

# Multilayer Coatings & Composite Coatings

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**Concordia University**

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# OUTLINES

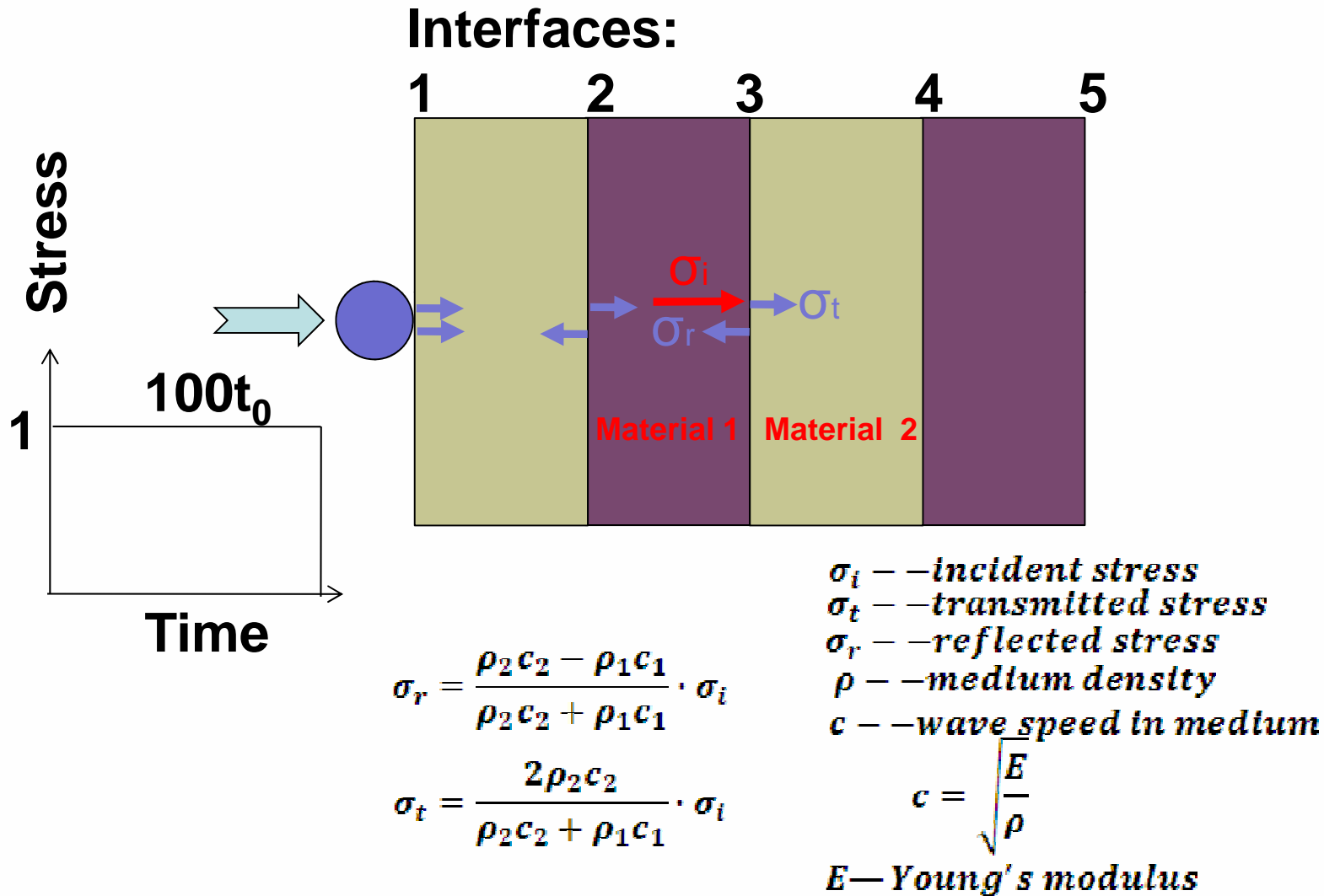
- Part I - Stress wave analysis & multilayer coatings
- Part II - Boronizing coatings
- Part III - TiC-TiB<sub>2</sub>-TiAl<sub>3</sub> coatings
- Part IV - Laser cladding coatings



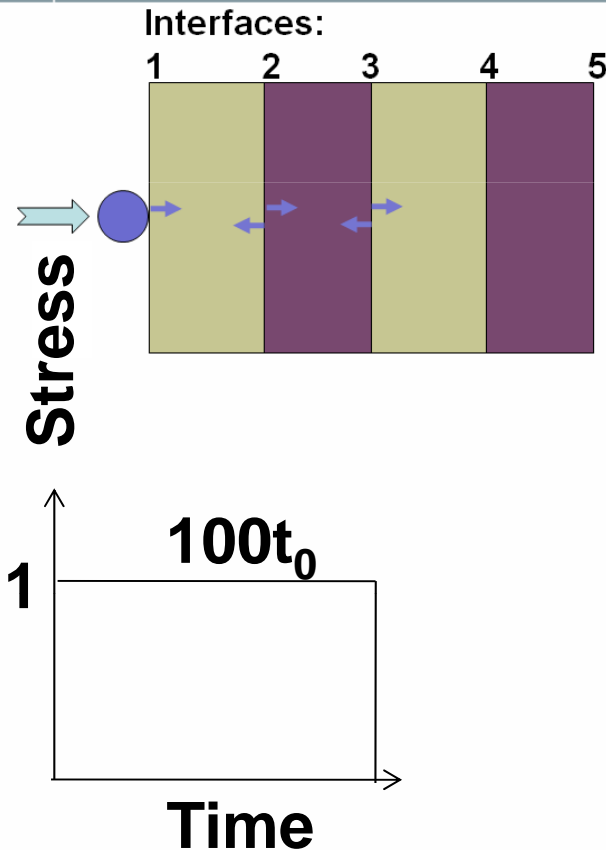
## **Part I**

# **Stress Wave Analysis & Multilayer Coatings**

## Background: Simplifications



## Background: Simplifications

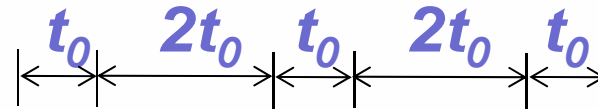
**Simplifications:****1. Single droplet** $(\Phi 16.65 \mu\text{m}, 500\text{m/s})$ **2. Linear and rectangle wave****3. Incident stress = 1 unit****4. Incident time range =  $100t_0$**  $(t_0 = 3.3\text{E}-10 \text{ s})$ **5. 100 pulses****6. No energy loss****7. Thickness design** ( $t_0$  by integer) $1t_0$ ----- $3.5 \mu\text{m TiN}$  /  $1.6 \mu\text{m Ti layer}$

1

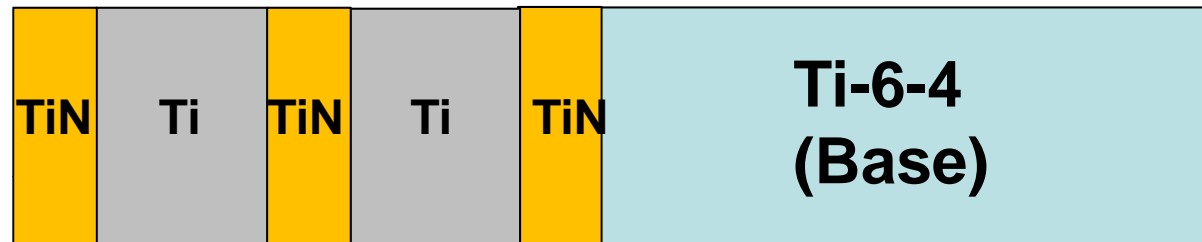
## Theoretical Background &amp; Simplifications

## Coating A

*Time the wave travel through each layer*



**Coating A**



Interface: 1 2 3 4 5 6

## Simplifications:

8. Base metal thickness: infinite

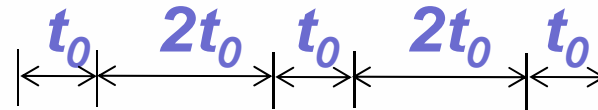

**2** **Calculated Results**

2

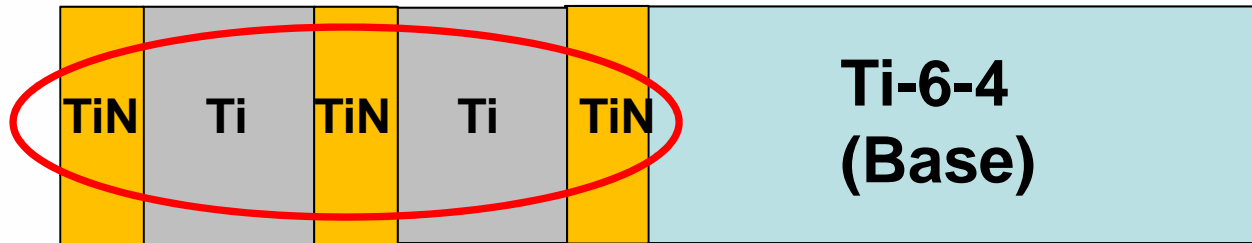
## Calculated Results

### Coating A Vs. Coating C

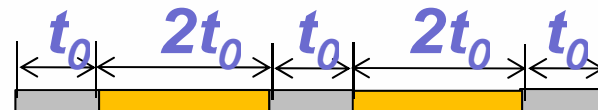
*Time the wave travel through each layer*



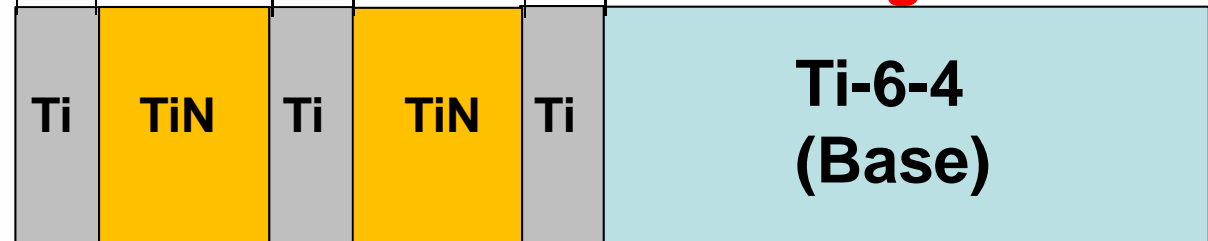
**Coating A**



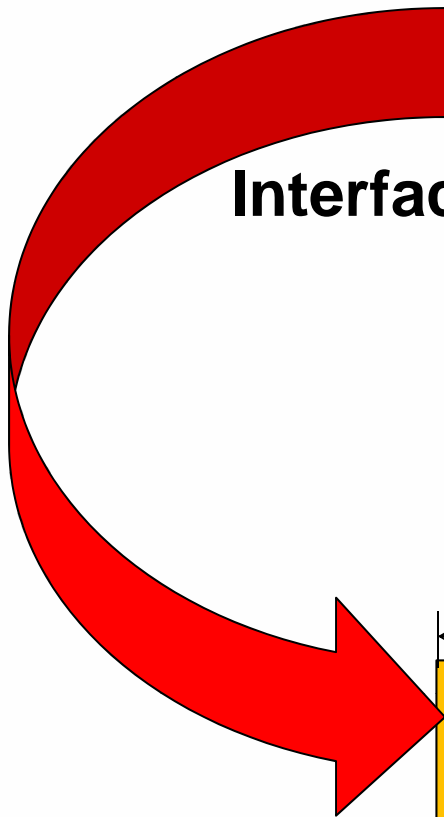
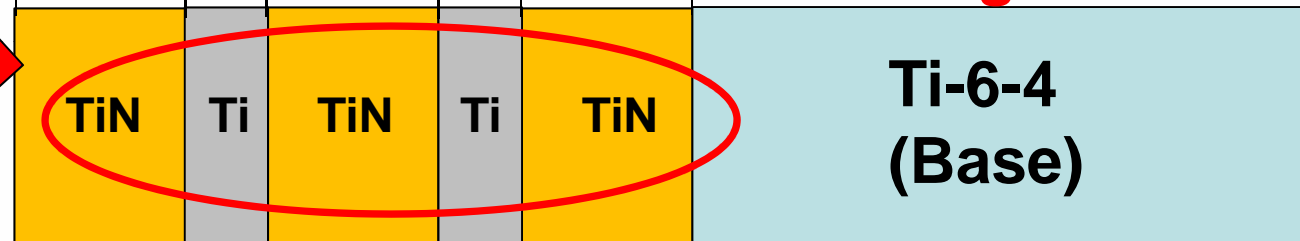
Interface: 1 2 3 4 5 6



**Coating B**



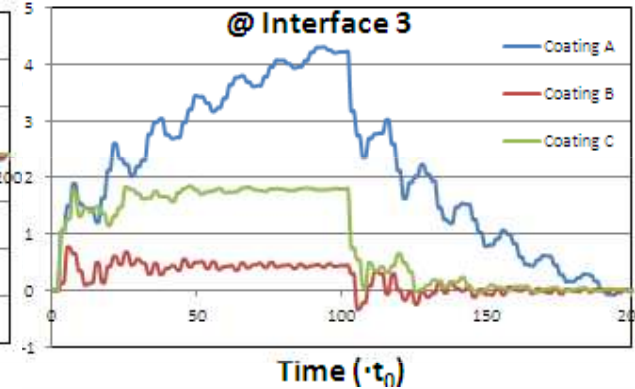
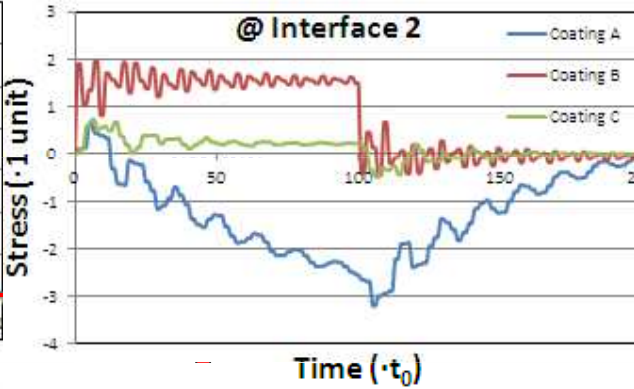
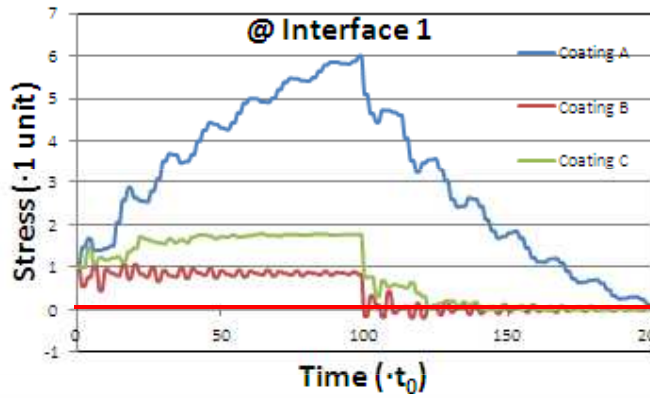
**Coating C**



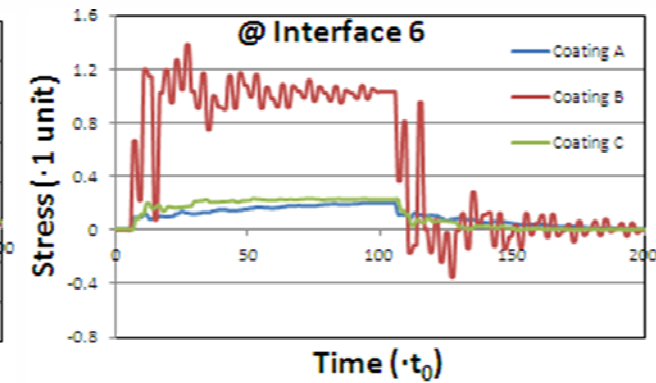
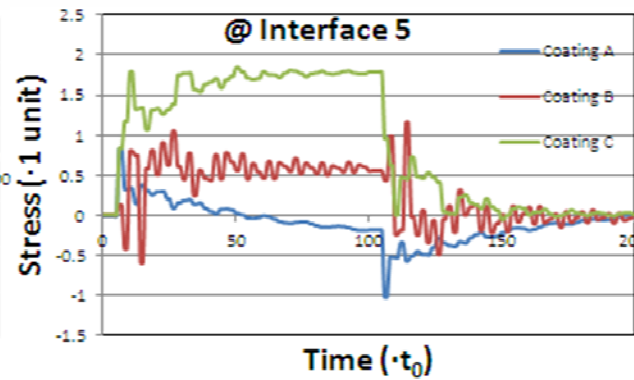
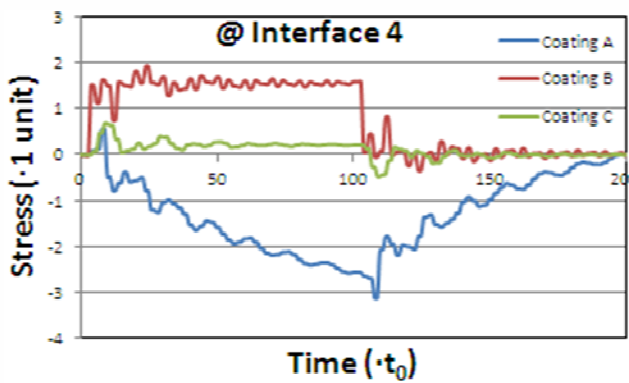


# 2

## Calculated Results



Tensile stress





## 3 Coating Design

## 3

## Coating Design

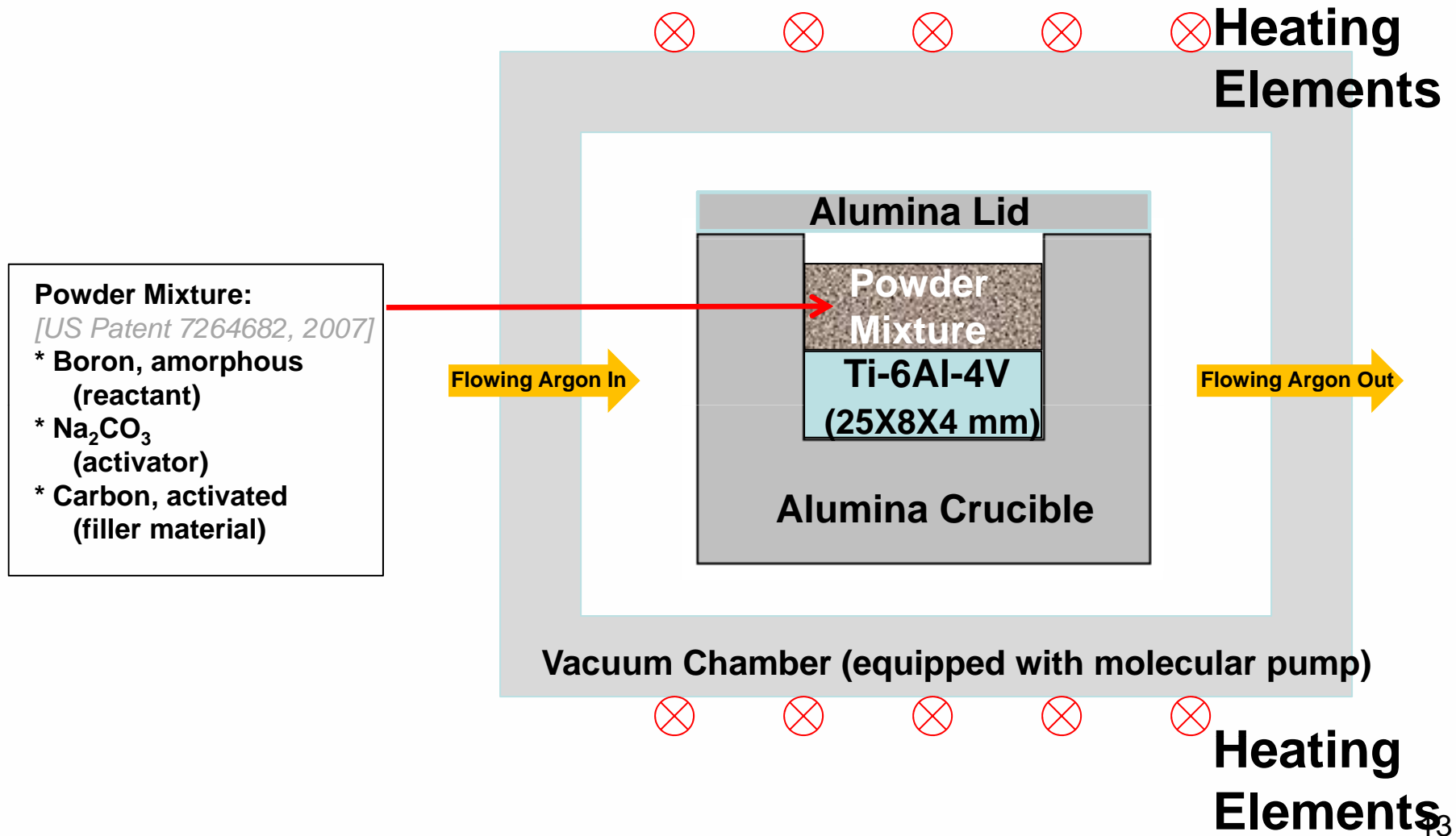
Coating #	Configuration (From inner to outside)	Layers Amounts	Thickness of Layer 1 ( $\mu\text{m}$ )	Thickness of Layer 2 ( $\mu\text{m}$ )	Thickness of Layer 3 ( $\mu\text{m}$ )	Thickness of Layer 4 ( $\mu\text{m}$ )	Thickness of Layer 5 ( $\mu\text{m}$ )	Thickness of Layer 6 ( $\mu\text{m}$ )	Thickness of Layer 7 ( $\mu\text{m}$ )
1	TiN (1T)	1	1.10						
2	TiN(5T)	1	5.52						
3	TiN(9T)	1	9.93						
4	TiN-Ti-TiN (2T-T-2T)	3	2.21	0.50	2.21				
5	TiN-Ti-TiN-Ti-TiN (2T-T-2T-T-2T)	5	2.21	0.50	2.21	0.50	2.21		
6	TiN-Ti-TiN-Ti-TiN (T-T-T-T-T)	5	2.21	0.50	2.21	0.50	2.21		
7	TiN-Ti-TiN-Ti-TiN (3T-T-3T-T-3T)	5	3.31	0.50	3.31	0.50	3.31		
8	TiN-Ti-TiN-Ti-TiN (T-2T-T-2T-T)	5	1.10	0.50	1.10	0.50	1.10		
9	TiN-Ti-TiN-Ti-TiN-Ti-TiN-Ti-TiN (2T-T-2T-T-2T-T-2T-T-2T)	9	2.21	0.50	2.21	0.50	2.21	0.50	2.21
10	TiN-TiAlN-TiN-TiAlN-TiN (2T-T-2T-T-2T)	5	2.21	1.07	2.21	1.07	2.21		
11	TiN-TiAlN-TiN-TiAlN-TiN-TiAlN (2T-T-2T-T-2T-T)	6	2.21	1.07	2.21	1.07	2.21	1.07	
12	TiN-CrN-TiN-CrN-TiN (2T-T-2T-T-2T)	5	2.21	0.78	2.21	0.78	2.21		
13	TiN-CrN-TiN-CrN-TiN-CrN (2T-T-2T-T-2T-T)	6	2.21	0.78	2.21	0.78	2.21	0.78	



**Part II**  
**Boronizing Coating Results**

# Boronizing Diffusion Coatings

Setup Illustration

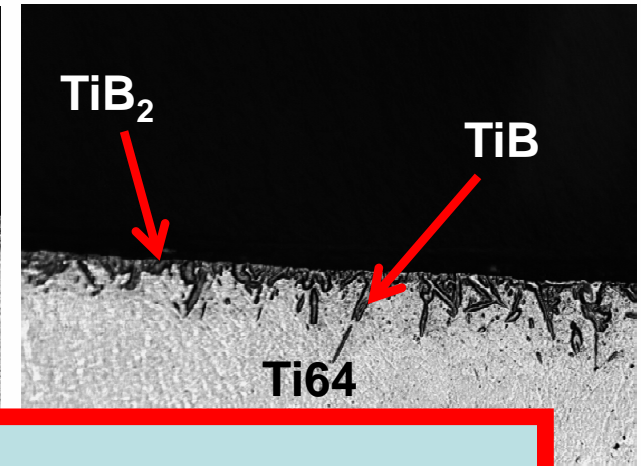
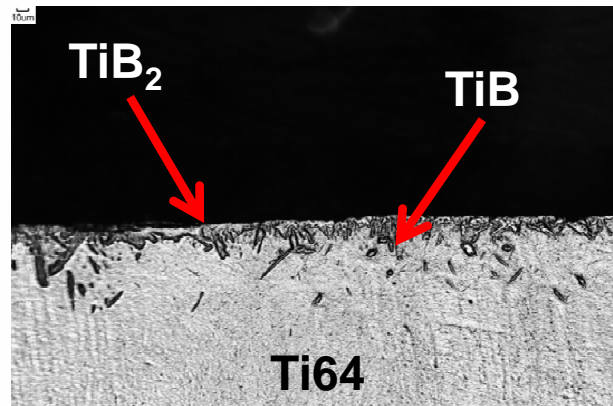
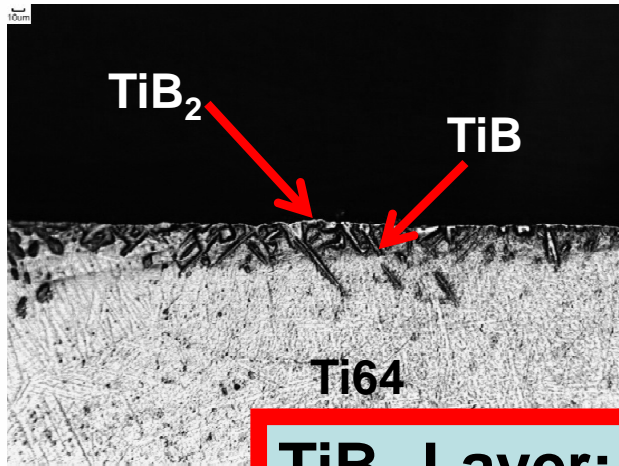


# Experiment Design

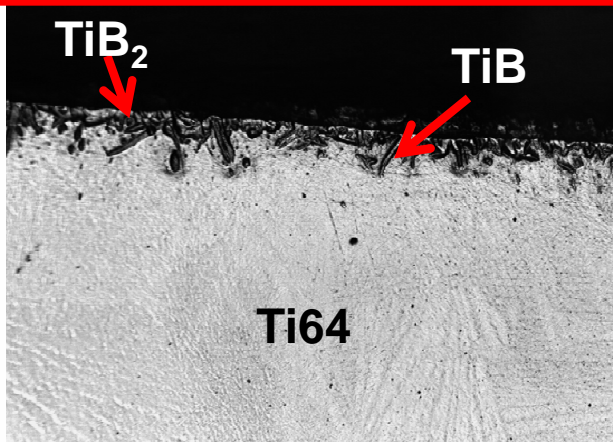
Composition #	B (wt%)	Na <sub>2</sub> CO <sub>3</sub> (wt%)	C(wt%)	Holding Time@1050C	Holding Time@1200C
B0	100%	-	-	24hrs	
B1	50%	45%	5%	24hrs	
B2	50%	35%	15%	12, 24, 48hrs	12 hrs
B3	50%	25%	25%	12, 24, 48hrs	12 hrs, 72hrs
B4	50%	15%	35%		72hrs
B5	50%	5%	45%	24, 72hrs	72hrs

# Effect of Powder Composition I

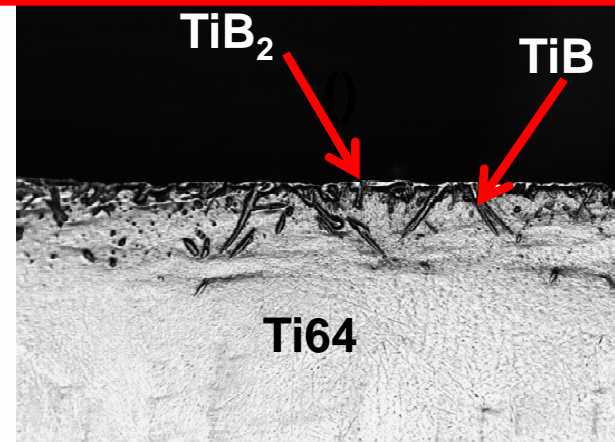
Same Heat Treatment: 1050°C 24 hrs



**TiB<sub>2</sub> Layer: Discontinuous**  
**Overall coating structure: No significant change**



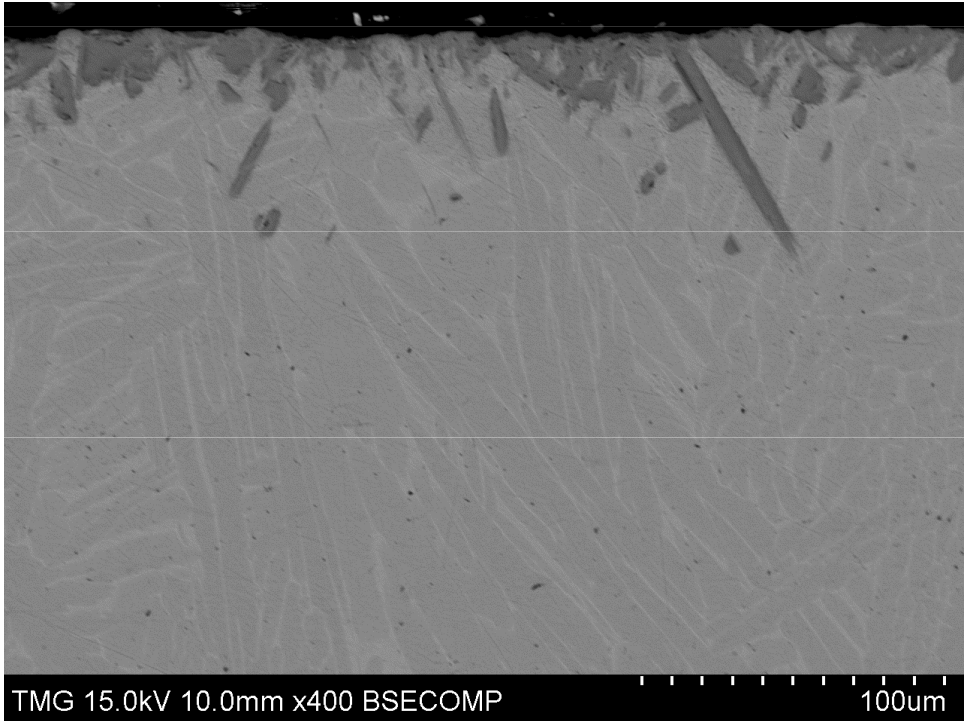
**B3: 50%B, 25%Na<sub>2</sub>CO<sub>3</sub>, 25%C**



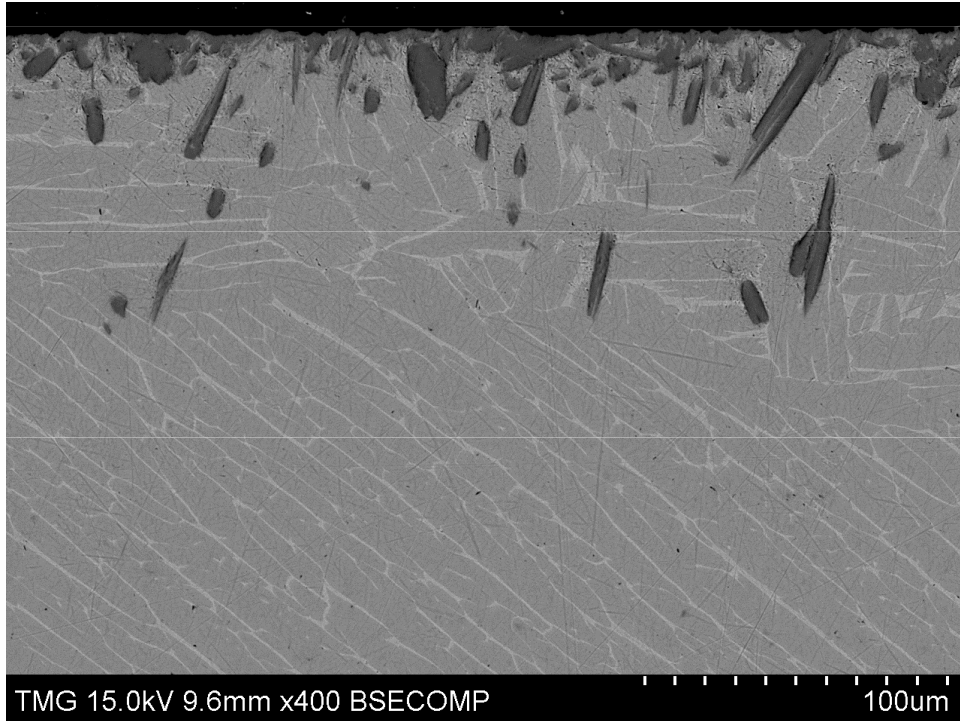
**B5: 50%B, 5%Na<sub>2</sub>CO<sub>3</sub>, 45%C**

# Effect of Powder Composition II

Same Heat Treatment: 1050°C 72 hrs



**B1**, 1050°C 72 hrs

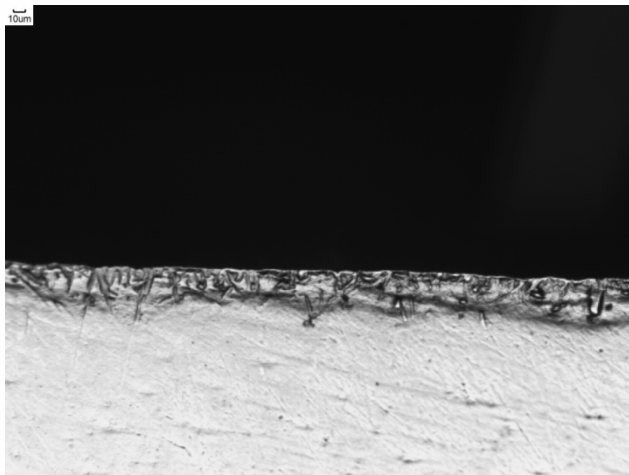


**B5**, 1050°C 72 hrs



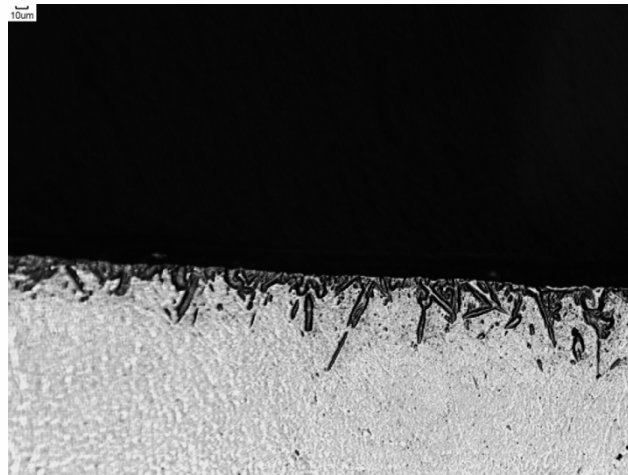
# Effect of Holding Time I

Same Composition B3, Same heating temperature



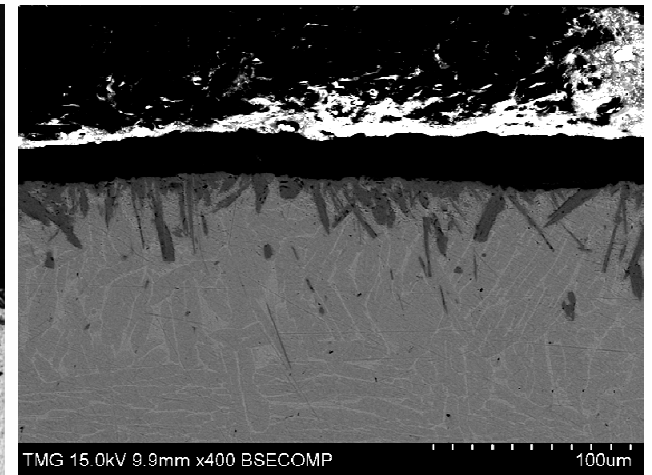
1050°C **12** hrs  
B3: 50%B, 25%Na<sub>2</sub>CO<sub>3</sub>, 25%C

*Optical*



1050°C **24** hrs  
B3: 50%B, 25%Na<sub>2</sub>CO<sub>3</sub>, 25%C

*Optical*



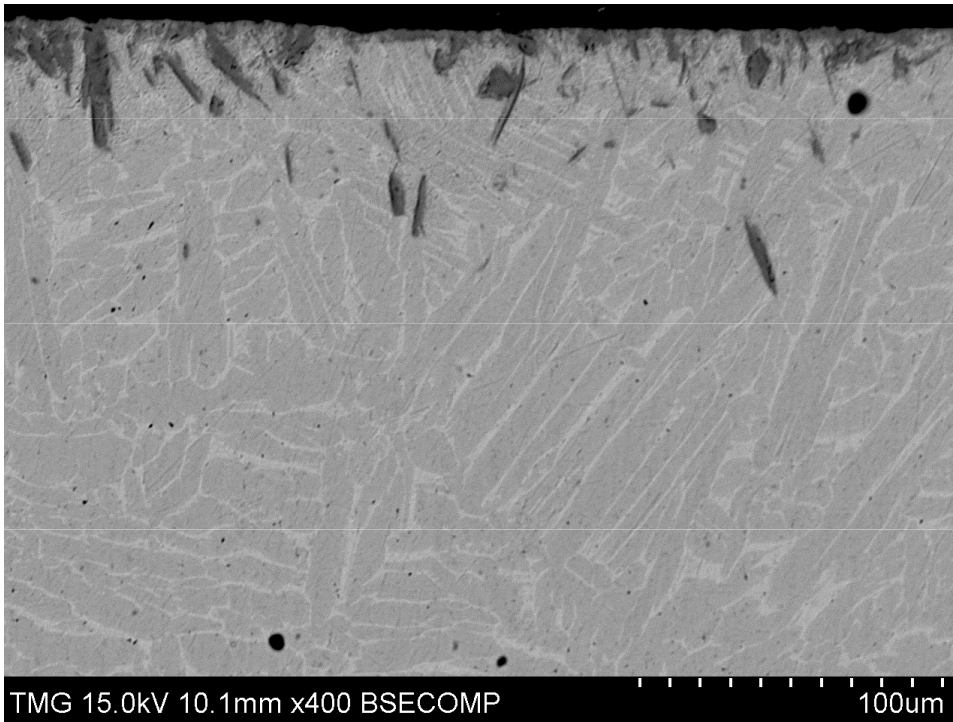
1050°C **48** hrs  
B3: 50%B, 25%Na<sub>2</sub>CO<sub>3</sub>, 25%C

*SEM (BSE)*

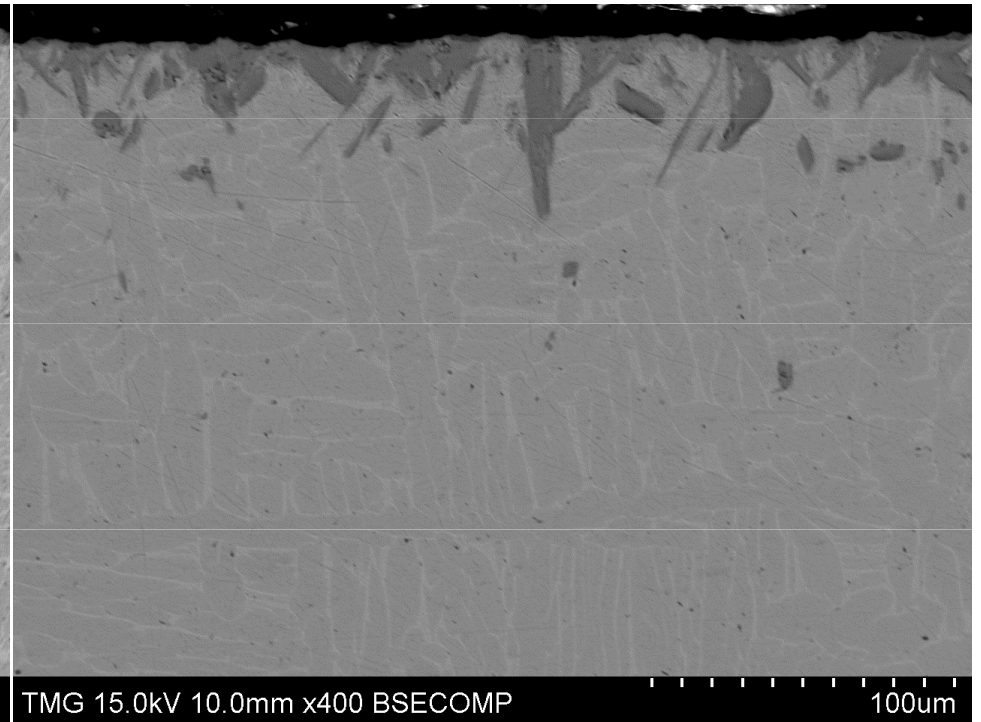
**TiB<sub>2</sub> Layer: Discontinuous**  
**Overall coating structure: No significant change**

## Effect of Holding Time II

Same Composition B1, Same heating temperature



B1, 1050°C 24 hrs

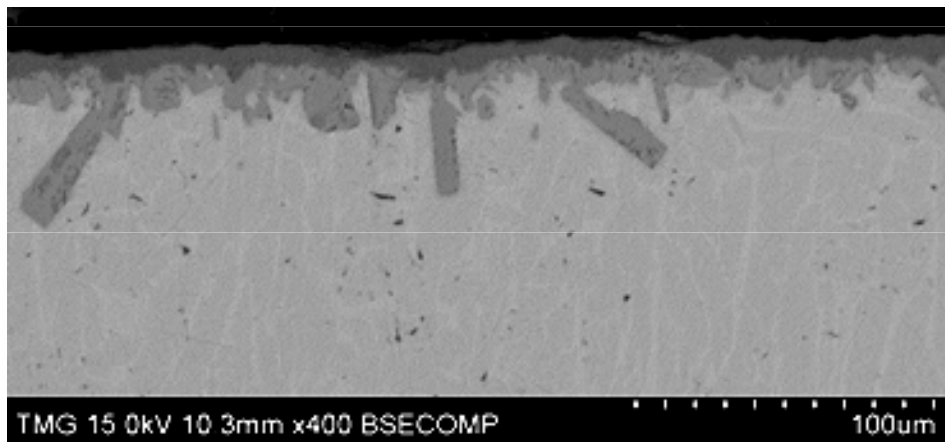


B1, 1050°C 72 hrs

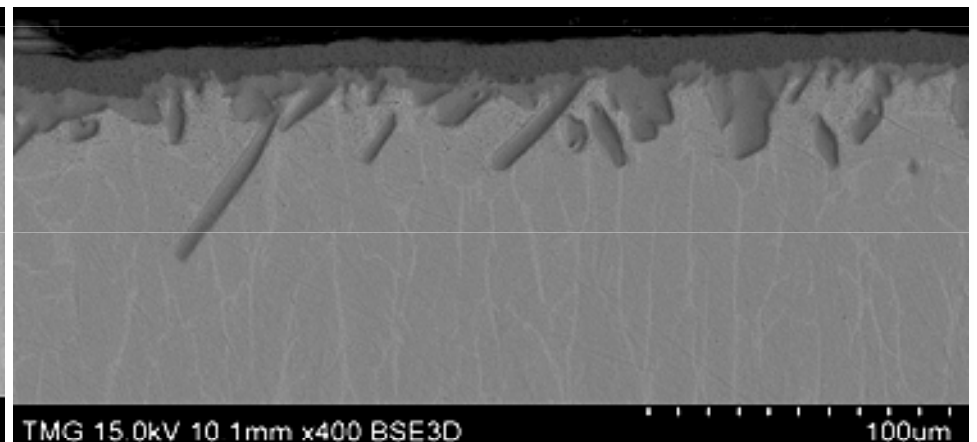
**TiB<sub>2</sub> Layer: Discontinuous**

**Overall coating structure: some change in TiB size**

# Further Exploration for Better Coatings



**B3, 1200°C, 72hrs**

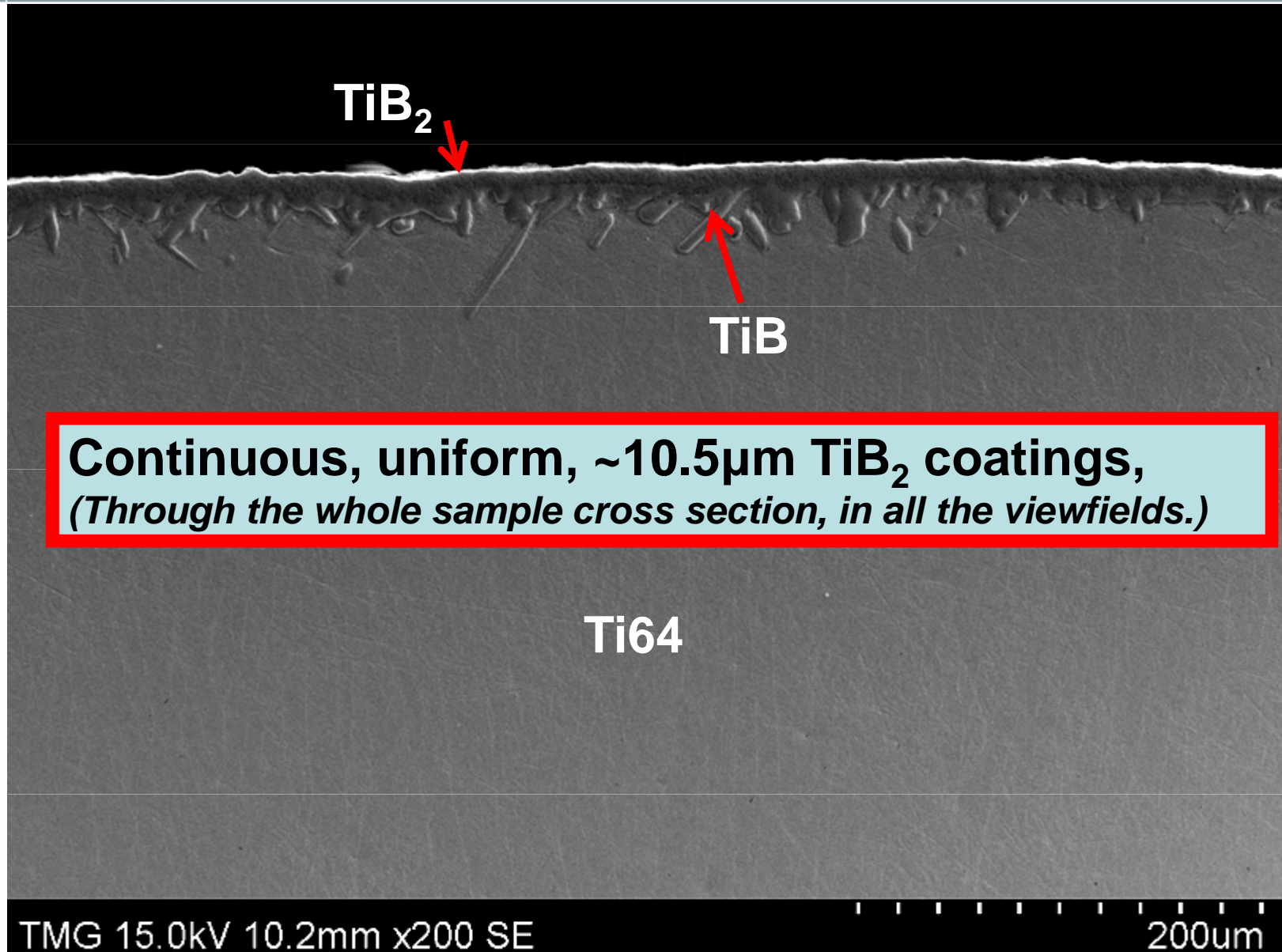


**B5, 1200°C, 72hrs**

# Best Coatings So Far

SEM (SE)

Composition B5, 1200°C X 72 hrs



TMG 15.0kV 10.2mm x200 SE

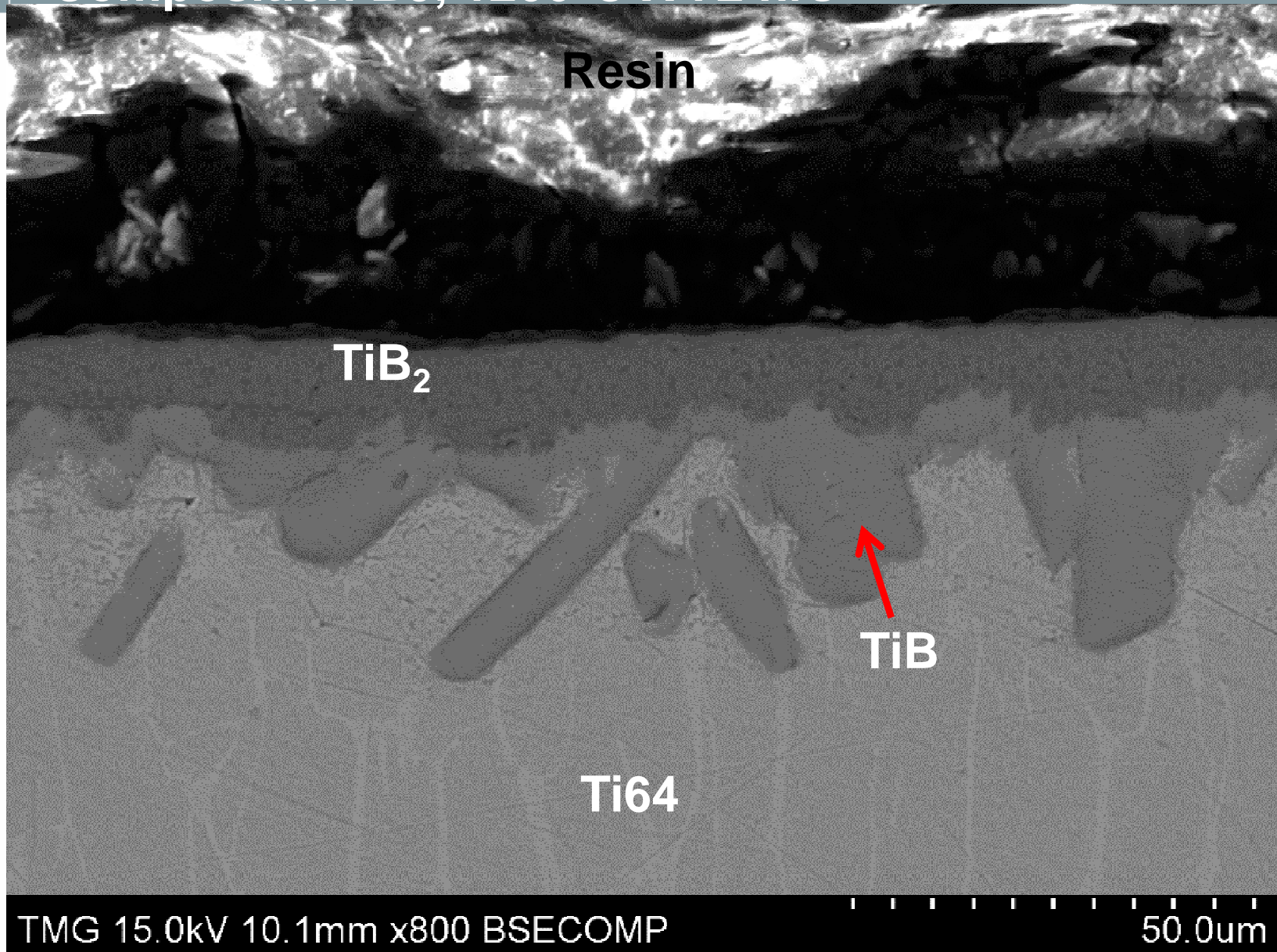
200 $\mu\text{m}$

20

# Best Coatings So Far

SEM (BSE)

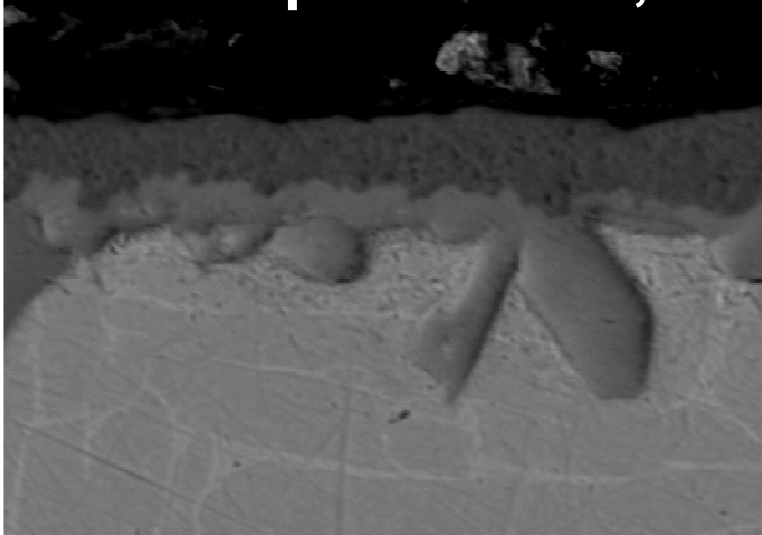
Composition B5, 1200°C X 72 hrs



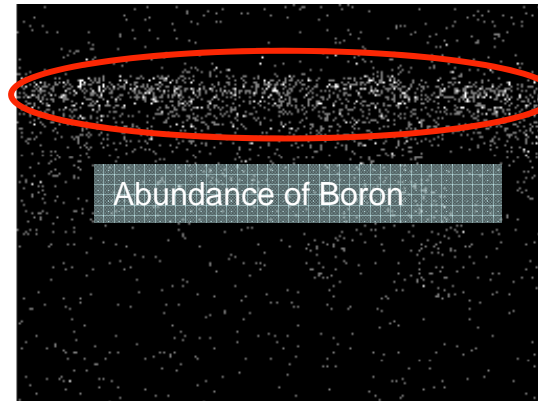
# Best Coatings So Far

## EDS (Mapping)

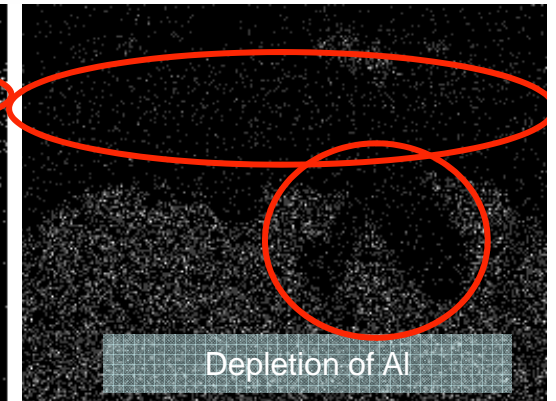
Composition B5, 1200°C X 72 hrs



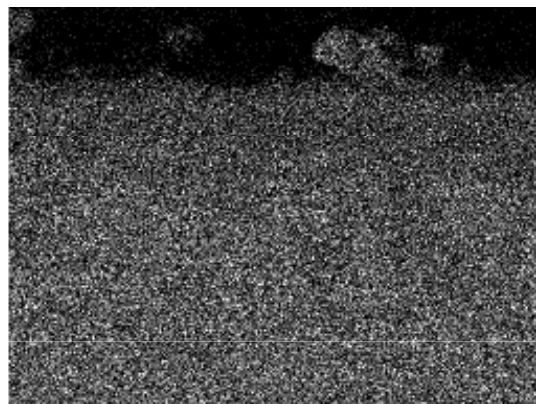
Electron Image 1



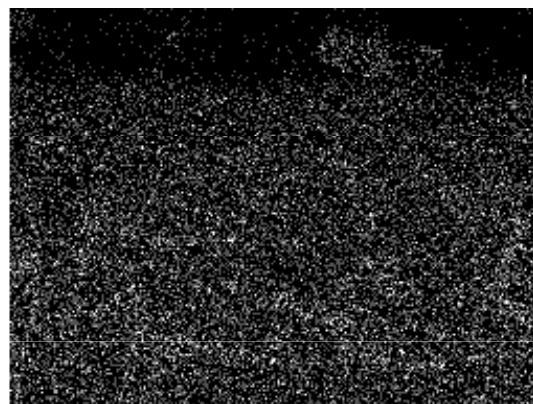
B Ka1\_2



Al Ka1



Ti Ka1

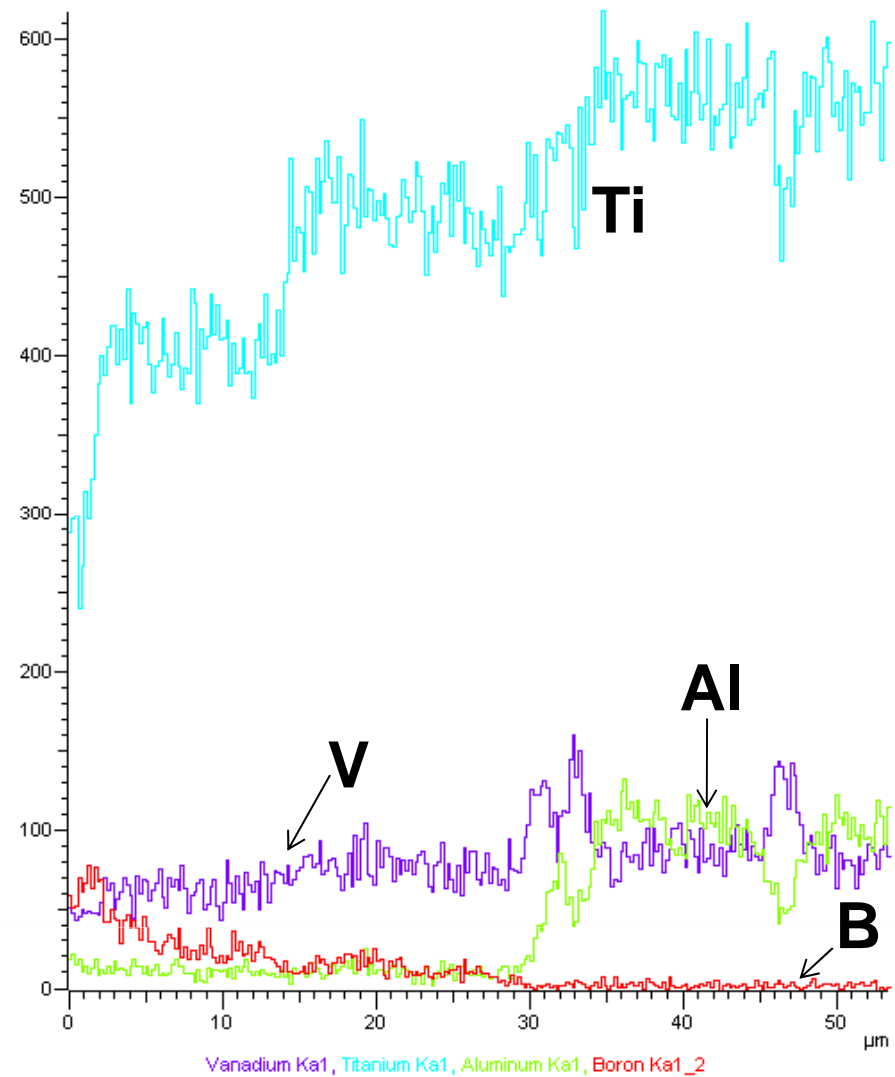
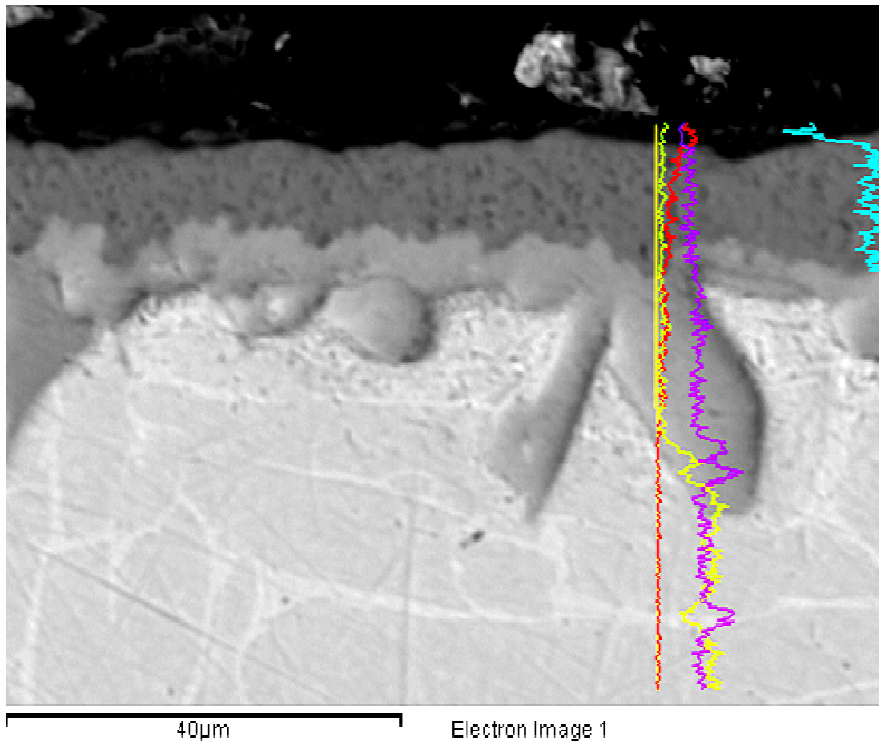


V Ka1

# Best Coatings So Far

# EDS (Line Scan)

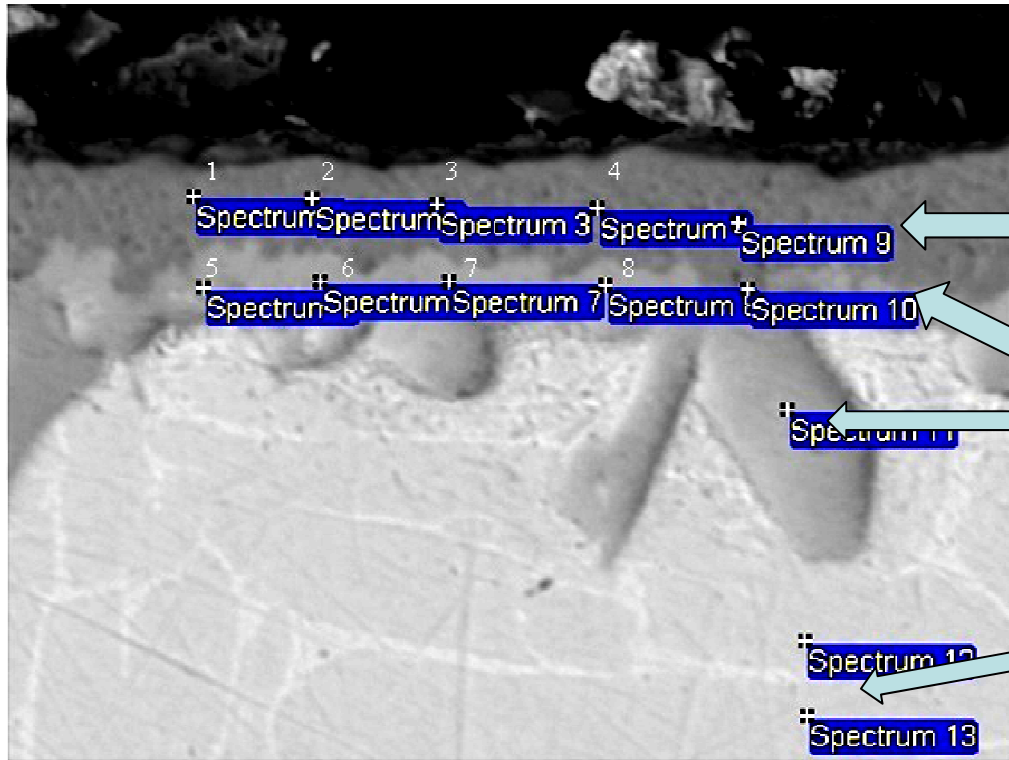
Composition B5, 1200°C X 72 hrs



# Best Coatings So Far

# EDS (Point Identification)

Composition B5, 1200°C X 72 hrs



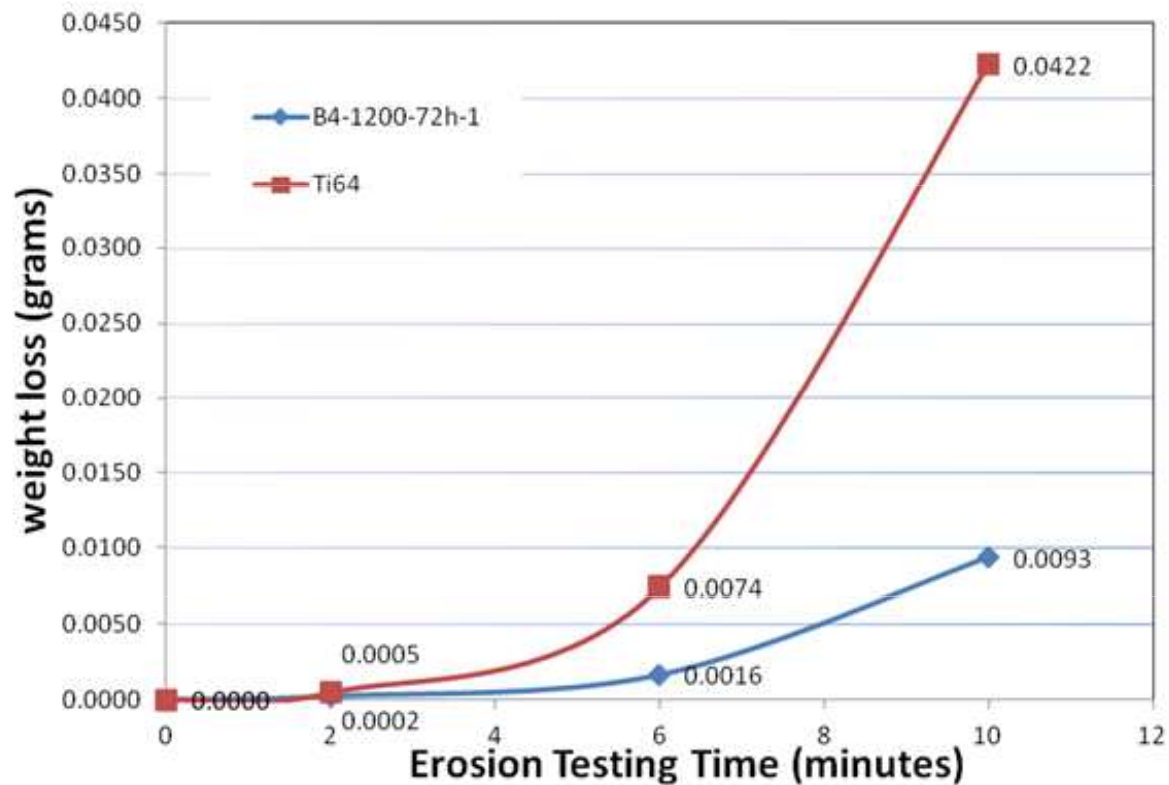
Electron Image 1

Spectrum	B, at%	Al, at%	Ti, at%	V, at%
Spectrum 1	74.08	0.02	24.86	1.05
Spectrum 2	72.98	0.01	26.15	0.86
Spectrum 3	73.77	0.03	25.48	0.71
Spectrum 4	72.18	0.02	27.04	0.75
Spectrum 9	70.69	0.05	28.24	1.02
Spectrum 5	25.02	2.35	70.20	2.43
Spectrum 6	41.13	0.07	56.85	1.95
Spectrum 7	41.72	0.56	55.74	1.98
Spectrum 8	44.72	-0.17	53.37	2.08
Spectrum 10	61.82	0.07	37.14	0.96
Spectrum 11	50.09	0.16	48.39	1.35
Spectrum 12		12.06	85.44	2.50
Spectrum 13		11.74	86.20	2.06
Ti64 Nomination		10.20	86.20	3.60

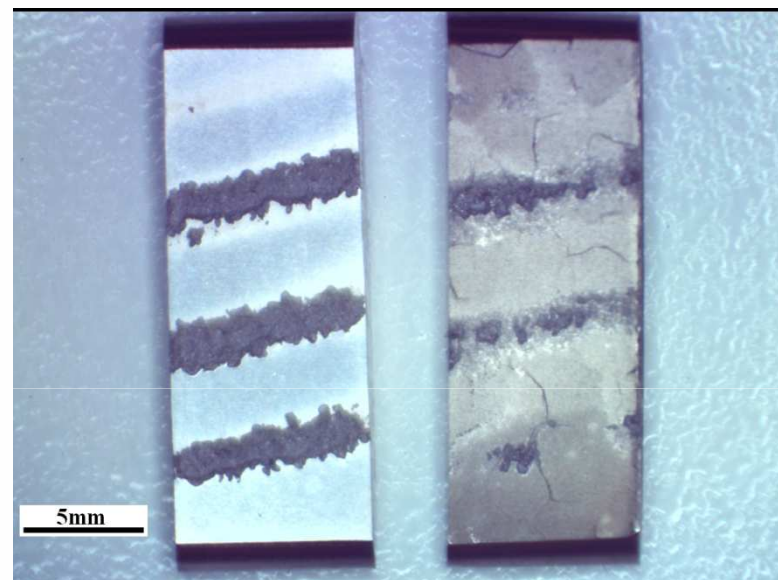
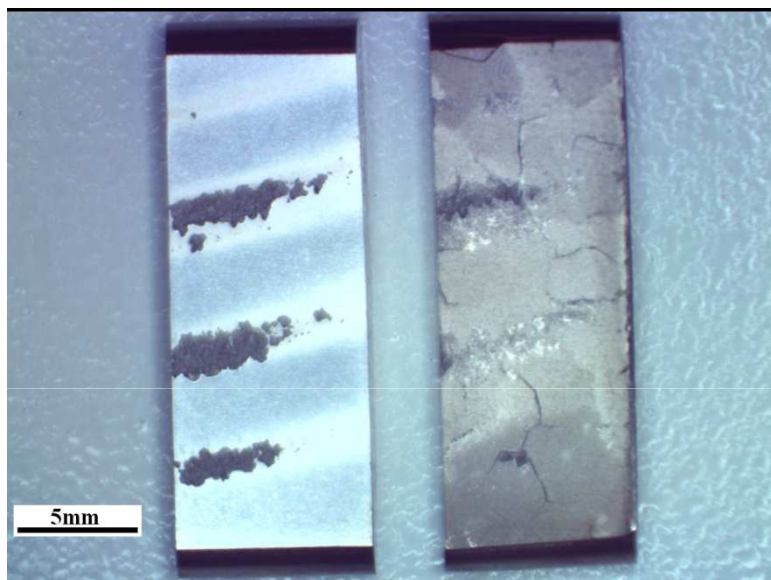
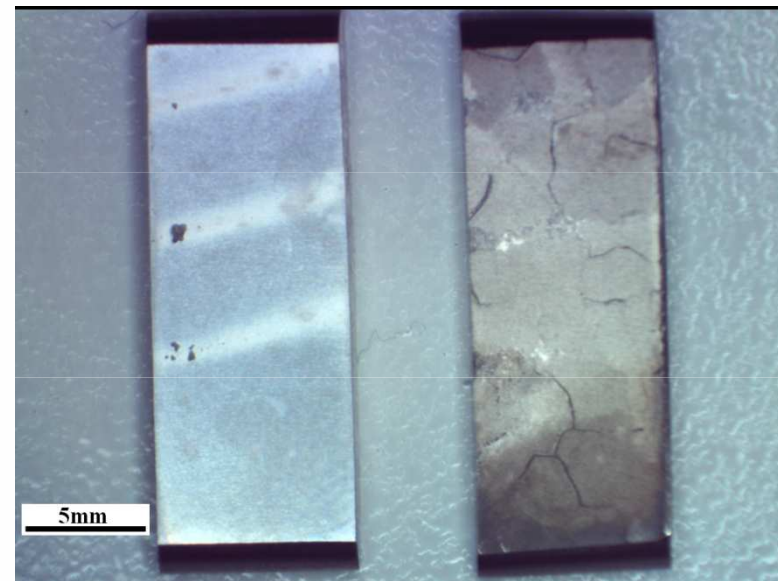
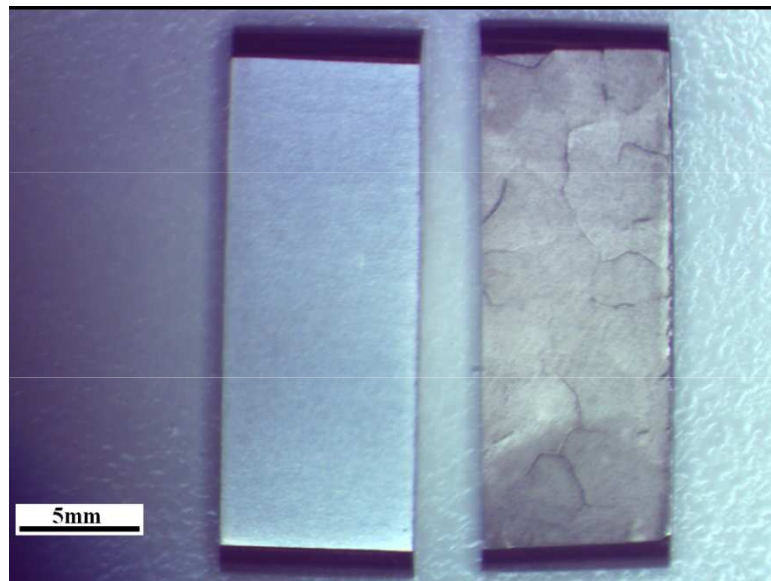


# Water Erosion Testing

- Samples preparation: Boronizing with powder composition B4, @1200°CX72hours
- RIG testing parameter:
- **Speed: 14000 RPM**
- **Time: 0-10 minutes**
- **Nozzle size: 400 μm**
- **Flow Rate: 0.050-0.070 L/min**



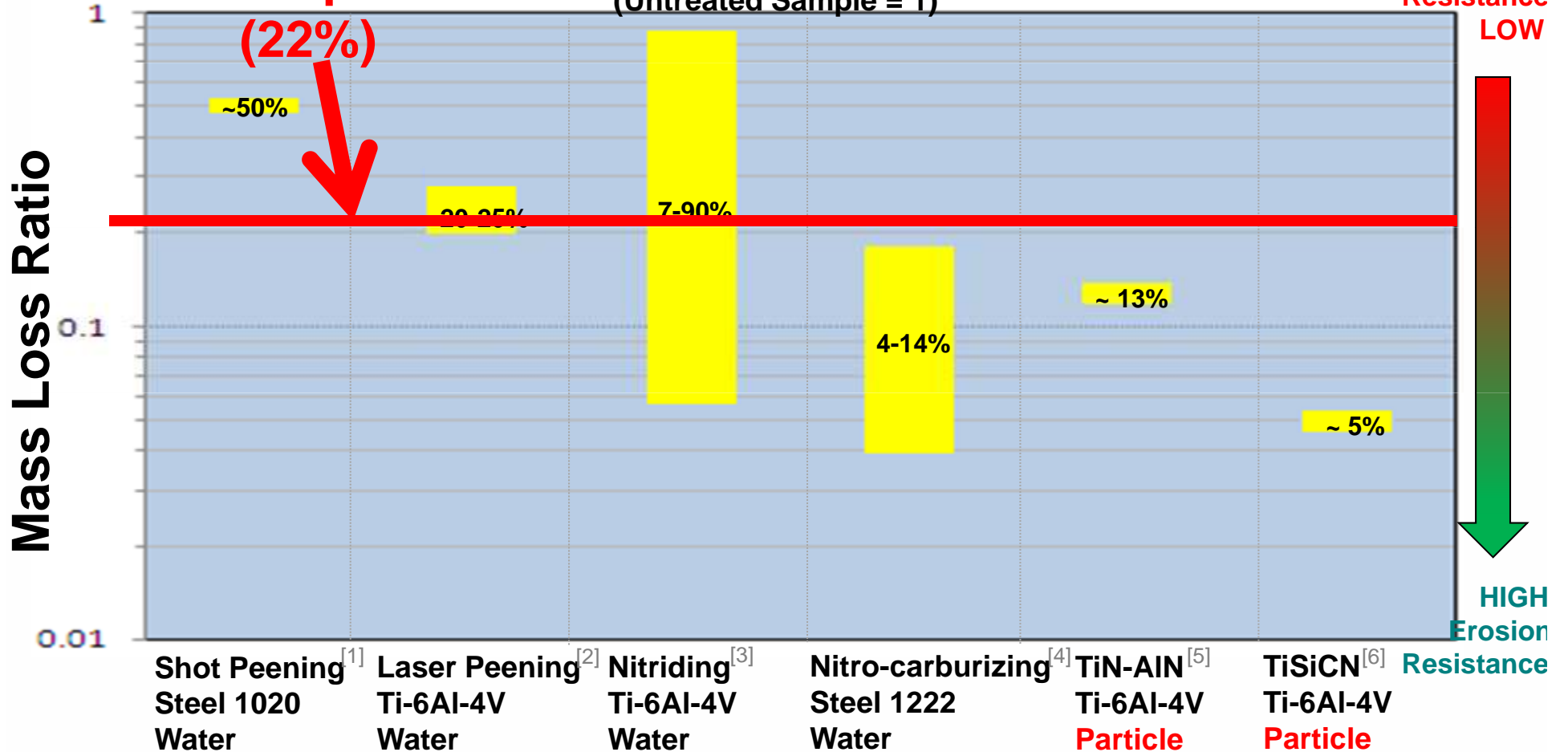
# Water Erosion Testing, B4- 1200°C X 72 hrs Vs Ti64



**Our first  
boronizing  
sample**

## Mass Loss Comparison

(Untreated Sample = 1)



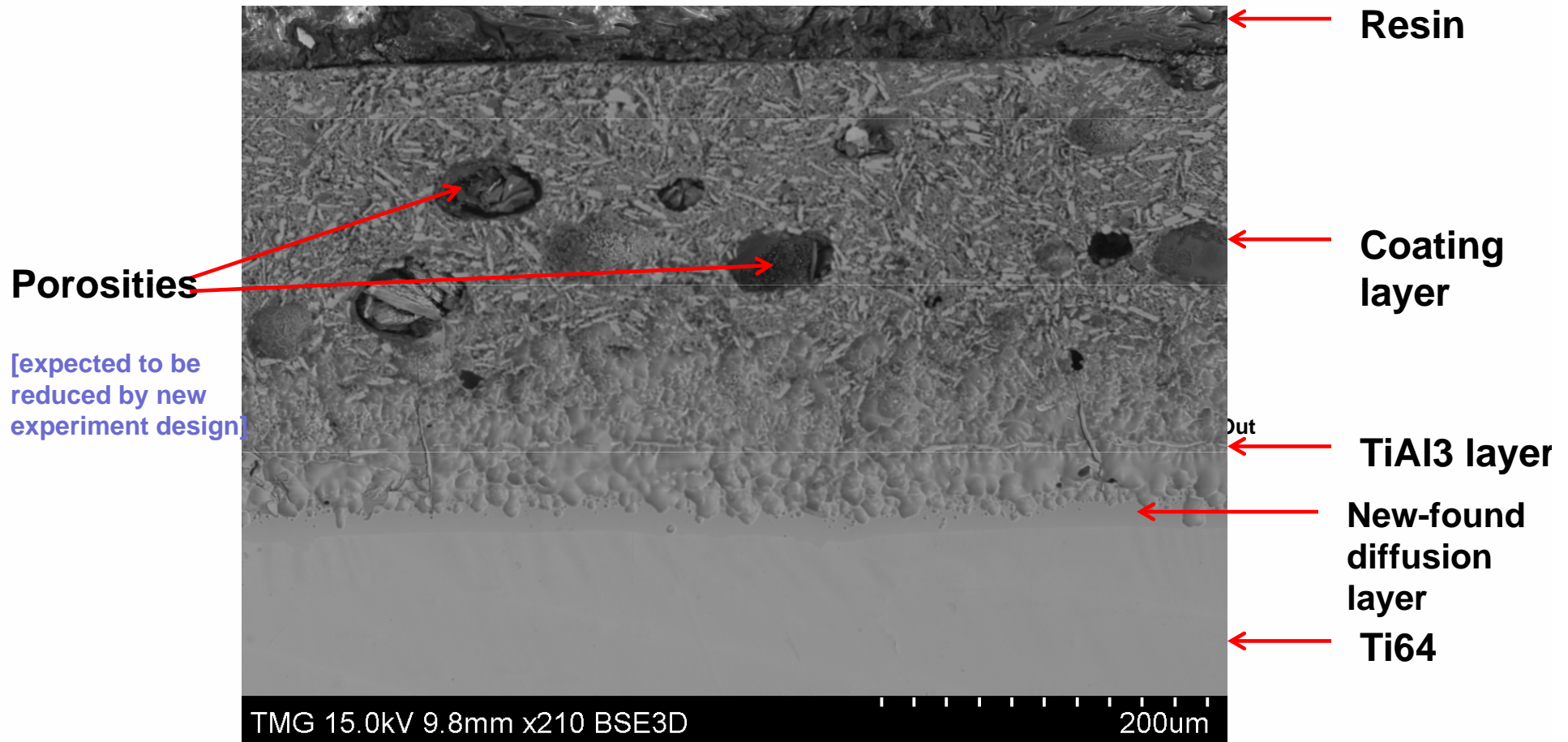
Ref: [1] MIC 1988, [2] Robinson 1995, [3] Ahmad 2009,  
[4] Pant 2010, [5] Rogers 2008, [6] Swaminathan 2008



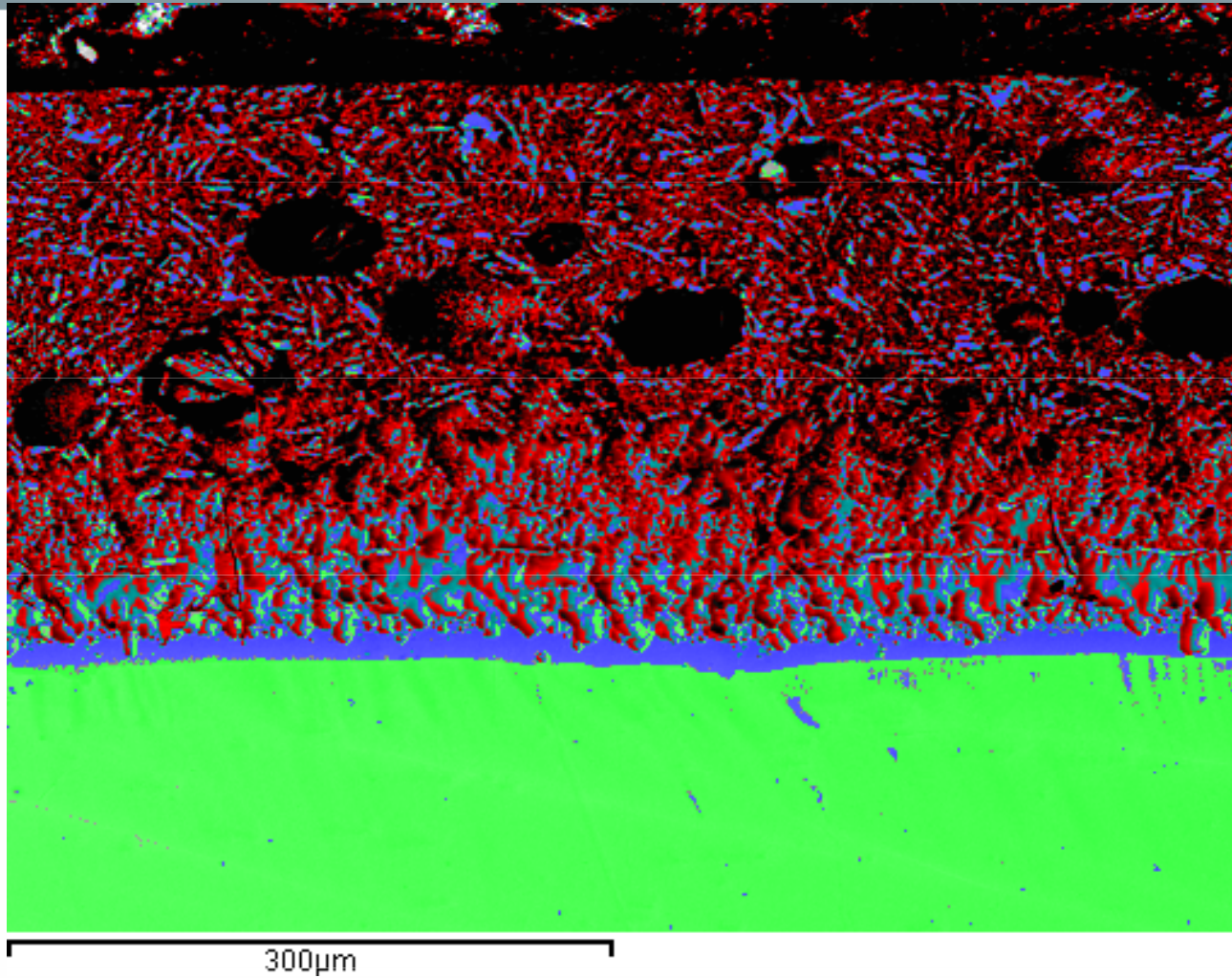
Part III

**TiC-TiB<sub>2</sub>-TiAl<sub>3</sub> Coatings**

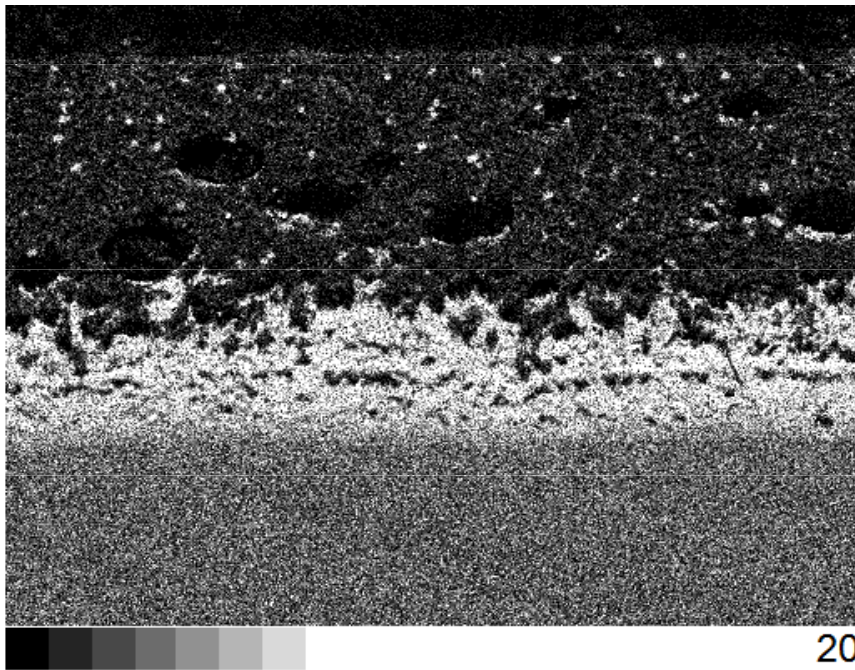
# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings



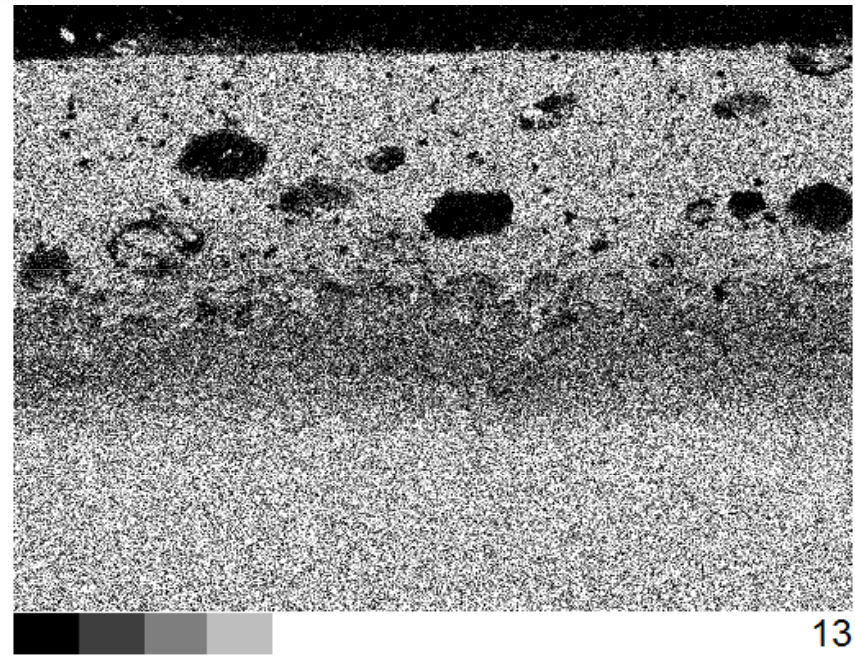
# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings



# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings



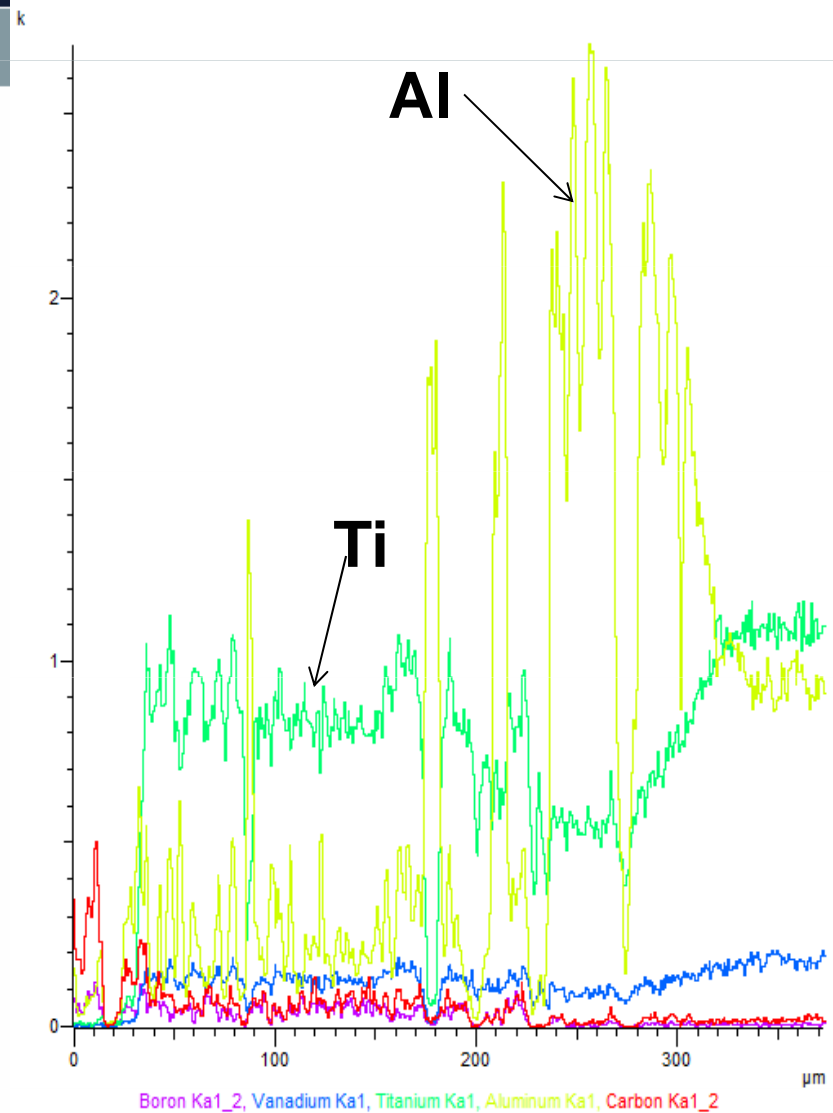
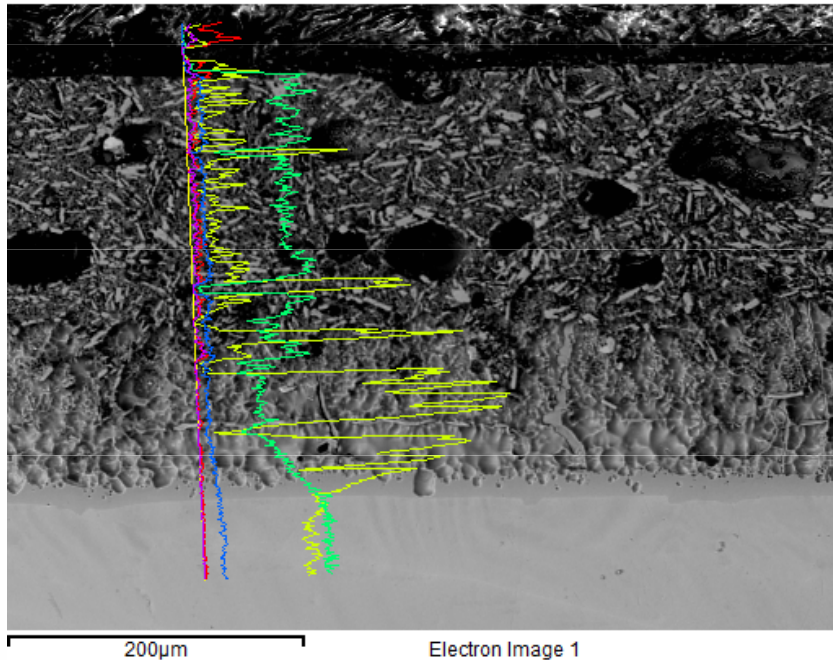
Al Ka1



Ti Ka1

**Al concentrated in the bonding field, indicating possibility of *good bonding & higher percentage of strengthening phases* in the coating**

# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings





# Water Erosion Testing

**Ti64  
Uncoated**

**Vacuum: 44-50 mBar  
Speed: 8000 RPM  
Time: 40 minutes  
Nozzle distance: 30mm  
Flow Rate: 0.065-0.070 L/min**

**TiC-TiB<sub>2</sub>-TiAl<sub>3</sub>  
coating**

**Weight Loss:**

**0.0005 g**



**Weight Loss:**

**0.0358 g**

# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

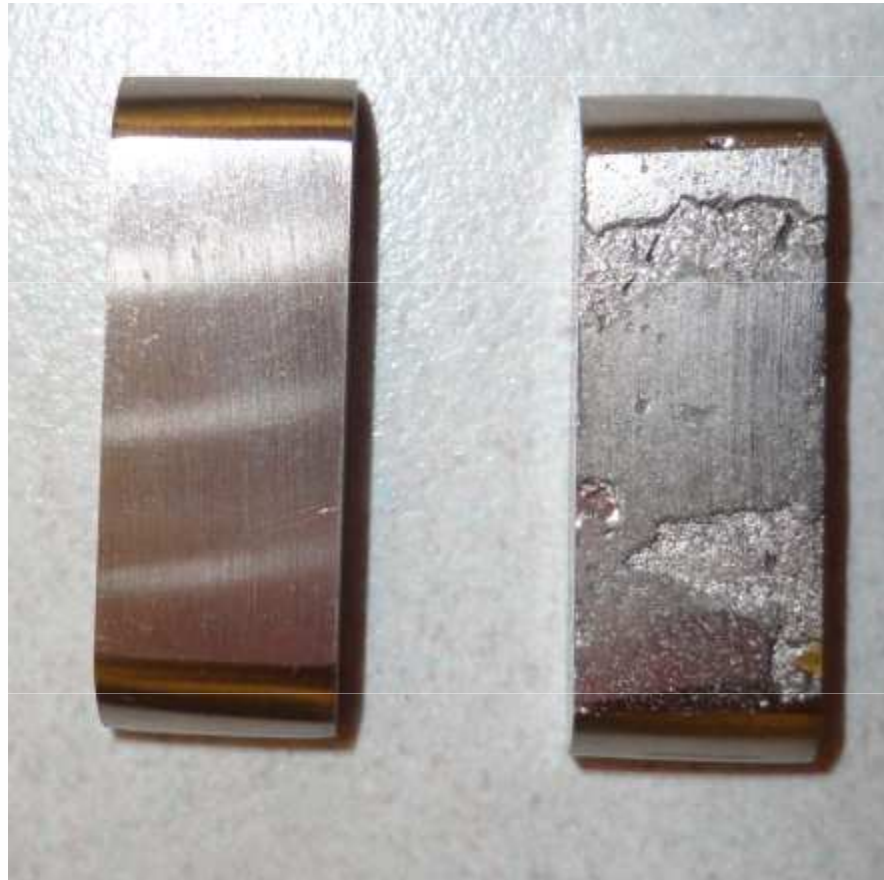
Ti64  
Uncoated

Vacuum: 44-50 mBar  
Speed: 8000 RPM  
Time: 40 minutes  
Nozzle size: 600 μm  
Nozzle distance: 30mm  
Flow Rate: 0.065-0.07 L/min

TiC-TiB<sub>2</sub>-TiAl<sub>3</sub>  
coating

Weight Loss:

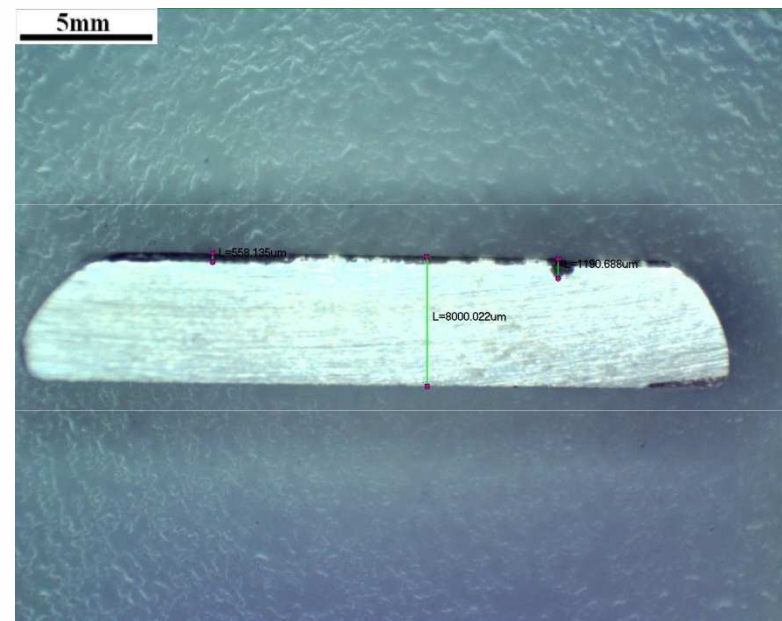
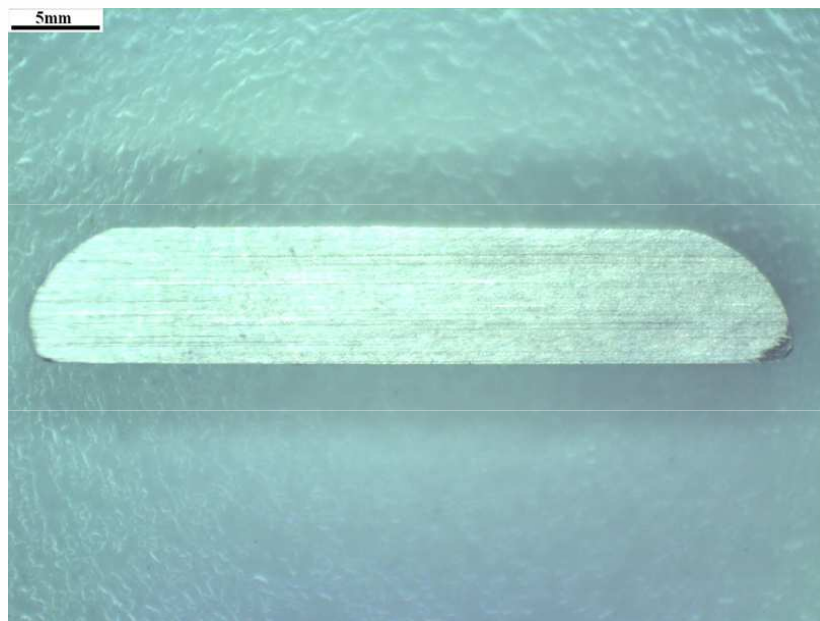
0.0005 g



Weight Loss:

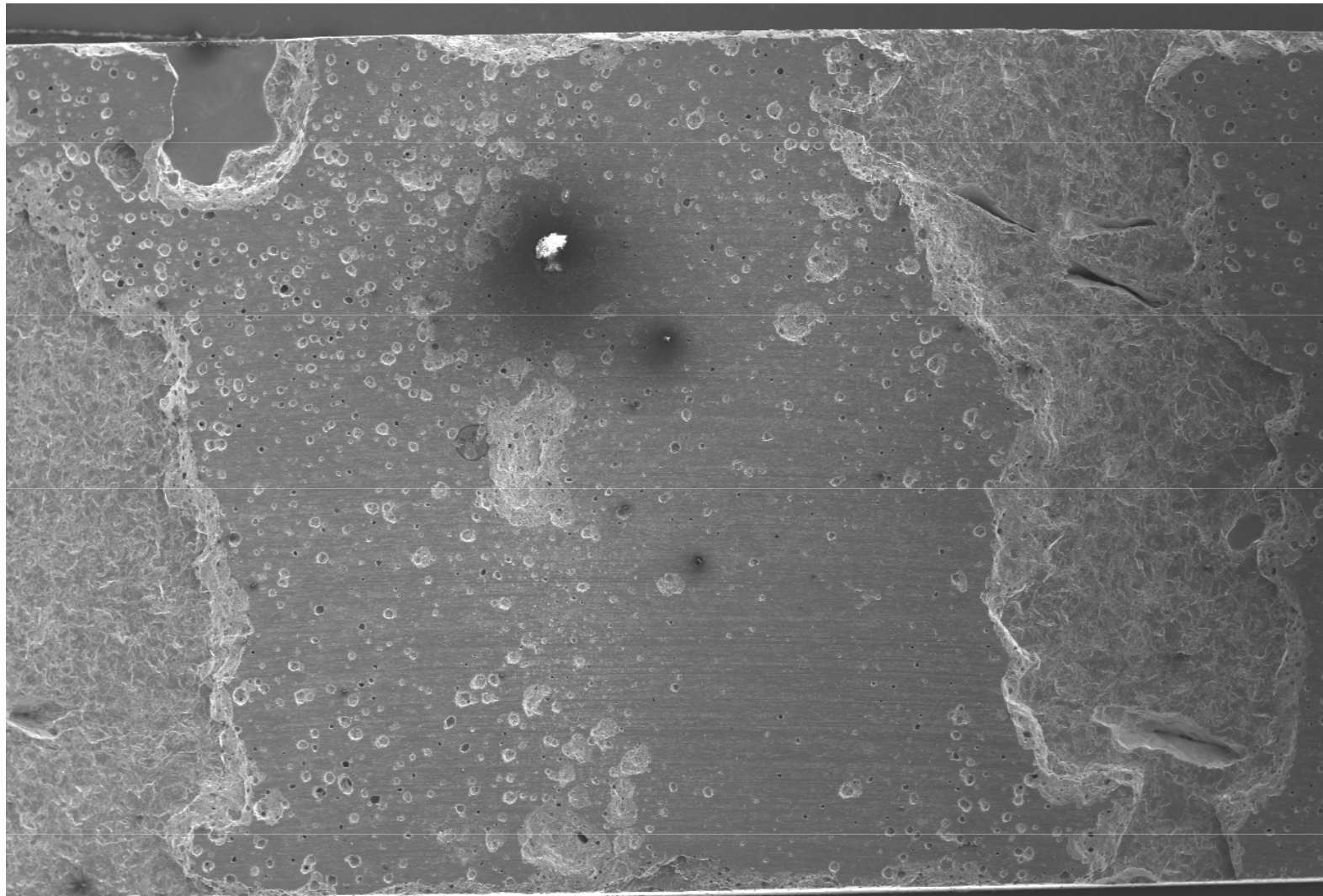
0.0358 g

# Profile of the edge of eroded coupons



# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

Eroded Surface SEM – Low magnification

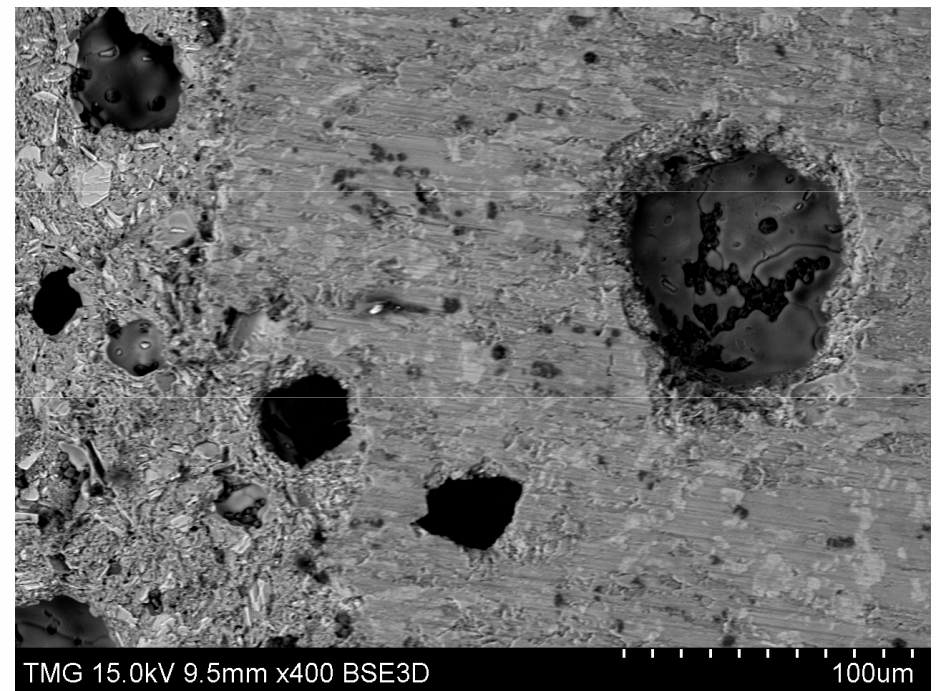
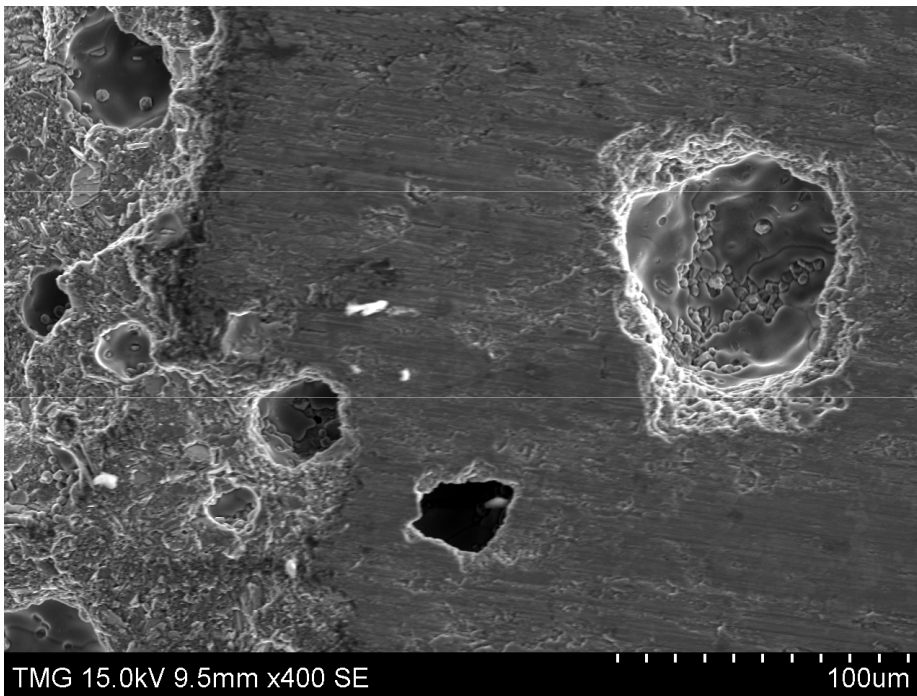


TMG 15.0kV 66.9mm x9 SE

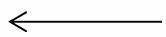
5.00mm

# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

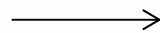
Edge of the stream – Original pores on the coating



**stream**

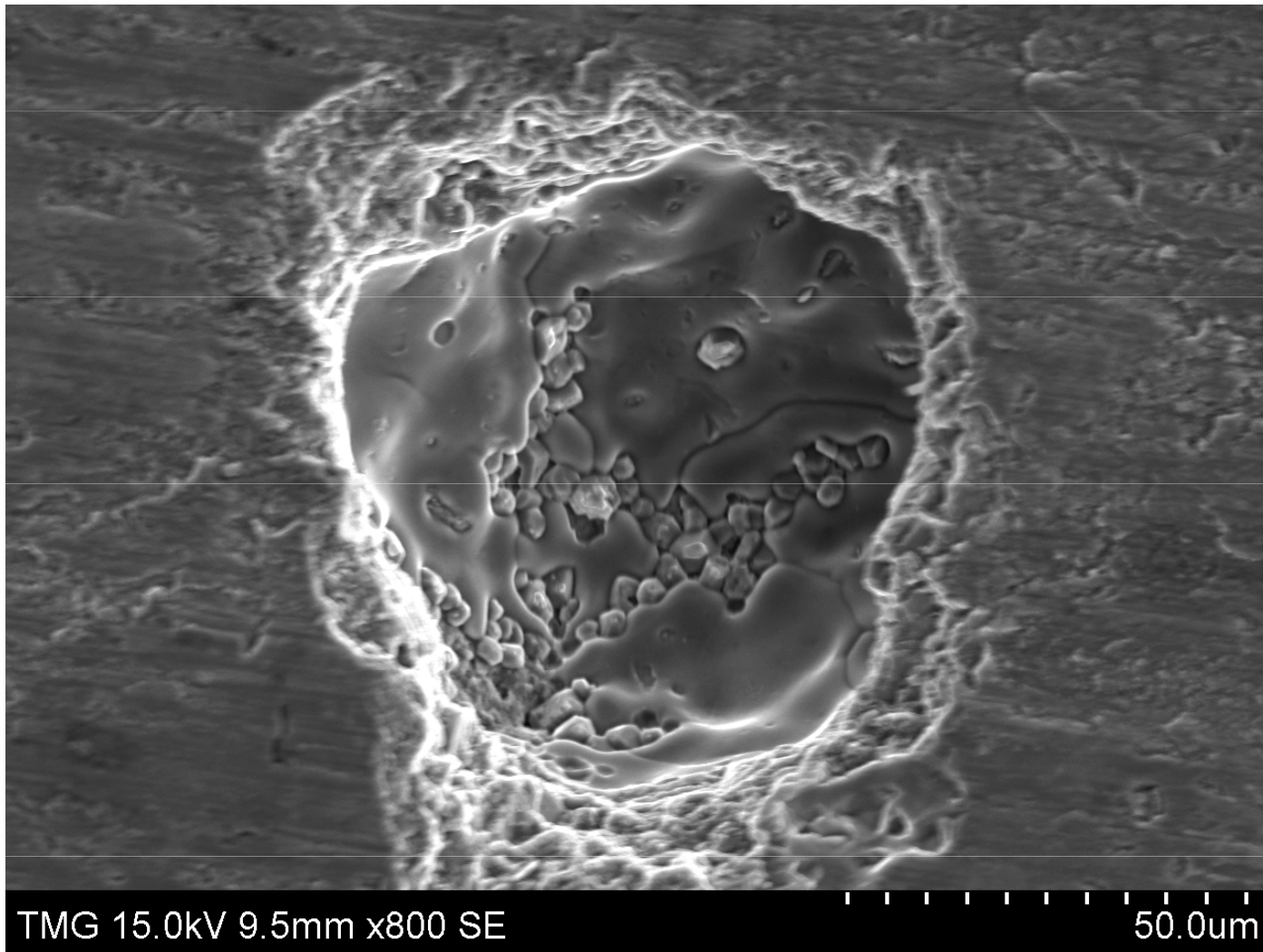


**Uneroded**



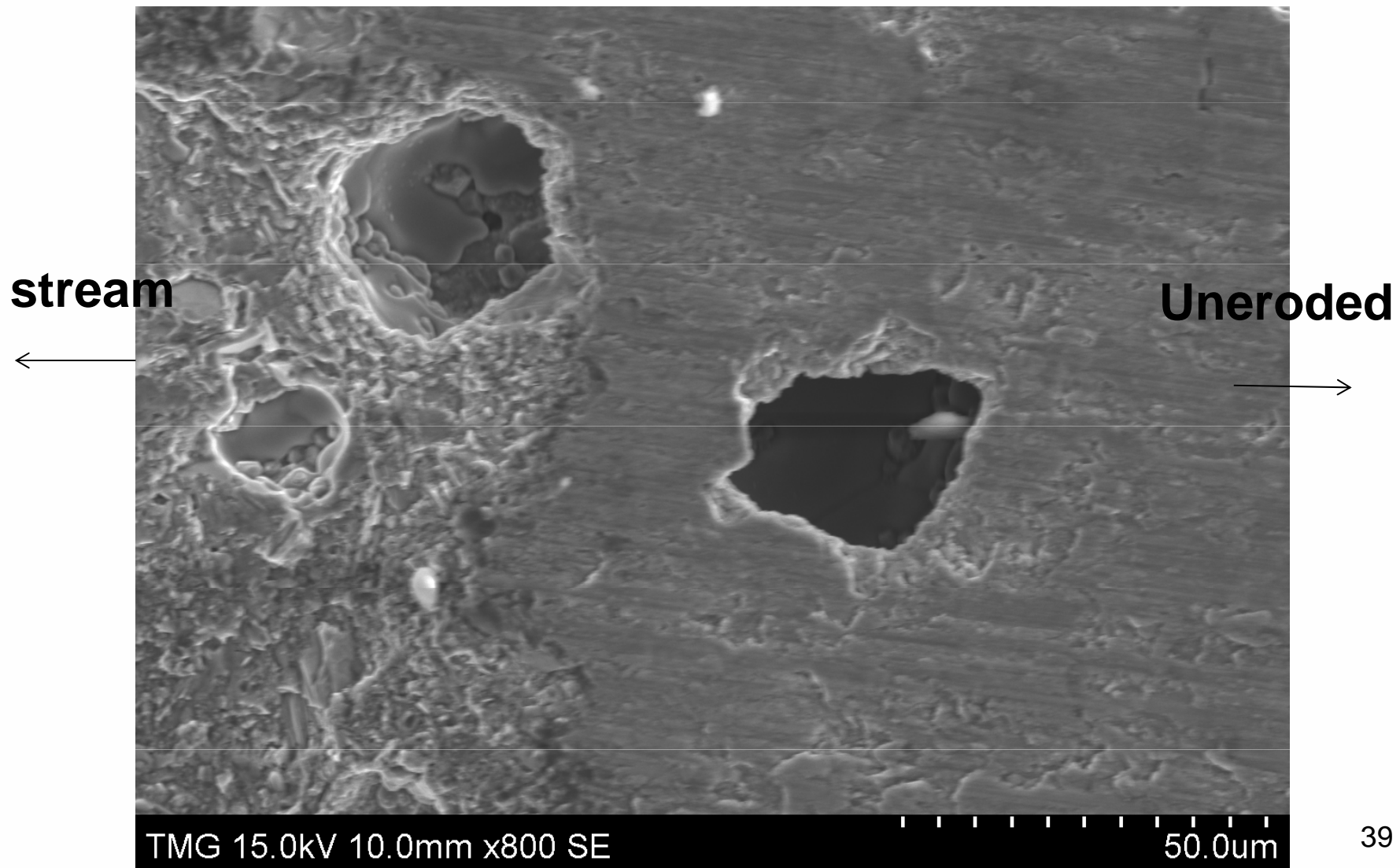
# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

Edge of the stream – Original pores on the coating



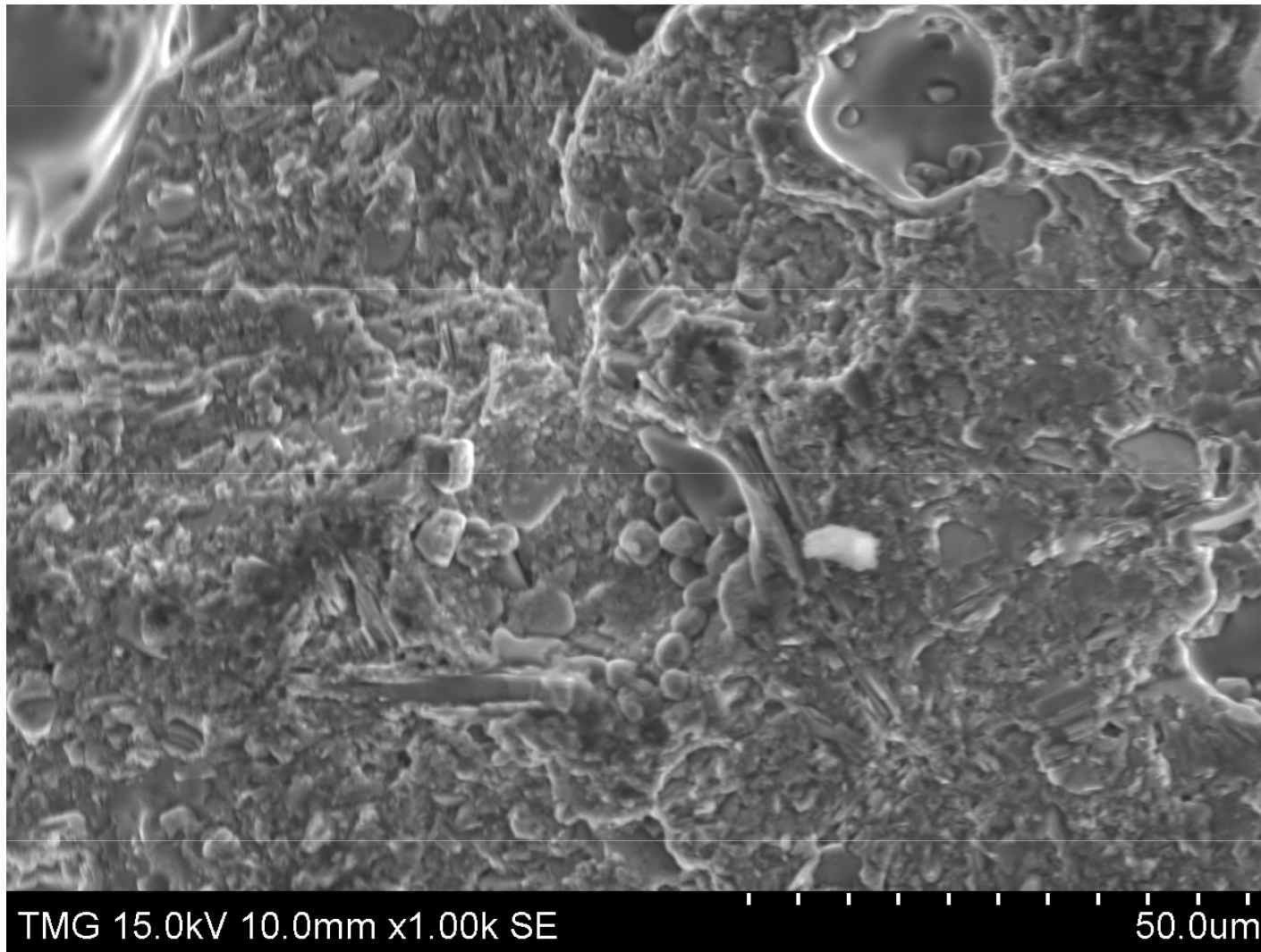
# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

Edge of the stream – Erosion of the coating



# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

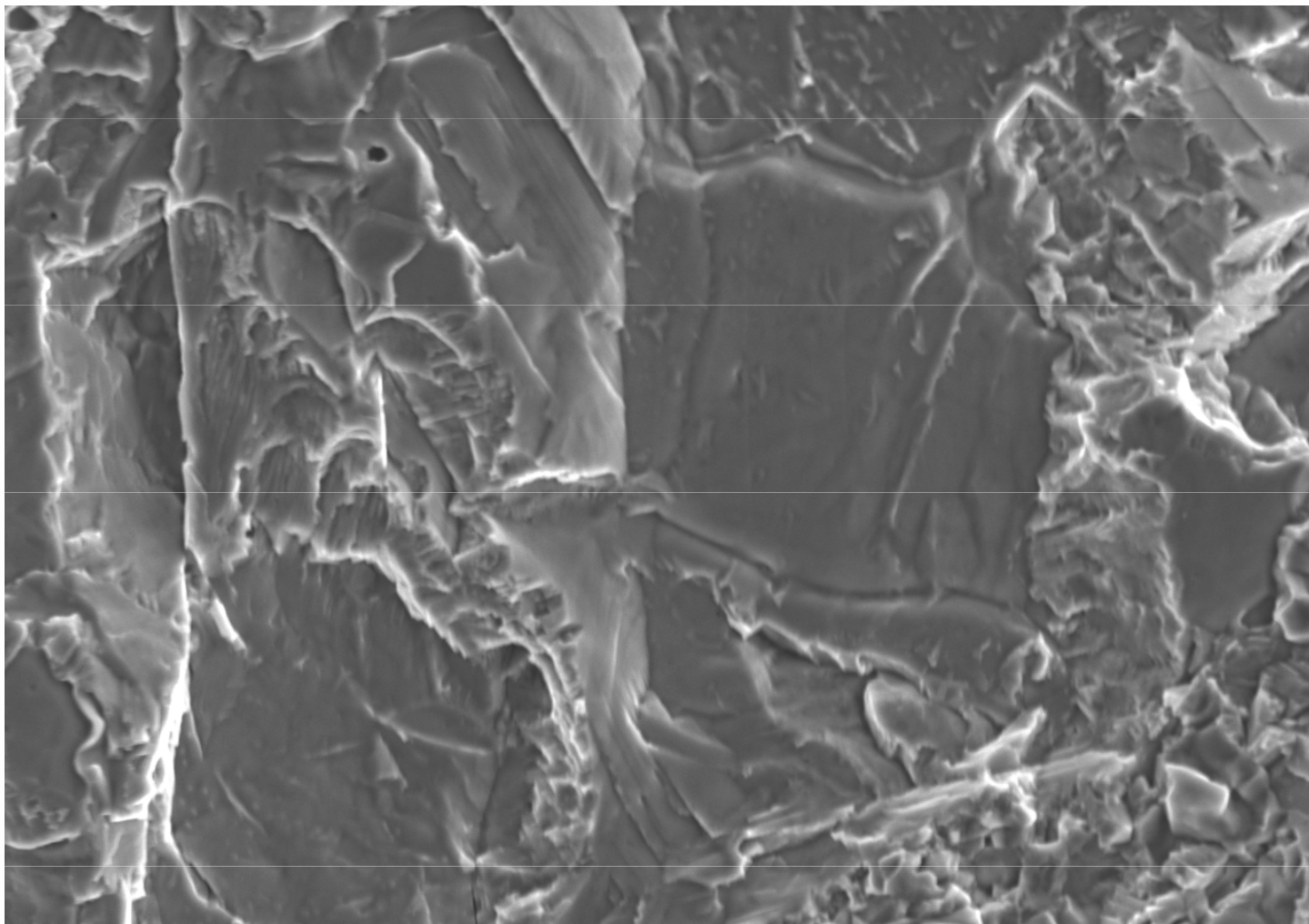
Edge of the stream – Erosion of the coating





# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

Center of the stream – Erosion of the substrate

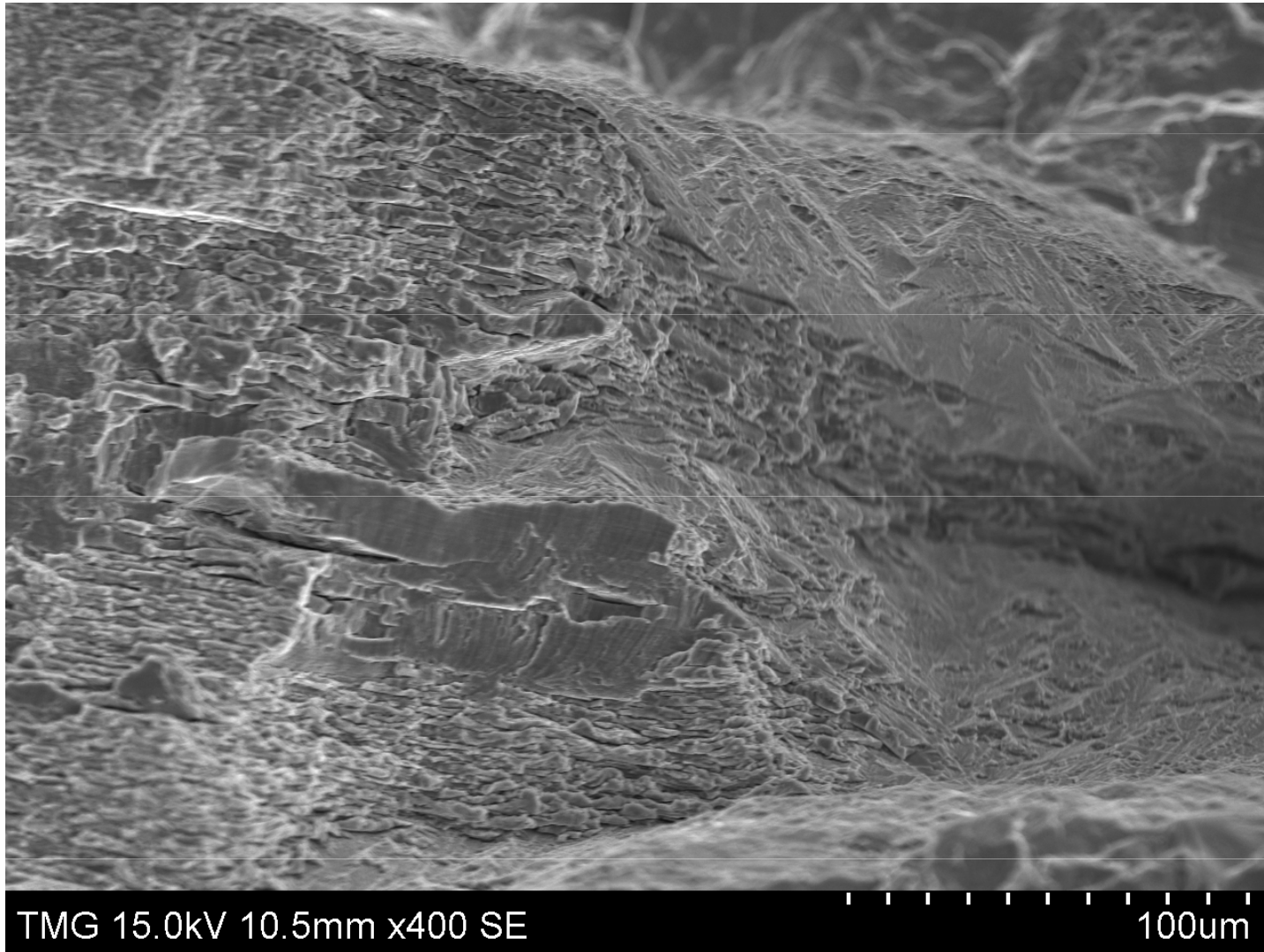


TMG 15.0kV 10.3mm x1.00k SE

50.0um

# TiC-TiB<sub>2</sub>/TiAl<sub>3</sub> In-situ Coatings

Center of the stream – Erosion of the substrate

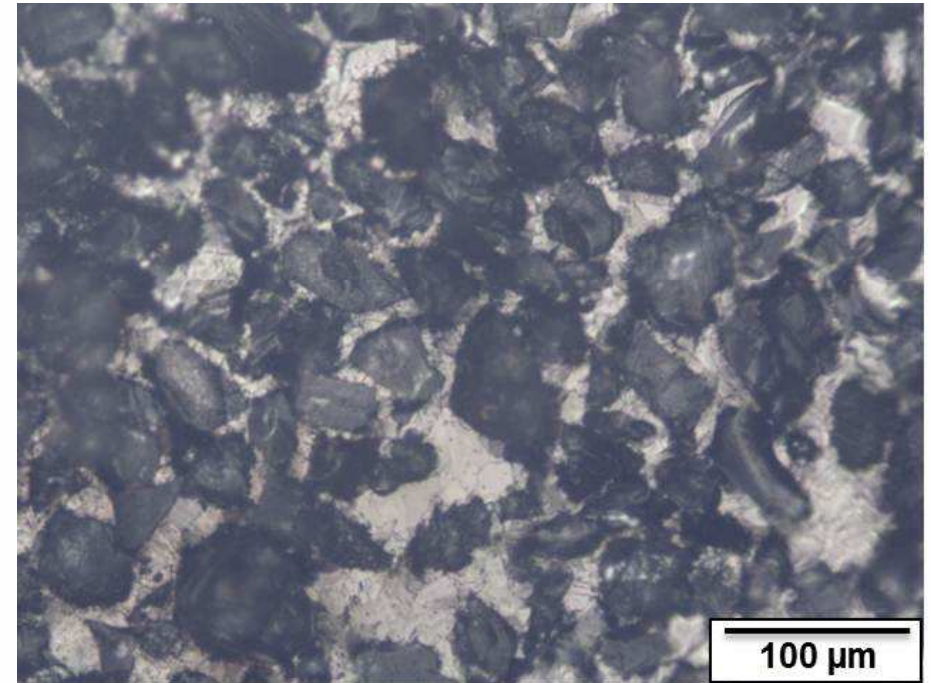
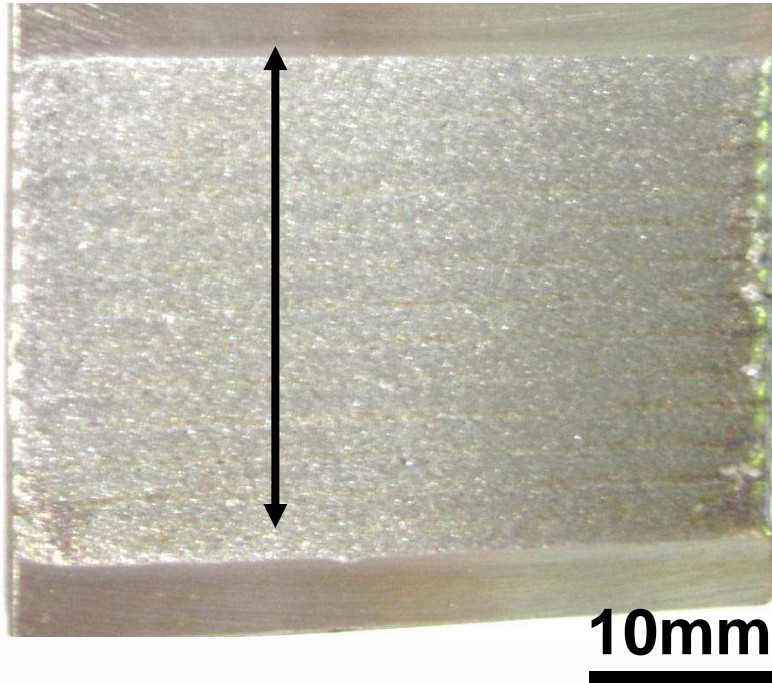




## Part IV

# Erosion Testing of $\text{Al}_2\text{O}_3$ Laser Cladding Coatings

# $\text{Al}_2\text{O}_3$ Laser Cladding Coating



**cladding surface**

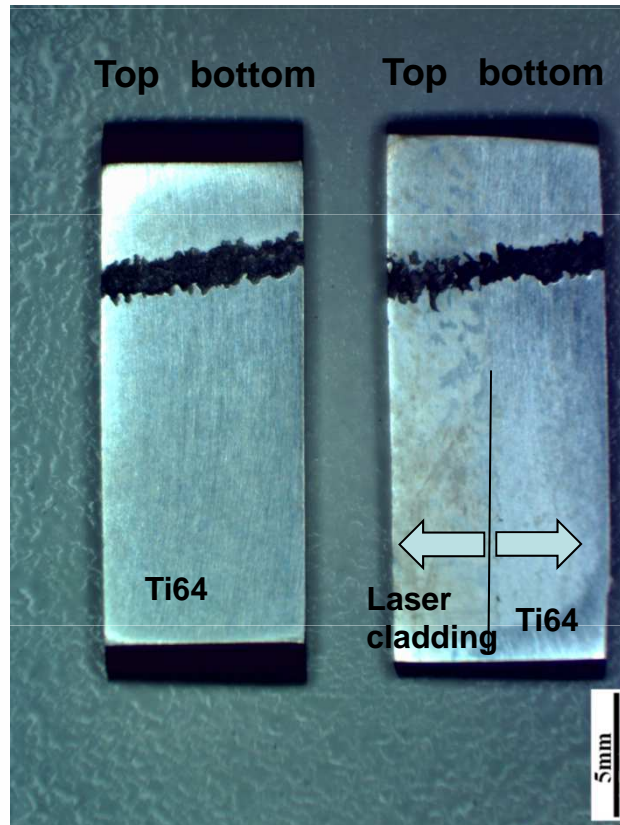
*by Thuan*

# Al<sub>2</sub>O<sub>3</sub> Laser Cladding Coating

Vacuum: 18-40 mBar  
Speed: 14000 RPM  
Time: 6 minutes  
Nozzle size: 400 μm  
Flow Rate: 0.03 L/min

Ti64  
Uncoated

Weight Loss:  
0.0135 g



TiC-TiB<sub>2</sub>-TiAl<sub>3</sub>  
coating

Weight Loss:  
0.0095 g

70% weight loss

41%



**Thank you!**

**Questions?**