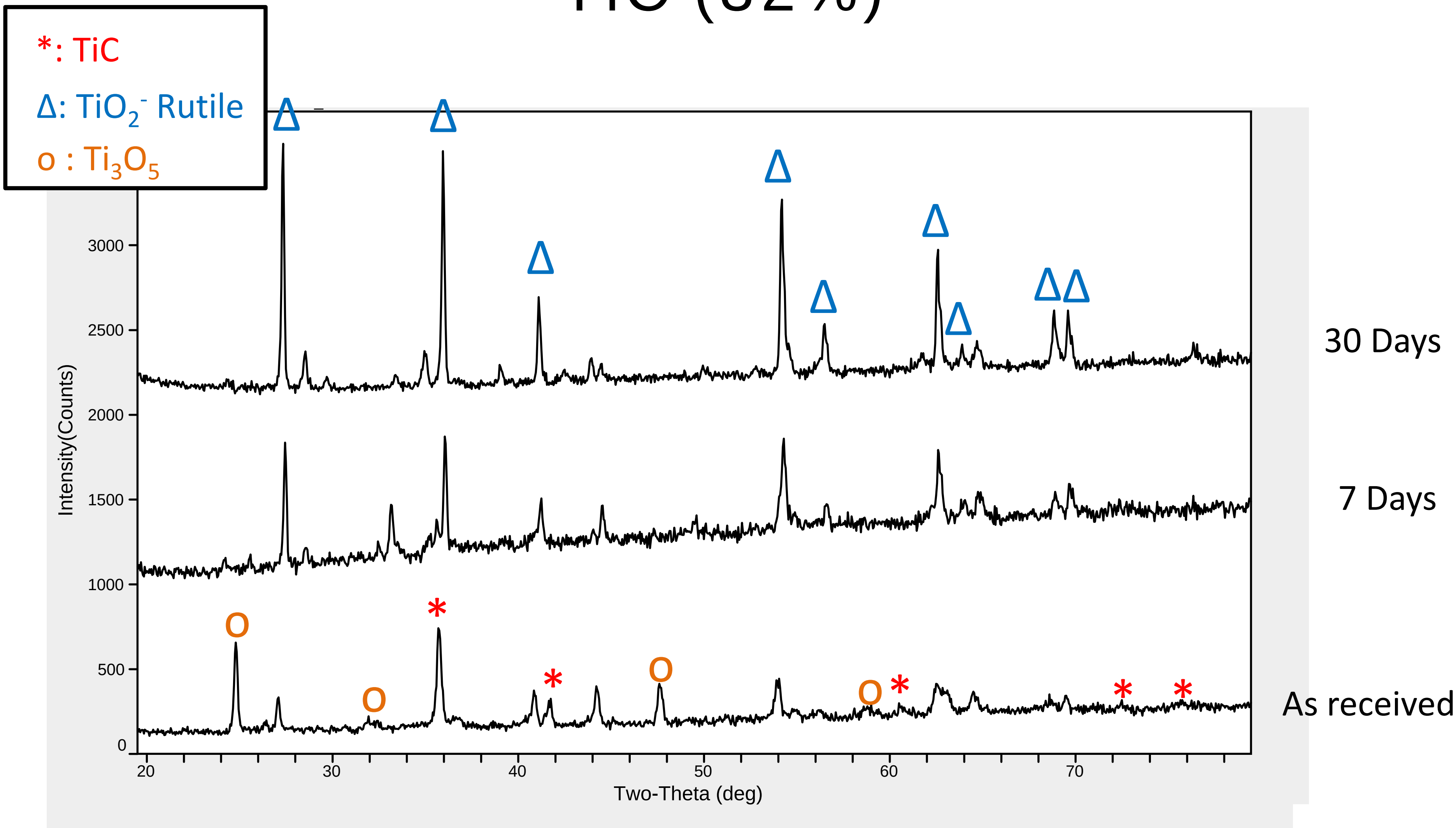
30 Days
750°C
Simulated Flue Gas Test



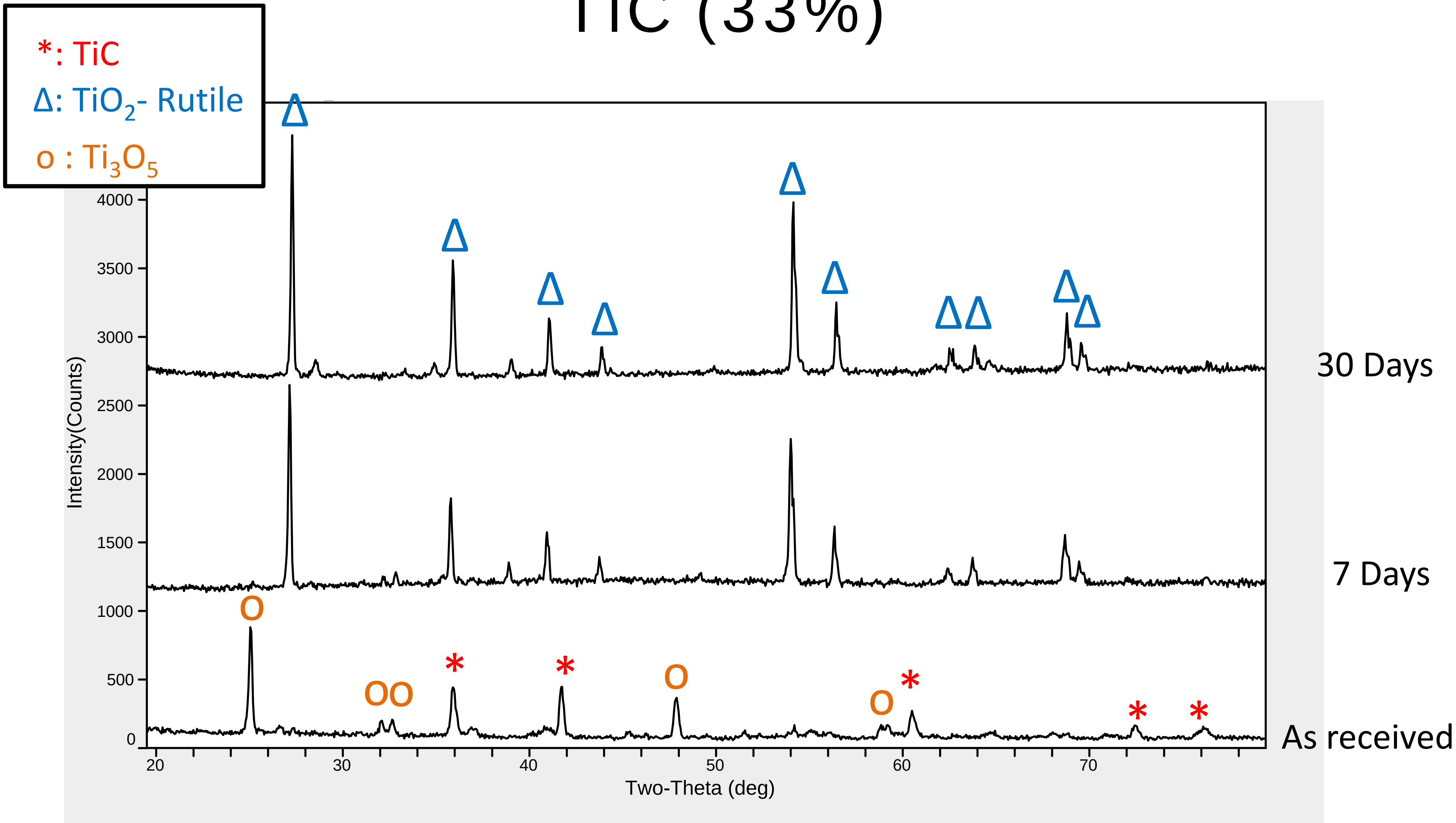
Impact of simulated flue gas at 750^{0}C 430 Substrate



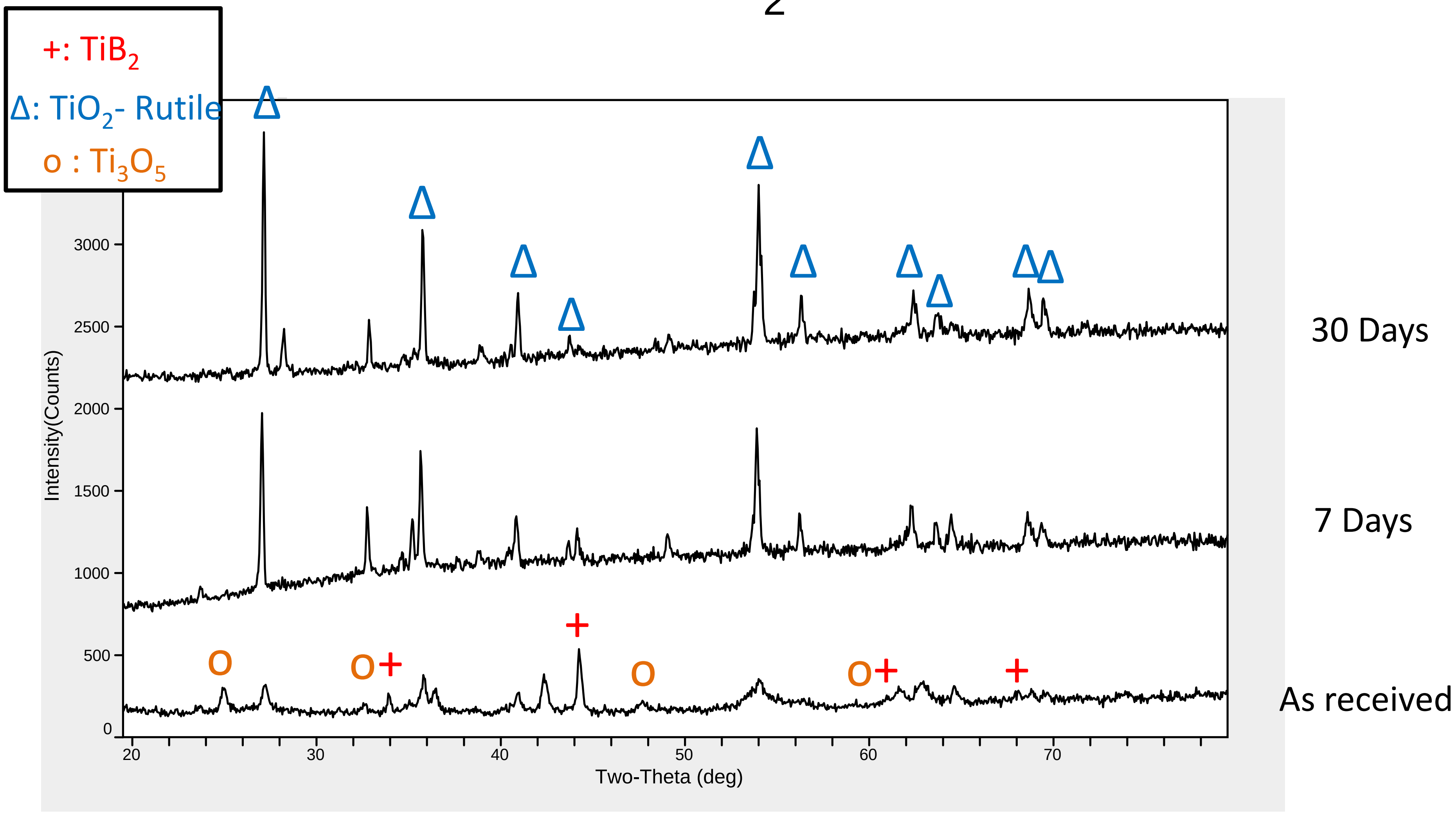
Impact of simulated flue gas at 750^{0}C
TiC (32%)



Impact of simulated flue gas at 750^{0}C TiC (33%)



Impact of simulated flue gas at 750^{0}C TiB_2



Summary of Coated 430 Samples after Simulated Flue Gas Tests

	750°C- 7 Days	750°C- 30 Days
TiC (32%)	**O** - Slight concentrate (Interface) - Lower (beyond interface) **TiO_2** - (surface)	**O** - Increased amount (Interface) - Lower (beyond interface) **Chromium Oxide** - (Interface) **TiO_2** - Sharper XRD peaks
TiC (33%)	**O** - Slight concentrate (Interface) - Lower (beyond interface) **Chromium Oxide** - (Interface) **TiO_2** - (surface)	**O** - Less (Interface) - Lower (beyond interface) **Chromium Oxide** – Thinner layer (Interface) **S** - concentrated (at Fe, surface) **TiO_2** - Sharper XRD peaks
TiB_2	**O** - Slight concentrate (Interface) - Lower (beyond interface) **Chromium Oxide** - (Interface) **TiO_2** - (surface)	**O** - Less (Interface) - Lower (beyond interface) **Chromium Oxide** – Thinner layer (Interface) **TiO_2** - Sharper XRD peaks
430	**Magnetite**	**Hematite** **Cr_2O_3** – (Surface)

On-going Task: P91 Steel Substrates

HVOF Spray coating	
Spray Parameters	
H2 Flow rate	76 LPM
O2 Flow rate	13 LPM
N2 Flow rate	1.8 LPM (Low Flow)/ 3.6 LPM (High Flow)
Spray Distance	27cm

Samples		Coating Time (min)	Coating Powder	Coating Conditions
A		0	Control, no coating	Glass blasted, then surface ground
B	Side A	12	TiC 32%C 1500C 2hr	Low N2 carrier flow
	Side B	3	TiC 32%C 1500C 2hr	High N2 carrier flow
C	Side A	12	Ti Metal	Low N2 carrier flow
	Side B	3	Ti Metal	High N2 carrier flow
D	Side A	12	TiC 32%C 1500C 2hr	High N2 carrier flow
	Side B	12+12	TiC 32%C 1500C 2hr	High N2 carrier flow
E		0	Glass Blasted Control	As-received metal had heavy surface corrosion
F	Side A	12	TiC 32%C 1500C 2hr	Glass blasted, Low N2 carrier flow
	Side B	12	TiC 32%C 1500C 2hr	Glass blasted, High N2 carrier flow

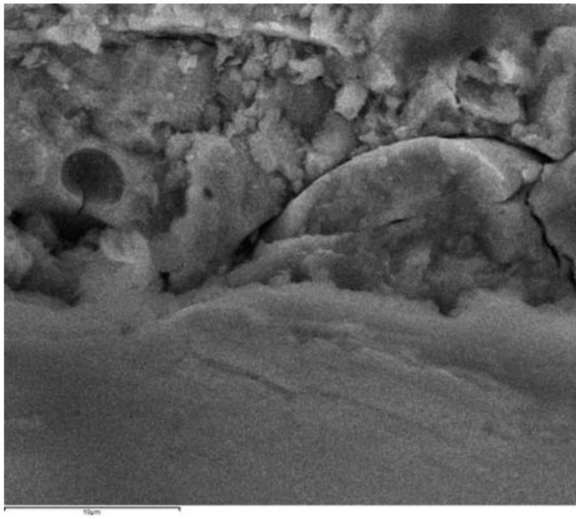
Achievements

- Facile synthesis of sub micro TiC and TiB_2 powders.
- HVOF thermal spray coating of the prepared powders on 304H, 430, and P91 substrates.
- Corrosion test analysis of coated 304H and 430 substrates.
- Increased longevity and corrosion resistance of the coated substrates subjected to fireside corrosion in AUSC SH/RH tubes and boiler tubes.

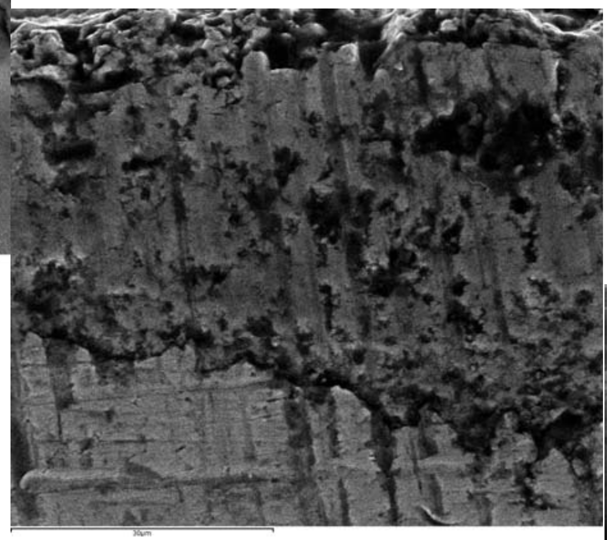
Acknowledgement

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

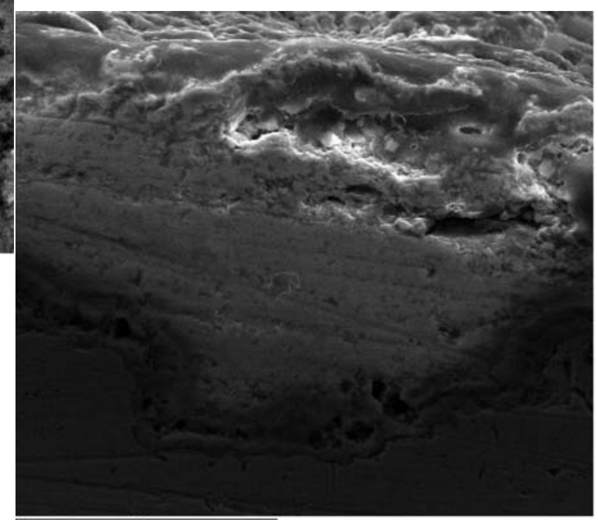
Thank You.



As received

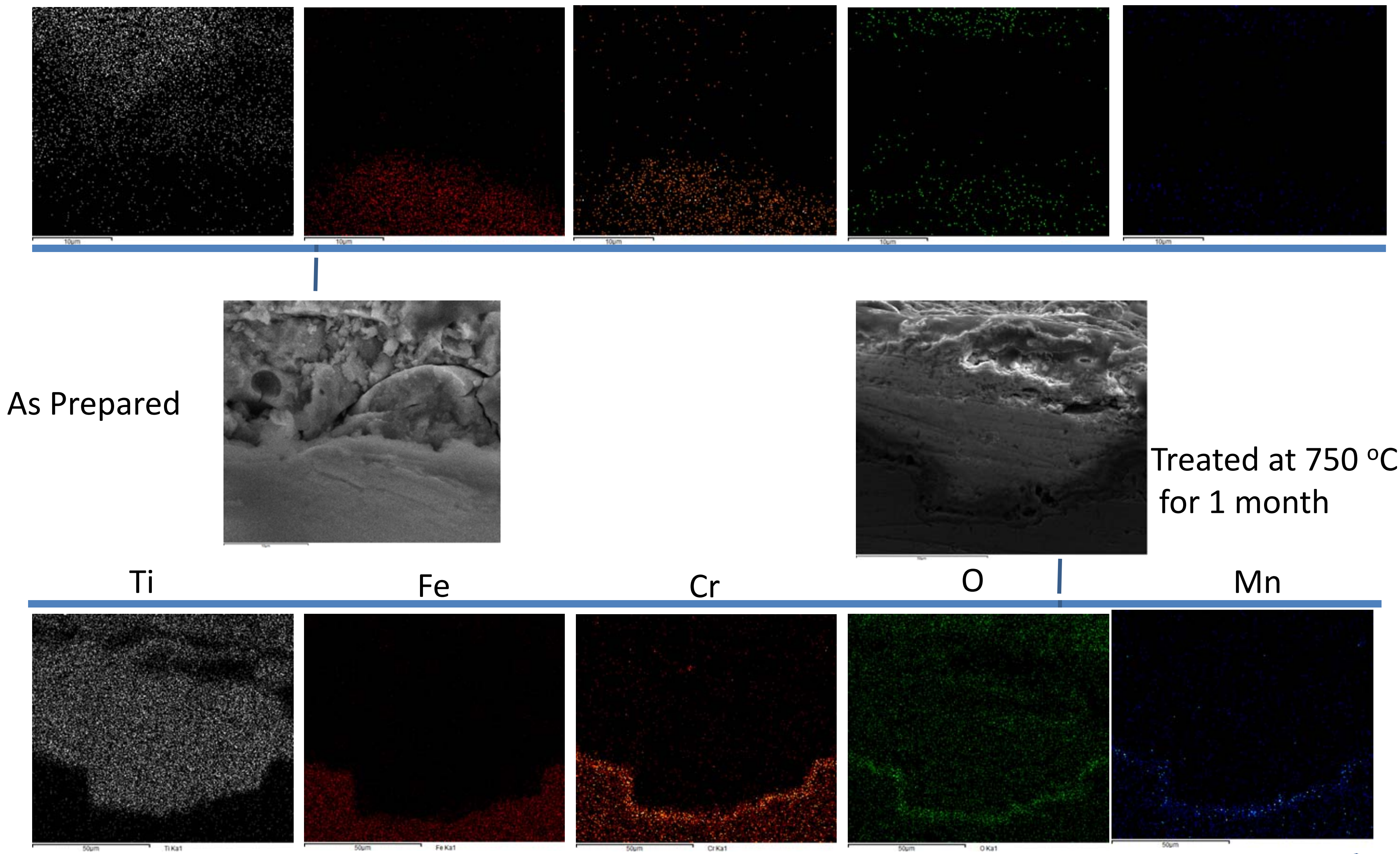


7 Days



30 Days

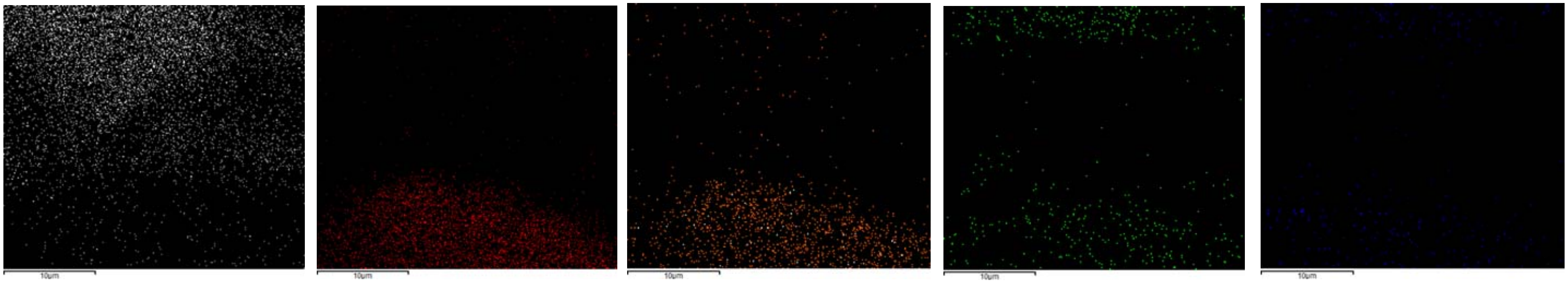
TiC (33%) Coated 430



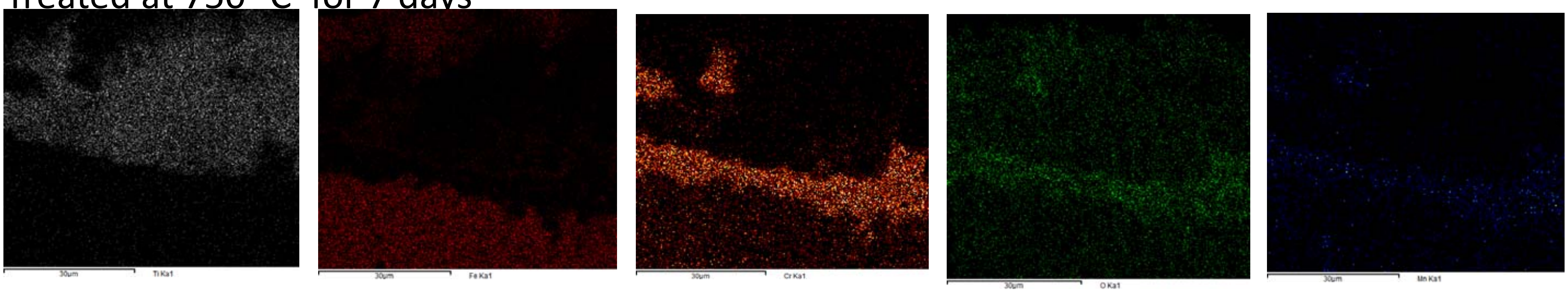
TiC (33%) Coated 430

Ti Fe Cr O Mn

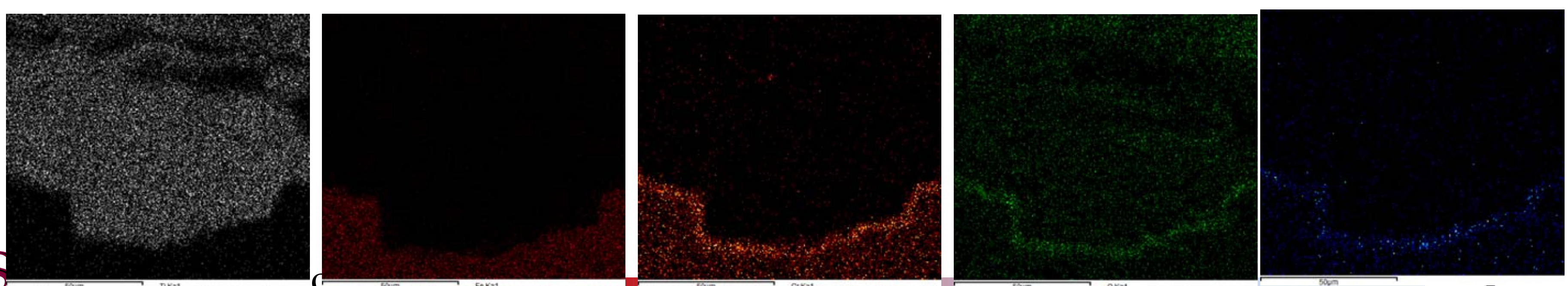
As Prepared

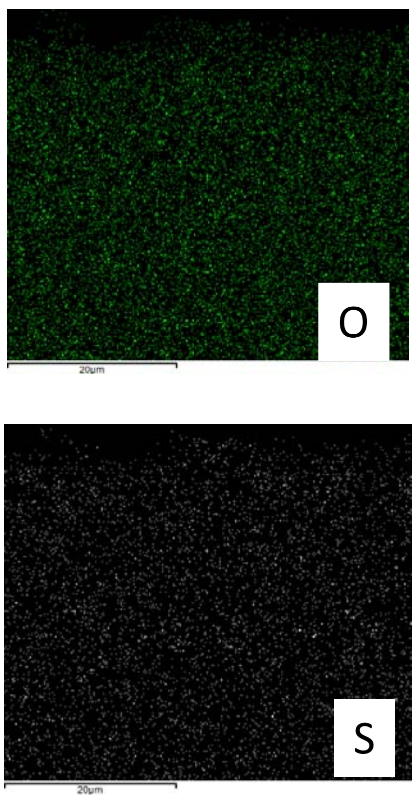


Treated at 750 ^oC for 7 days

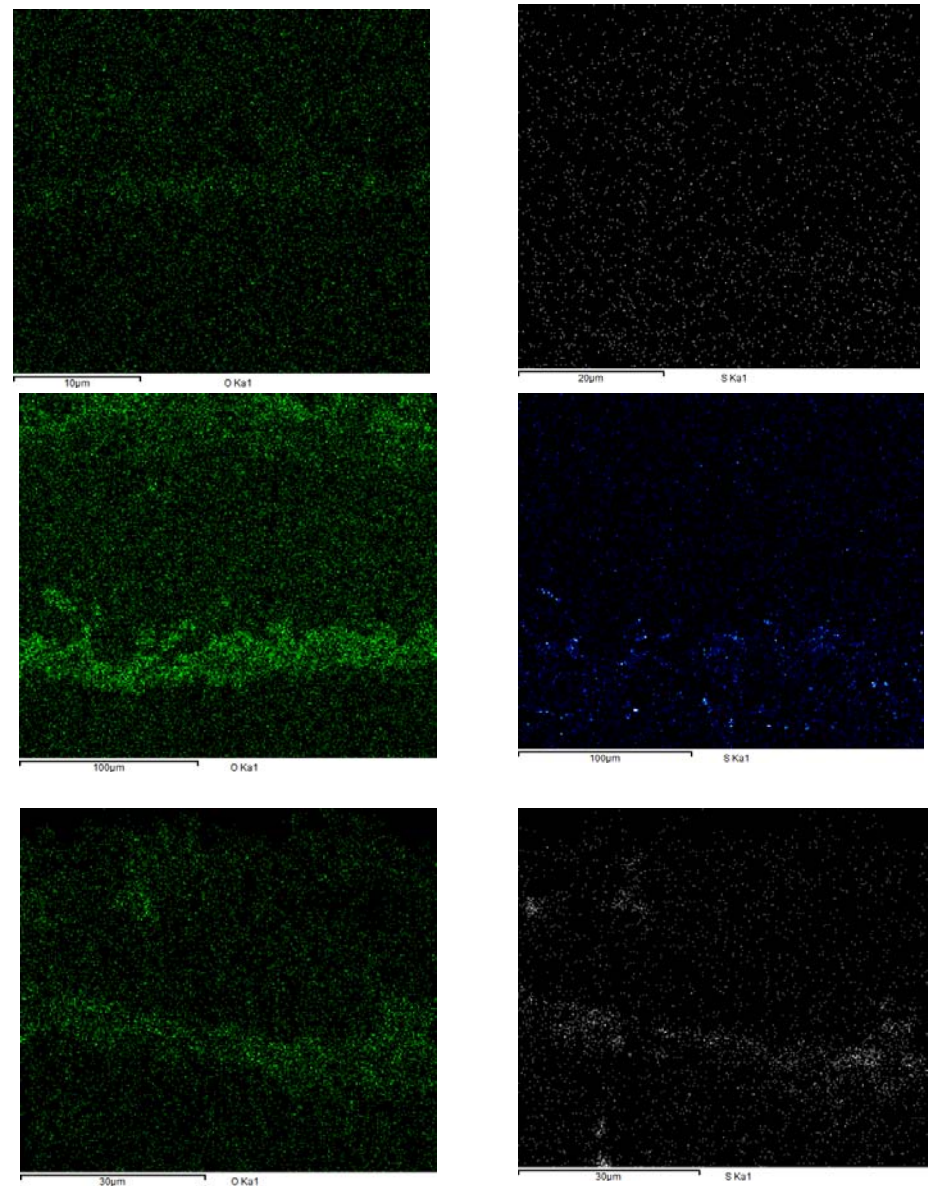


Treated at 750 ^oC for 30 days





O S

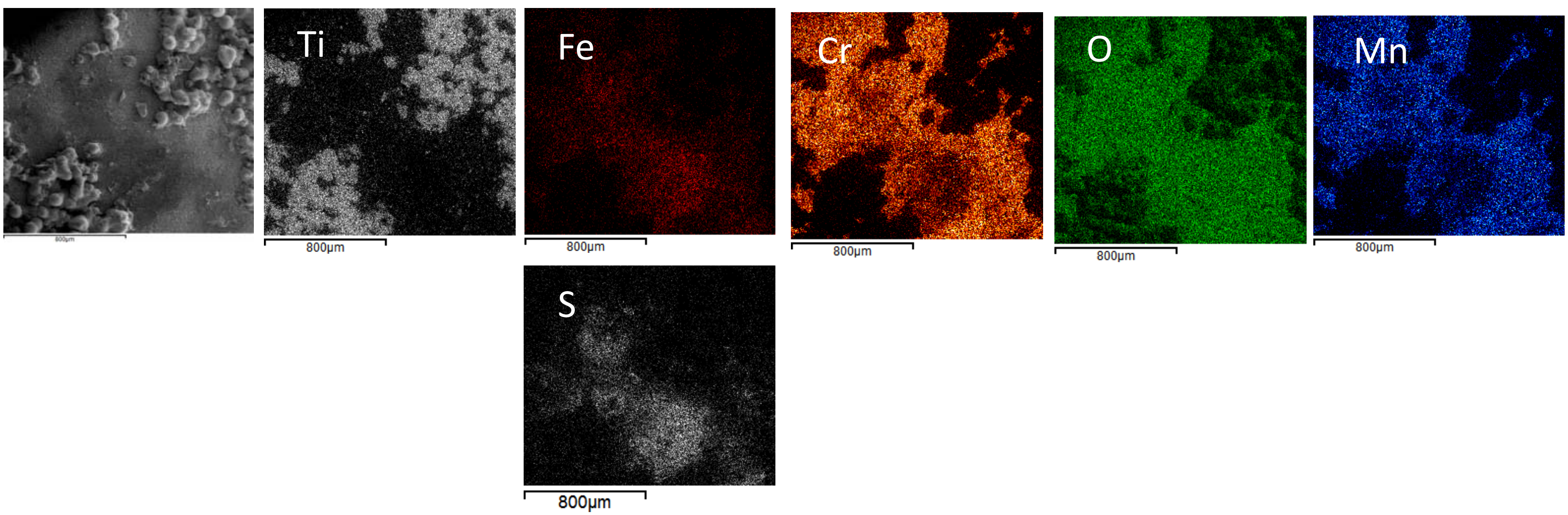


TiC 32%

TiB_2

TiC 33%

Simulated Flue Gas Test: 30 Days



Objectives and Tasks

Major Project Objectives

- Synthesis of nanoparticles of TiC by a patented process.
- Extension of the process to synthesize nano sized TiB_2 powder.
- Optimization for HVOF spray coating of the TiC and TiB_2 on select ferritic, austenitic and nickel alloy samples generally used for water wall tubing, high temperature boiler sections, turbine blades and USC tubing applications.
- Laboratory evaluation of the corrosion resistance of the coatings employing simulated flue gas and simulated ash.
- Selection of optimum alloy protection system in different temperature/chemical regimes
- Field evaluation of fabricated probes of select coating in actual boiler/turbine environment

Task I: **Project Management and Planning.**

Task II: **TiC and TiB_2 powder synthesis**

Task III: **Sample Acquisition**

Task IV: **HVOF Spray Coating**

Task V: **Corrosion Studies**

Task VI: **Post Exposure Characterization**