# 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

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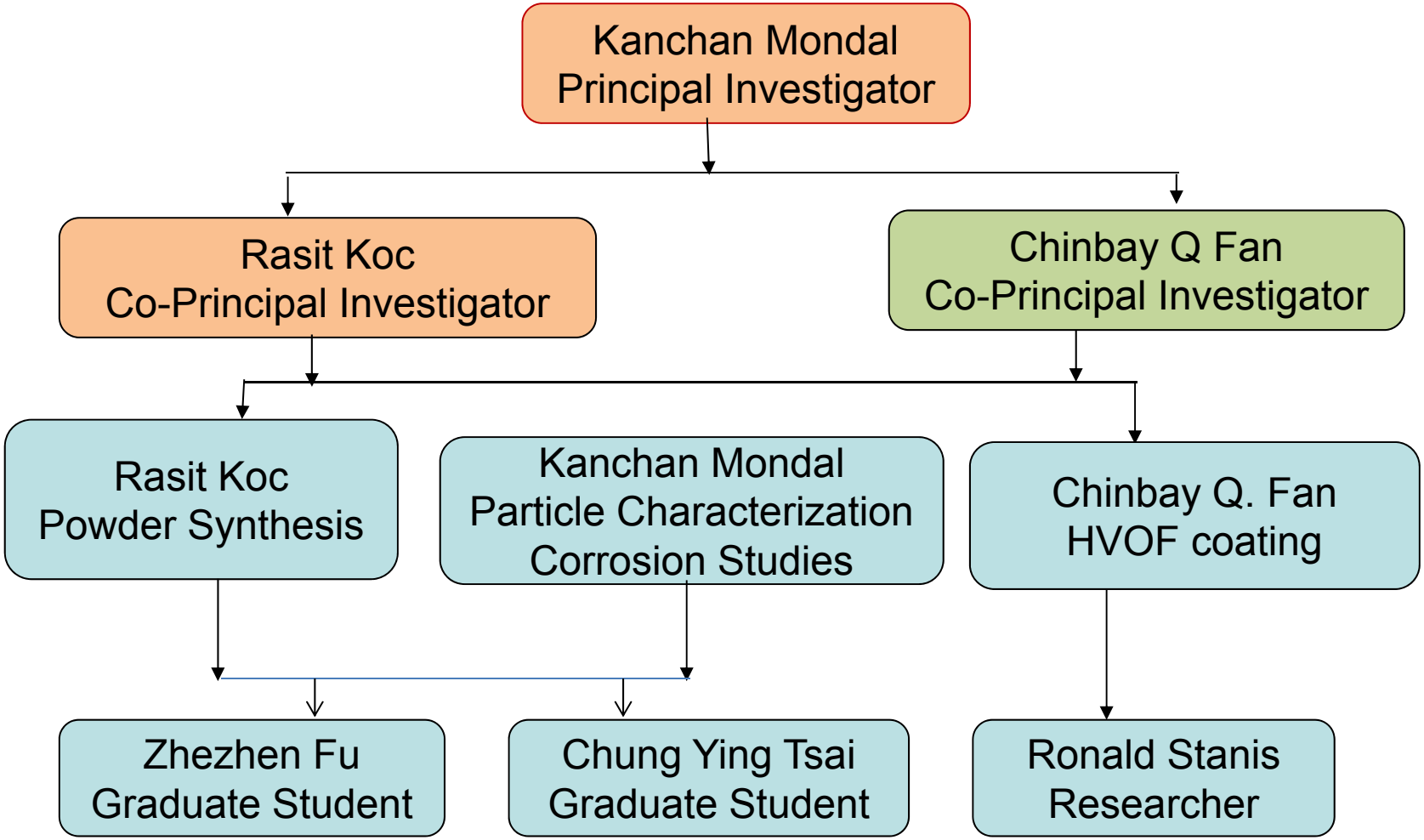
**June 11-13, 2013**

SIU CARBONDALE Southern Illinois University

gti

# PROJECT TEAM




# HVOF, Flame Spray Coatings

GTI project number 21397
Chinbay Fan and Ronald Stanis

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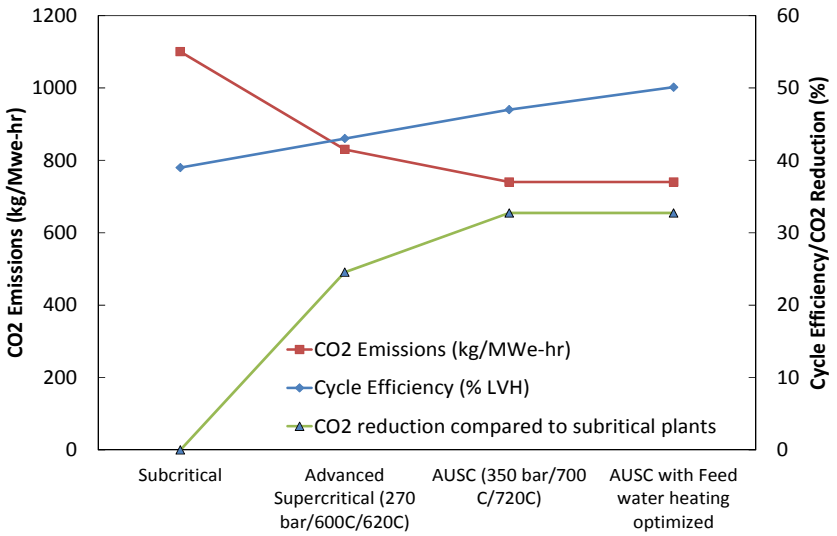
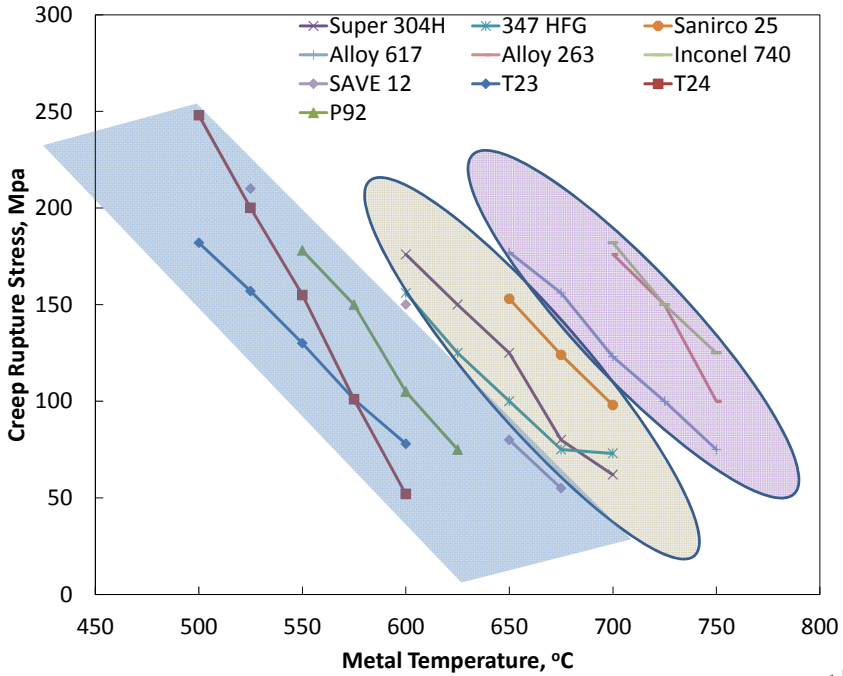
# Background




- 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



# Objectives and Tasks

**Major Project Objectives**

- Synthesis of nanoparticles of TiC by a patented process.
- Extension of the process to synthesize nanosized $TiB_2$ 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**

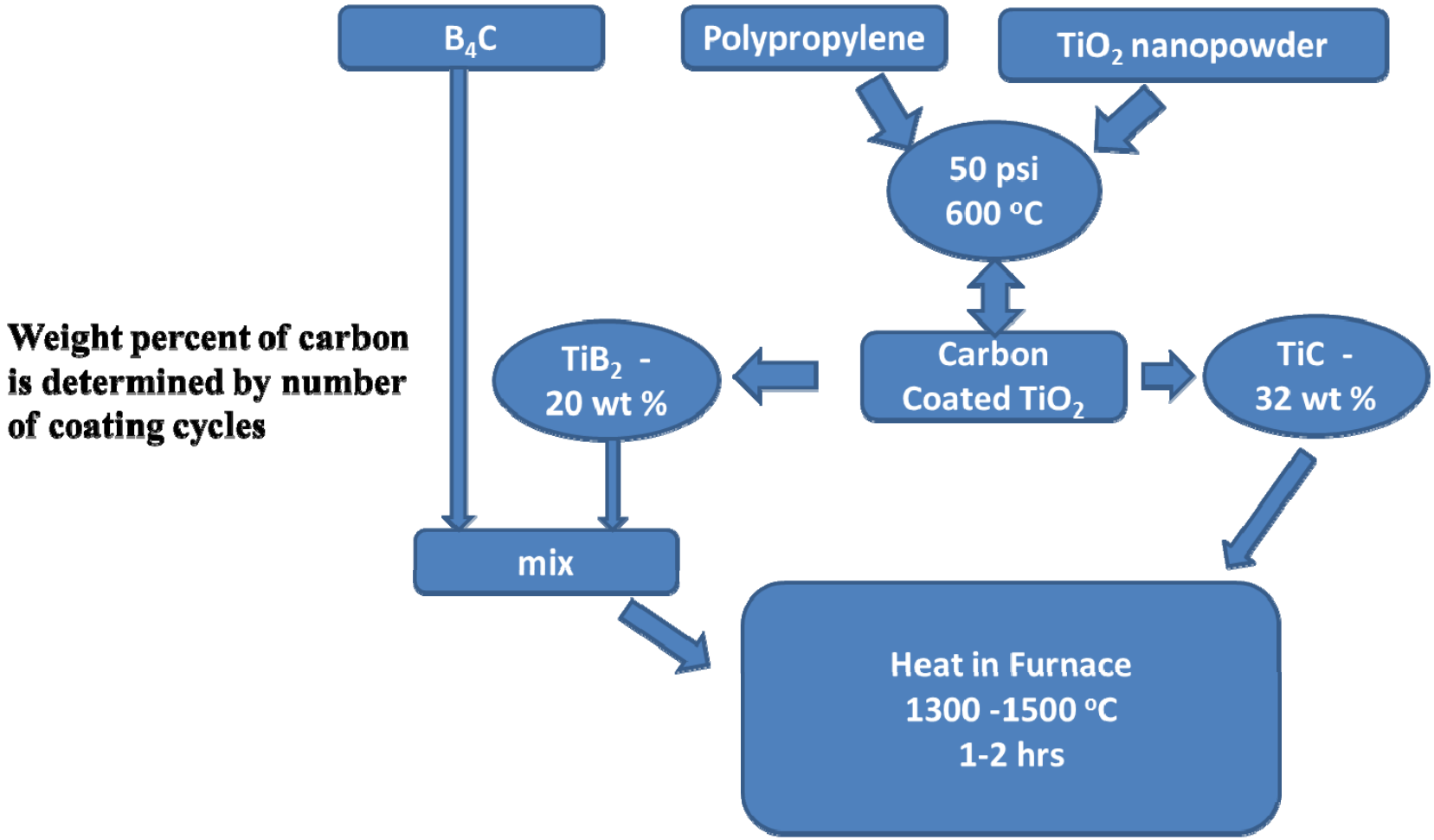
***Task V:*** **Corrosion Studies**

***Task VI:*** **Post Exposure Characterization**

# 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 $^{o}$C |
| 6 | Haynes 230 | Nickel Alloy | SH tubes, HP turbine rotor – 700$^{o}$C |
| 7 | Inconel 740 | Nickel Alloy | SH tubes, HP turbine - casing, piping, rotor-760 $^{o}$C |
| 8 | Haynes 263 | Nickel Alloy | HP turbine casing – 700 $^{o}$C |
| 9 | P91/P92 | Ferritic | Low Temp SH/RH |
| 10 | T91/T92 | Ferritic | Low Temp SH/RH, HP turbine piping – 620$^{o}$C |
| 11 | Save 12 | Ferritic | HP turbine casing, rotor, blades – 620 $^{o}$C |
| 12 | T23/T24 | Ferritic | Furnace Tubes |

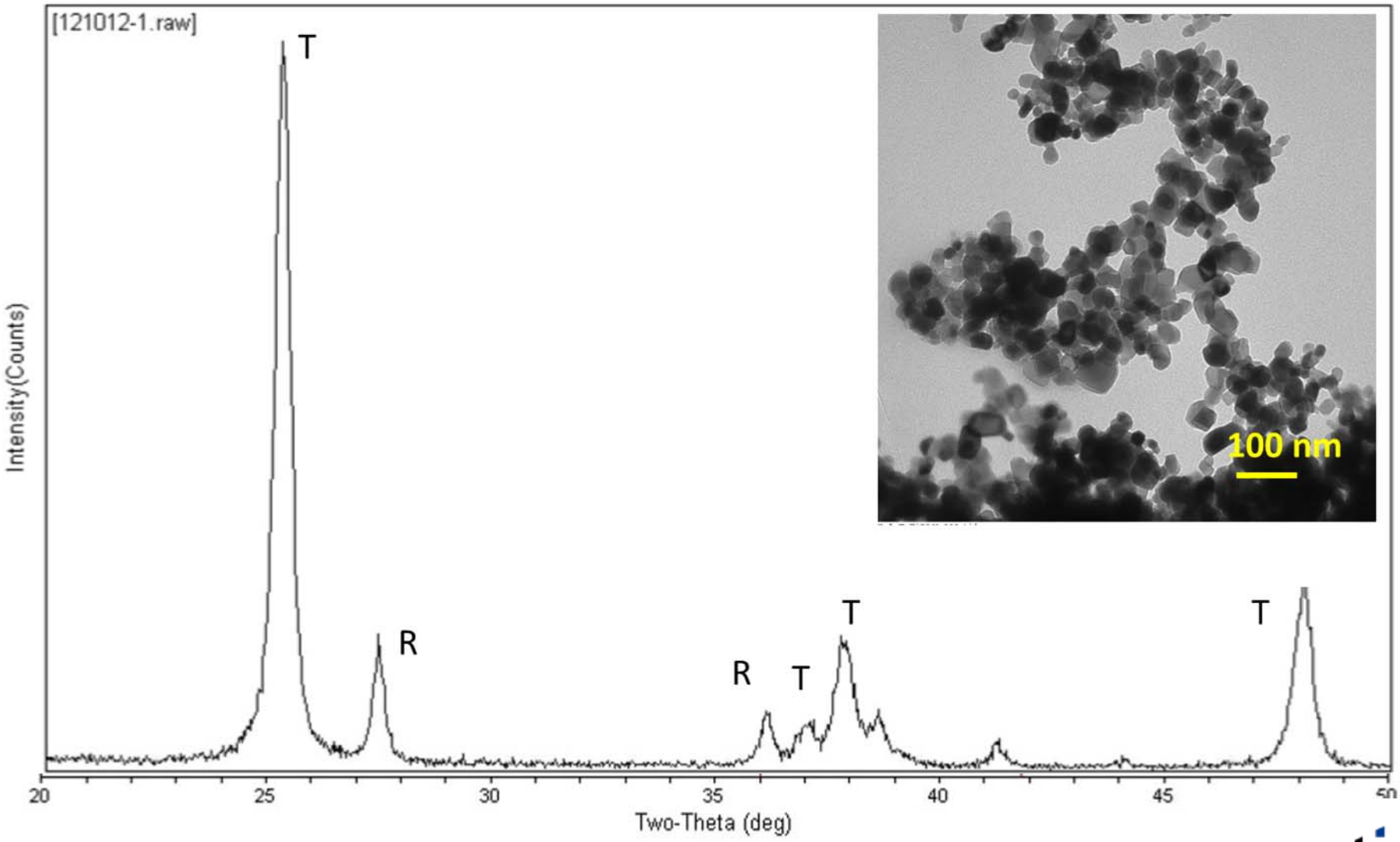
# Carbothermal Process for TiC and $TiB_2$ Powder Synthesis



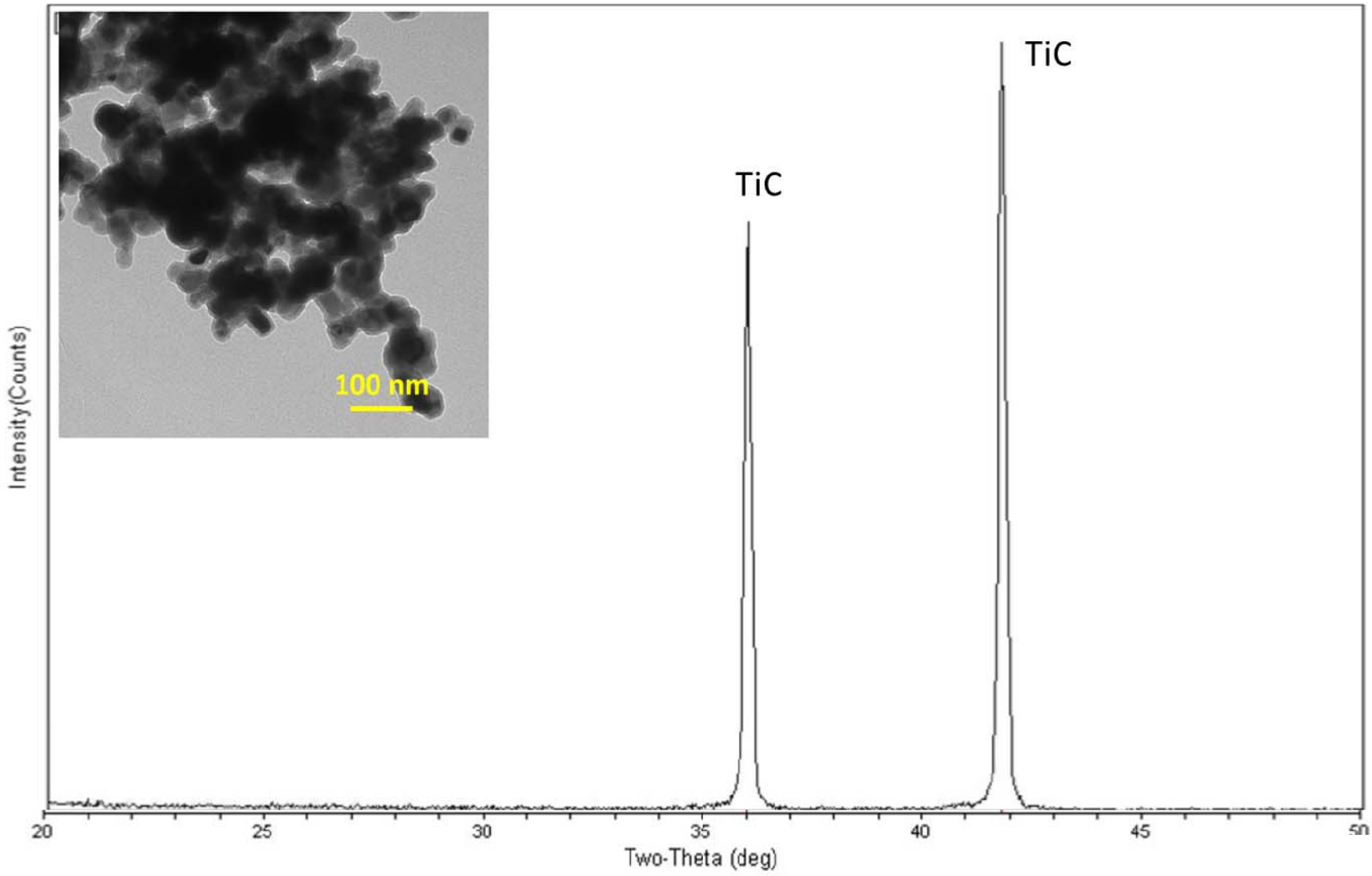

**Weight percent of carbon is determined by number of coating cycles**

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

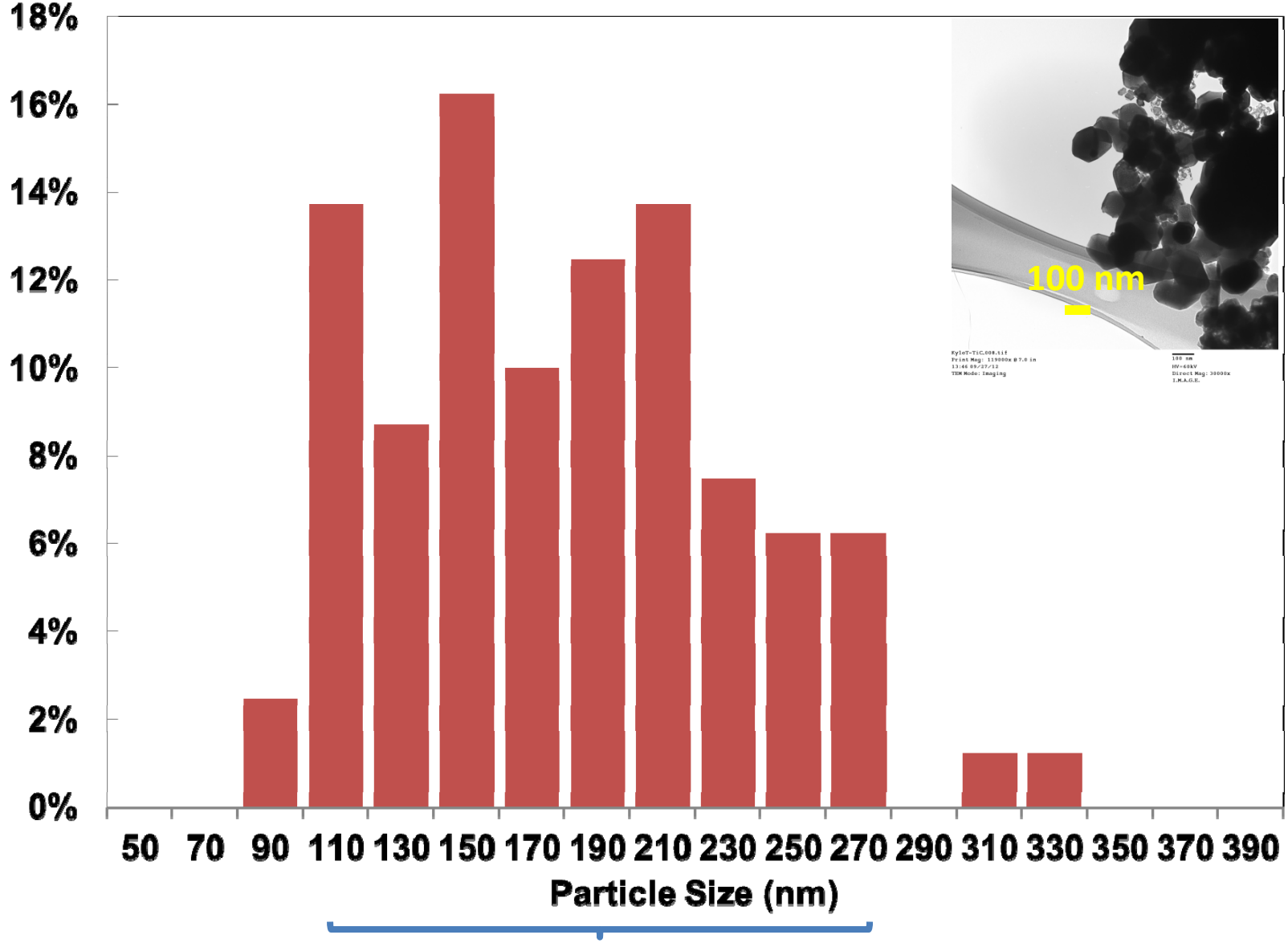
# Precursor Titania Nanoparticles



# Resultant TiC Nanopwder



# Resultant TiC Nanopwder



## Powder Physical Properties

| | 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 |

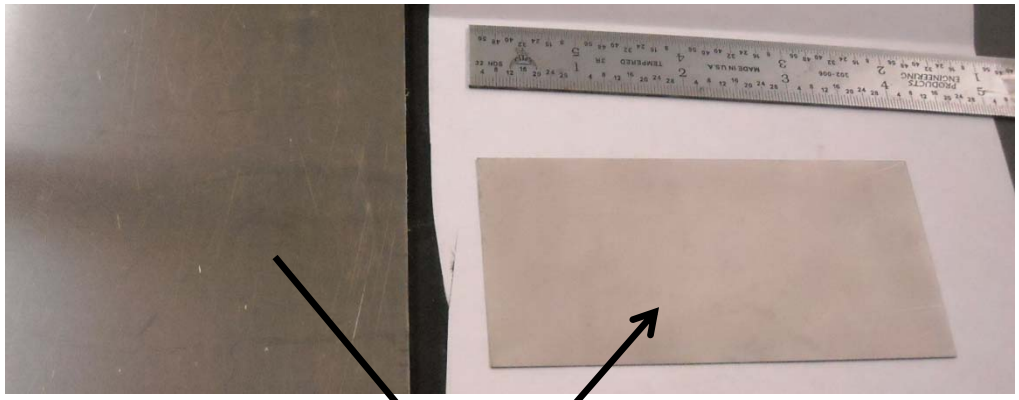
## Substrate Composition

**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)**

# GTI Flame Spray System

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


SS 304H As received After surface roughening



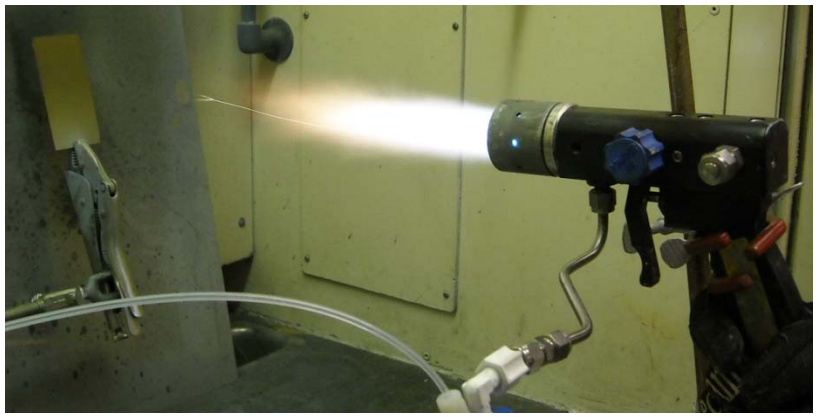
Water honing

<u>Safety is first priority</u>

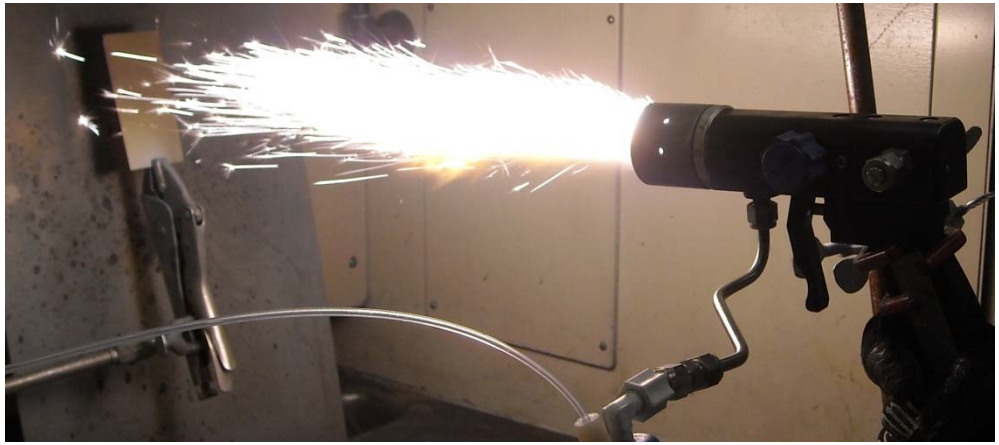
- Hearing protection
- Eye protection (light)
- Face Shield
- Flame arrestors
- Two person operation
  - One holding gun
  - One operating gas flows
- Emergency Stop Button

# Spray Deposition

Just Flame

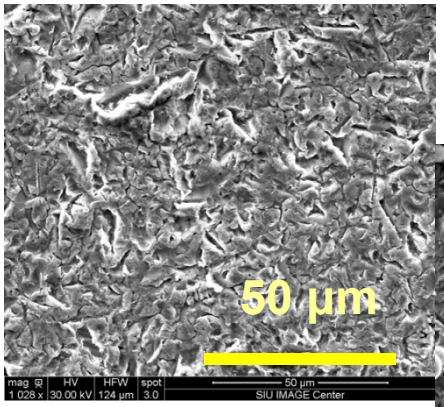


Flame with Powder

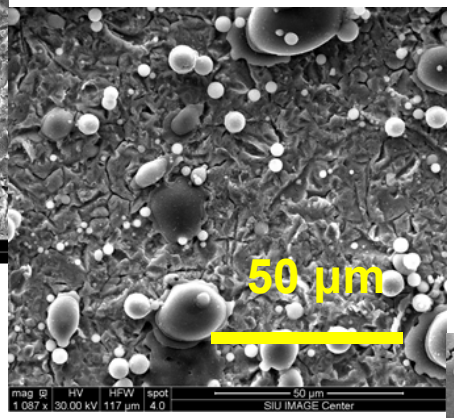


Partially Covered Samples

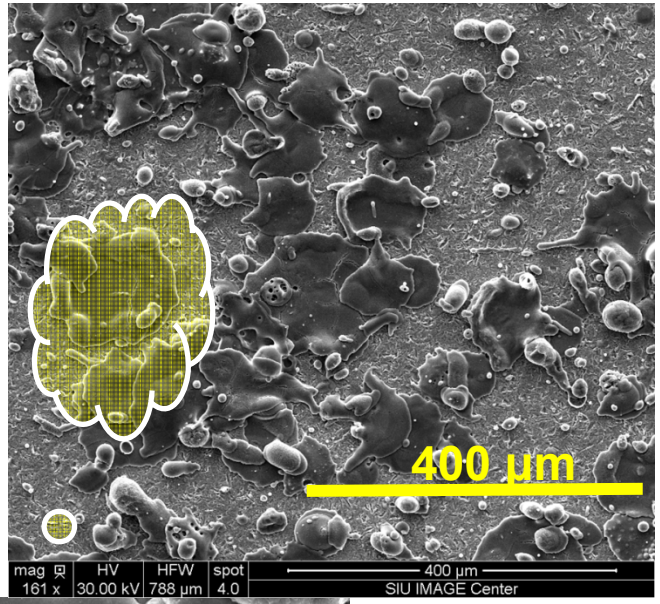
# Substrate Morphology

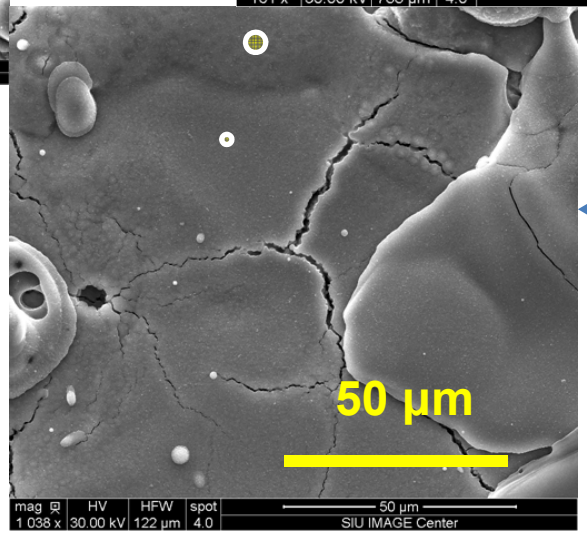



*Water Honed*
*Uncoated*



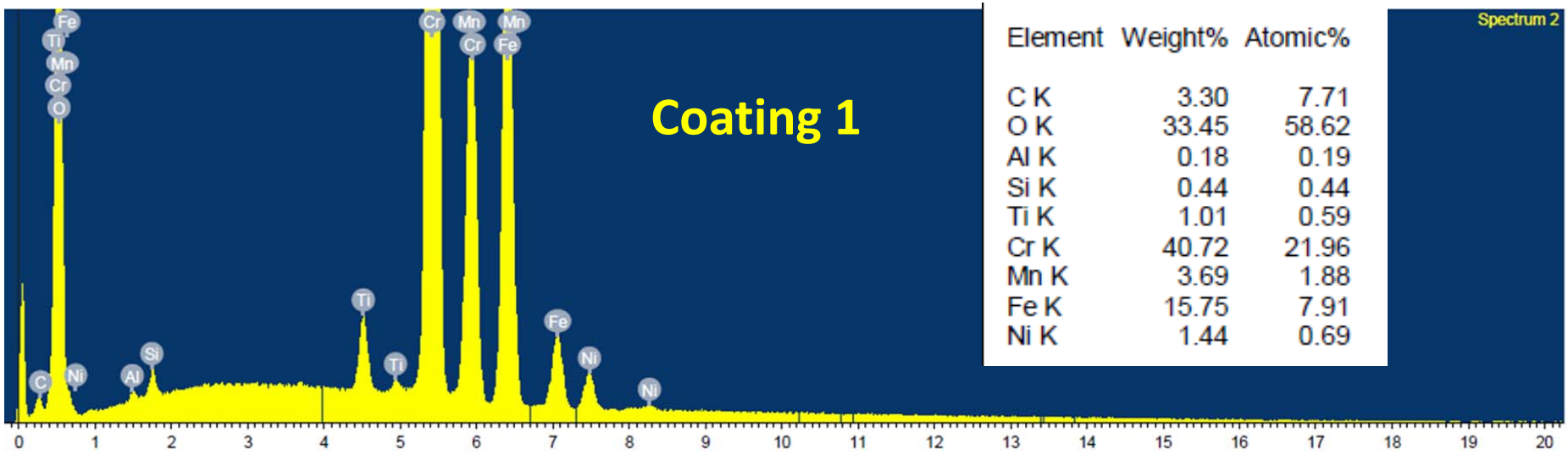

*Coating 1*

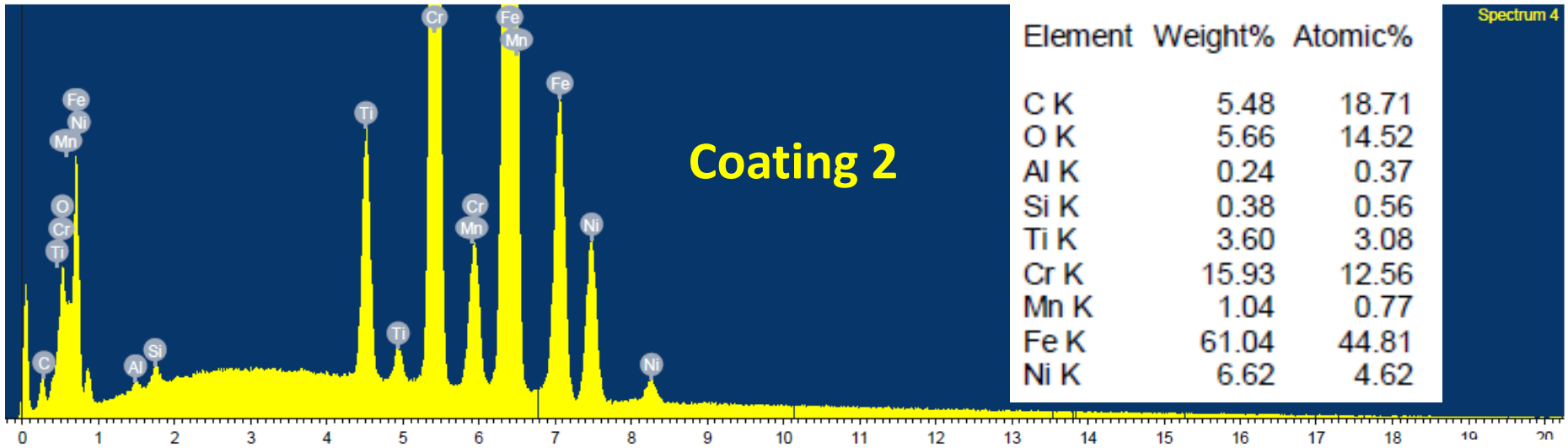


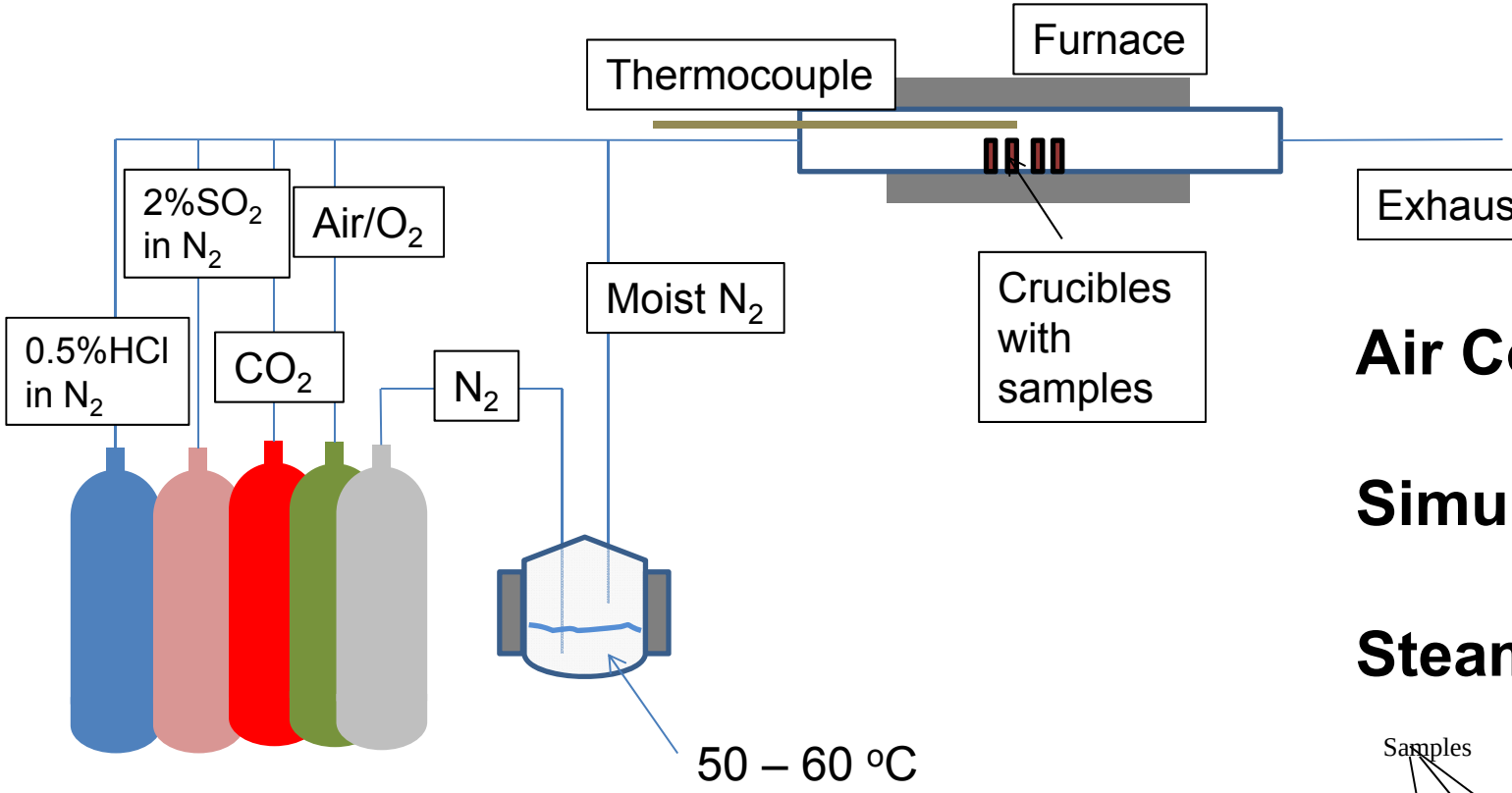

*Coating 2*

# Elemental Composition



# Corrosion Experimental Setup



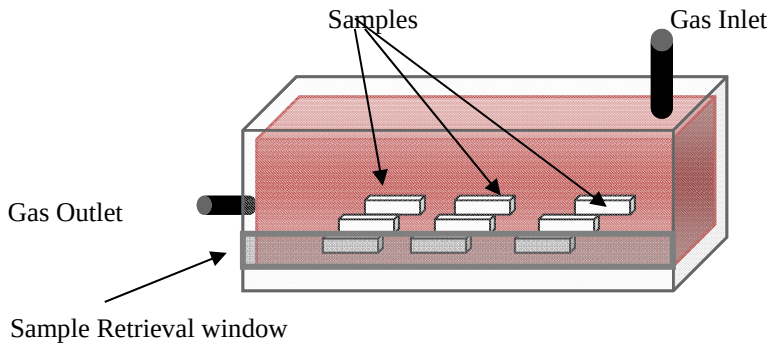

**Air Corrosion**

**Simulated Ash**

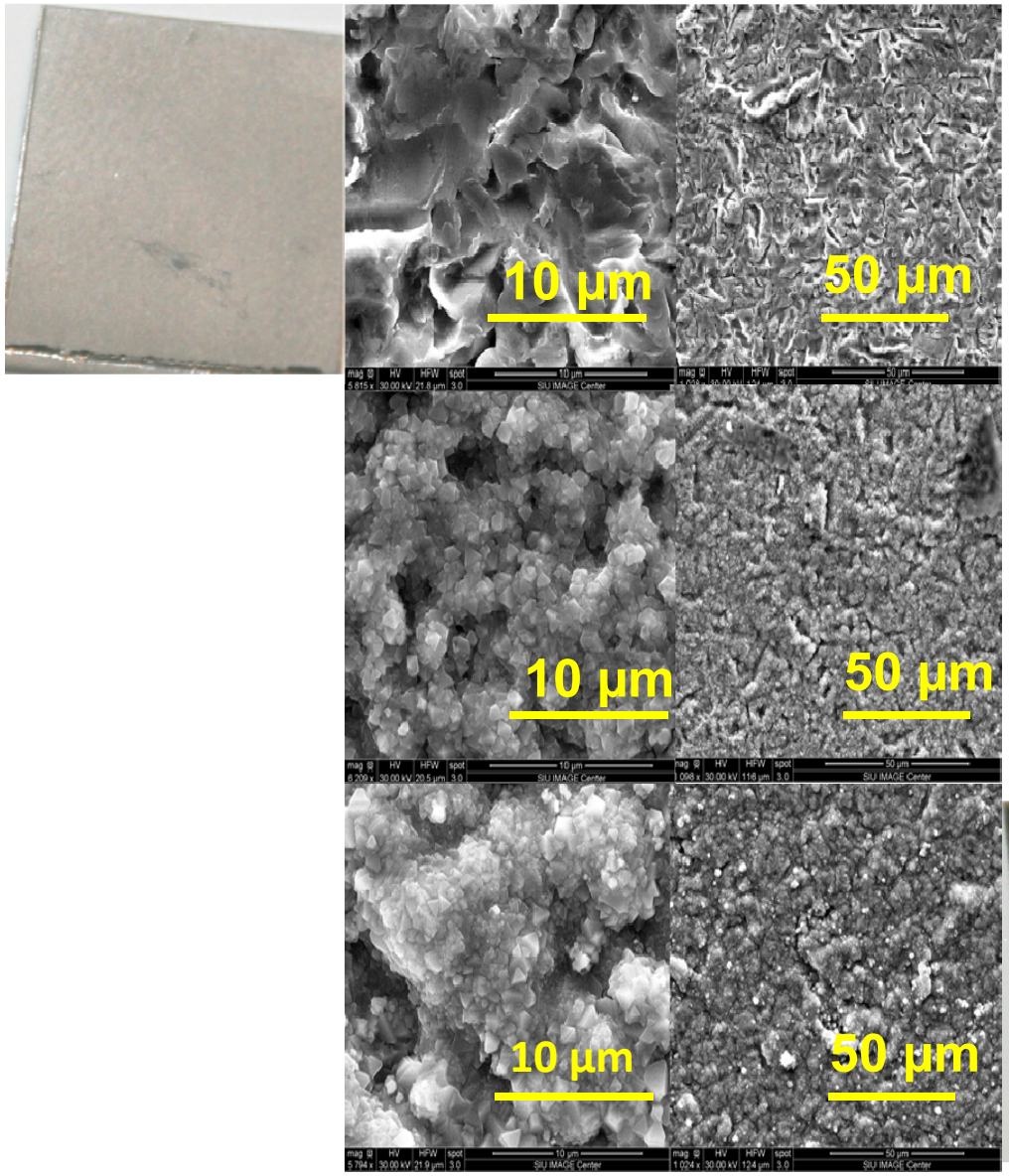
**Steam Oxidation**

**Tube Furnace**

**Box Furnace**



# Air Oxidation of 304 H – 750 °C

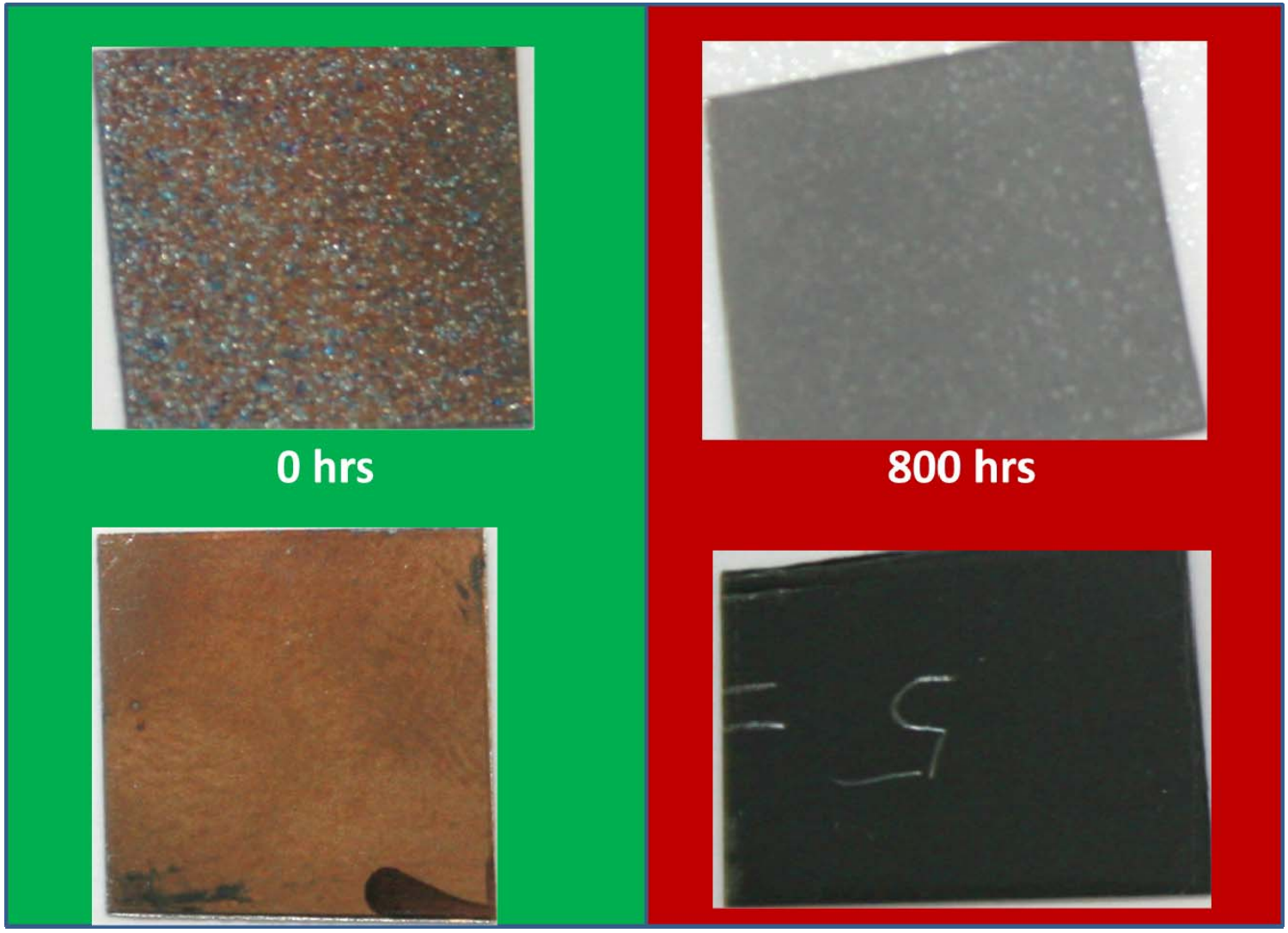



**0 hrs**

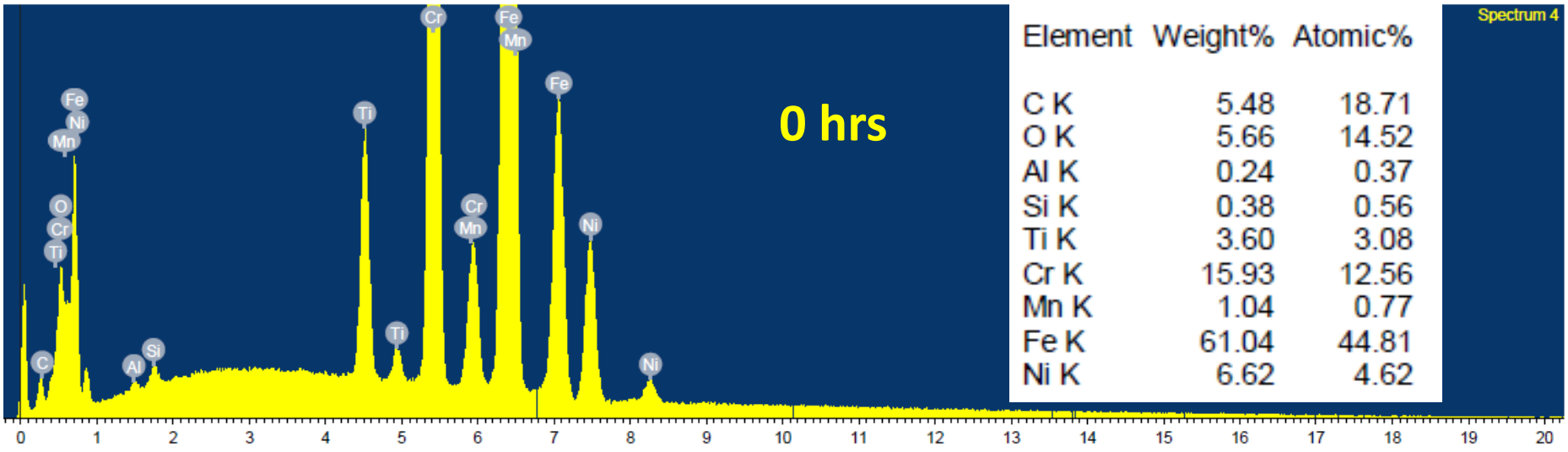
**200 hrs**

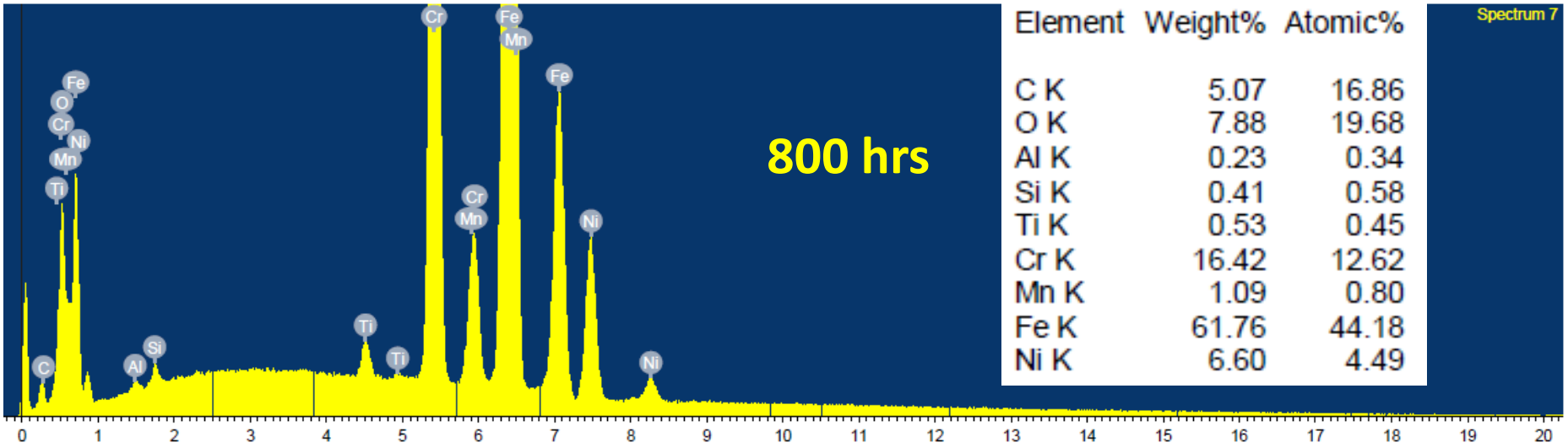
**800 hrs**

# Air Oxidation of TiC Coated 304 H at 750 °C– Coating 2

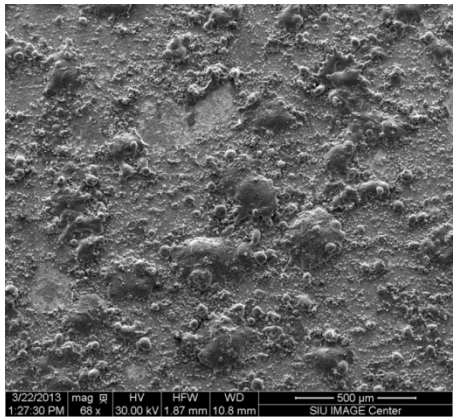
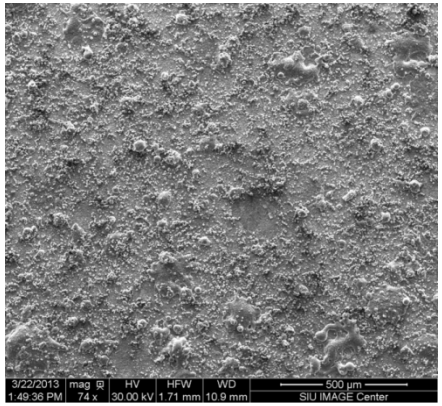
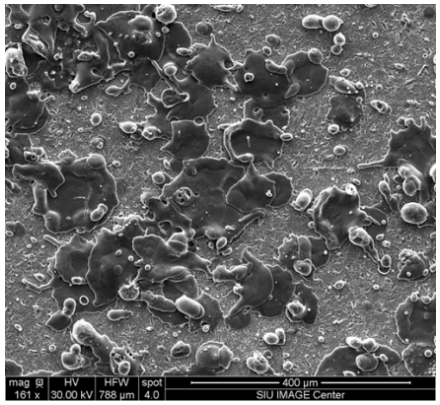
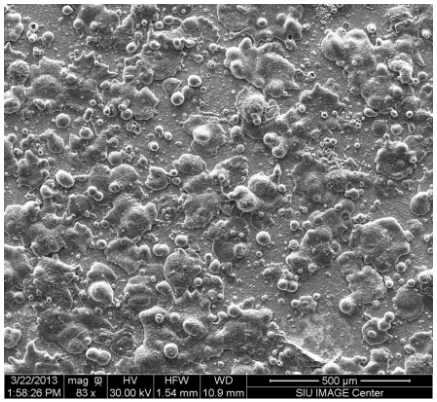


# Elemental Composition Before and After Corrosion Tests

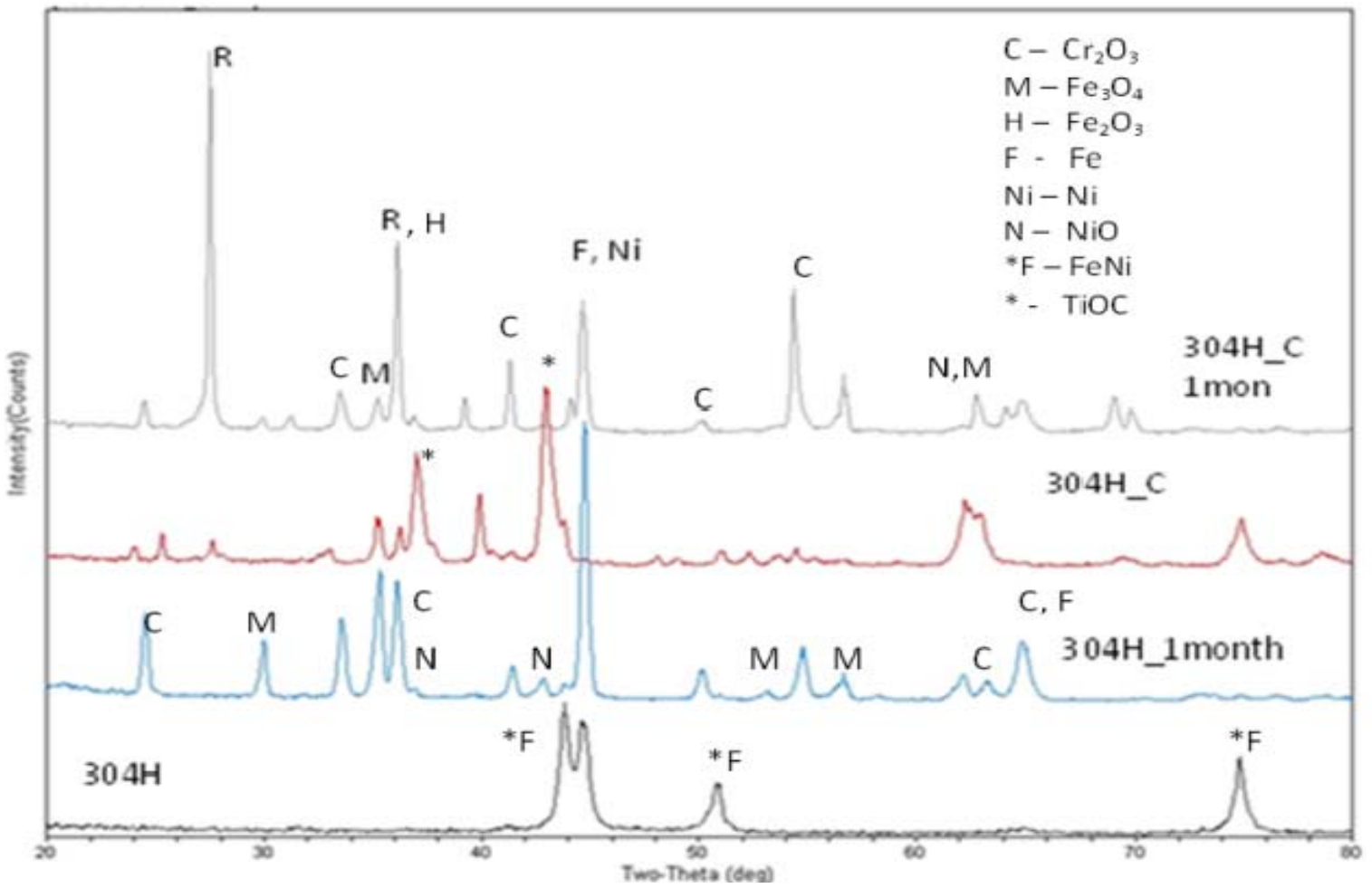


# Air Oxidation of TiC Coated 304 H at 750 °C

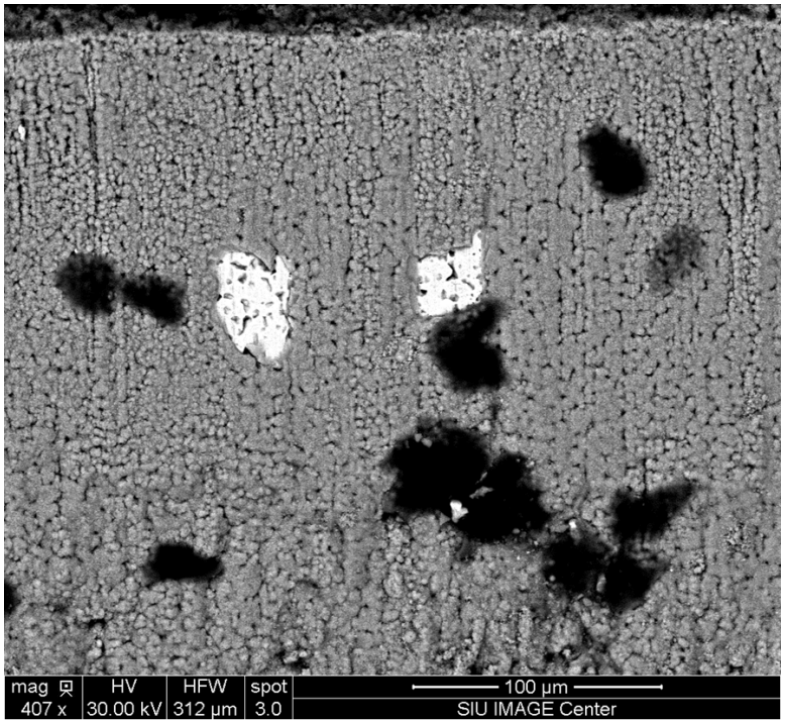
| | 0 hrs | 800 hrs |
|---|---|---|
| Coating 1 |  |  |
| Coating 2 |  |  |

# Impact of Air Oxidation at 750 °C

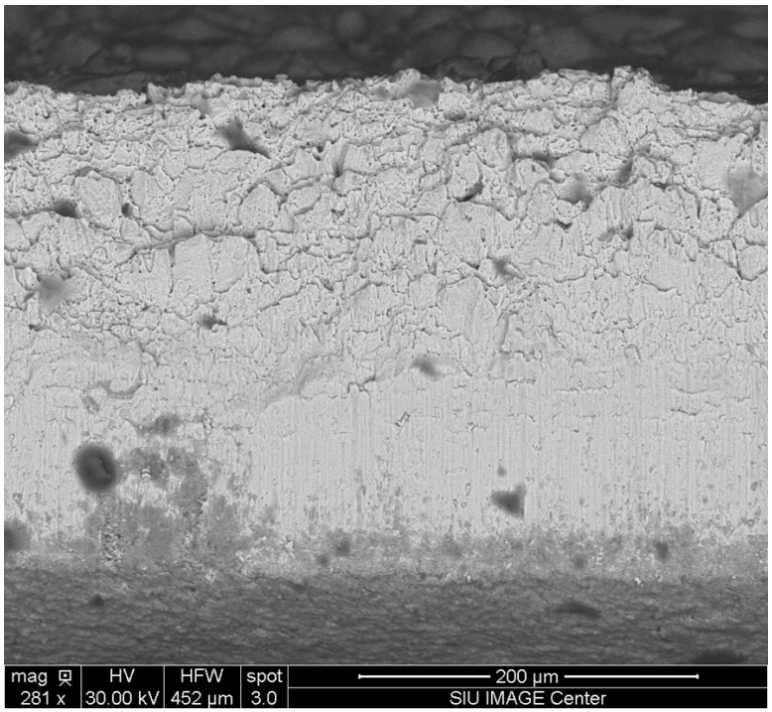


# Back Scattering Image Uncoated and TiC Coated 304 H

## Cross sectional View



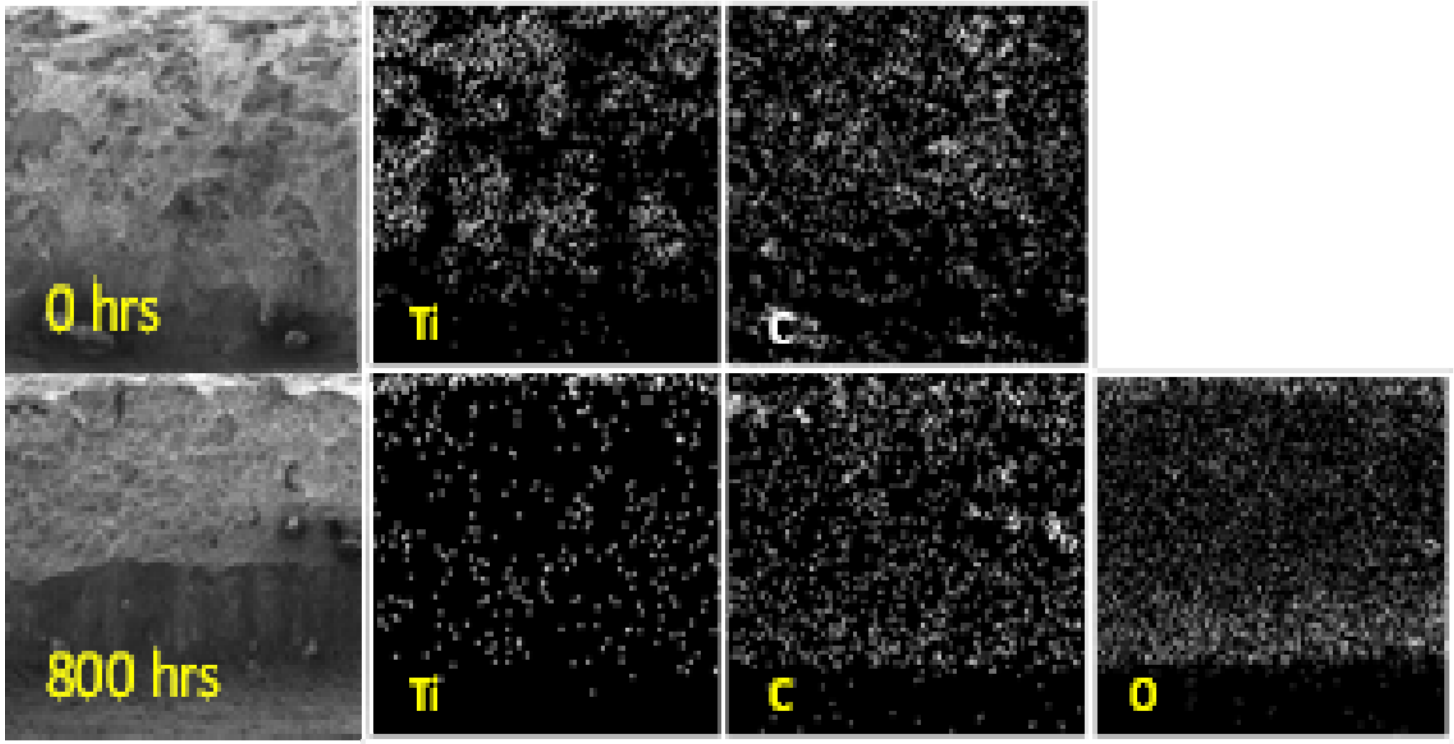

Uncoated
750 °C
800 hrs



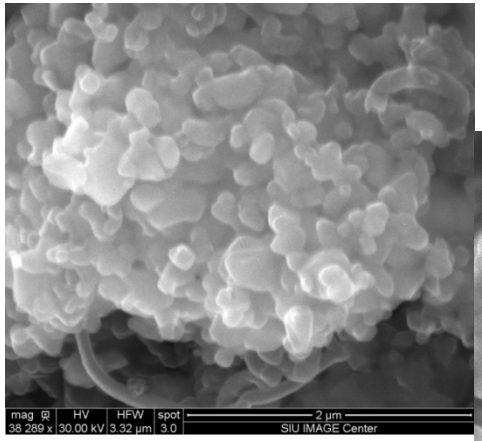

Coating 2
750 °C
800 hrs

# Elemental Spatial Distribution of TiC Coated 304 H

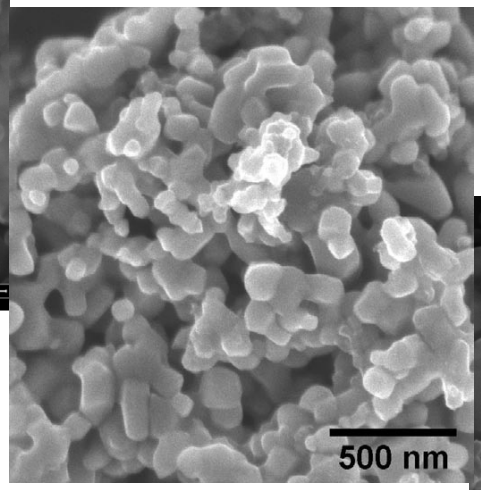
## Cross sectional View



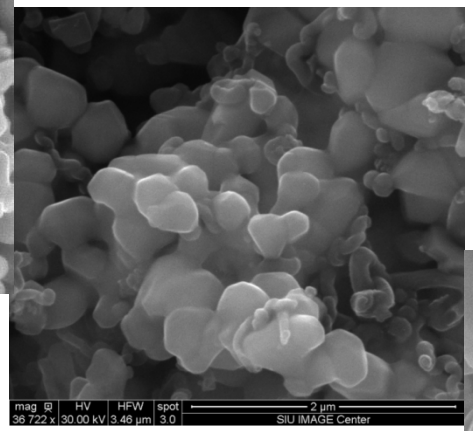
# Effect of Synthesis Conditions on TiC Size Distribution




1300 C,
1 hr

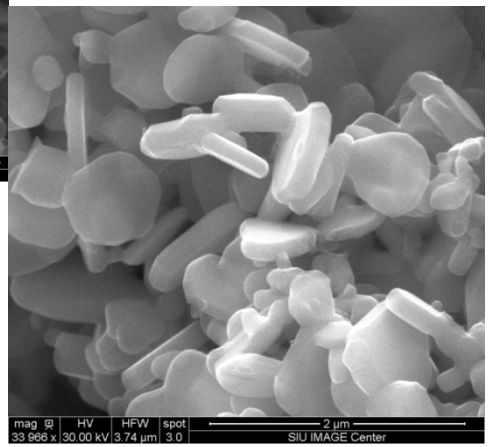



1400 C,
1 hr



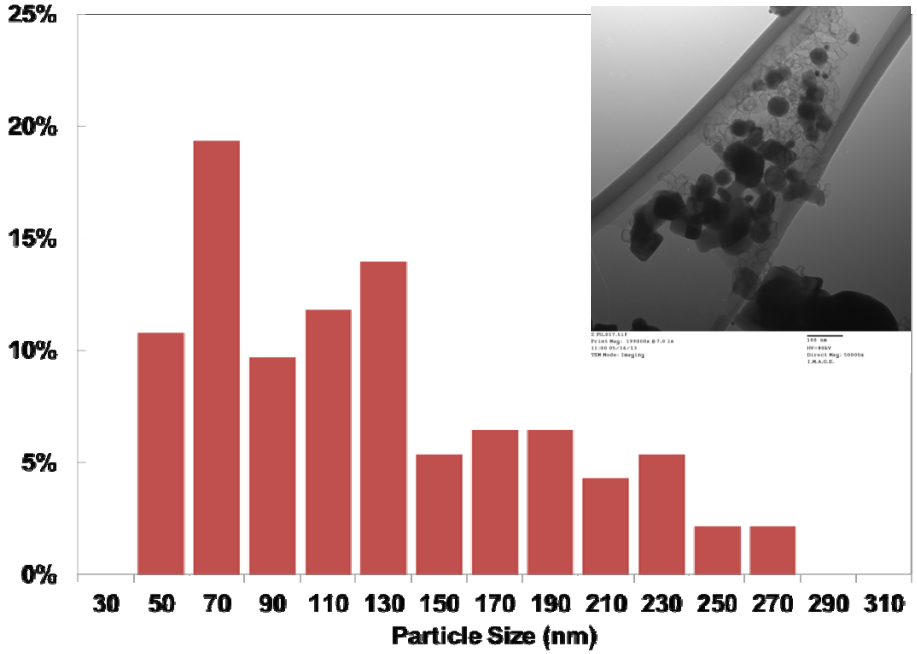

1500 C,
1 hr

1500 C,
2 hr



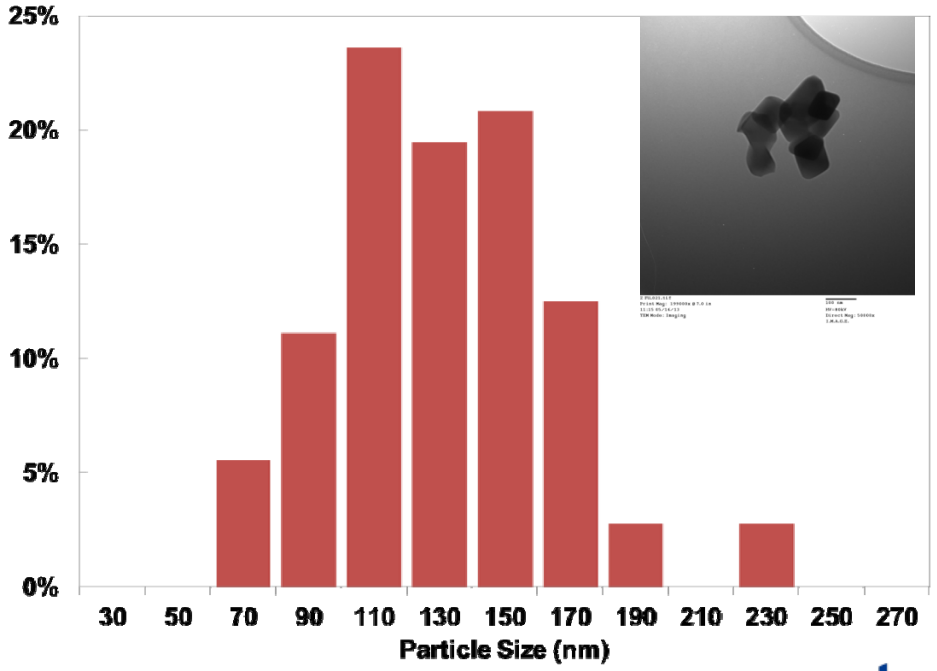

1 µm

# Effect of Synthesis Conditions on TiC Size Distribution

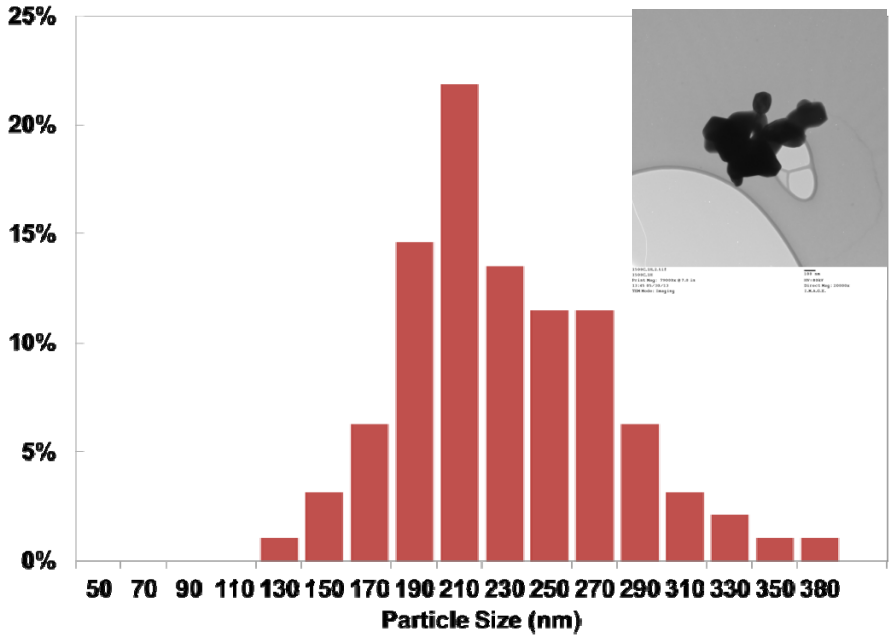



1300 C,
1 hr

1400 C,
1 hr

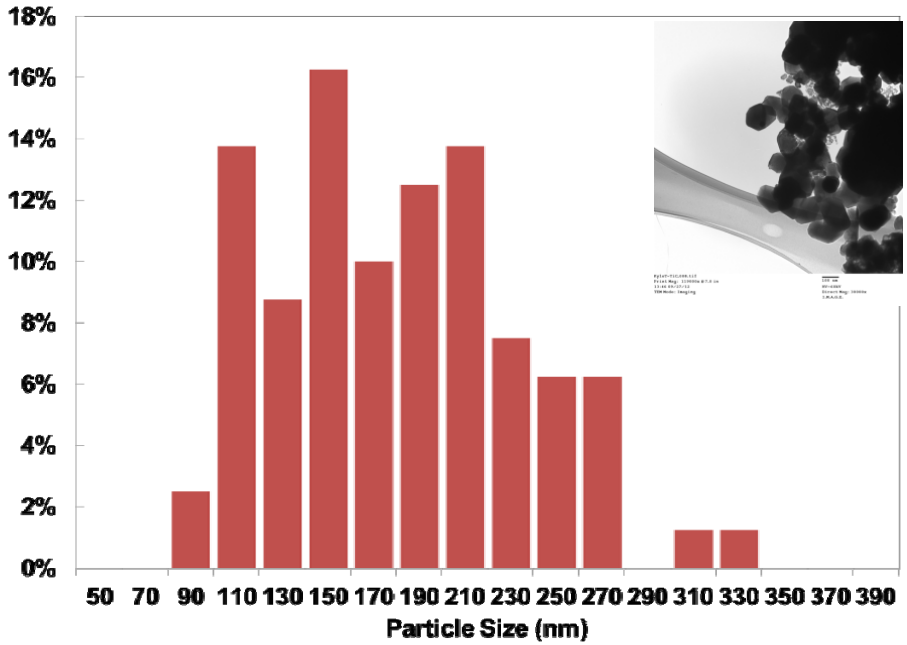


# Effect of Synthesis Conditions on TiC Size Distribution

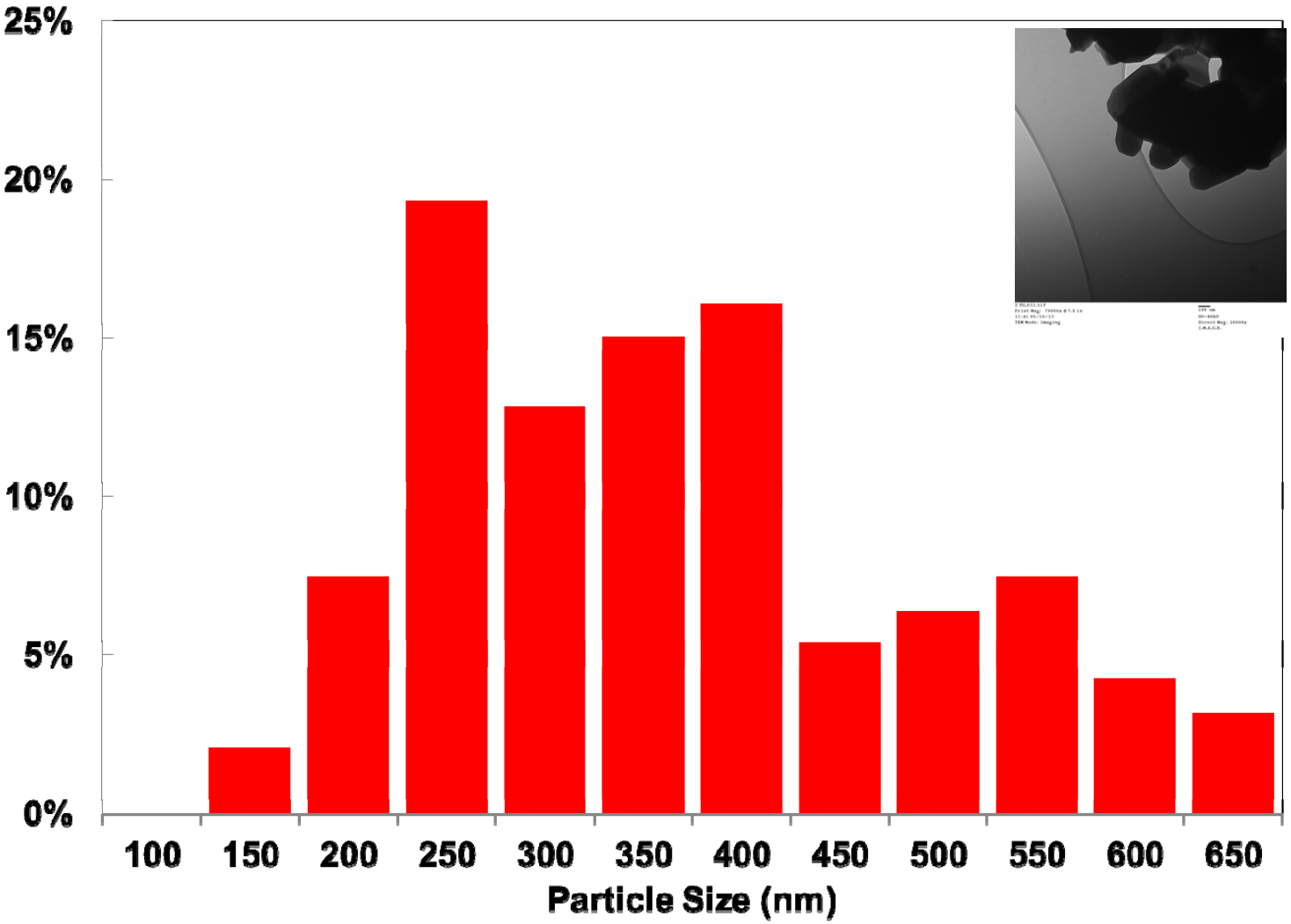



1500 C,
1 hr

1500 C,
2 hr



# Synthesis of $TiB_2$ Nanopowders



# Achievements:

- Facile synthesis of sub micron TiC and $TiB_2$ powders.
- HVOF thermal spray coating of these powders on 304 H substrates.
- Some corrosion characterization of the coated substrates that increased the longevity of the substrate subjected to fireside corrosion in AUSC boiler tubes