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

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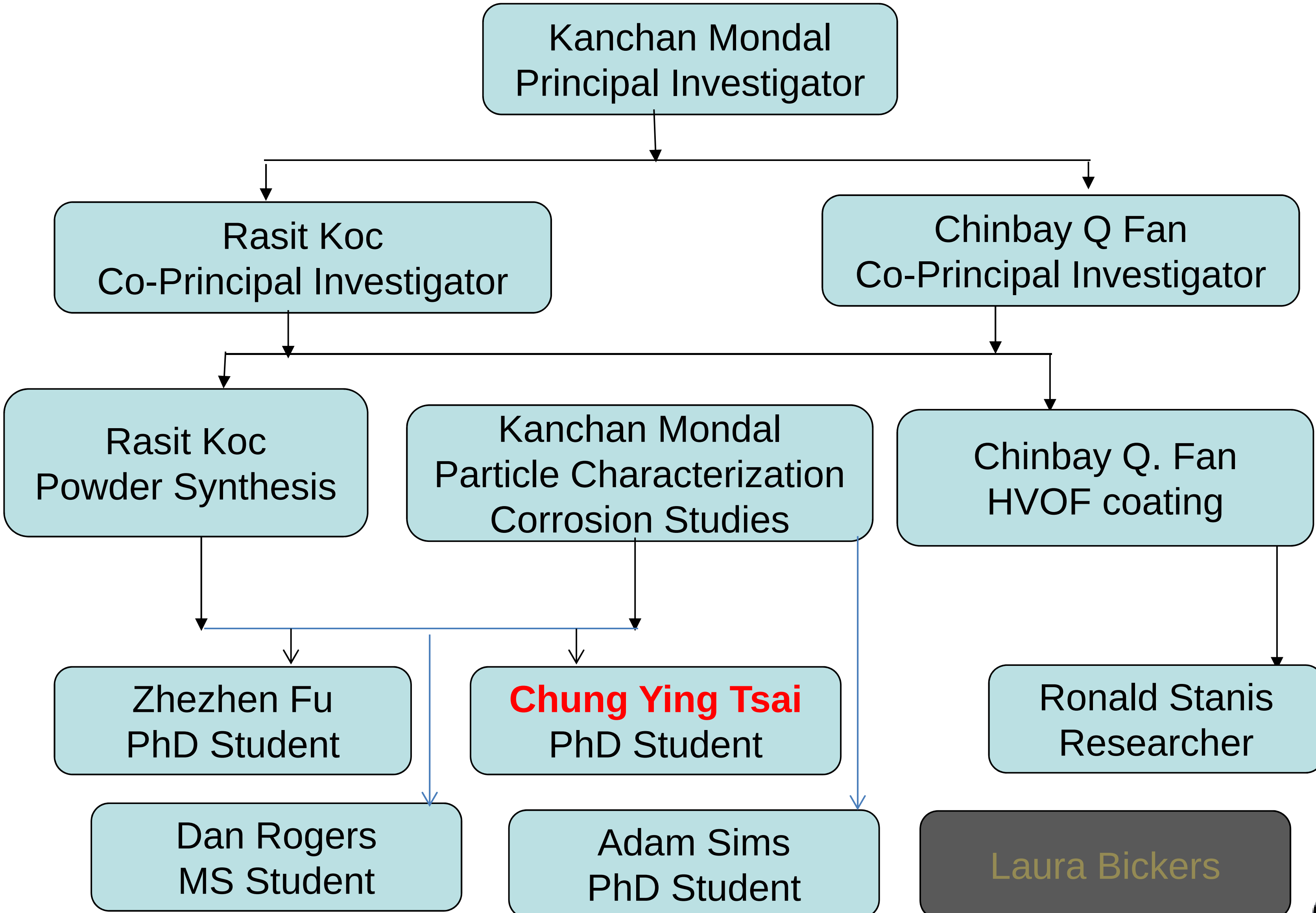
SIU Southern Illinois University CARBONDALE

gti

PROJECT TEAM



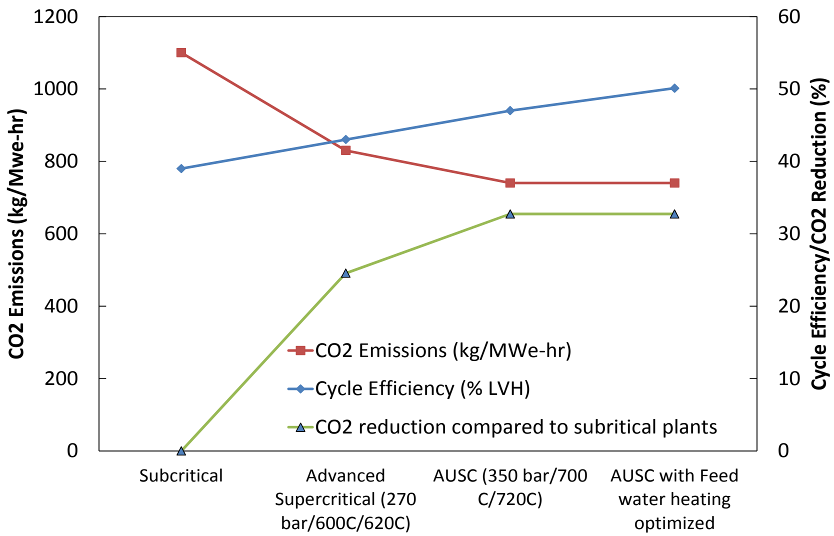
the Energy to Lead

HVOF, Flame Spray Coatings

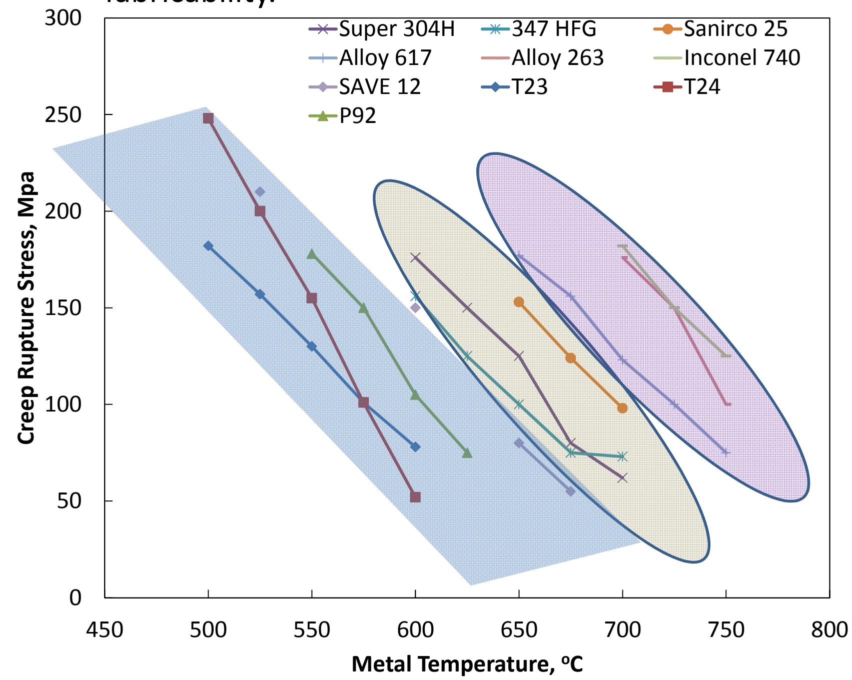
GTI project number 21397
Chinbay Fan and Ronald Stanis

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

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

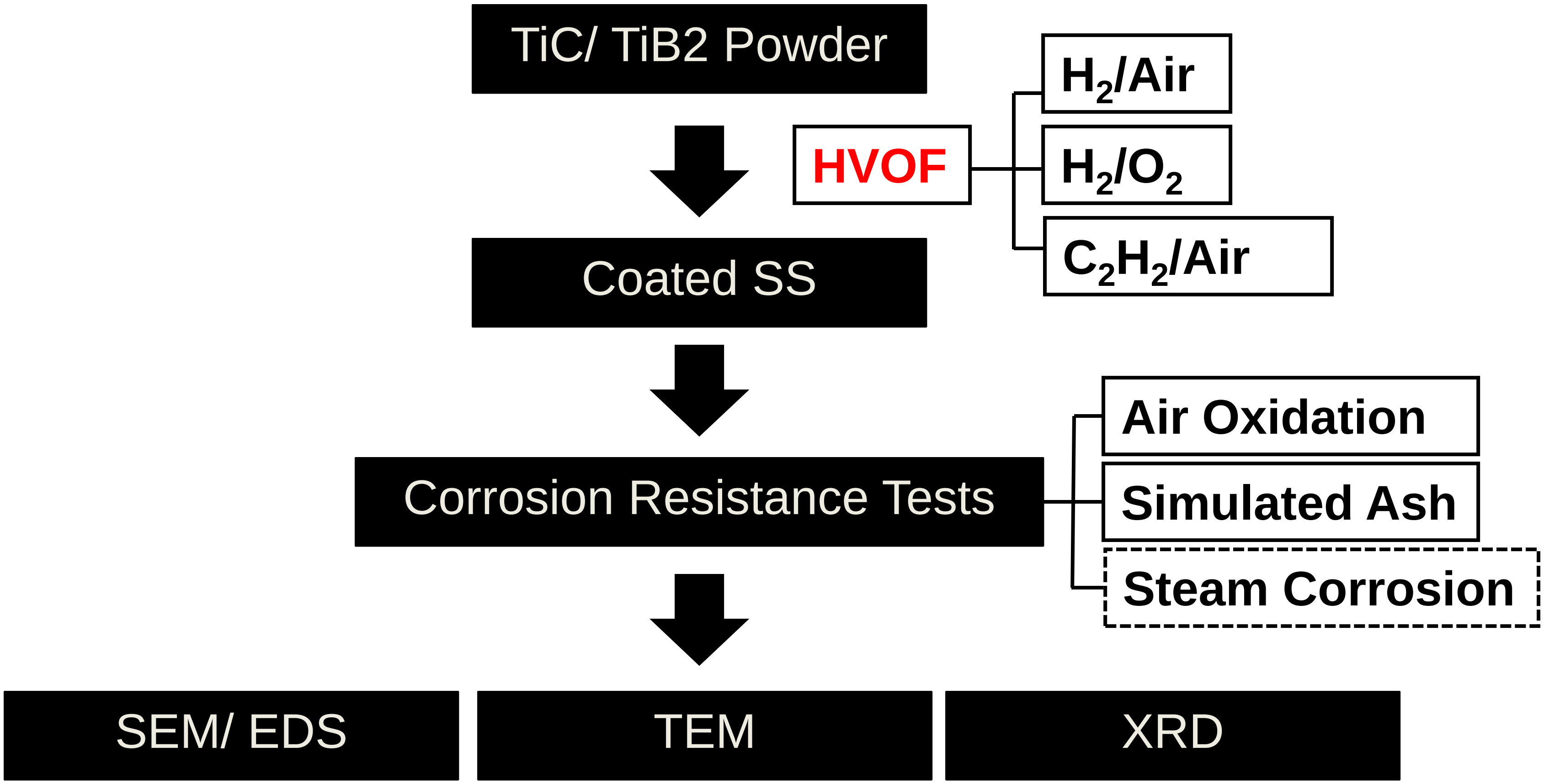
	Substrate Material	Class	Applicable Component
1	Super 304H	Austenitic	SH/RH tubes
2	347HFG	Austenitic	SH/RH tubes
3	Sarnico 25	Austenitic	SH/RH tubes
4	HR3C	Austenitic	SH/RH tubes
5	STD617/CCA 617	Nickel Alloy	Tubing, HP turbine-casing, piping, rotor - 700 °C
6	Haynes 230	Nickel Alloy	SH tubes, HP turbine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

Powder Physical Properties

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

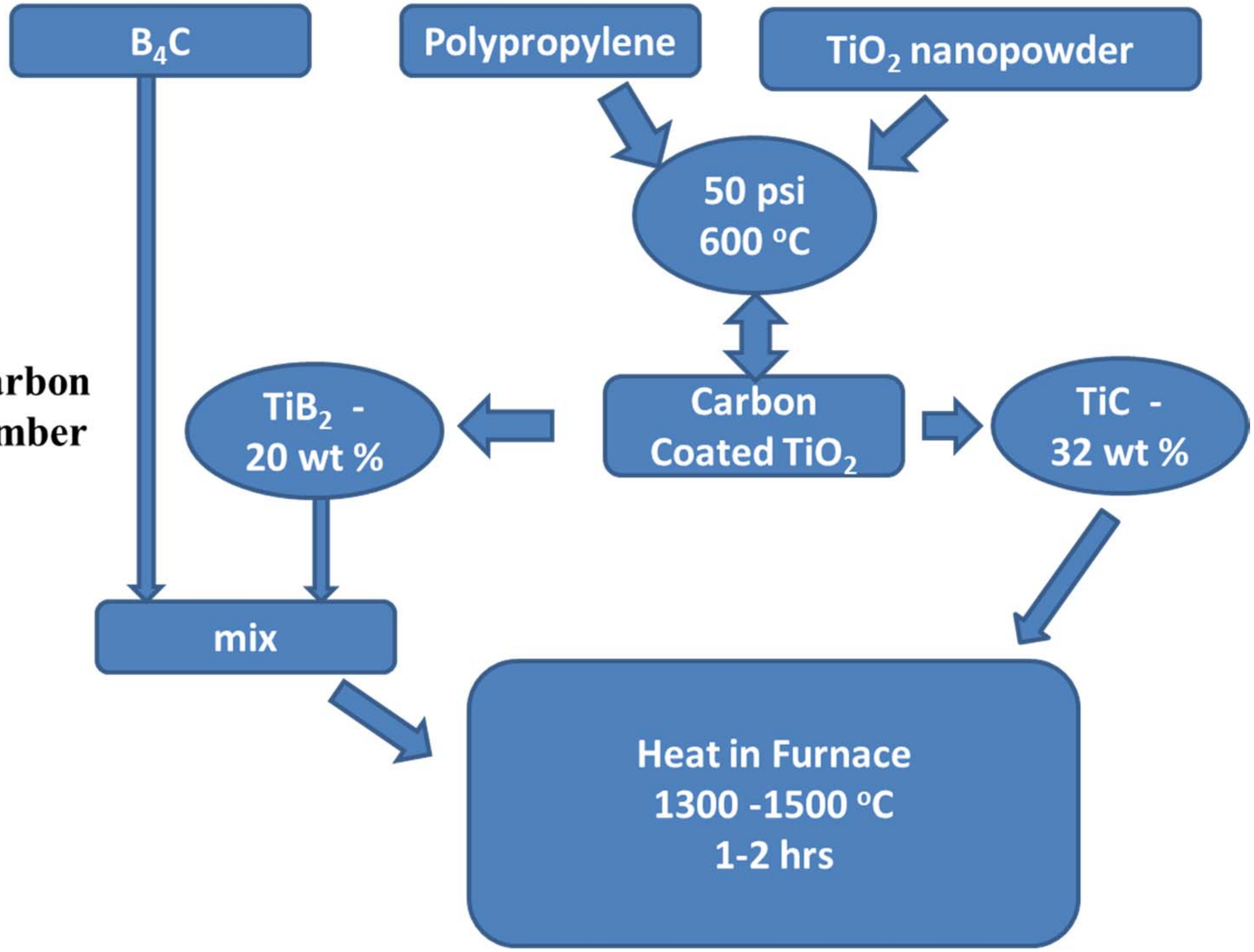
	Melting Temp	Density	Hardness	Young's
	^{o}C	g/cm^3	GPa	GPa
TiC	3070	4.65	28	456
TiB_2	2900	4.5	34	570
B_4C	2500	2.52	38	450

Research Approach

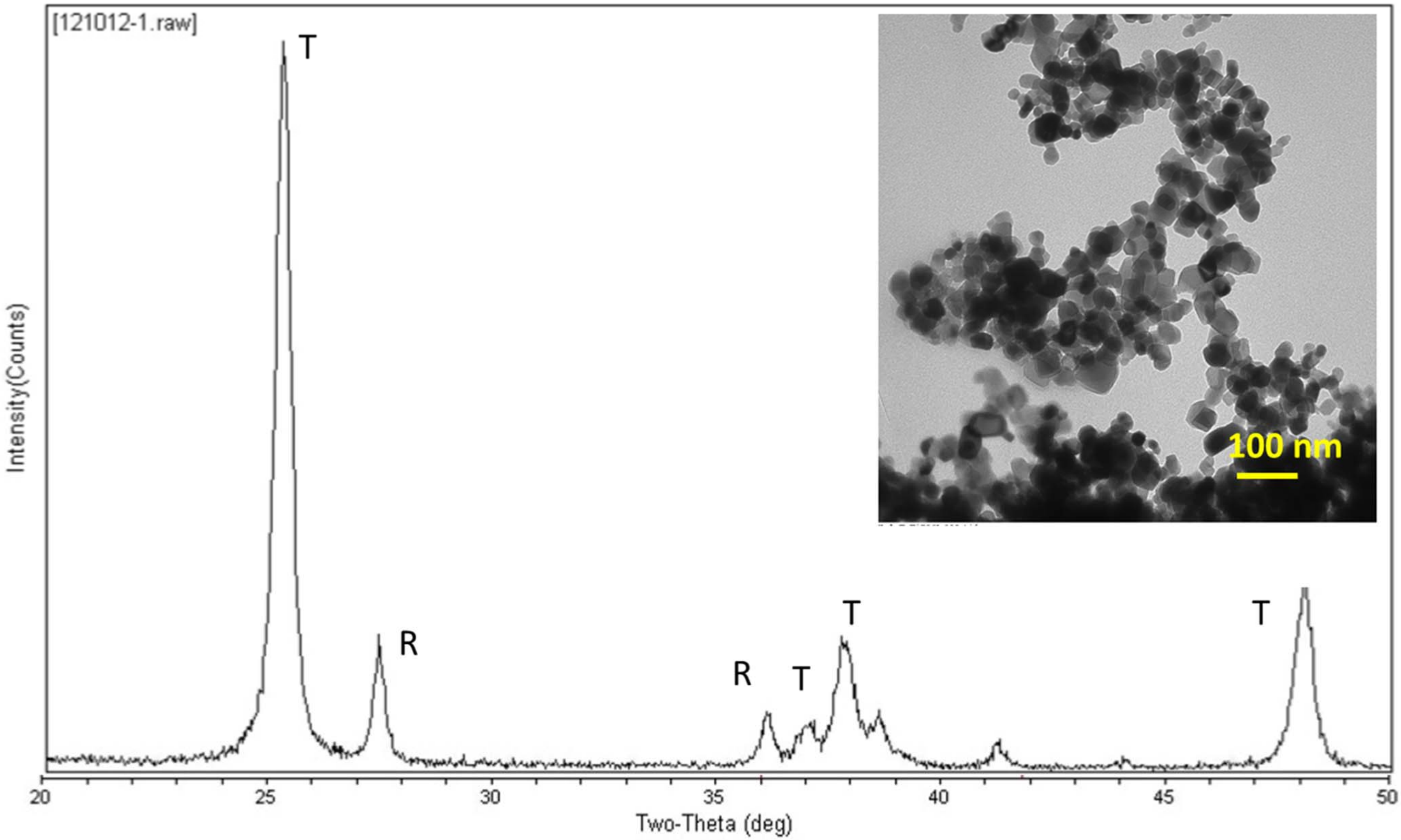


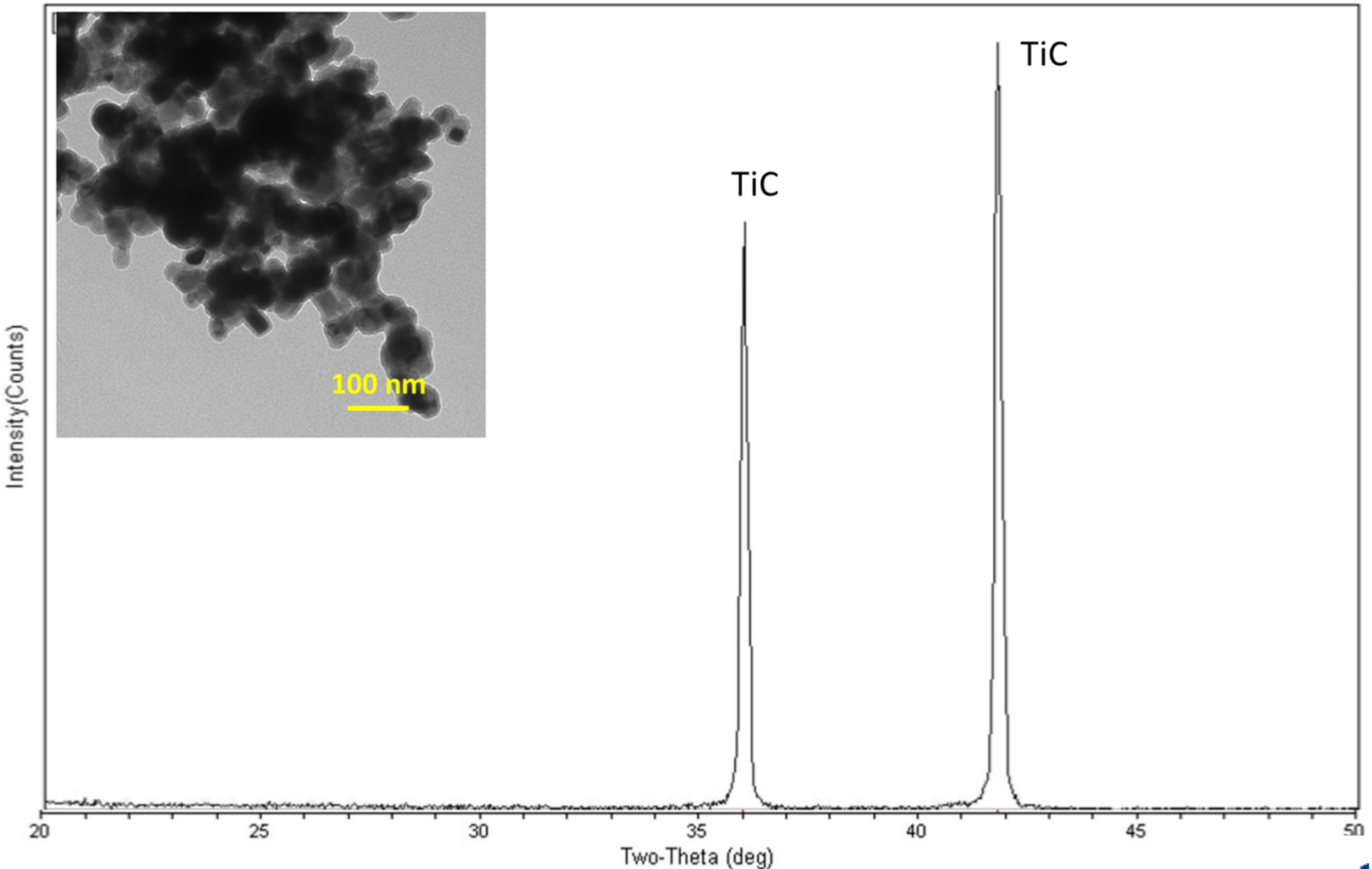
Carbothermal Process for TiC and TiB_2 Powder Synthesis

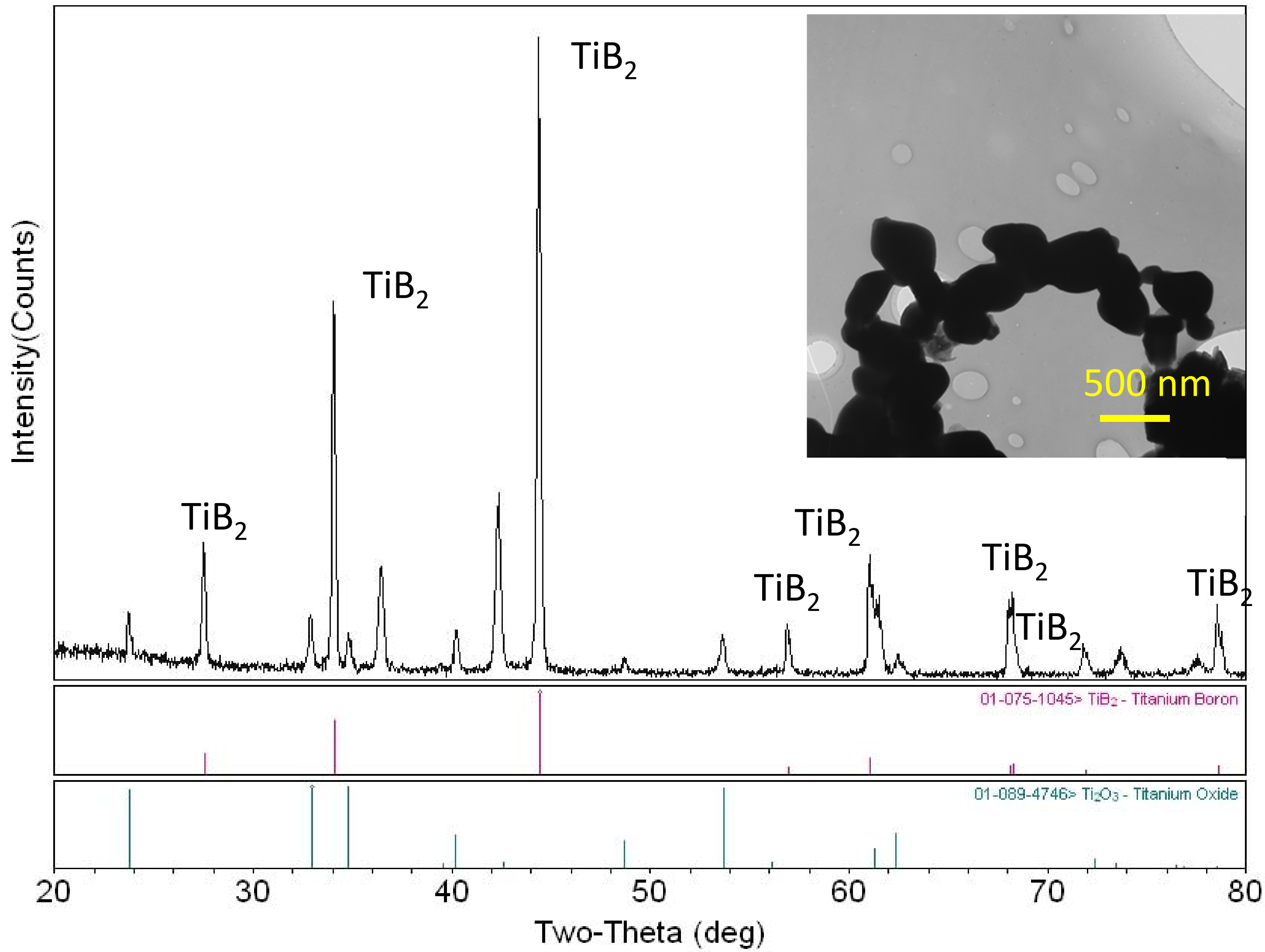
Weight percent of carbon is determined by number of coating cycles

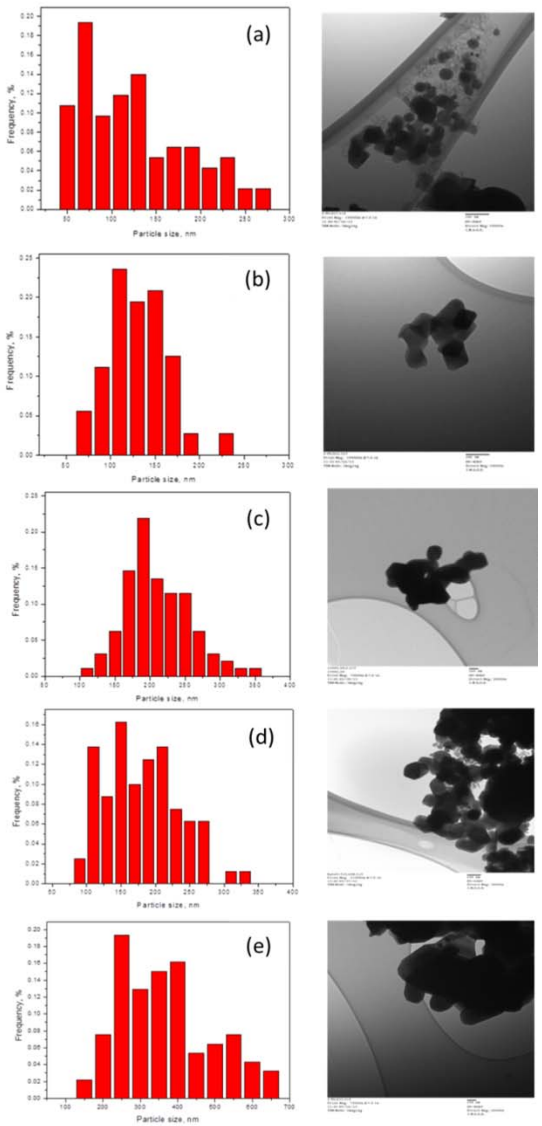


Different temperatures and reaction time were run to get fine particle size and distribution


[121012-1.raw]
T
R
R
T
T
T
100 nm
Intensity(Counts)
20
25
30
35
40
45
50
Two-Theta (deg)


TiC
TiC
100 nm
Intensity(Counts)
20
25
30
35
40
45
50
Two-Theta (deg)


TiB2
TiB2
TiB2
TiB2
TiB2
TiB2
TiB2
TiB2
500 nm
01-075-1045> TiB2 - Titanium Boron
01-089-4746> Ti2O3 - Titanium Oxide
Intensity(Counts)
20
30
40
50
60
70
80
Two-Theta (deg)



(a) 1300^{o}C, 1h,

(b) 1400^{o}C, 1h,

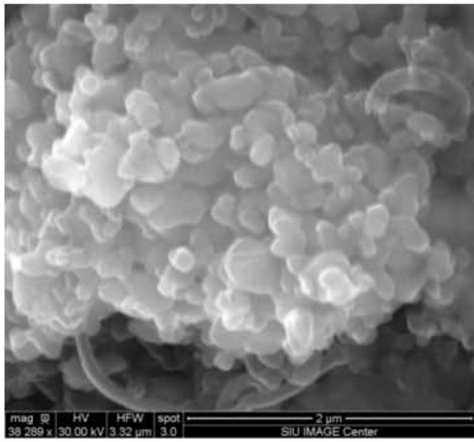
(c) 1500^{o}C, 1h,

(d) 1500^{o}C, 2h

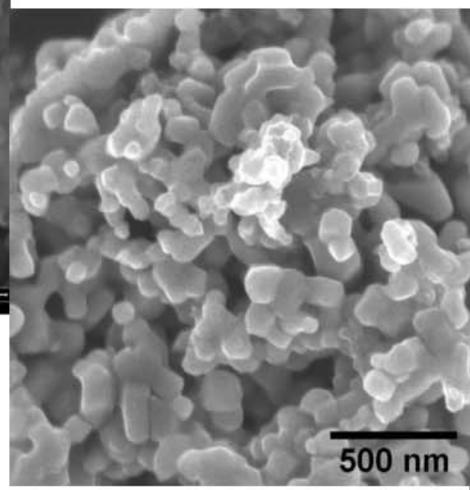
TiC

(e) TiB_2 1500^{o}C, 2h

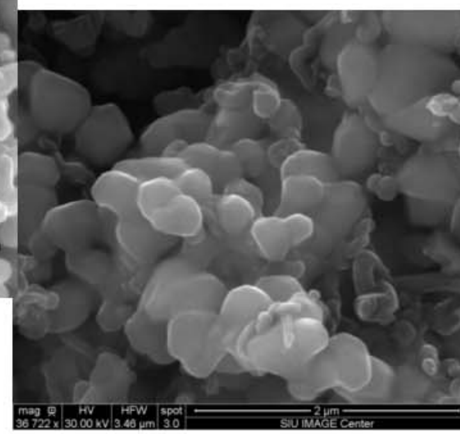
Effect of Synthesis Condition on TiC Size Distribution



1300 C,
1 hr

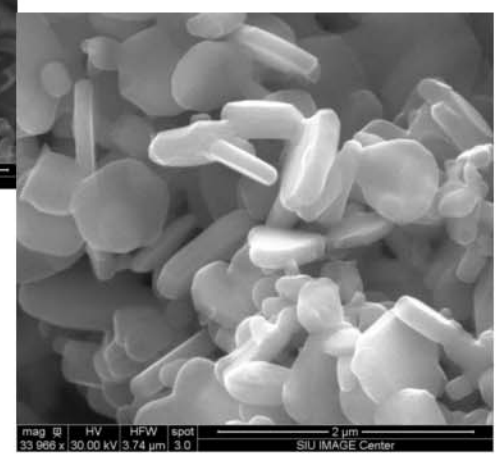


1400 C,
1 hr



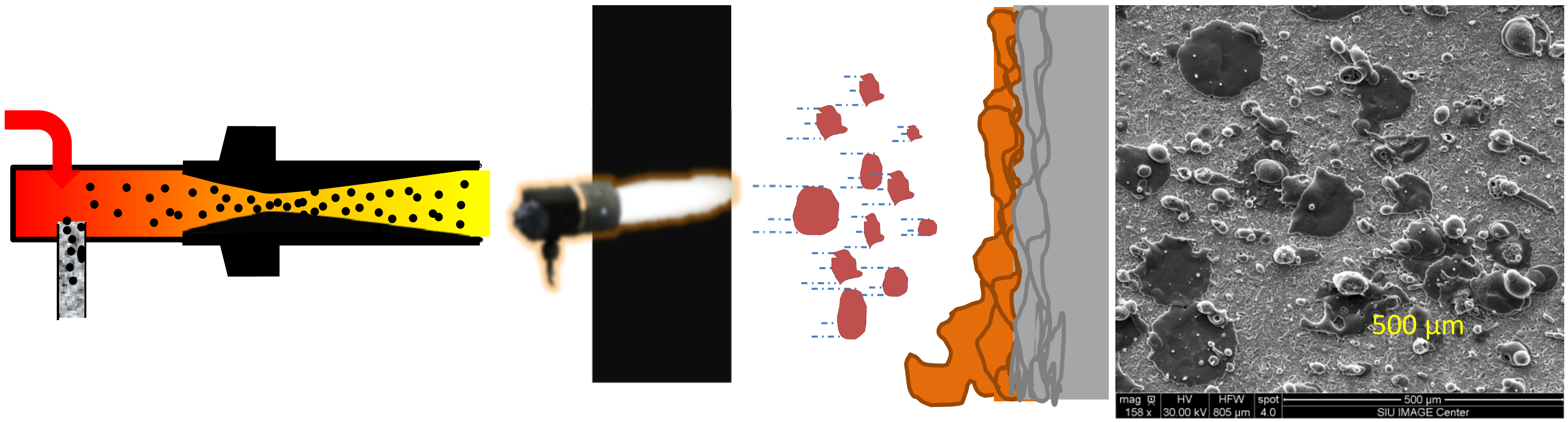
1500 C,
1 hr

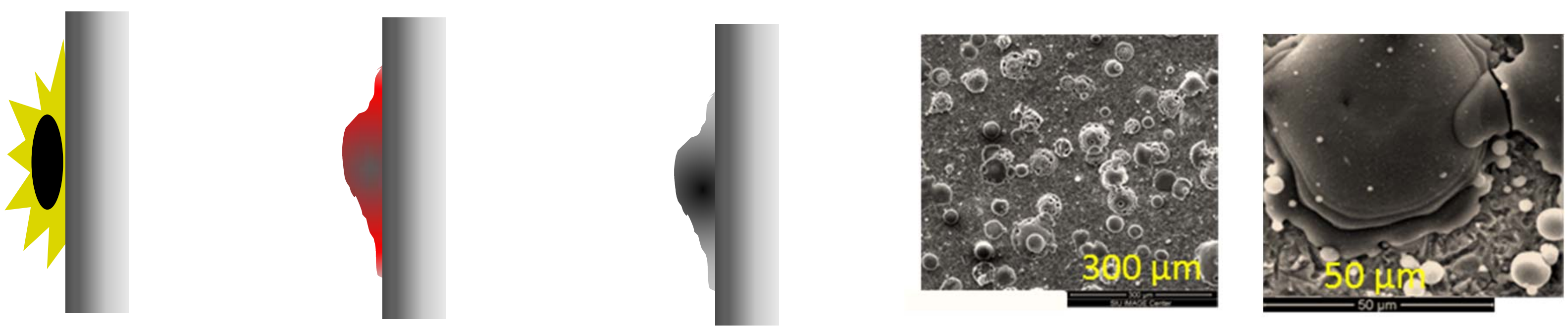
1500 C,
2 hr



1 µm

HVOF THERMAL SPRAY COATING



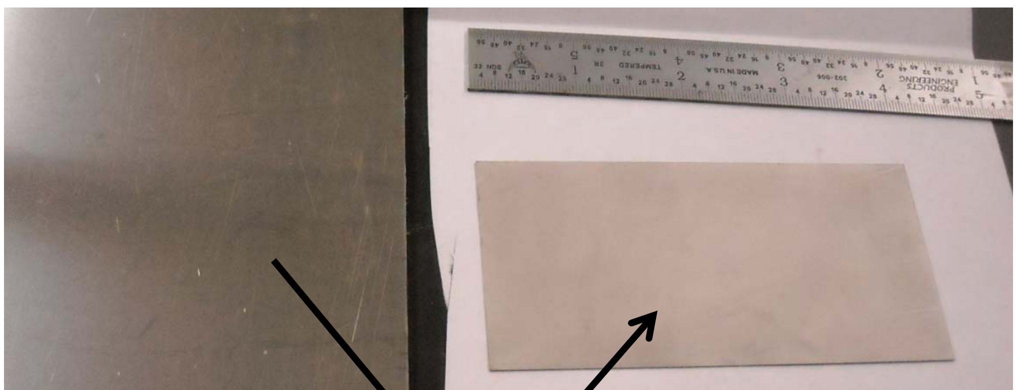


Impingement Spreading Solidification

GTI Flame Spray System

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

SS 304H As received   After surface roughening



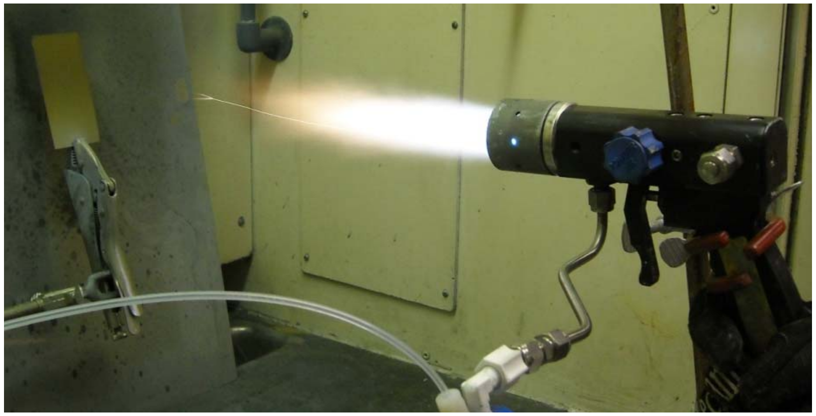
Water honing

<u>Safety is first priority</u>

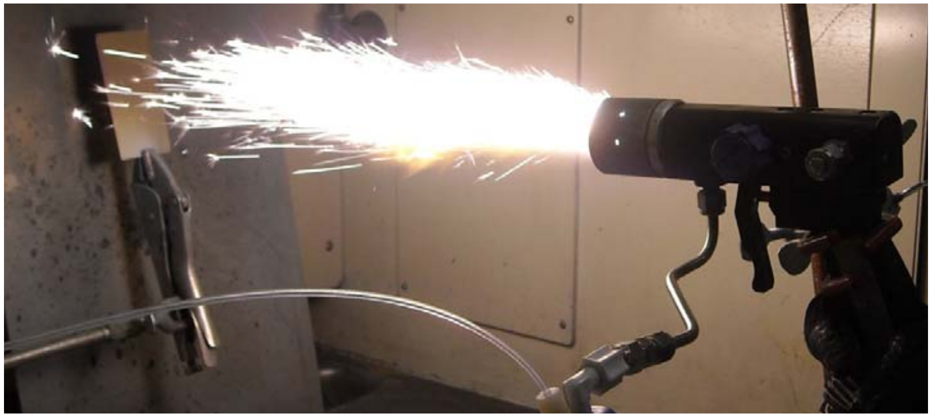
- **Hearing protection**
- **Eye protection (light)**
- **Face Shield**
- **Flame arrestors**
- **Two person operation**
  - **One holding gun**
  - **One operating gas flows**
- **Emergency Stop Button**

Spray Deposition

Just Flame



Flame with Powder

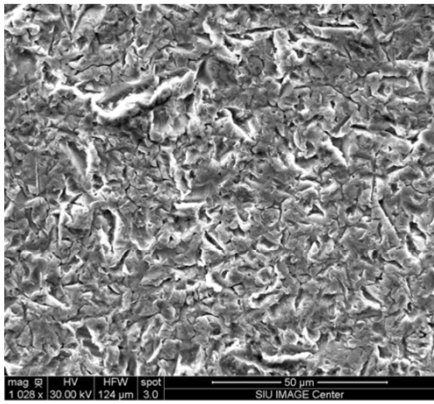


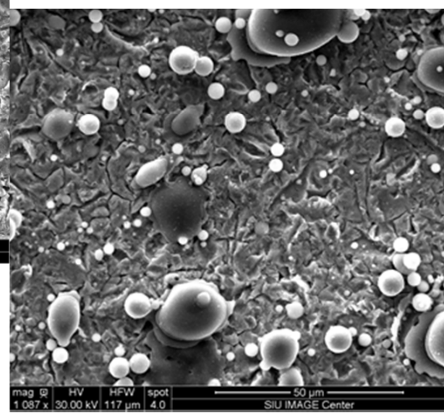
Partially Covered Samples

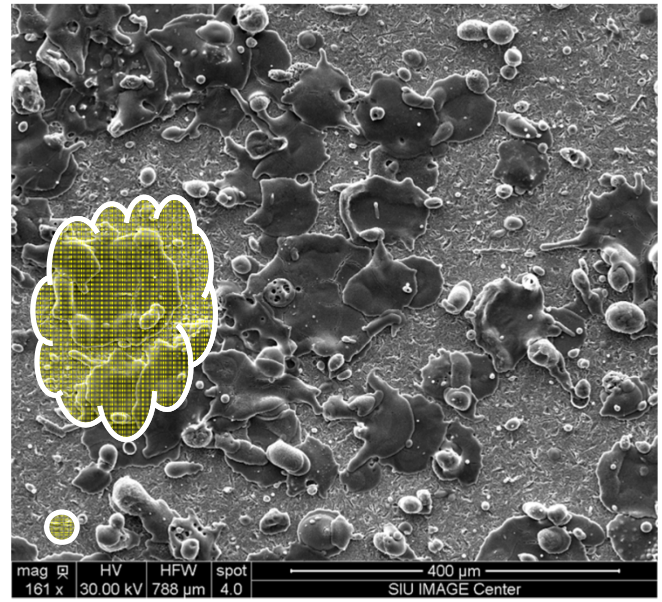
SS 304H C(0.04-0.1) Si(0.75) Mn (2) P (0.045) S (0.03) **Cr (18-20) Ni (8-10.5)**

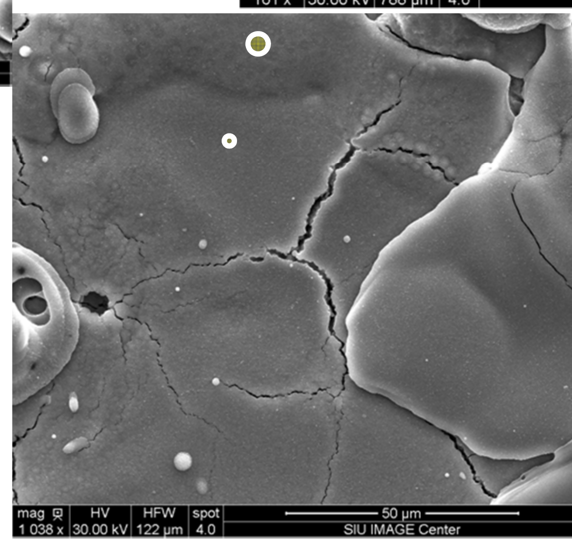
SS 430 C(0-0.12) Si (0-1) Mn (0-1) **Cr(16-18) Ni(0)**

HVOF Coating of 304 H

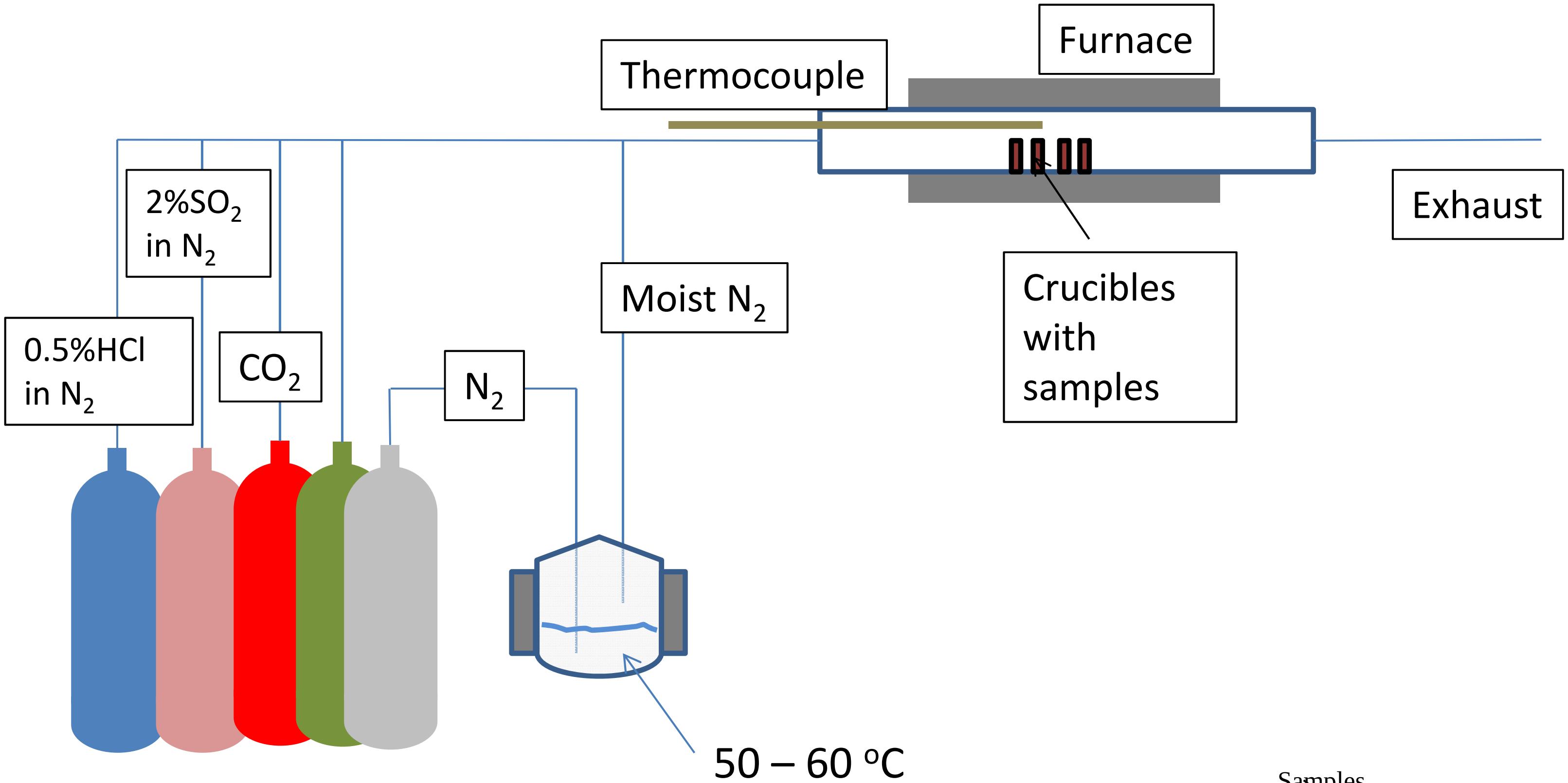


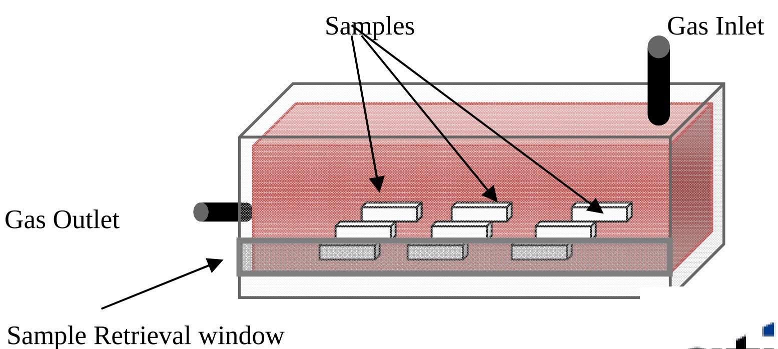




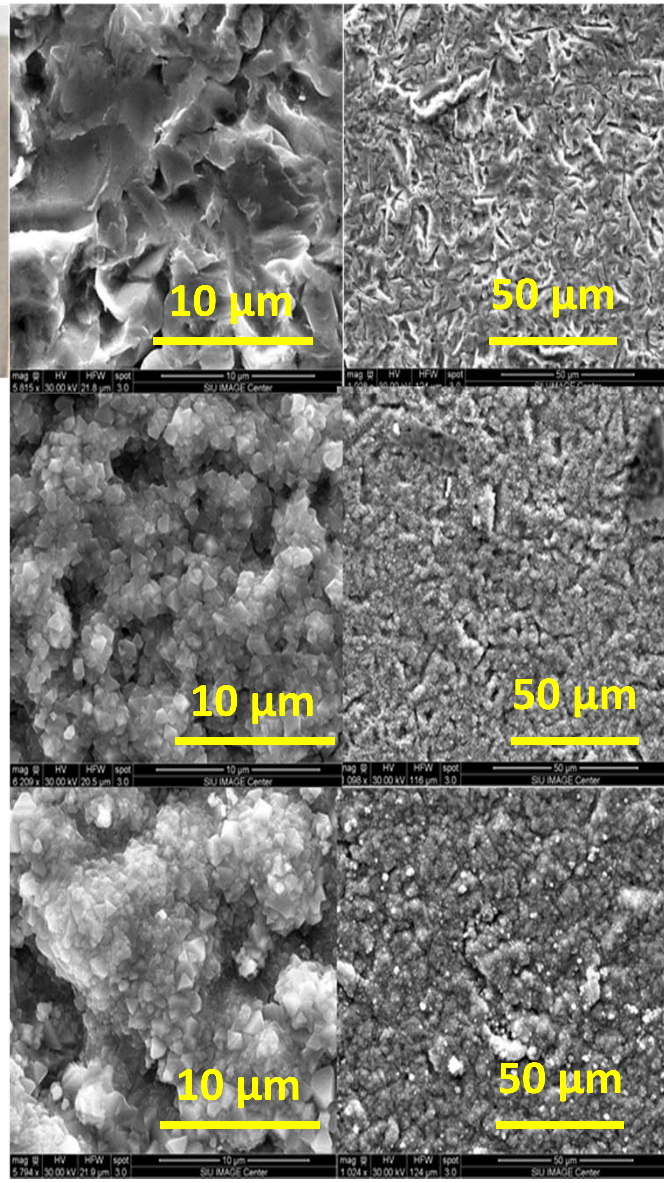


Corrosion Setup





Air Oxidation of 304 H – 750 ^{o}C



0 hrs

200 hrs

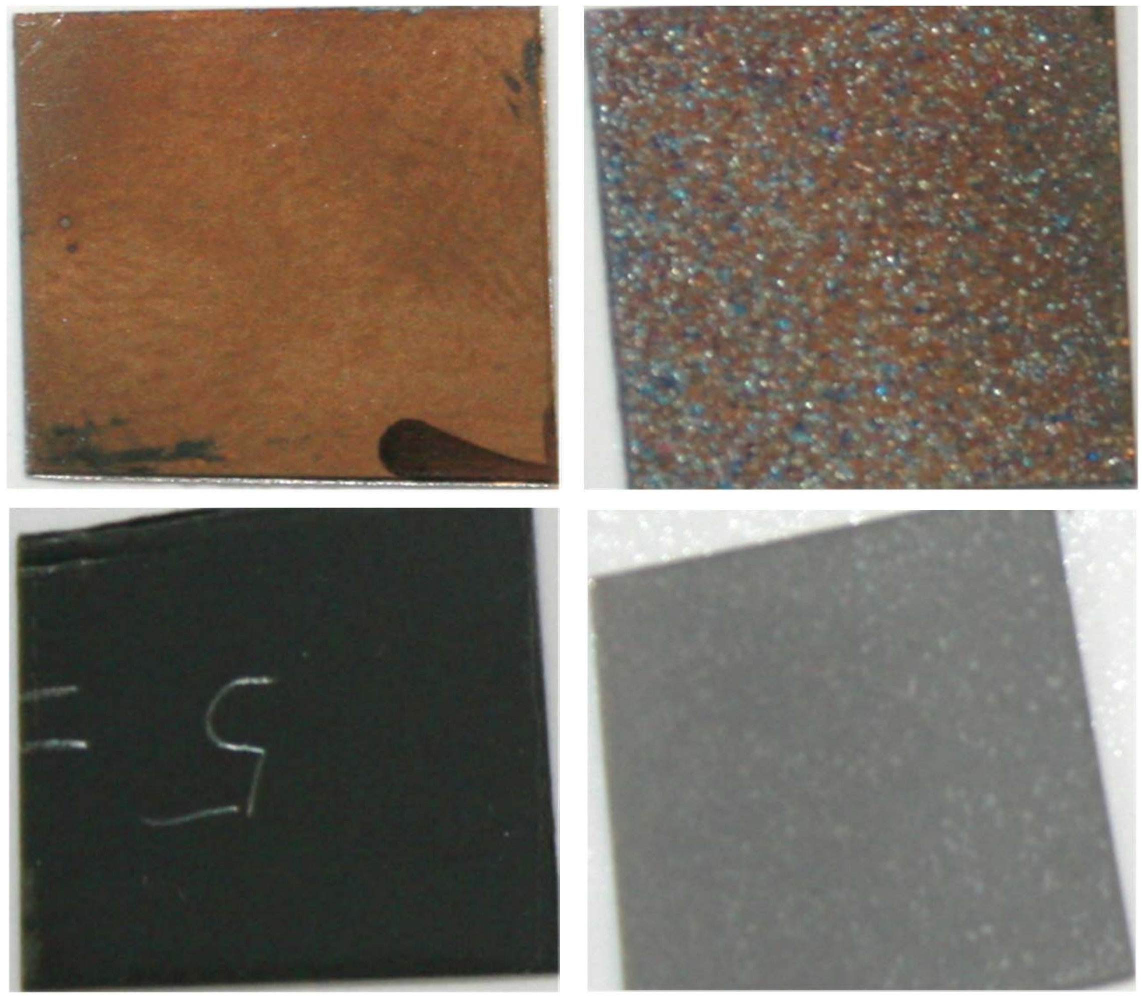
800 hrs

Air Oxidation of TiC Coated 304H at 750^{0}C

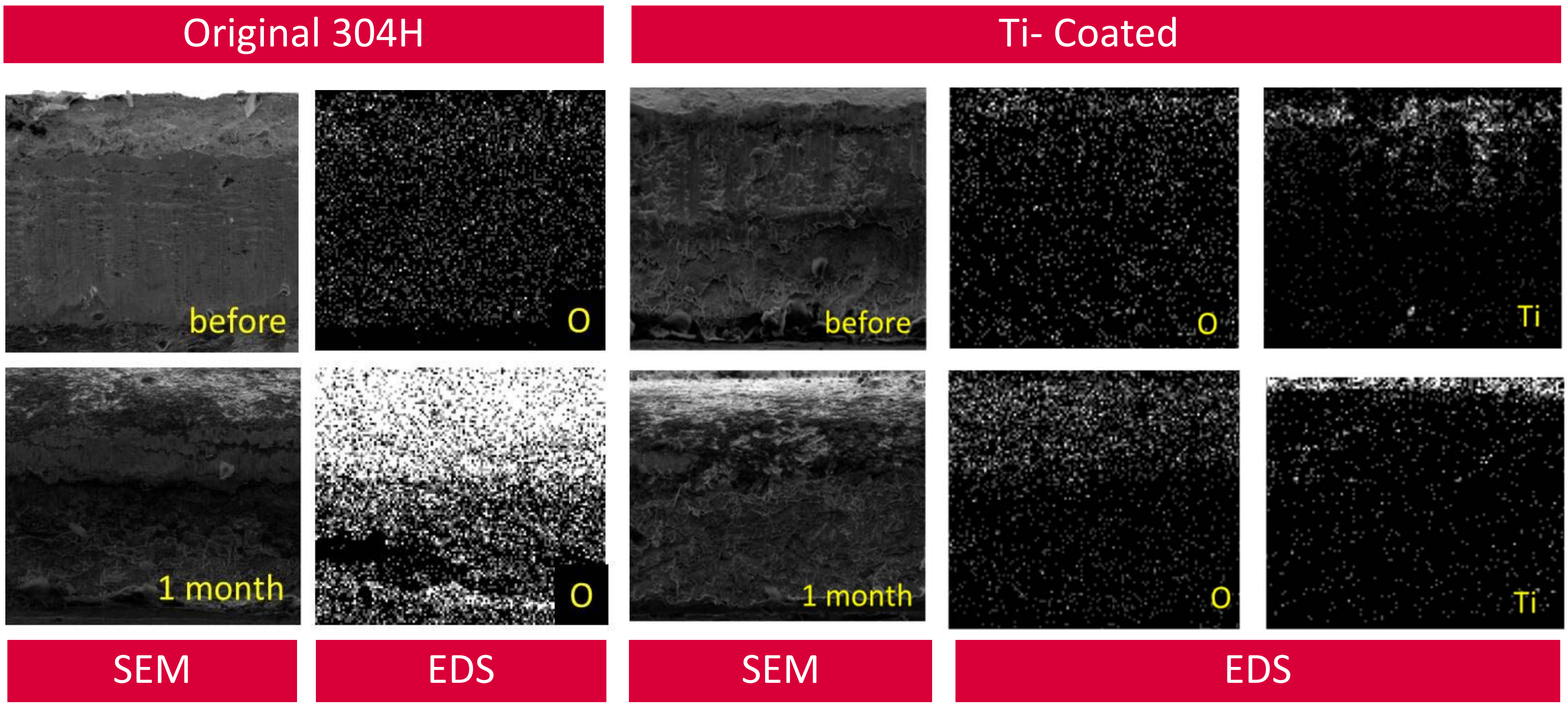
Uncoated | Coated

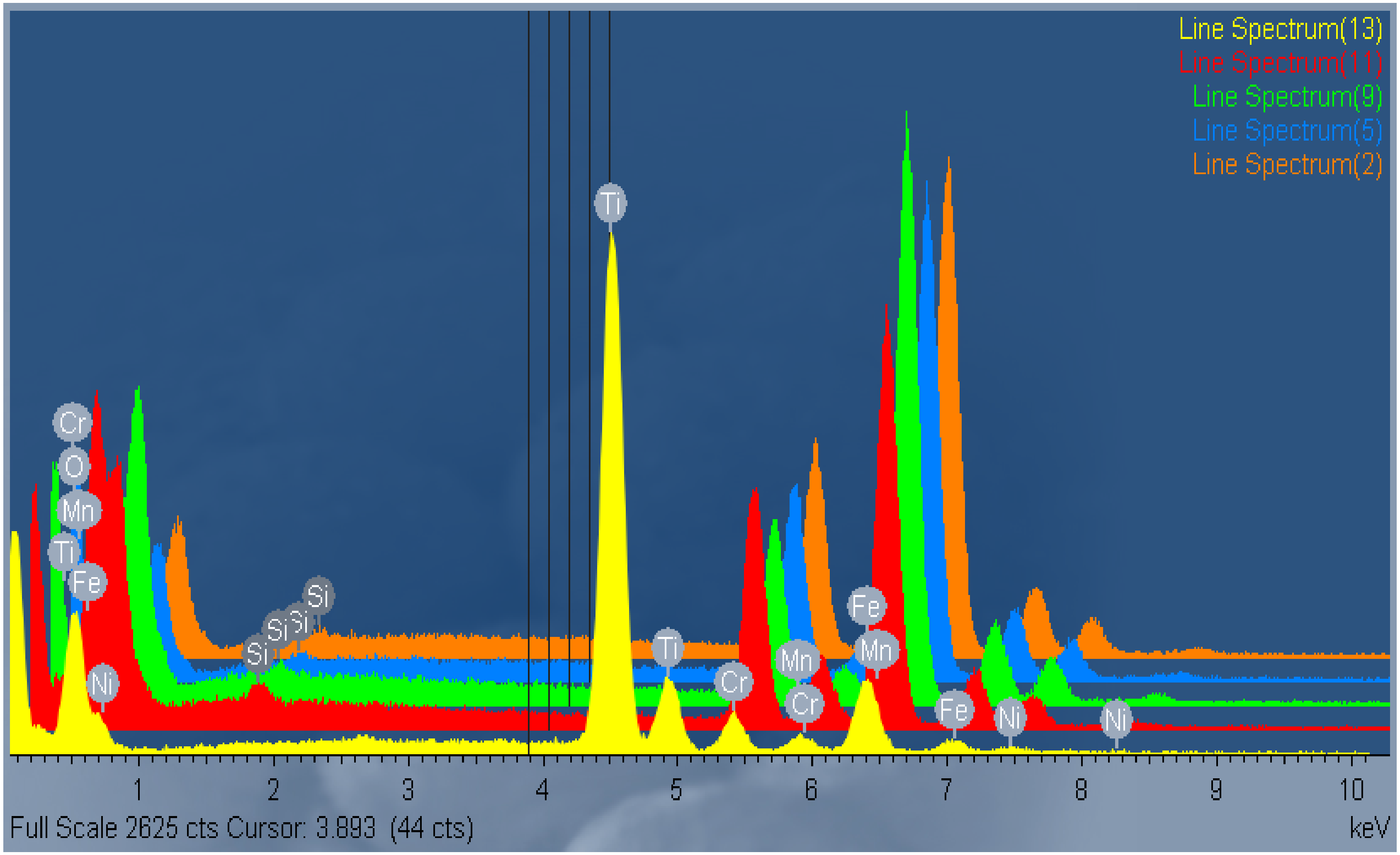
0 Hours

800 Hours



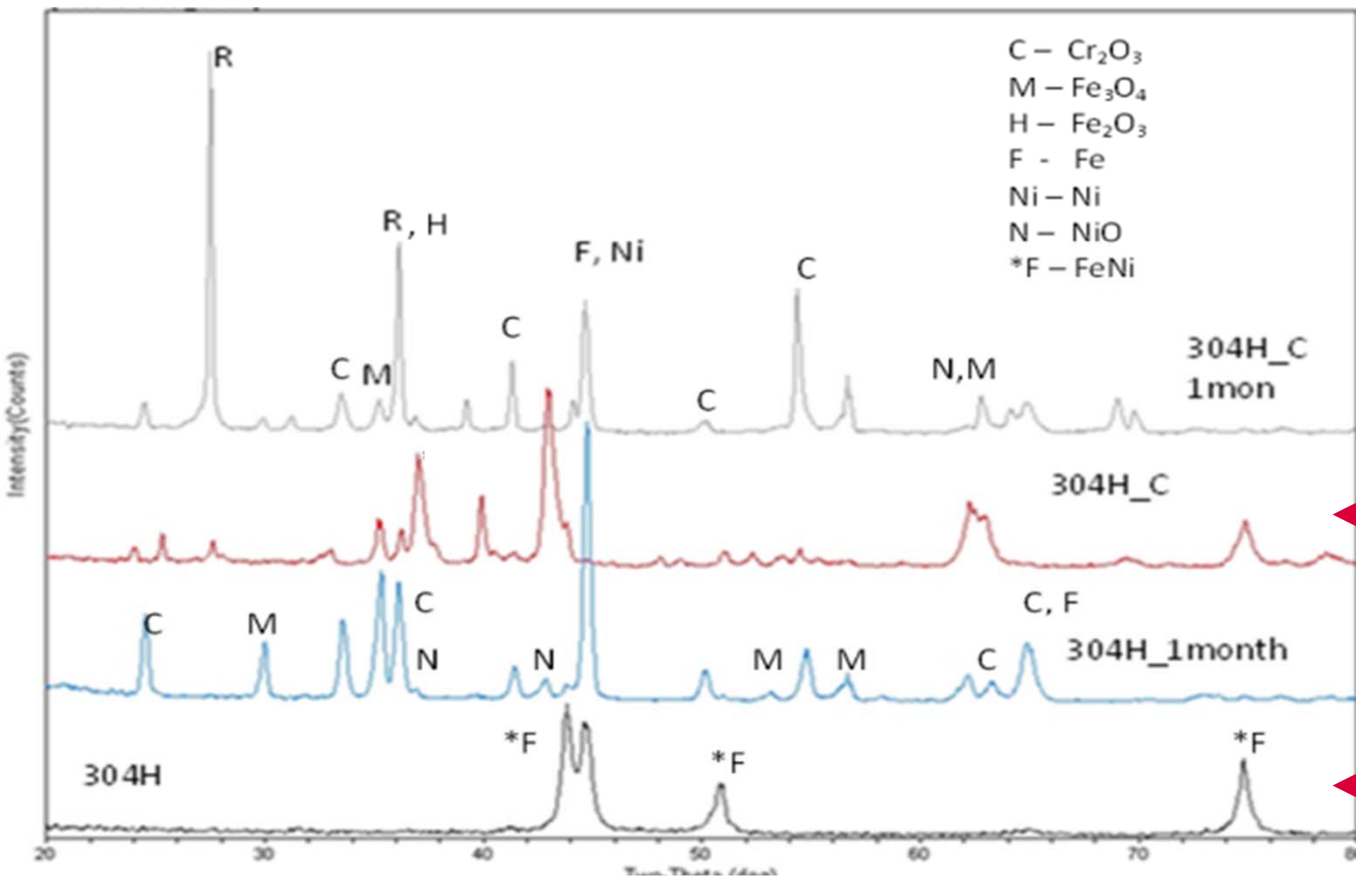
Impact of Air Oxidation at 750^{0}C





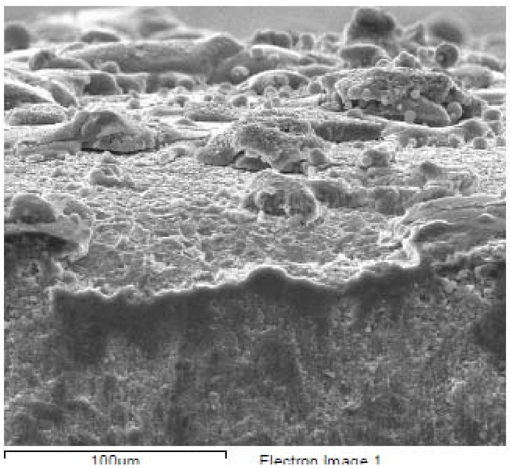
Line Spectrum(13)
Line Spectrum(11)
Line Spectrum(9)
Line Spectrum(5)
Line Spectrum(2)
Ti
Cr
O
Mn
Ti
Fe
Ni
Si
Si
Si
Si
Ti
Cr
Mn
Cr
Fe
Mn
Fe
Ni
Ni
1
2
3
4
5
6
7
8
9
10
Full Scale 2625 cts Cursor: 3.893 (44 cts)
keV

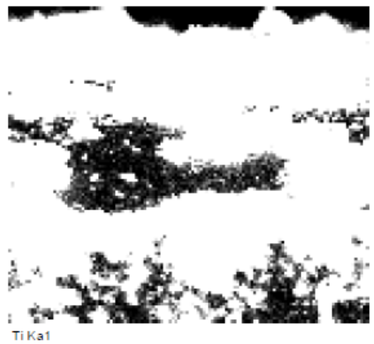
Impact of Air Oxidation at 750^{0}C



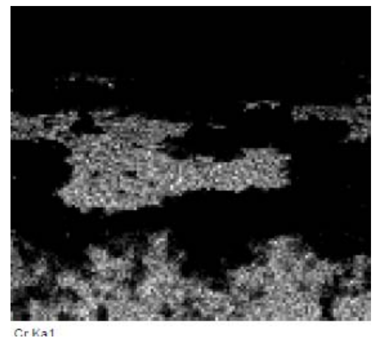
coated

uncoated

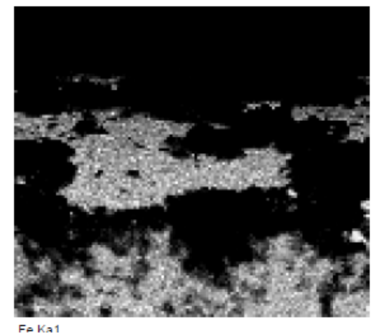




Ti

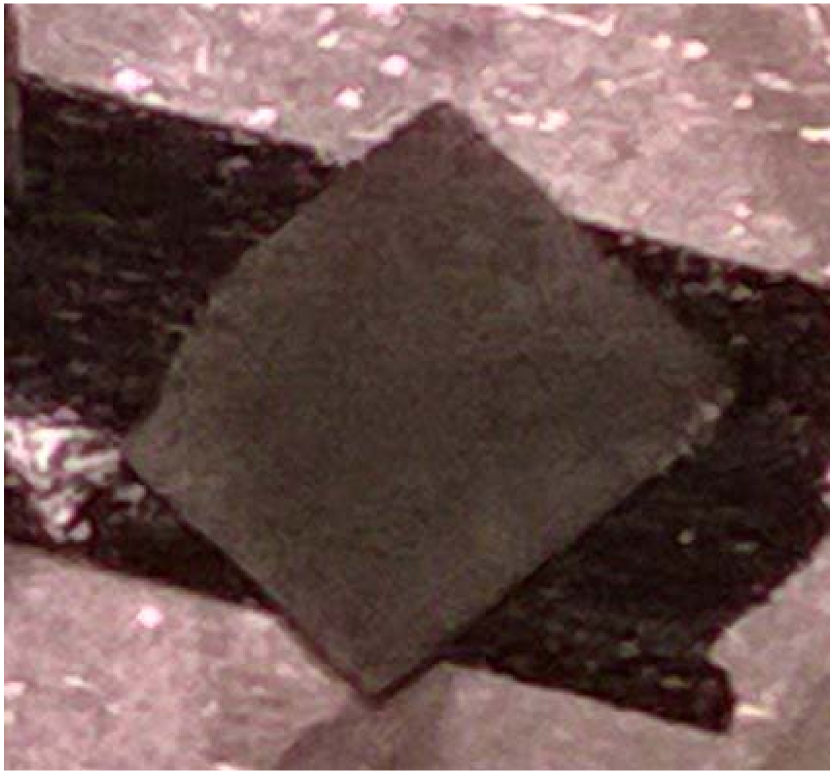


Cr



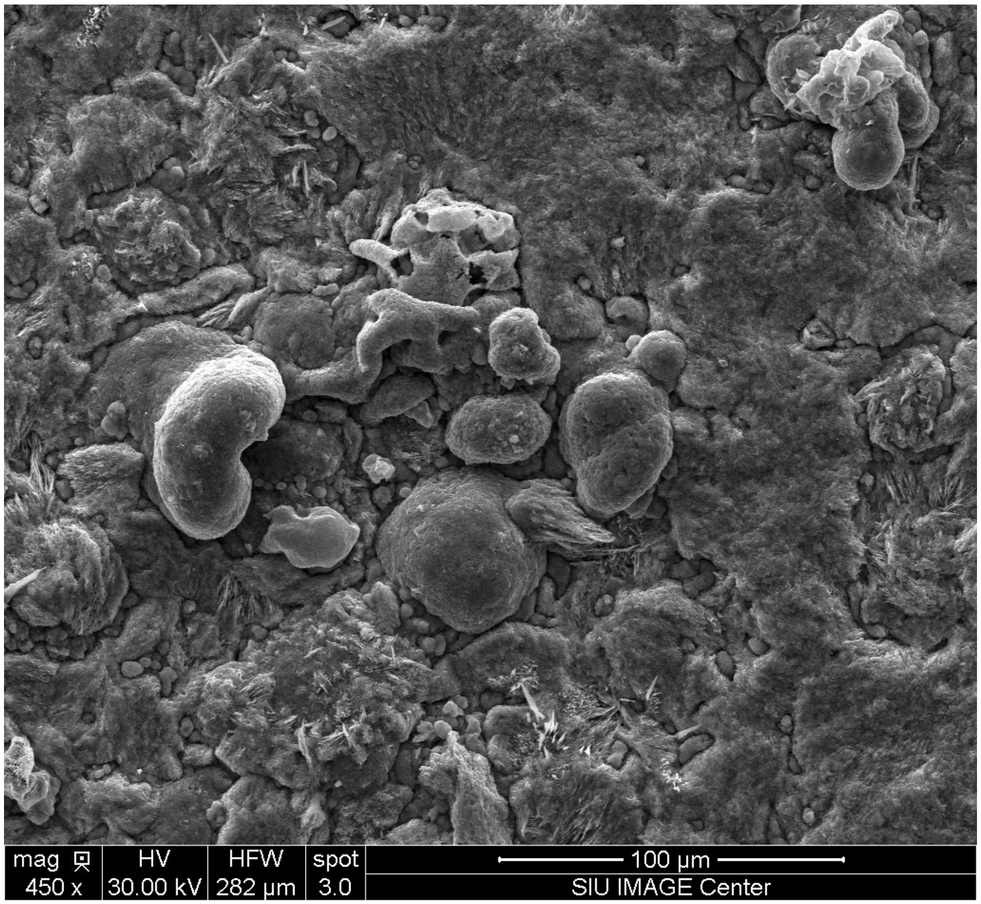
Fe

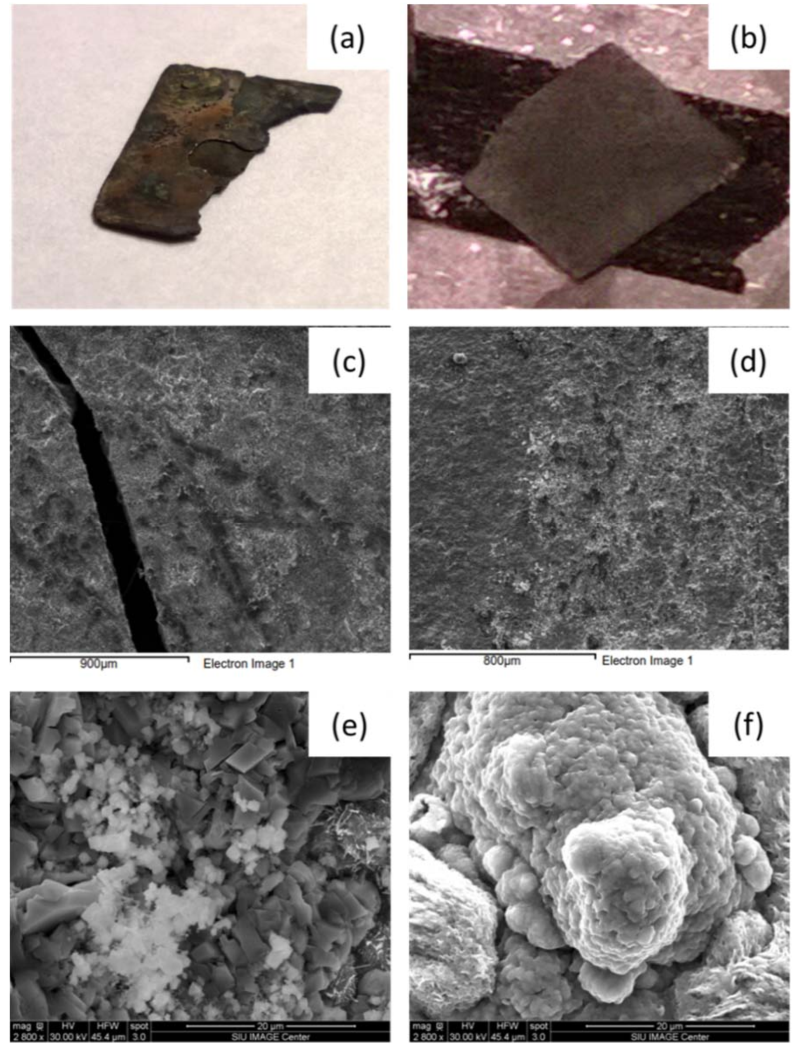
Impact of Salt Corrosion - 750^{o}C

Uncoated	Coated
	

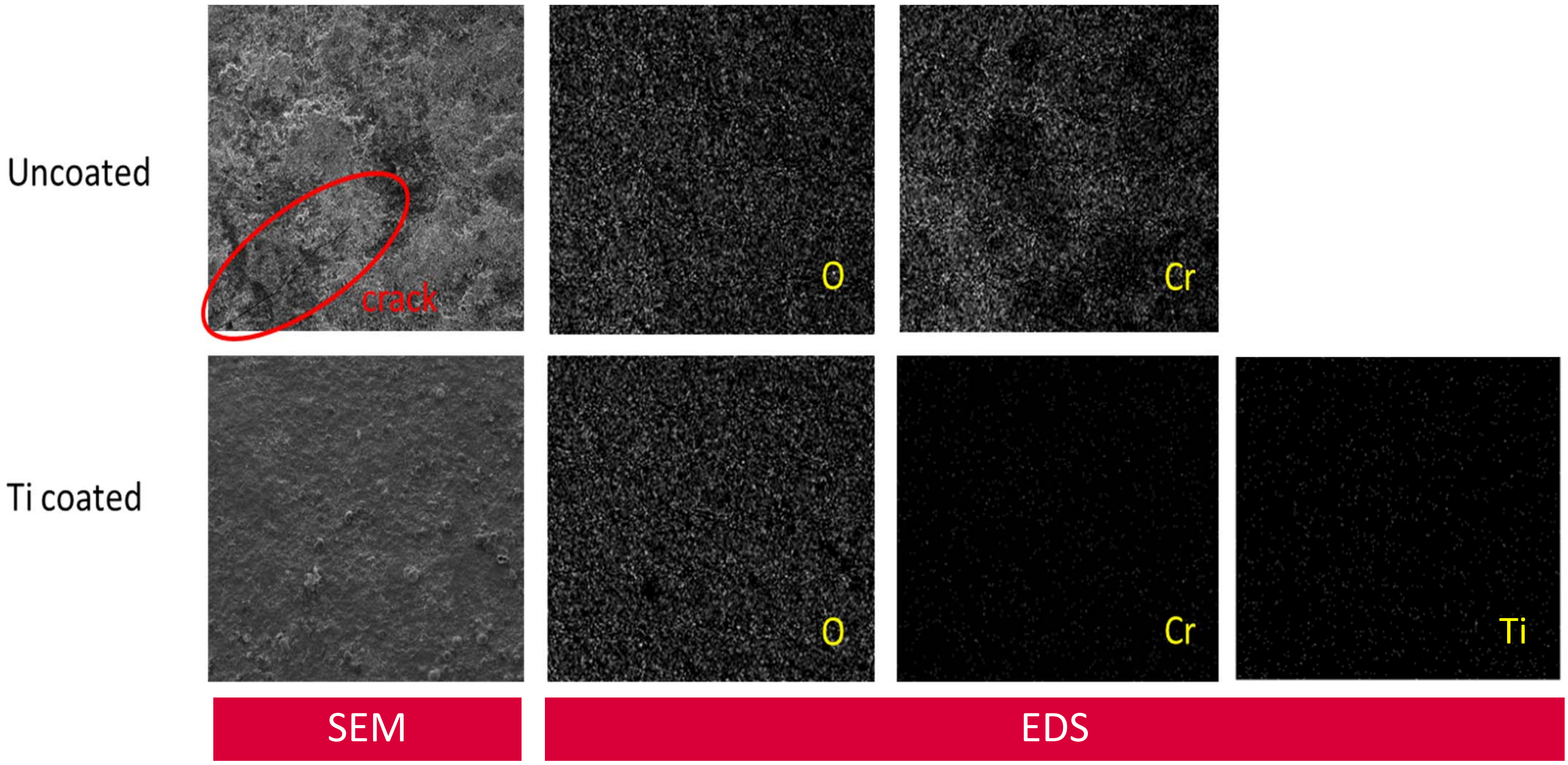
$Na_2SO_4:NaCl:K_2SO_4:KCl = 1:1:1:1$

Impact of Salt Corrosion - 750^oC





Impact of Salt Corrosion - 750^{0}C

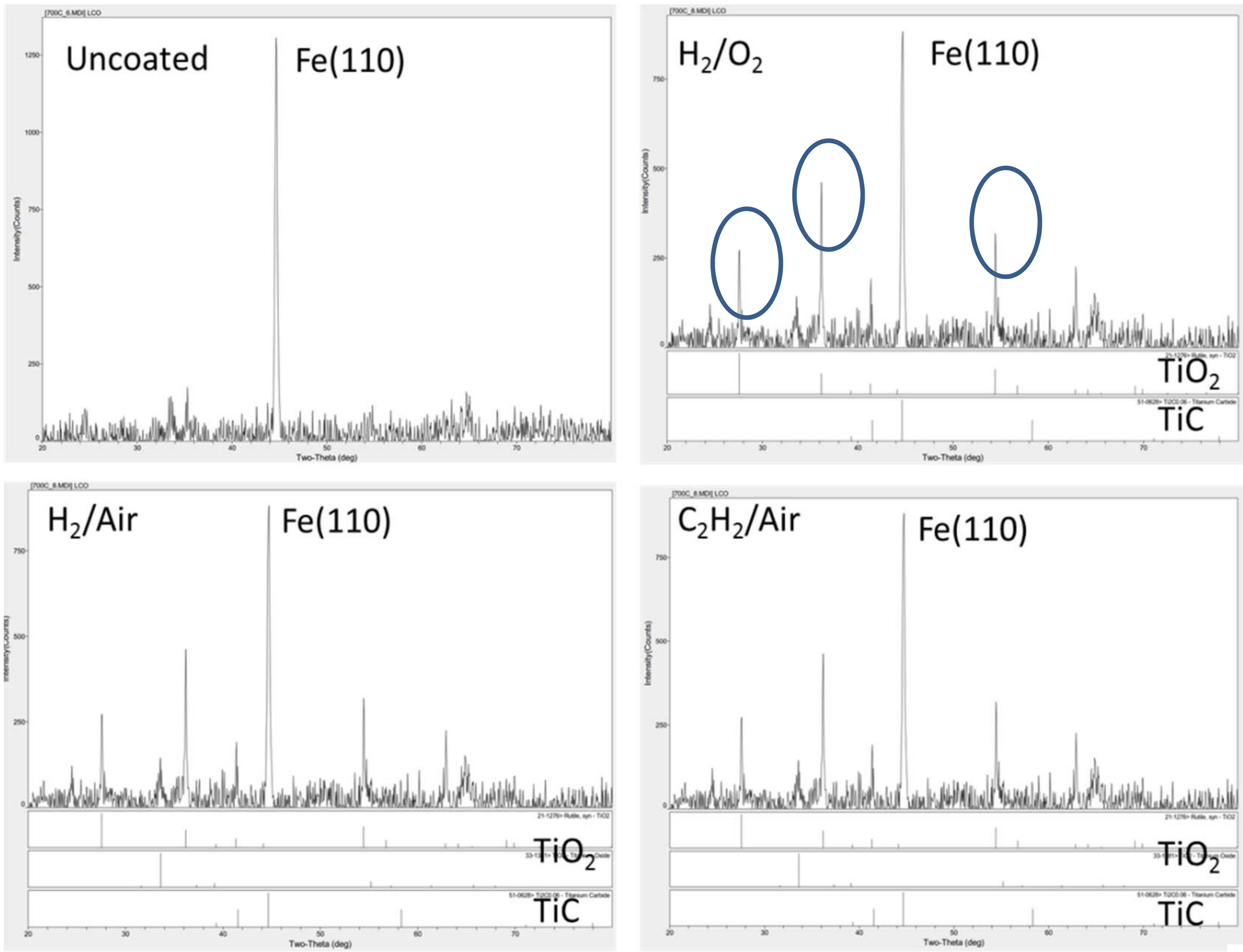


Impact of HVOF Conditions

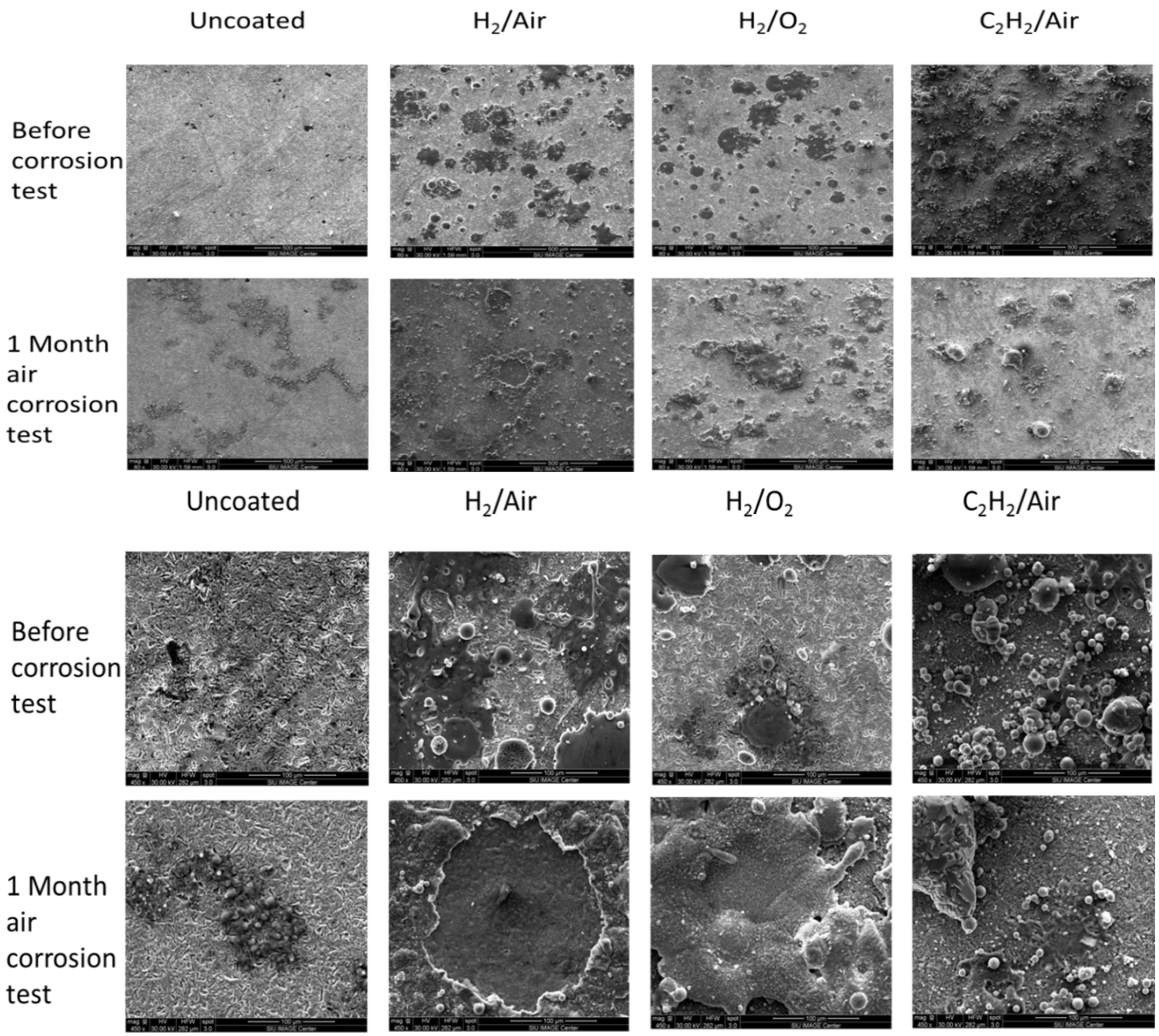
Simulated Flyash Corrosion – 750 °C

Sample	Spray Conditions							
	H2	O2	Air	C2H2	T (C)	d (cm)	Ti (at %)	Ash Corrosion (Wt Loss %)
Control							-	38.47
H_2/Air	46		9		3200	25	2.6	11.58
H_2/O_2	46	12			3200	25	10.93	1.44
C_2H_2/Air			9	24	2500	25	5.24	14.08
H_2/O_2	46	12			3200	25	1.91	18.26
H_2/O_2	46	12			3200	25	3.02	17.00
C_2H_2/Air			9	24	2500	25	1.29	24.63
C_2H_2/Air			9	24	2500	25	6.54	22.86
C_2H_2/Air			9	24	2500	25	8.86	12.05
C_2H_2/Air			9	24	2500	25	3.43	23.52

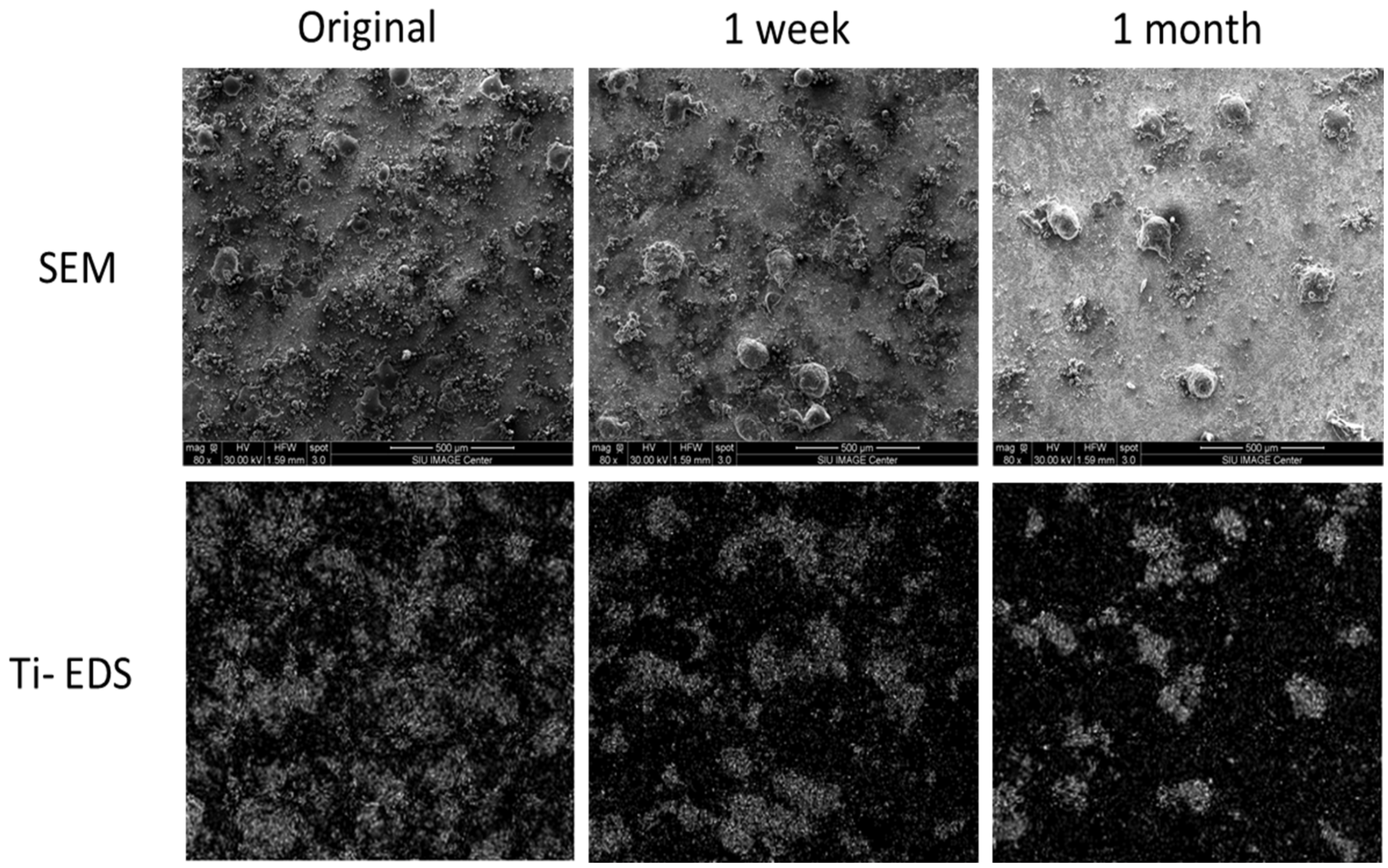
Impact of HVOF Conditions



Impact of HVOF Conditions on Oxidation



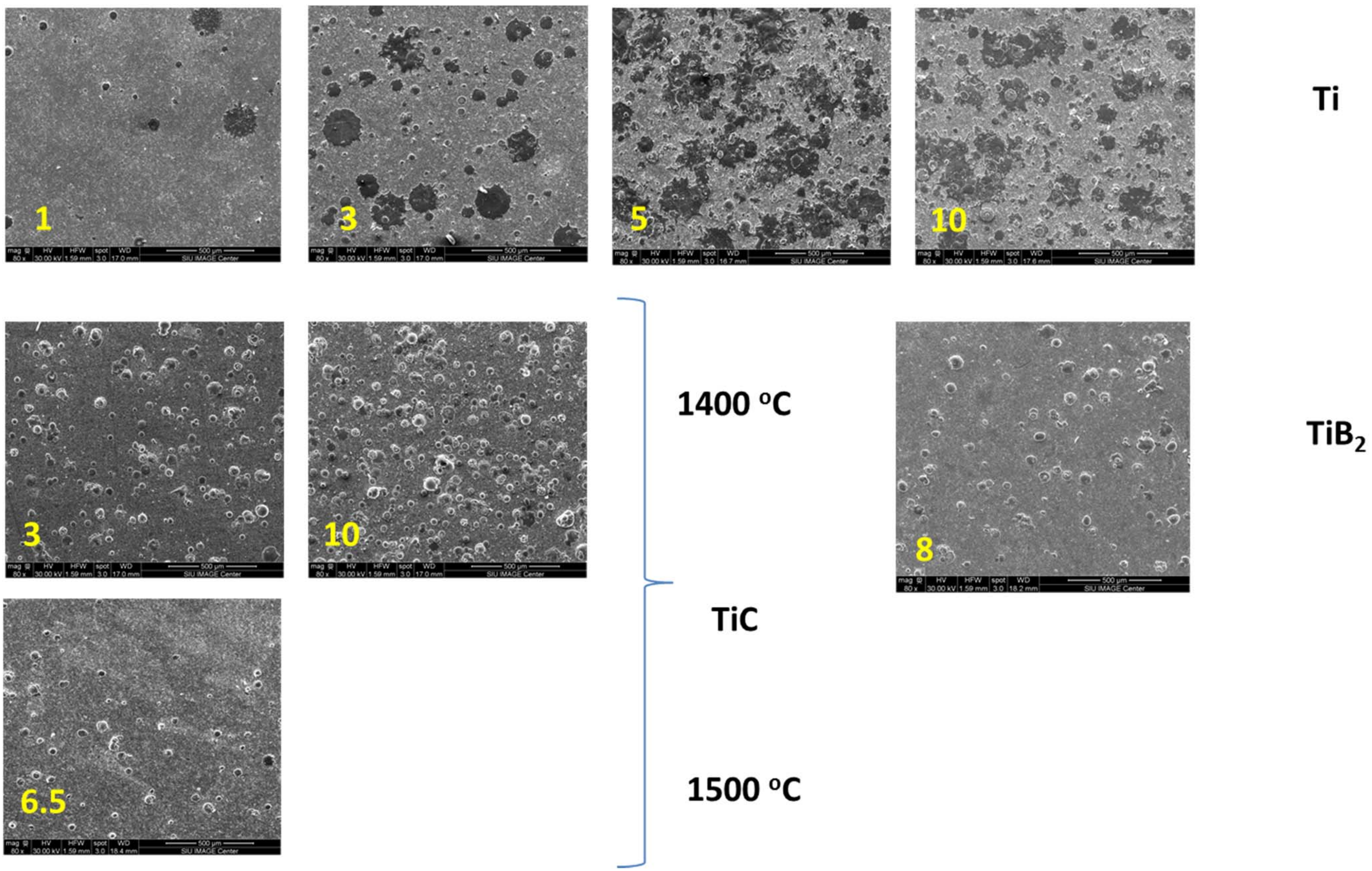
Ti in Surface Coating upon Oxidation

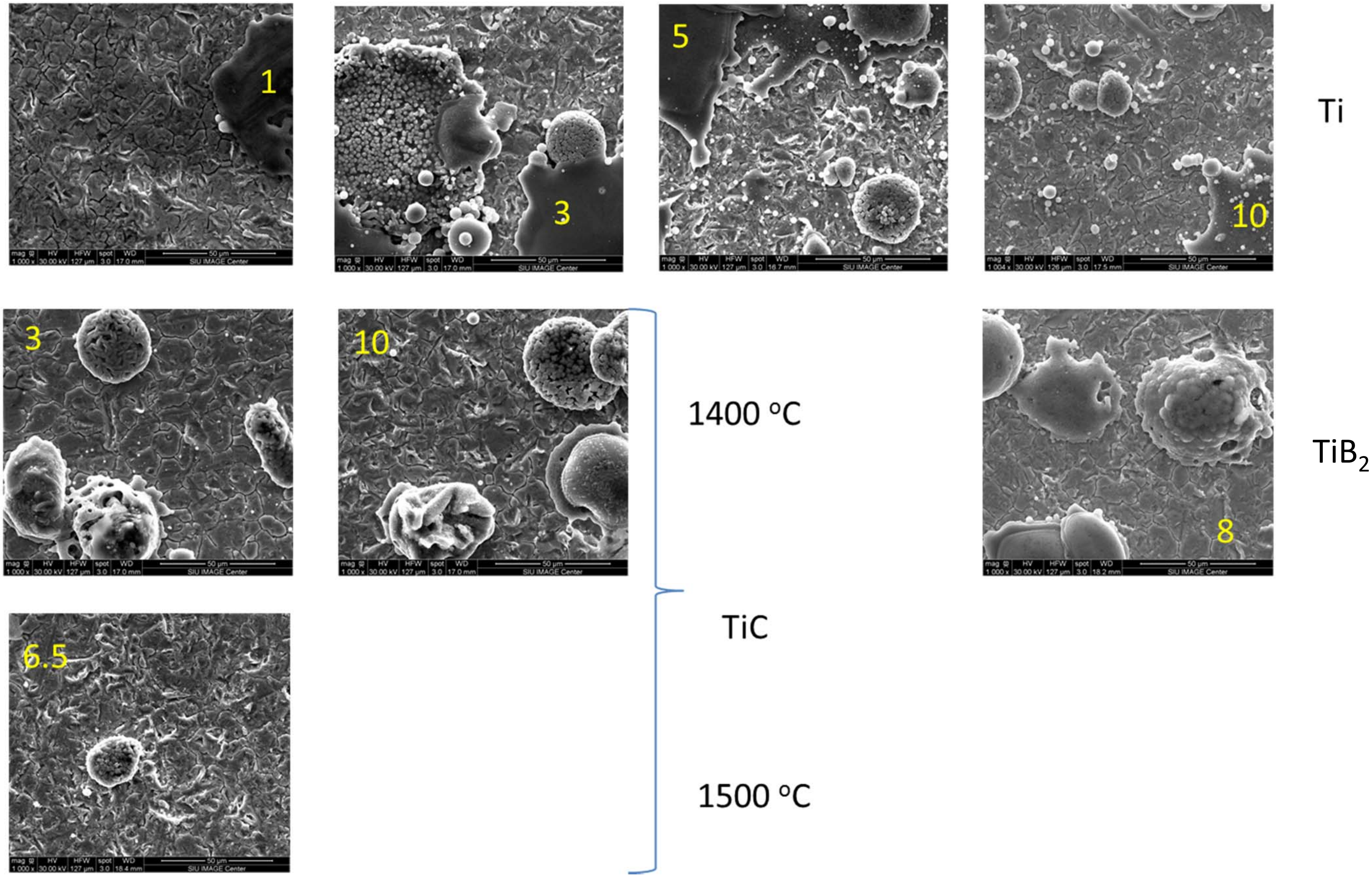


HVOF Optimization

Effect of Coating Time

Spray Parameters	
H_2 Flow Rate	76 LPM
O_2 Flow Rate	13 LPM
N_2Flow Rate	1.8 LPM
Spray Distance	27 cm
Temperature	3200^{o}C
Spray Times	1, 3, 5, 6.5, 8, 10


1
3
5
10
Ti
3
10
1400 °C
TiC
1500 °C
6.5
8
TiB2


1
3
5
10
Ti
3
10
1400 °C
8
TiB_2
TiC
6.5
1500 °C

Achievements:

- Facile synthesis of TiC and TiB_2 nanosized powders with narrow size distribution.
- HVOF thermal spray coating of these powders on 304 H and 430 SS substrates.
- Air and salt corrosion characterization of the coated substrates that increased the longevity of the substrate subjected to fireside corrosion in AUSC boiler tubes