Investigation of materials performances in high moisture environments including corrosive contaminants typical of those arising by using alternative fuels in gas turbines

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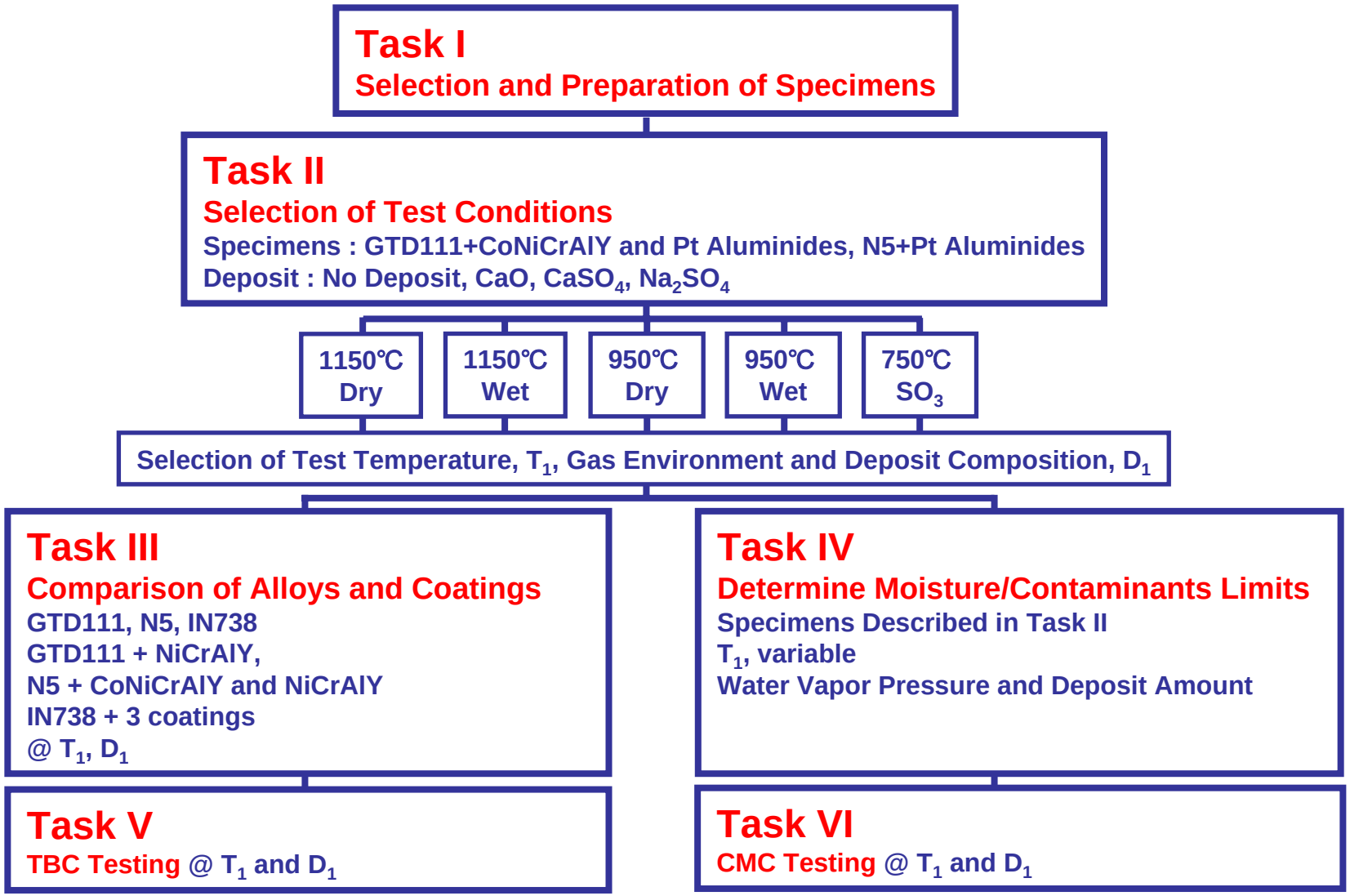
Project Approach

Schematic Flow Diagram for the Present Project



Program Objectives

1. Develop a fundamental understanding of the degradation process in moisture environments and in such environments where the specimens have deposits which are typical of deposits that will be encountered from the use of alternate fuels.

2. Attempt to describe how moisture/contaminant levels and temperature affect the corrosion processes.

3. Determine the alloy compositions and coatings that are most resistant to corrosion induced by deposits from alternative fuels.

4. Compare and describe the failure mechanisms of state-of-art TBCs (Thermal Barrier Coatings) operating with conventional fuels and with alternative fuels.

5. Compare the degradation of a CMC(Ceramic Matrix Composite) under conditions typical of gas turbines using conventional fuels and environments containing water vapor and contaminants representative of turbines using alternate fuels.

Summary of Key Results

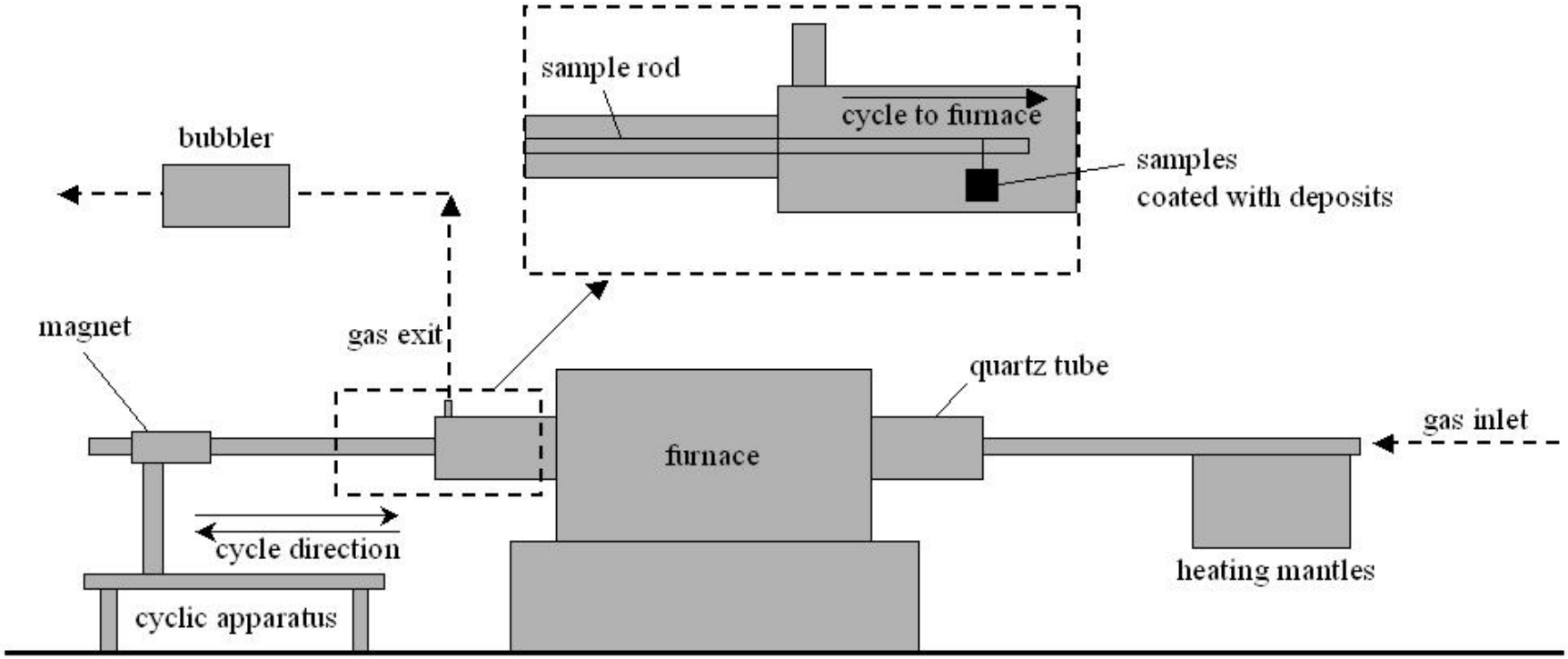
Obtained to date (First Year) for Platinum Aluminide Coatings on Rene′ N5

1. Deposits from gas turbine burning syngas have been analyzed.
   - Deposits of Fe_2O_3 with traces of Ca and S were determined.
   - Substantial erosion was observed.

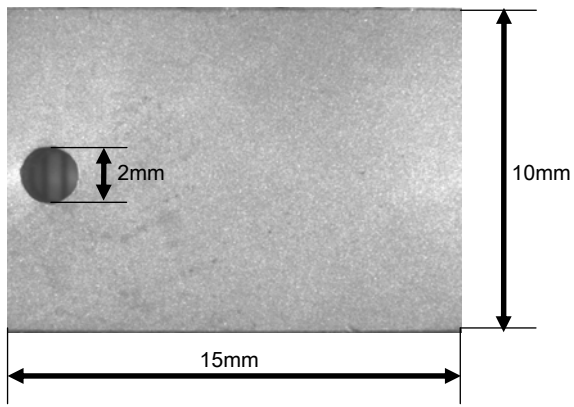
2. Cyclic oxidation test have been performed with deposits of Na_2SO_4, CaO and $CaSO_4$ at 750℃, 950℃ and 1150℃ in dry and wet air.
   - At 750℃, severe attack (low temperature hot corrosion) was induced by Na_2SO_4 deposits.
   - At 750℃, CaO and $CaSO_4$ deposits did not cause substantial degradation.
   - At 950℃, CaO deposits caused more severe degradation than Na_2SO_4 and $CaSO_4$ deposits.
   - This attack induced by CaO was more severe in wet compared to dry air.
   - The CaO deposits also caused more severe degradation compared to Na_2SO_4 and $CaSO_4$ deposits at 1150℃.

3. The mechanism by which CaO cause increased degradation has not been determined as yet. Less attack by Na_2SO_4 above 900℃ is probably being caused by evaporation.

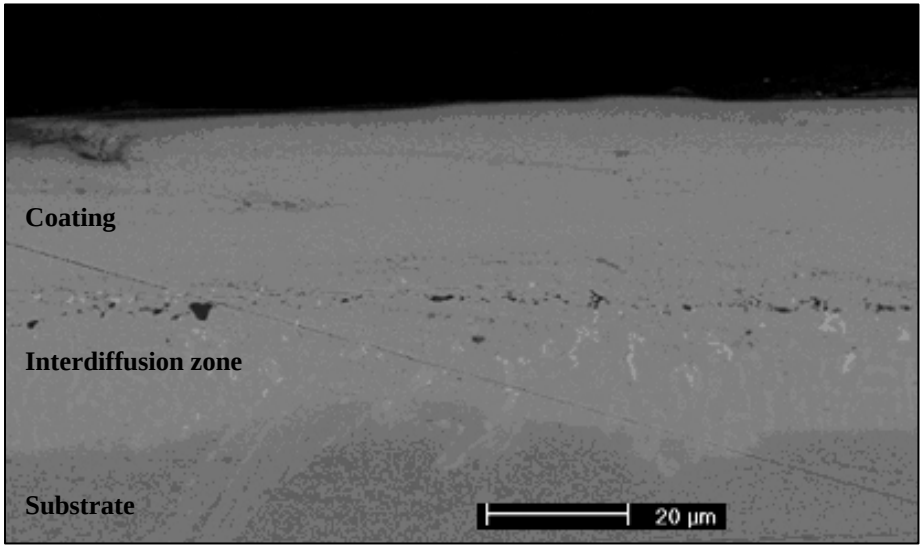
Experimental



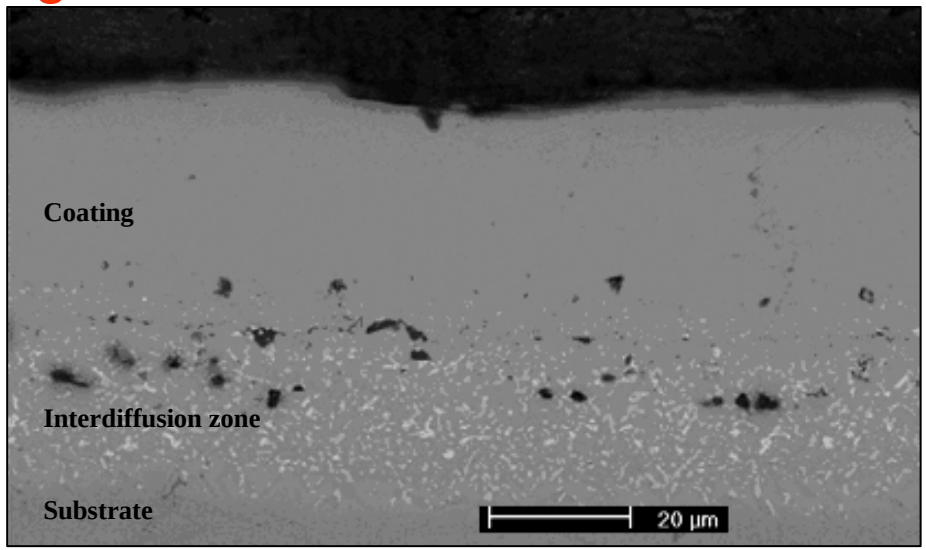
- Coupon Specimens (15×10×4mm with a 2mm-φ hole)
- Grit-blasted at 30psi for 45 minutes
- 1~2mg/cm^2 Na_2SO_4, CaO, $CaSO_4$ applied every 20 hrs
- Weight change measurements every 20hrs
  after washing off deposits
- Dry air : -46℃ dew point
- Wet air : P_{H2O}= 0.1atm
- 45 minutes hot zone/15 minutes cool zone cyclic test



As coated Platinum Aluminide Coating

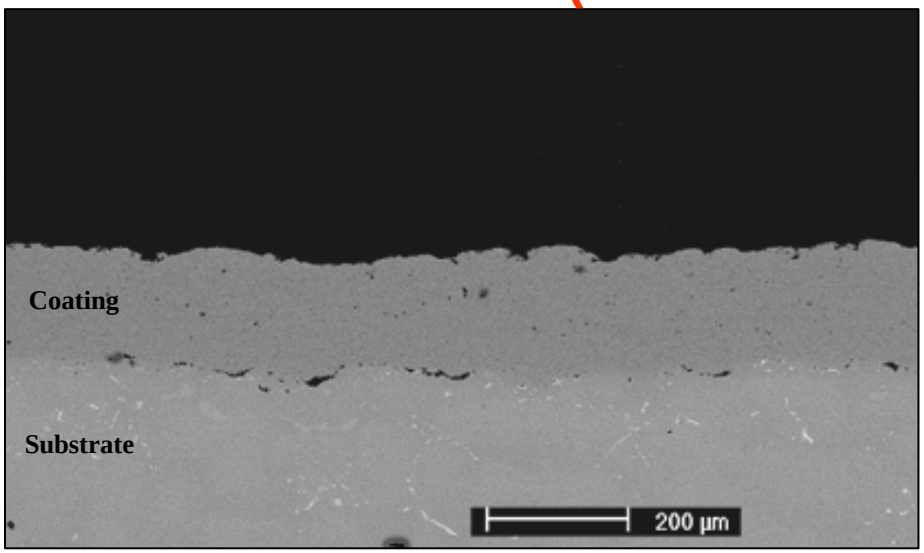


(a) On GTD111

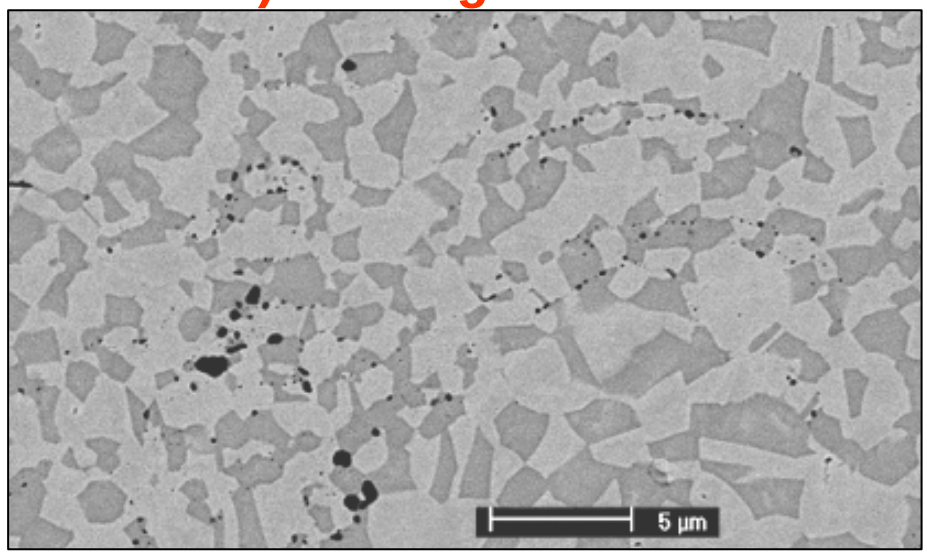


(b) On Rene′ N5

As coated CoNiCrAlY (Co-32Ni-22Cr-10Al-0.3Y) Coating



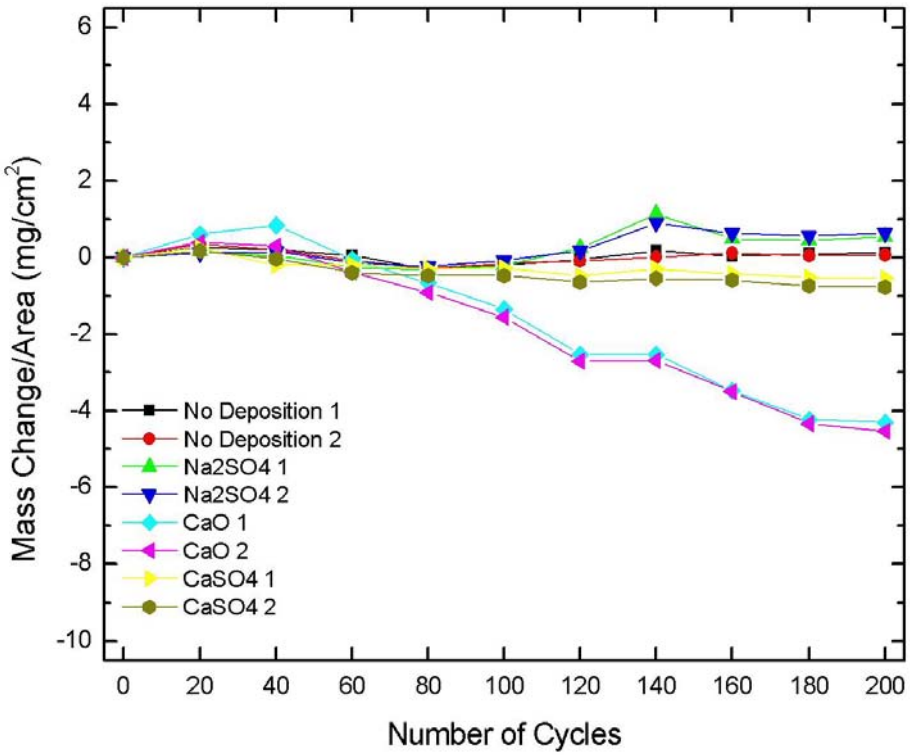
(a) On GTD111



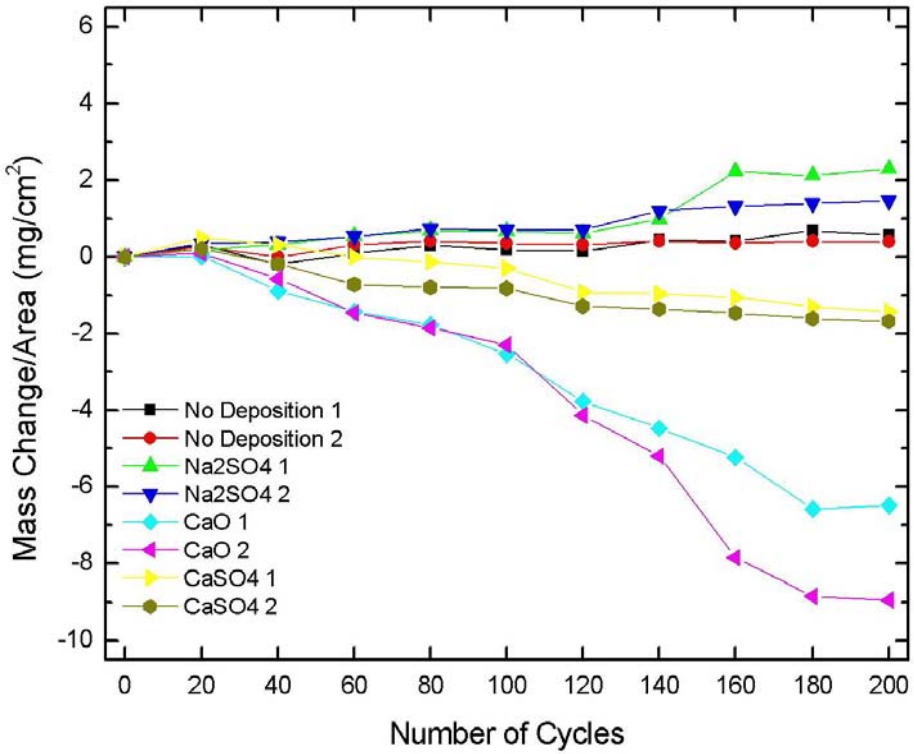
(b) Al-depleted α (bright), Al-rich β (dark) phase and Aluminum oxides (black particles)

Weight change versus time measurements

Rene′ N5 + Platinum Aluminide samples with different deposits cyclically exposed at 950℃ for 200 hours



(a) In wet air

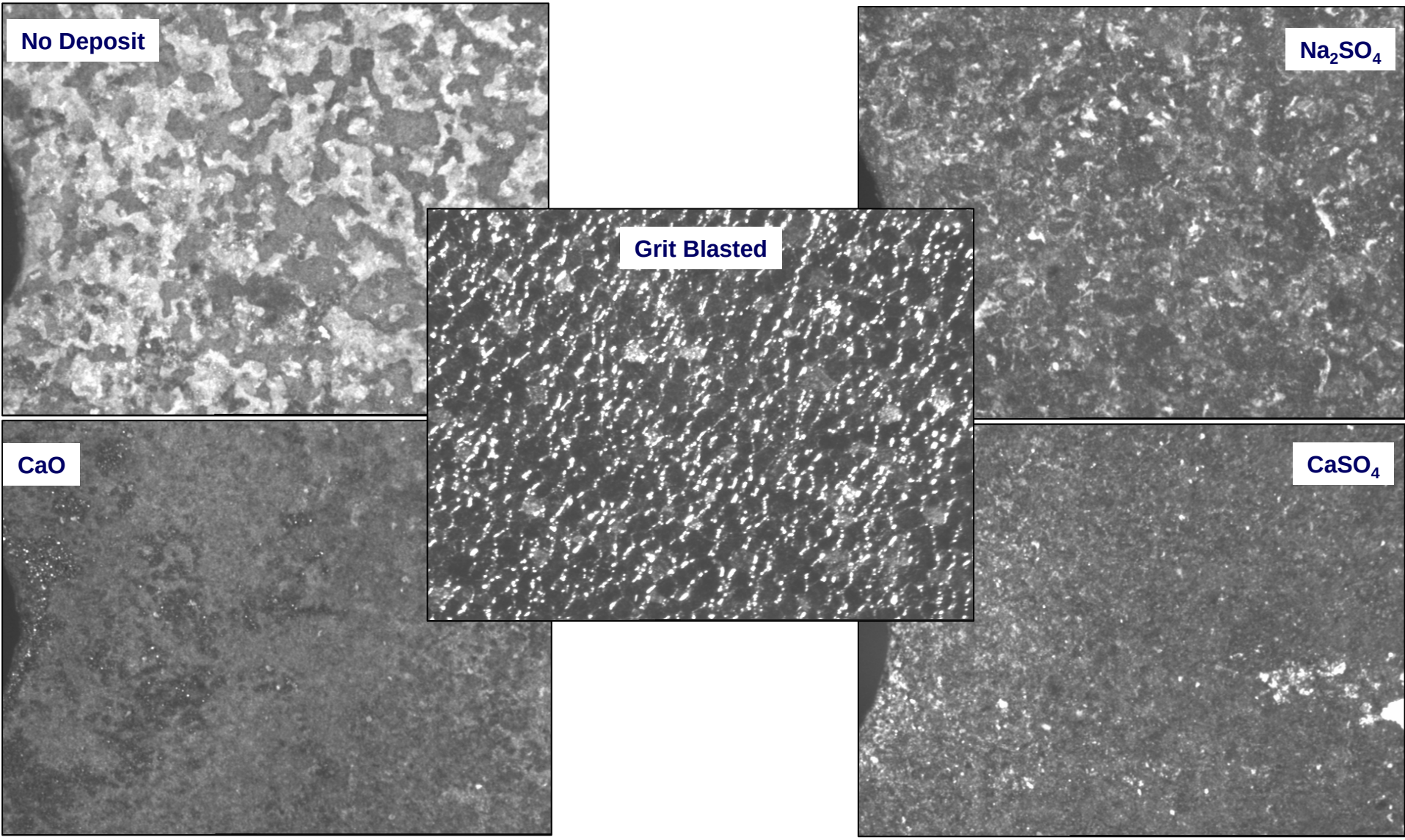


(b) In dry air

Substantially large weight losses for specimens with CaO deposits compared to Na_2SO_4 and $CaSO_4$ deposits as well as specimens with no deposits.

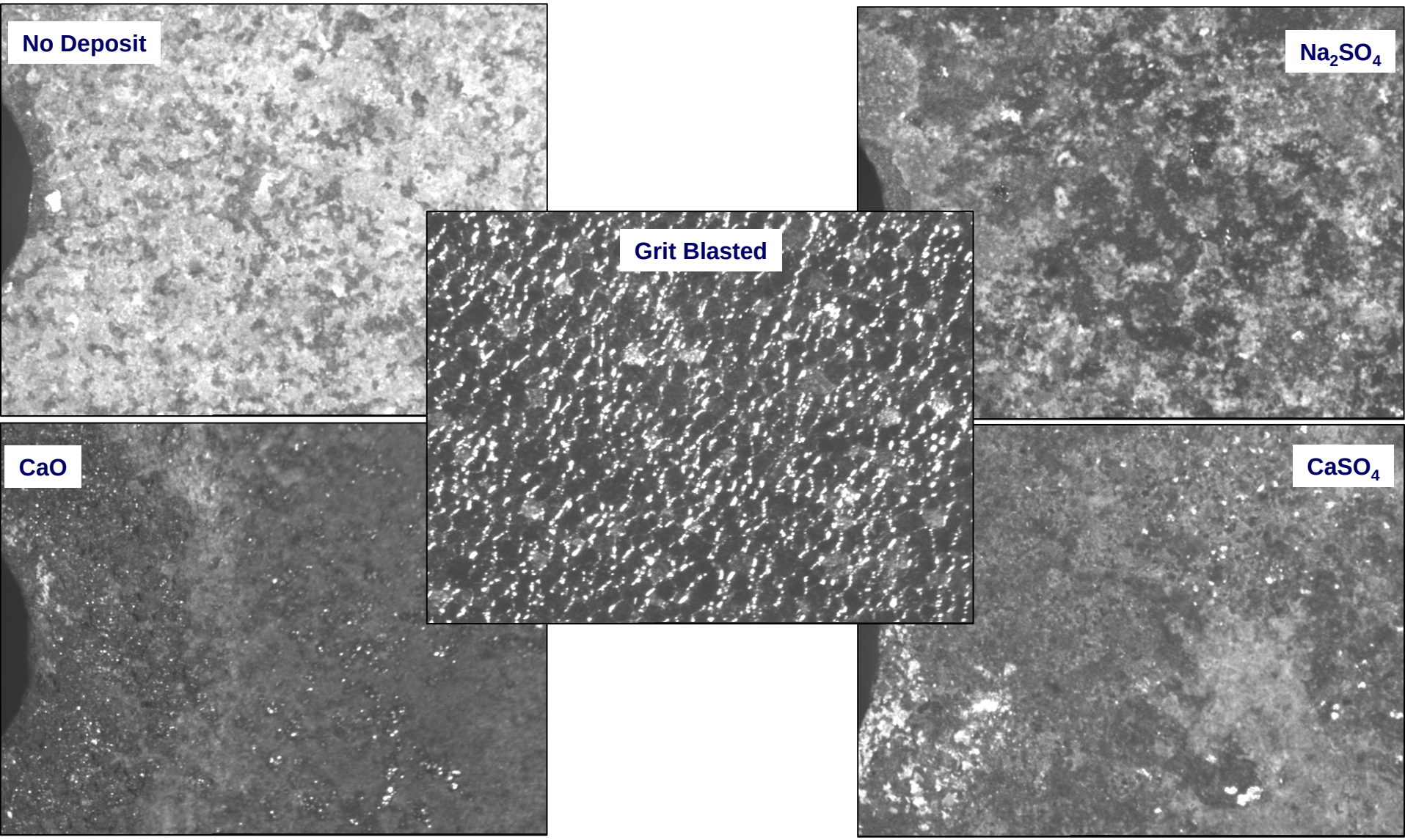
Stereographic Micrographs (50x)

N5 + Pt Aluminide at 950℃ under wet conditions after 200 cycles exposure



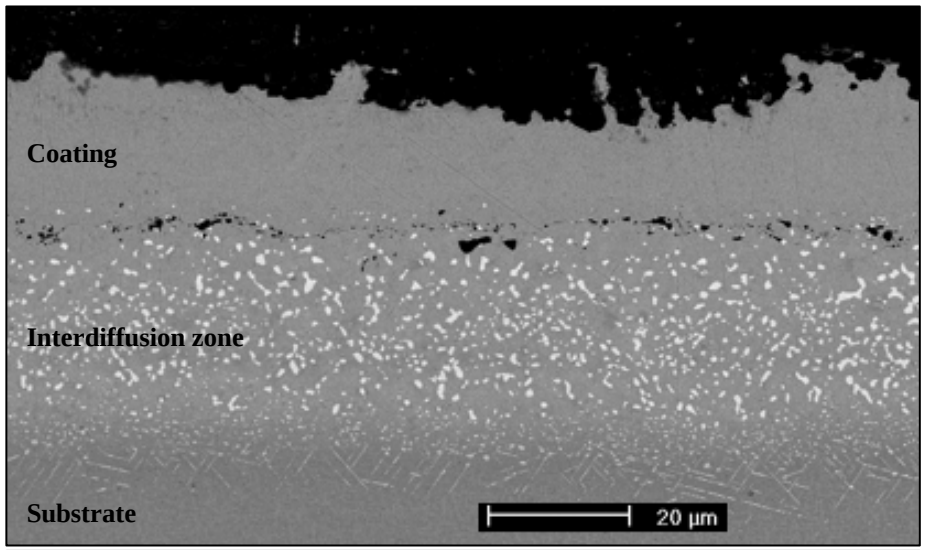
Stereographic Micrographs (50x)

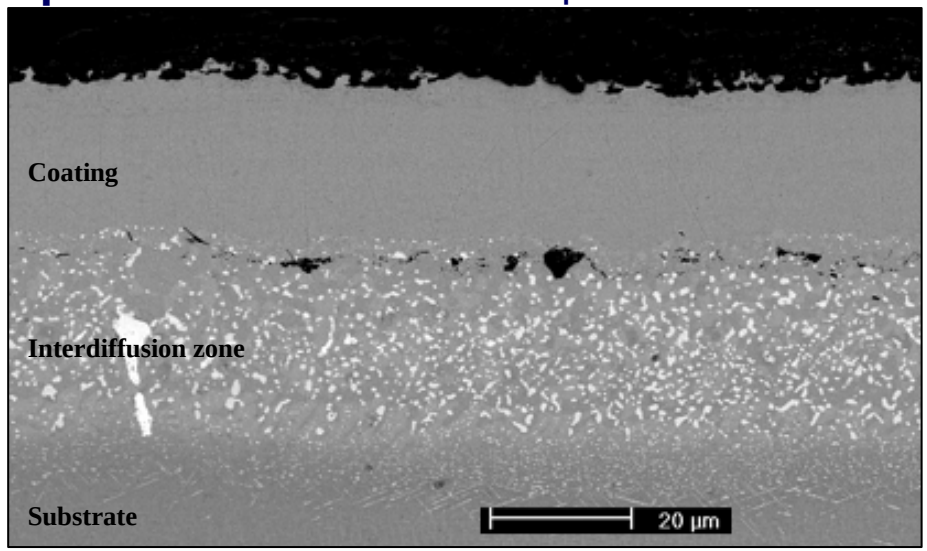
N5 + Pt Aluminide at 950℃ under dry conditions after 200 cycles exposure

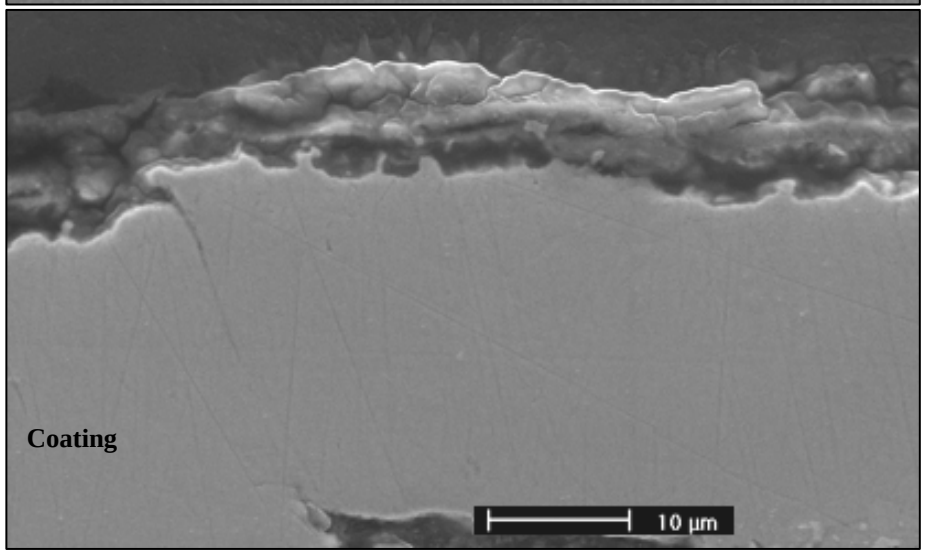


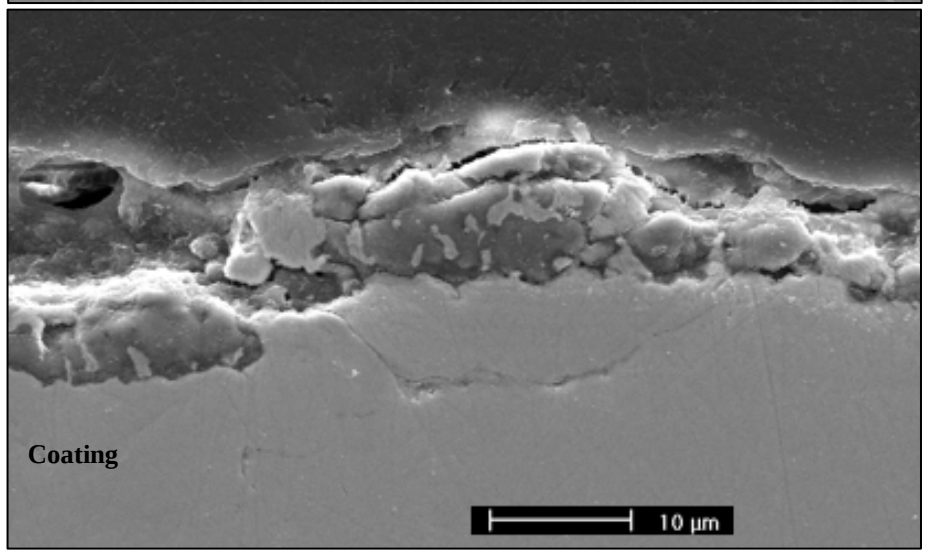
Scanning Electron Micrographs (Cross-section)

Rene′ N5 + Platinum Aluminide / 950°C / **No deposits** / after 200 hours exposure







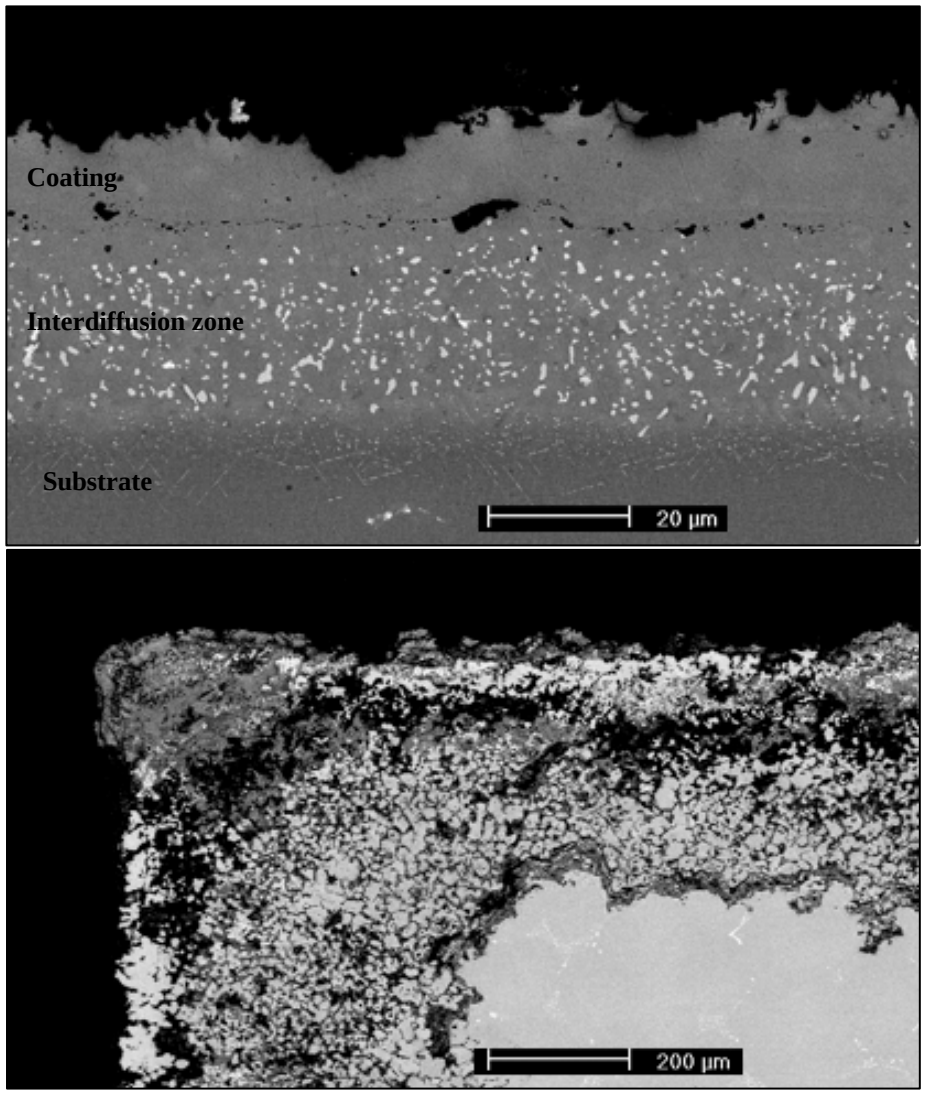


(a) In wet air

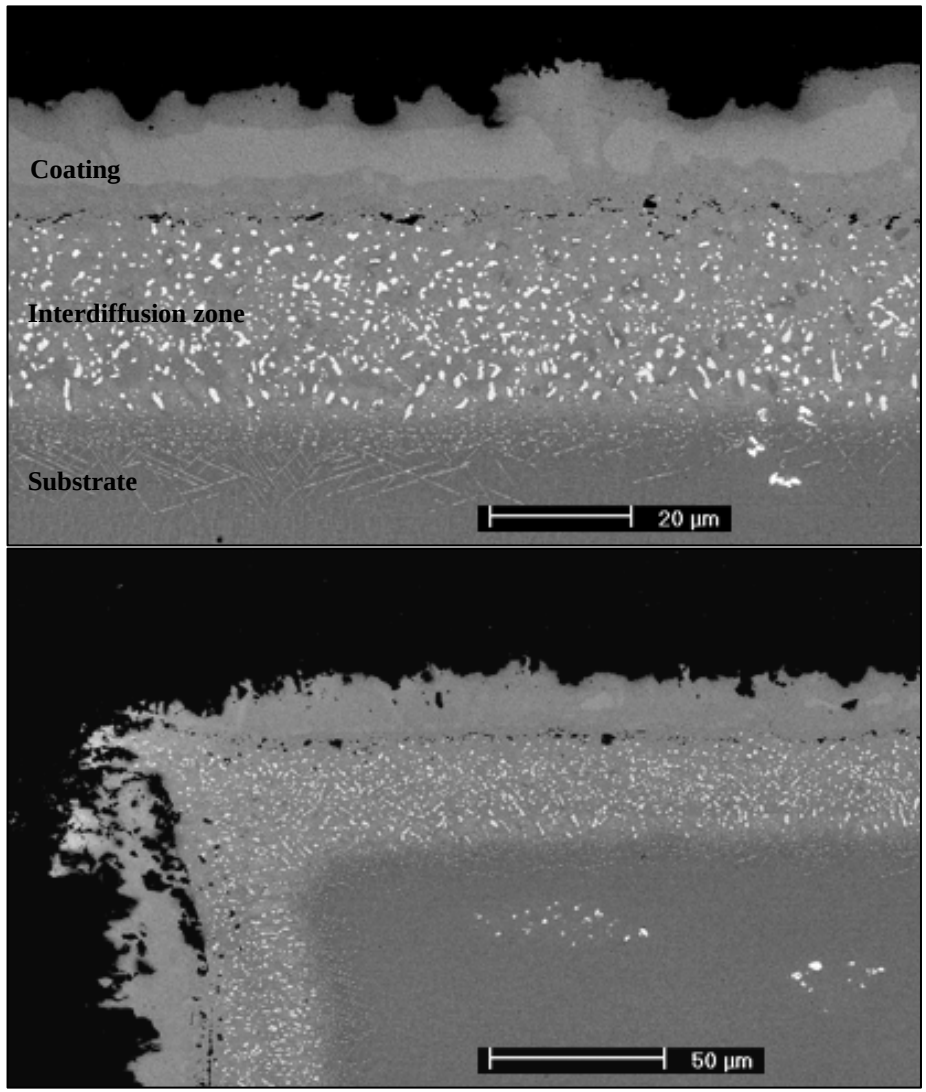
(b) In dry air

Scanning Electron Micrographs (Cross-section)

Rene′ N5 + Platinum Aluminide / 950°C / **CaO** / after 200 hours exposure



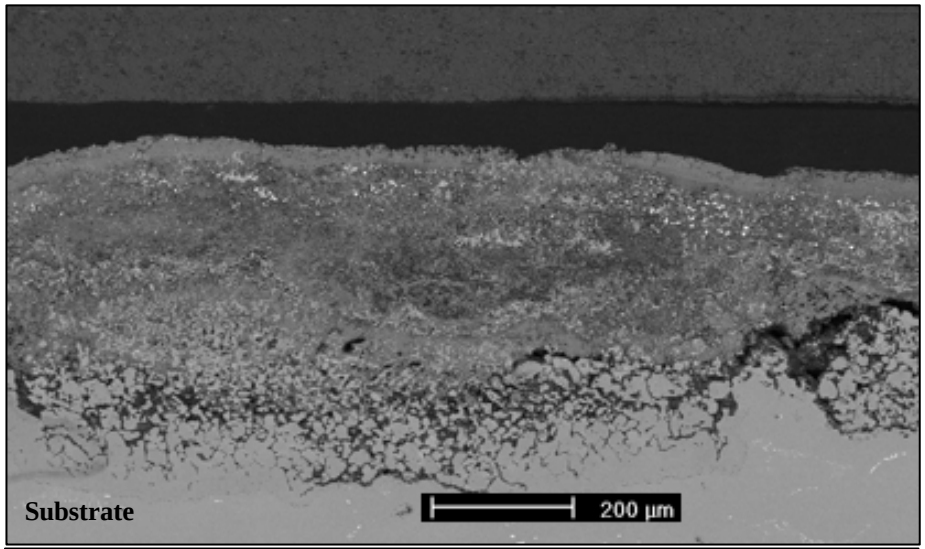
(a) In wet air

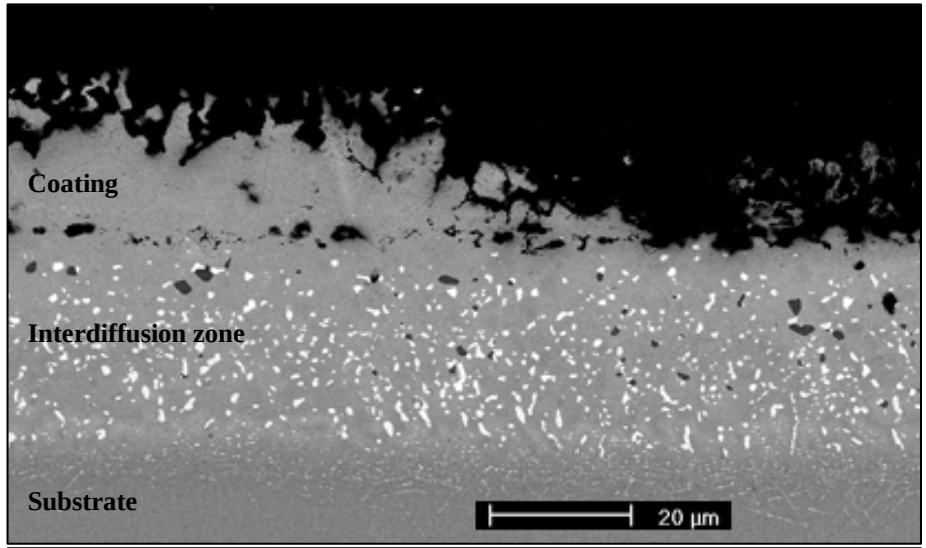


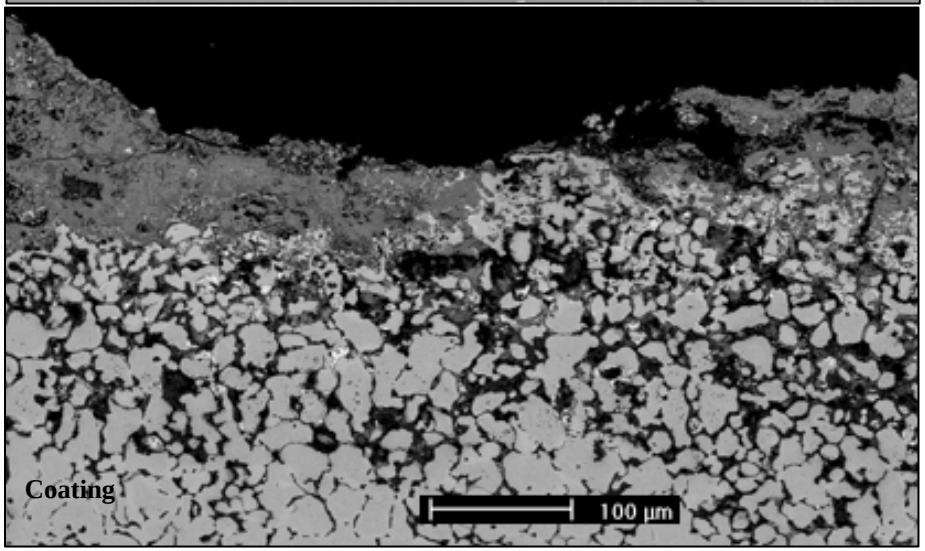
(b) In dry air

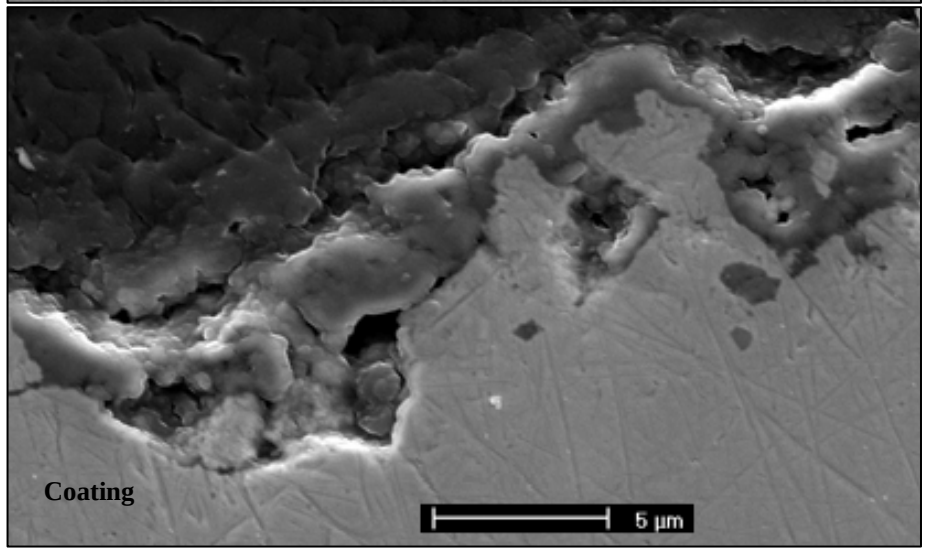
Scanning Electron Micrographs (Cross-section, cont'd)

Rene′ N5 + Platinum Aluminide / 950°C / **CaO** / after 200 hours exposure







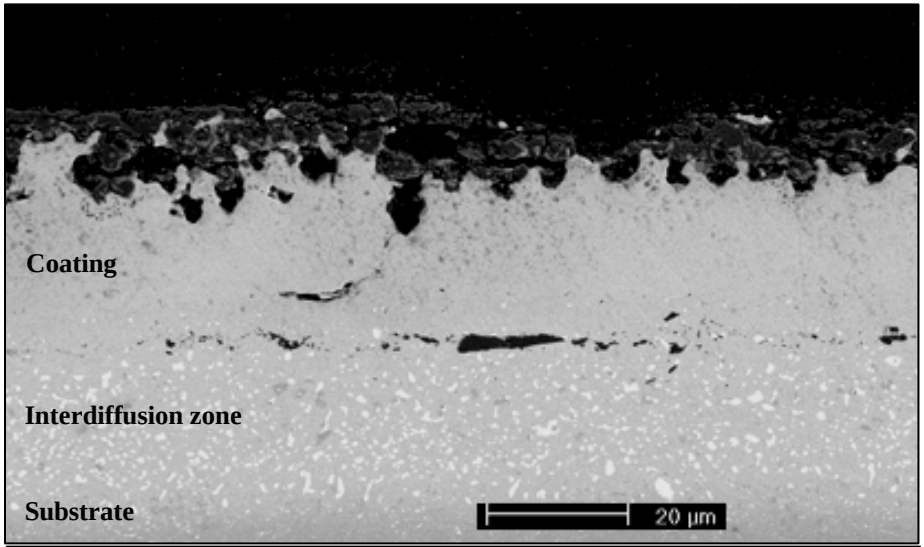


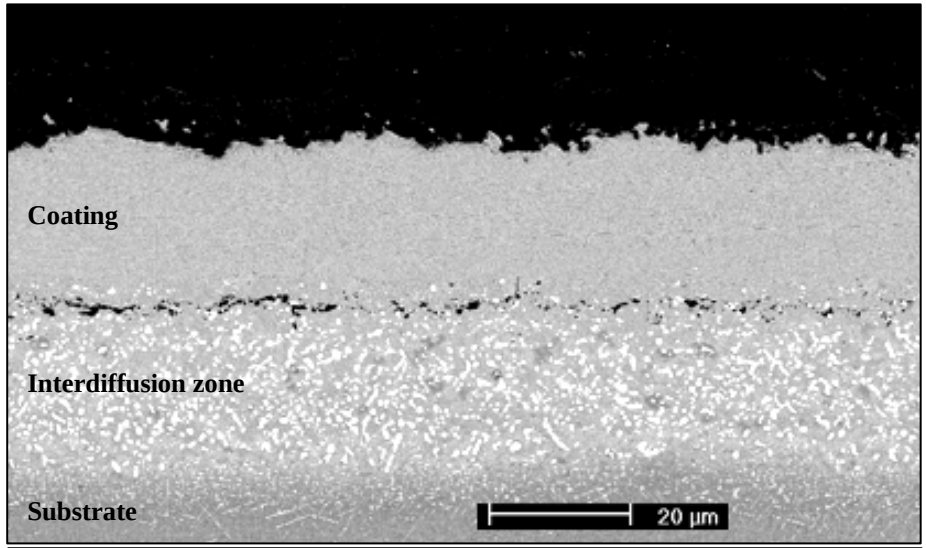
(a) In wet air

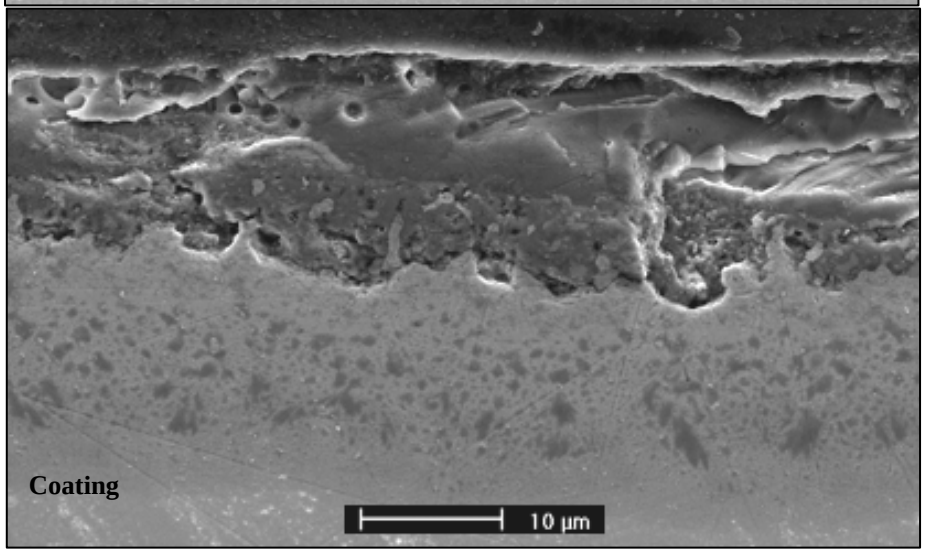
(b) In dry air

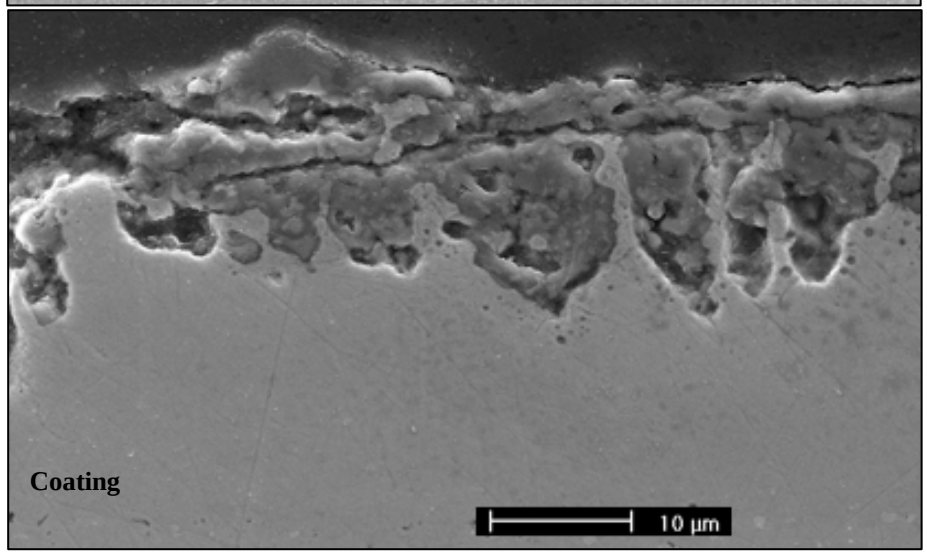
Scanning Electron Micrographs (Cross-section)

Rene′ N5 + Platinum Aluminide / 950℃ / Na_2SO_4 / after 200 hours exposure







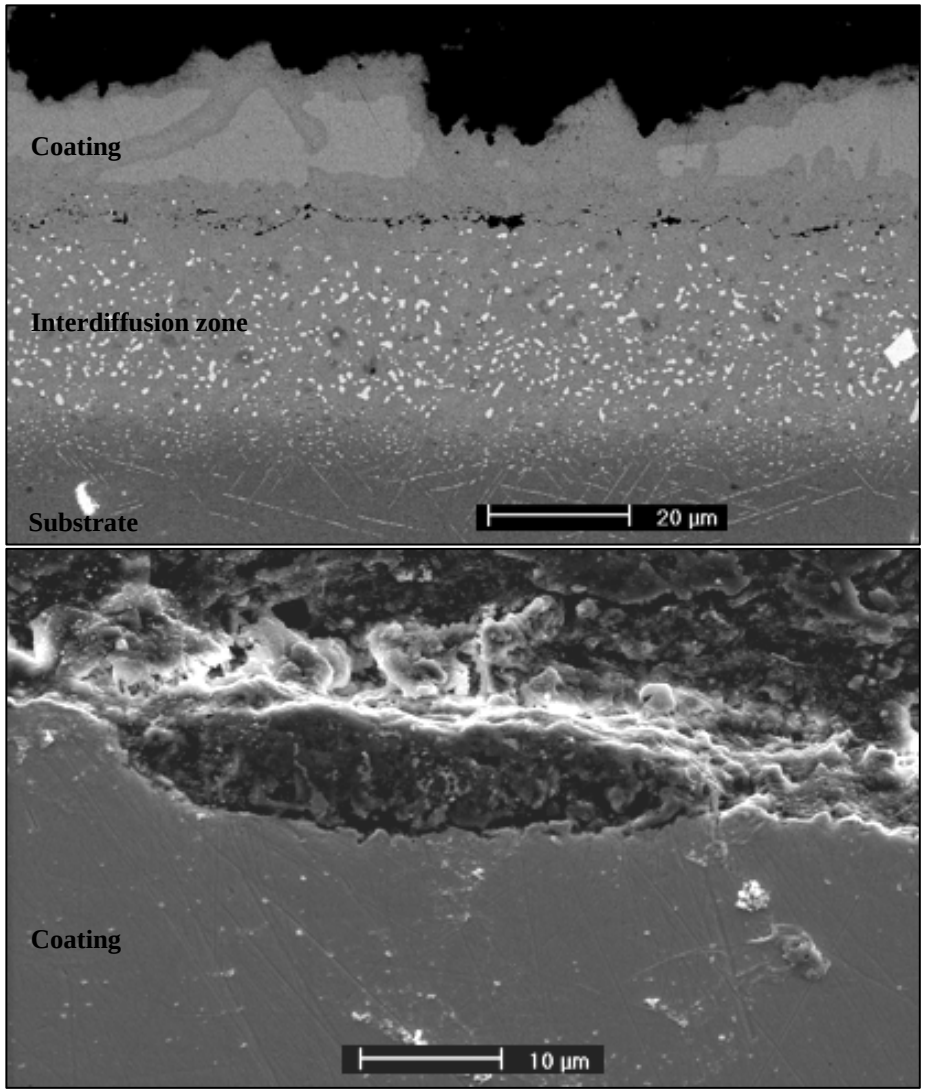


(a) In wet air

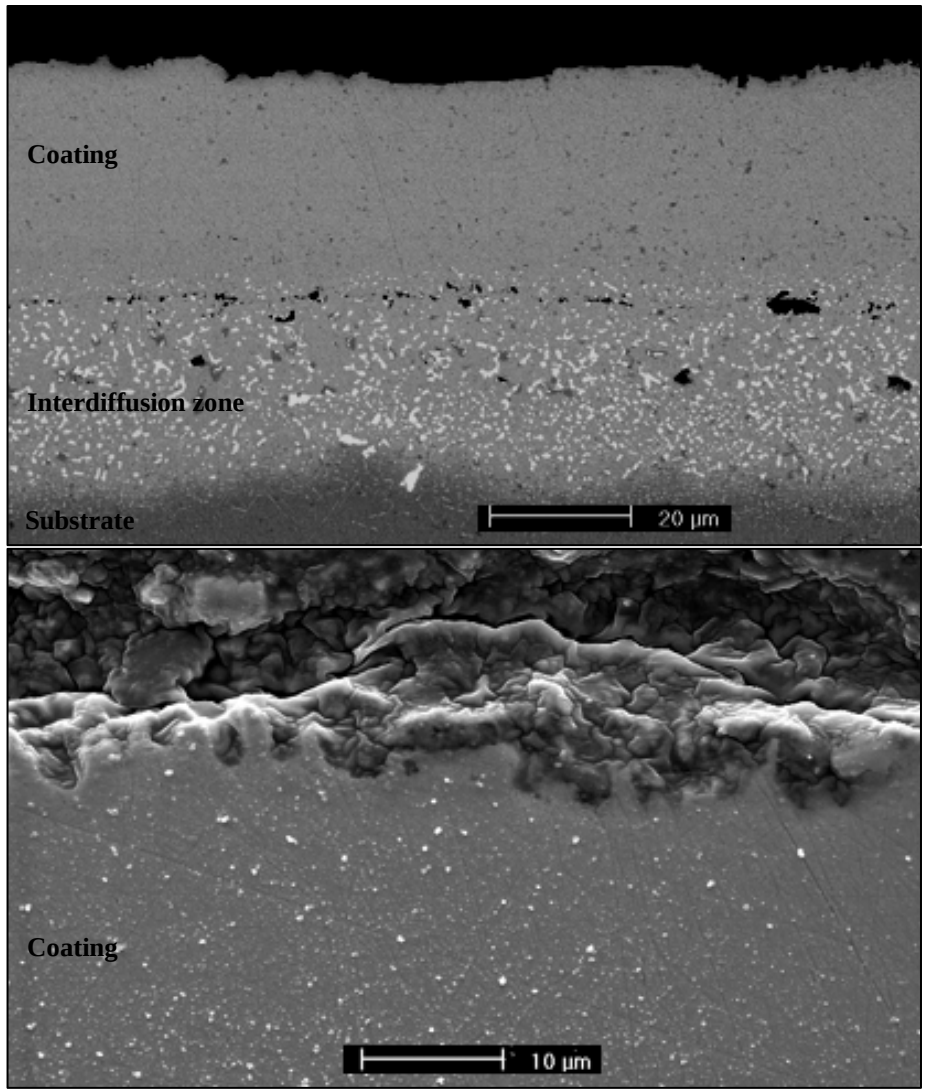
(b) In dry air

Scanning Electron Micrographs (Cross-section)

Rene′ N5 + Platinum Aluminide / 950℃ / **$CaSO_4$** / after 200 hours exposure



(a) In wet air



(b) In dry air

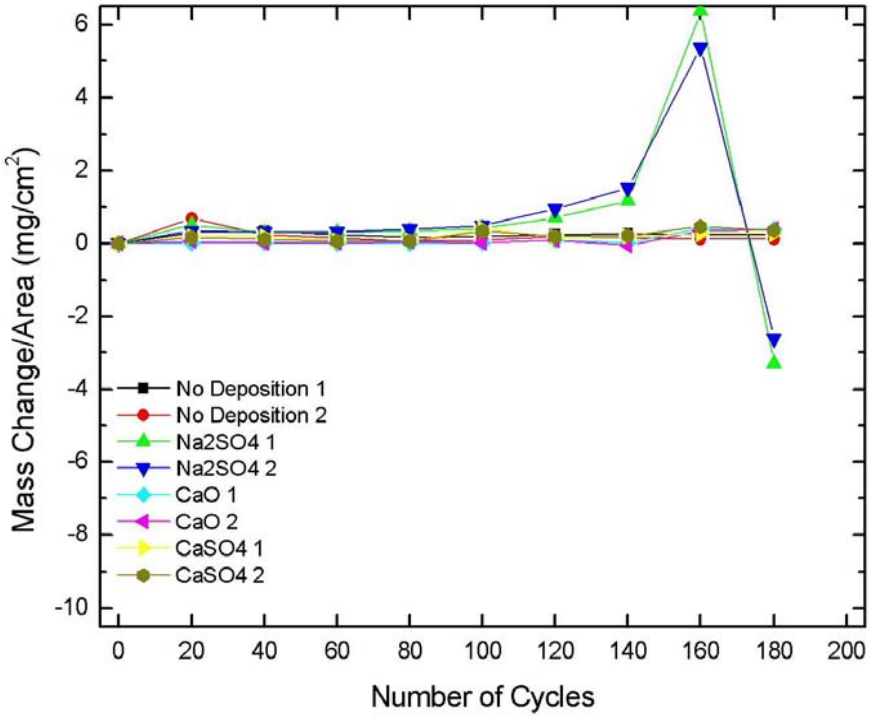
Summary of Results

For Platinum Aluminide coatings on Rene′ N5 at 950℃

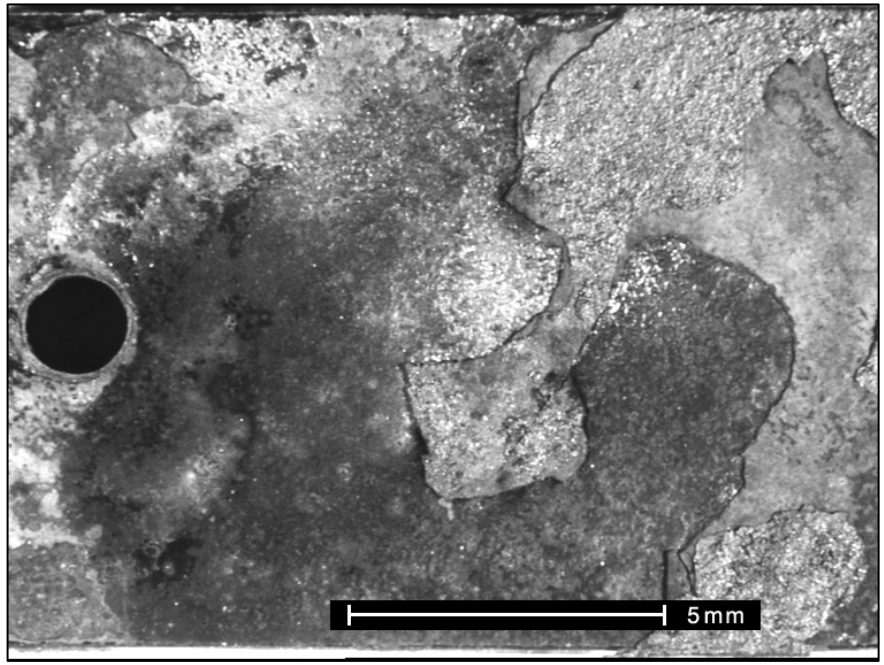
1. Substantial attack induced by deposits of CaO compared to other deposits.
2. Attack with all deposits was more severe in wet air.
3. In case of no deposits, significant amount of degradation in wet air.

Weight change versus Time measurements

Rene′ N5 + Platinum Aluminide samples with different deposits cyclically exposed at 750℃ in dry air with $P_{SO3} = 2.2\times10^{-4}$atm for 180 hours



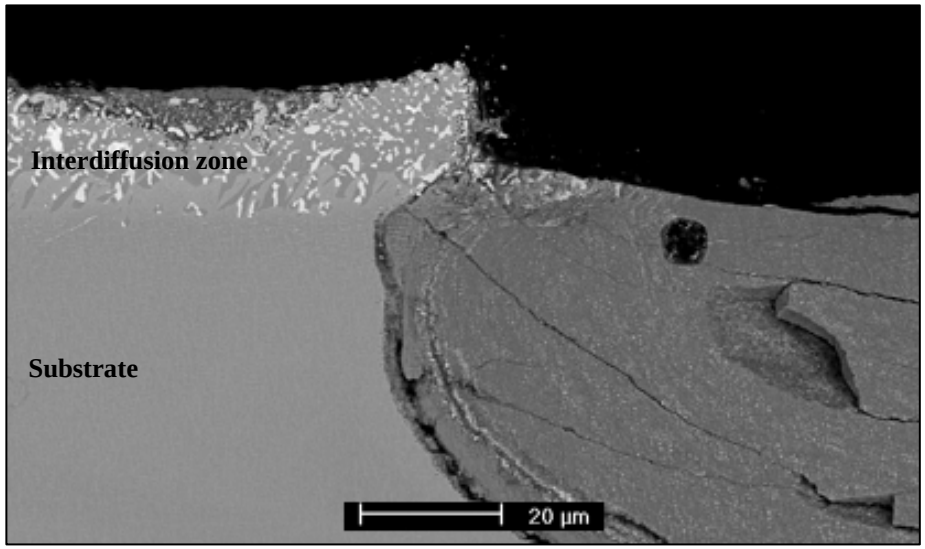
(a) Weight change versus time measurements for Platinum Aluminide coated Rene′ N5 samples with different deposits exposed at 950℃ in air containing 1000 ppm SO_2

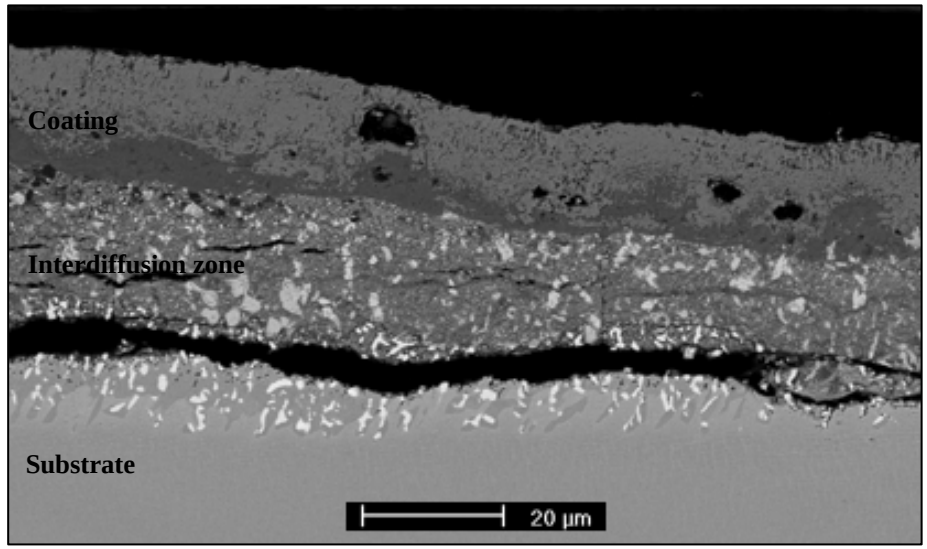


(b) Stereographic micrograph of Platinum Aluminide coated Rene′ N5 sample with Na_2SO_4 deposit at 750°C after 180 hours exposure in dry air containing 1000 ppm SO_2

Scanning Electron Micrographs (Cross-section)

Rene′ N5 + Platinum Aluminide / 750℃ / **Na_2SO_4** / after 180 hours exposure





(a) Low temperature hot corrosion

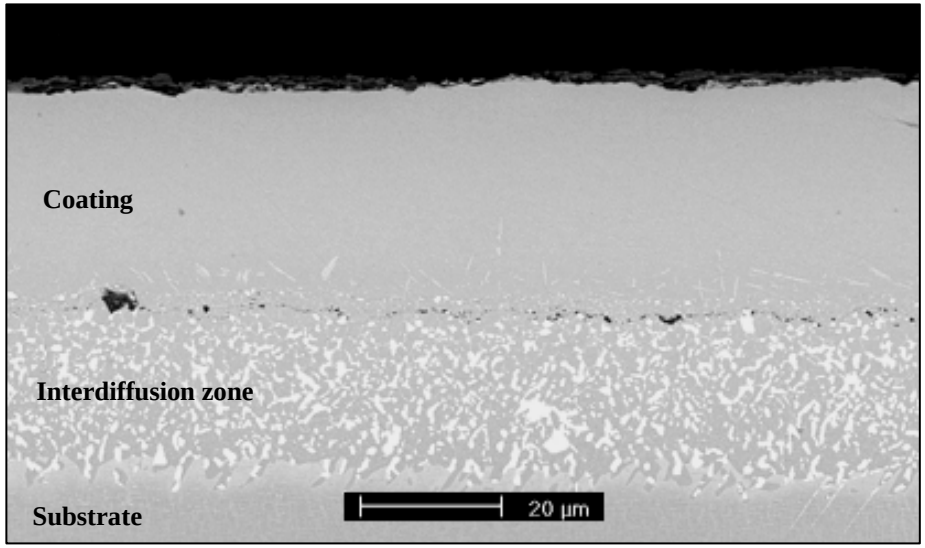
(b) Severely degraded coating

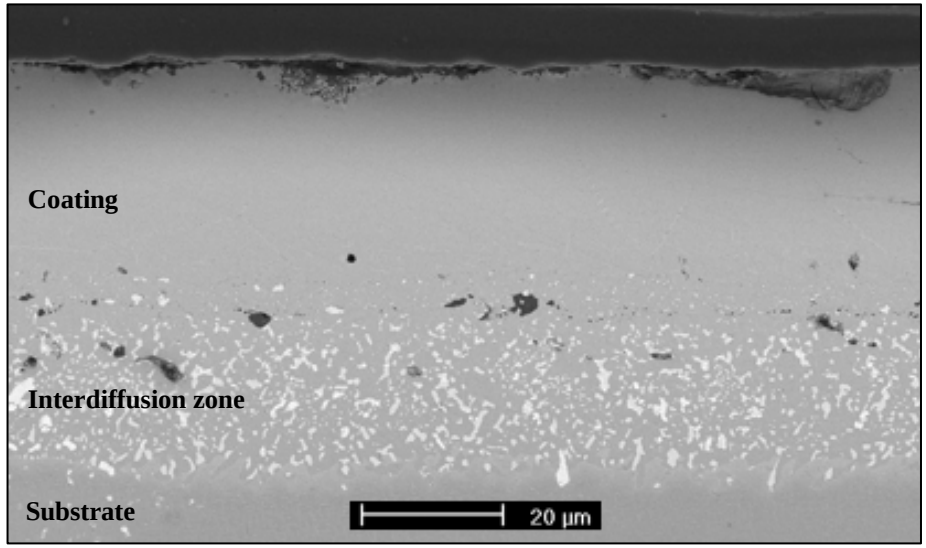
- Specimens with Na_2SO_4 deposits were severely degraded 750℃.

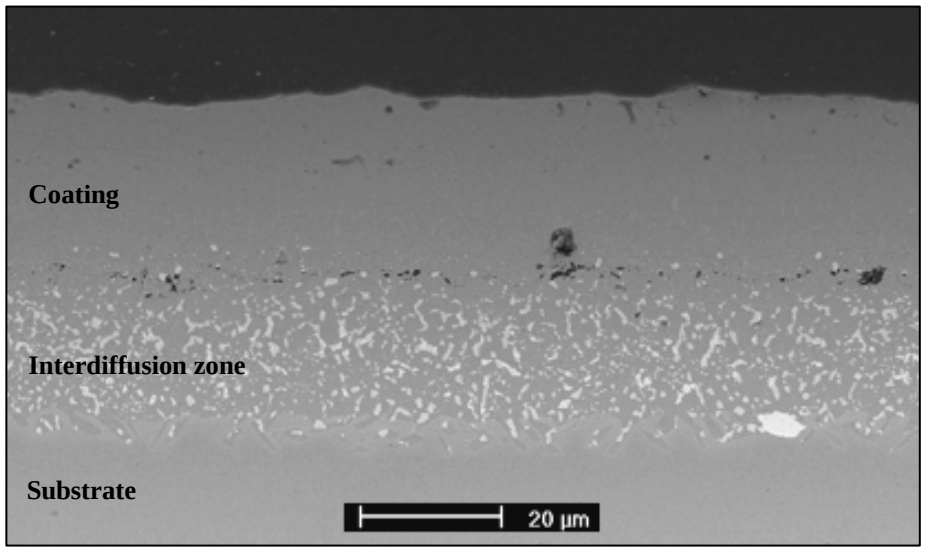
- Other specimens with No Deposits, CaO and $CaSO_4$ showed very little or no degradation at 750℃

Scanning Electron Micrographs (Cross-section)

Rene′ N5 + Platinum Aluminide / 750℃ / **No Deposit,CaO,$CaSO_4$** / after 180 hours exposure







No Deposit

CaO

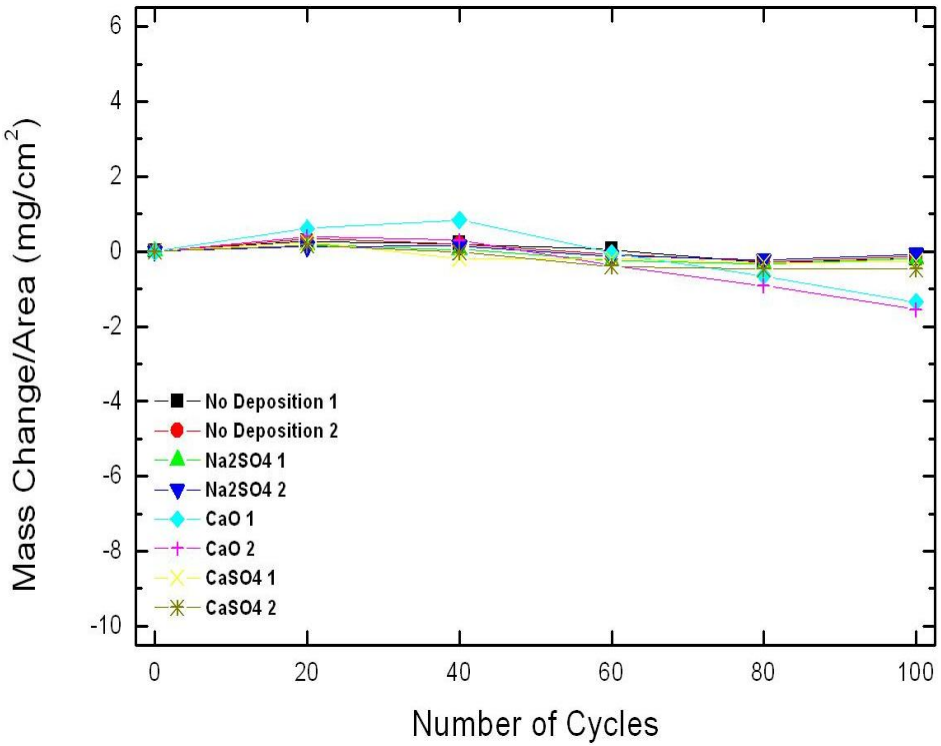
$CaSO_4$

Conclusion

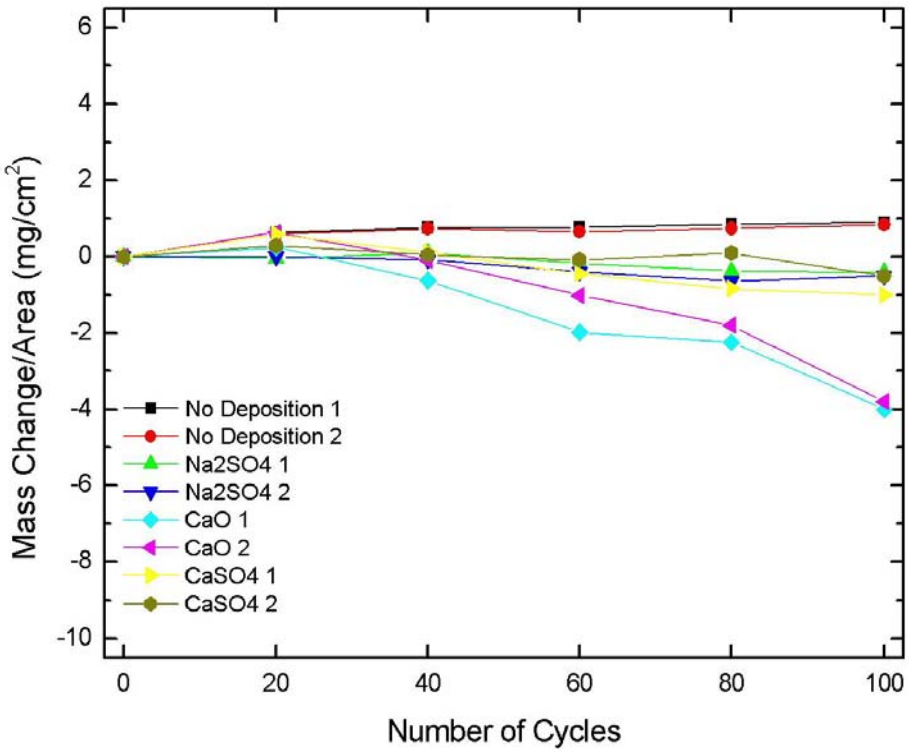
Future testing should not be done at 750℃

Weight change versus Time measurements

Rene′ N5 + Platinum Aluminide samples with different deposits cyclically exposed at 1150℃ in wet air for 100 hours



(a) at 950℃ in wet air after 100 cycles



(b) at 1150℃ in wet air after 100 cycles

- Larger weight losses at 1150 ℃ for CaO than observed at 950℃.

- Metallographic analysis of specimens exposed at 1150℃ are in progress.

Concluding Remarks

For Platinum Aluminide coatings on Rene′ N5 at 750℃

1. Testing conditions for the remaining tasks (III, IV, V, VI) should be using CaO deposits at a temperature of either 950℃ or 1150℃.

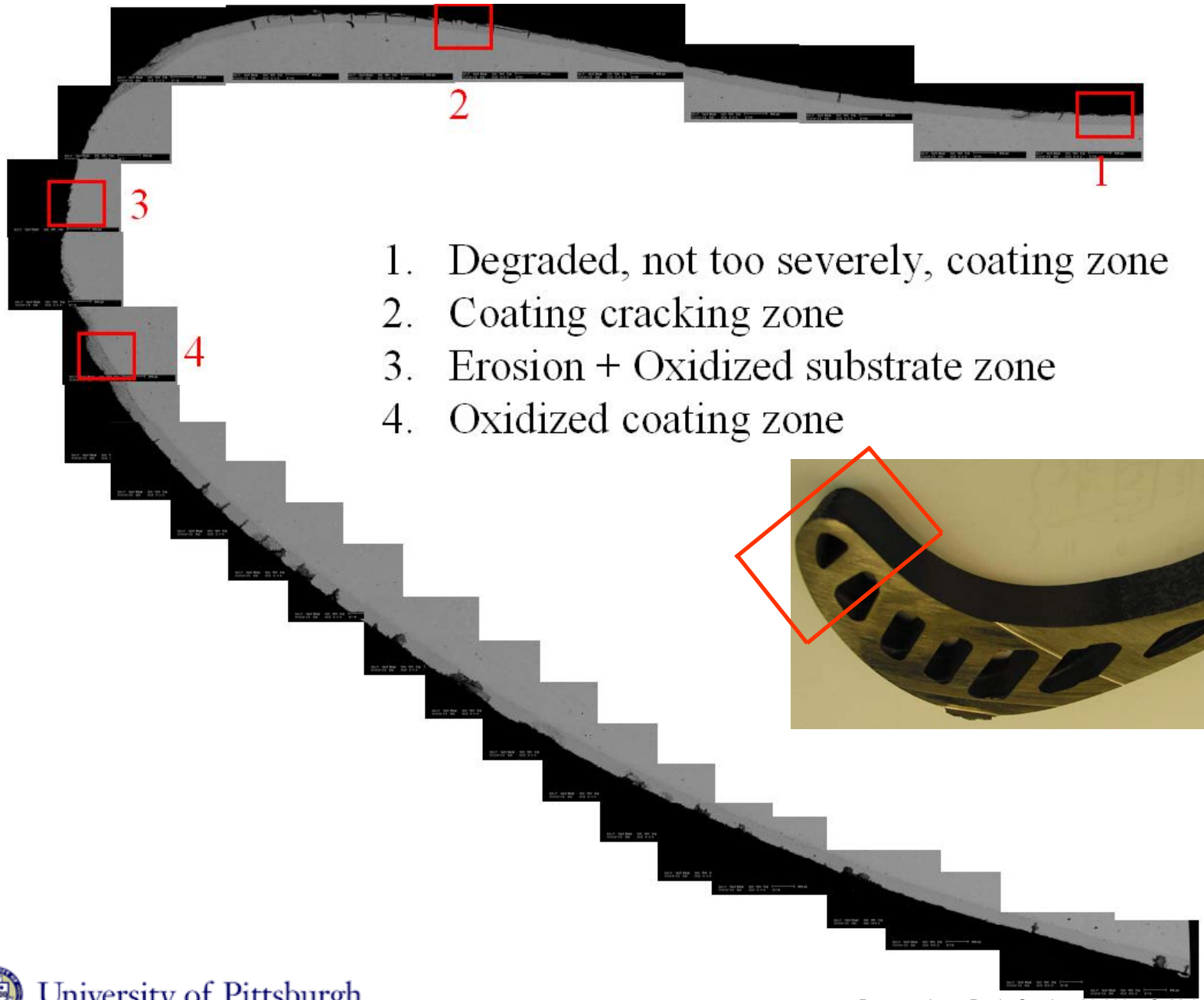
2. The test temperature will be selected based upon the results obtained with CoNiCrAlY coatings.

3. The gas environment should be wet air (p_{H2O}=0.1atm), but Task IV will examine moisture/contaminant limits at the selected test temperature.

4. The effects of other deposits (e.g. CMAS) may be considered based on any information that becomes available from gas turbines using syngas.

Additional Slides

Observation : Service Exposed Turbine Buckets from TECo Polk 1 Gas Turbine



1. Degraded, not too severely, coating zone
2. Coating cracking zone
3. Erosion + Oxidized substrate zone
4. Oxidized coating zone

Project Approach

Compositions of Alloys (wt%)

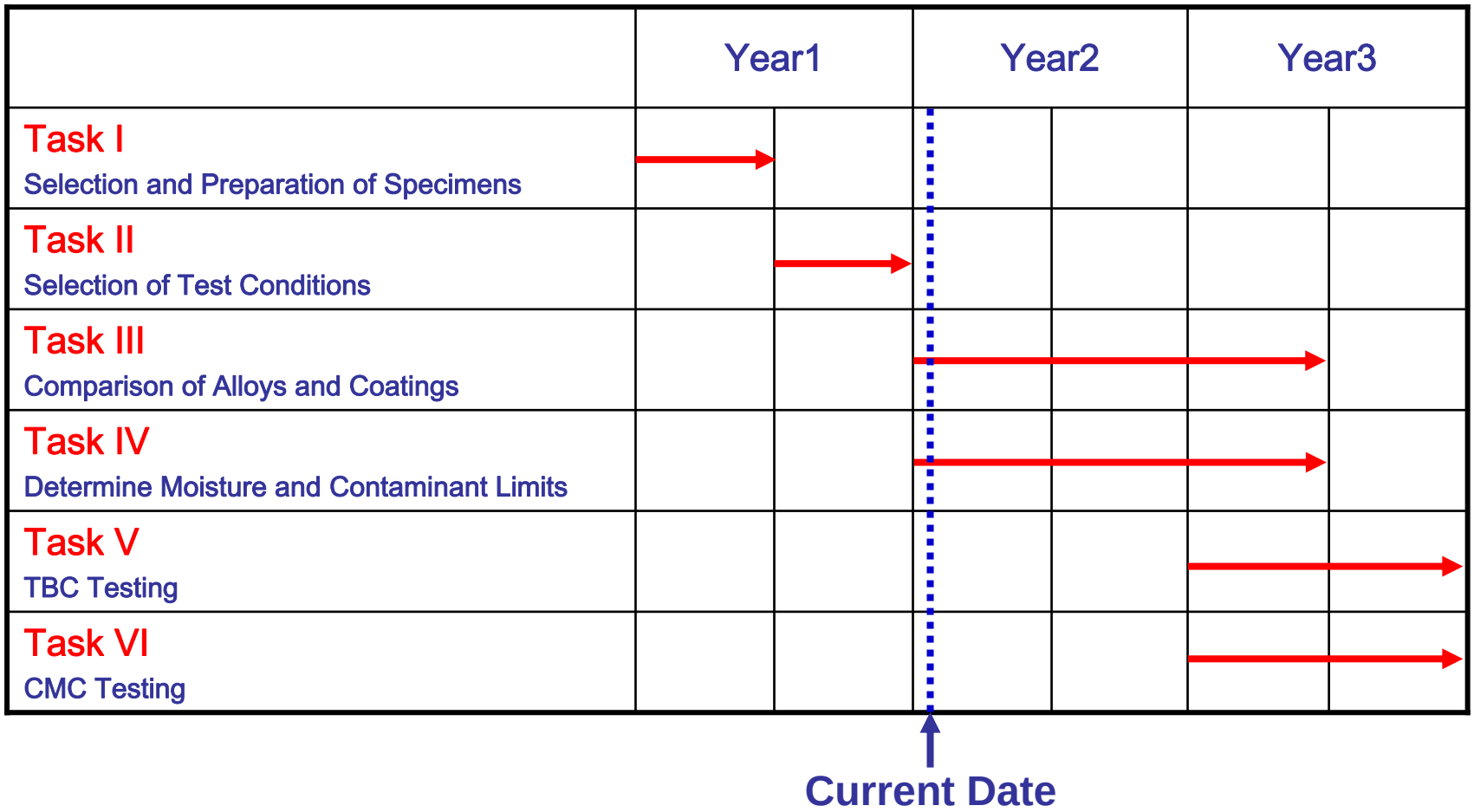
Alloy	Ni	Cr	Al	Co	Ta	W	Mo	Ti	B	Hf	Re
IN738	Bal.	16.0	3.4	8.5	1.7	2.6	7.1	3.4	.001	---	---
RenéN5	Bal.	7.0	6.2	7.5	6.5	6.0	0.6	1.0	---	0.1	3.0
GTD111	Bal.	14.0	3.0	9.5	2.8	2.8	1.5	4.9	.01	---	3.0

Compositions of Coating Materials (wt%)

Coating	Co	Ni	Cr	Al	Y
CoNiCrAlY	Bal.	32.0	22.0	10.0	0.3
NiCrAlY	---	Bal.	22.0	10.0	0.3

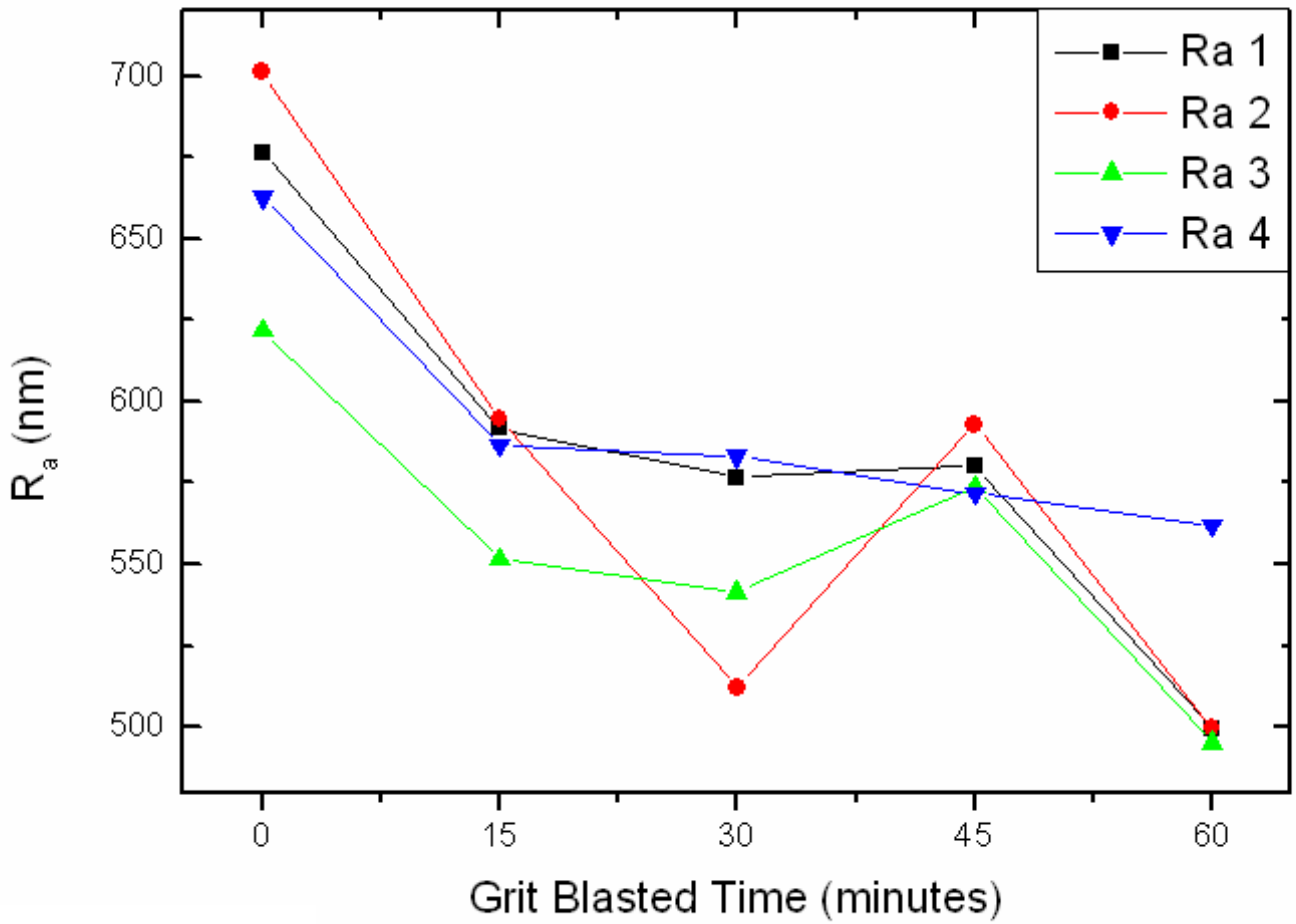
Project Approach

Timeline

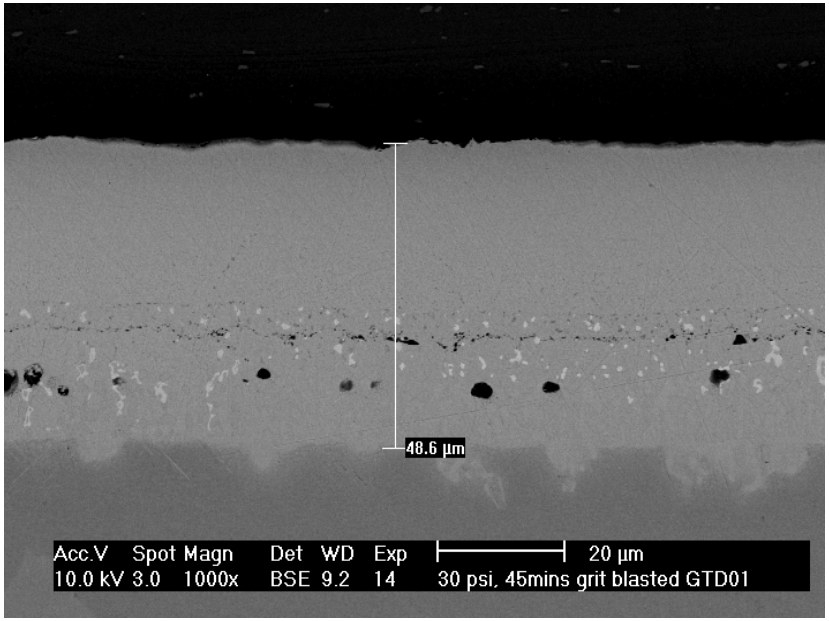


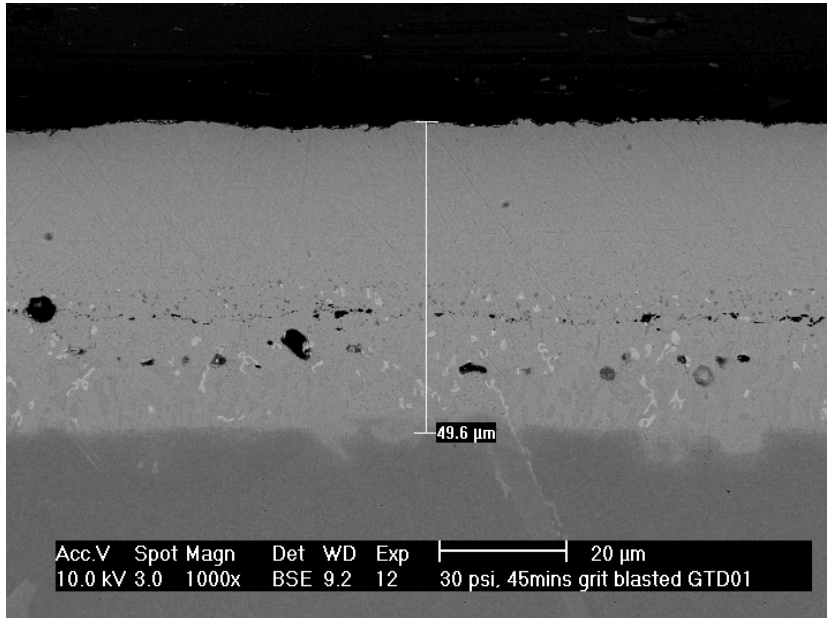
R_a vs. Grit Blasted time at 30psi (GTD111 with Pt Aluminide)

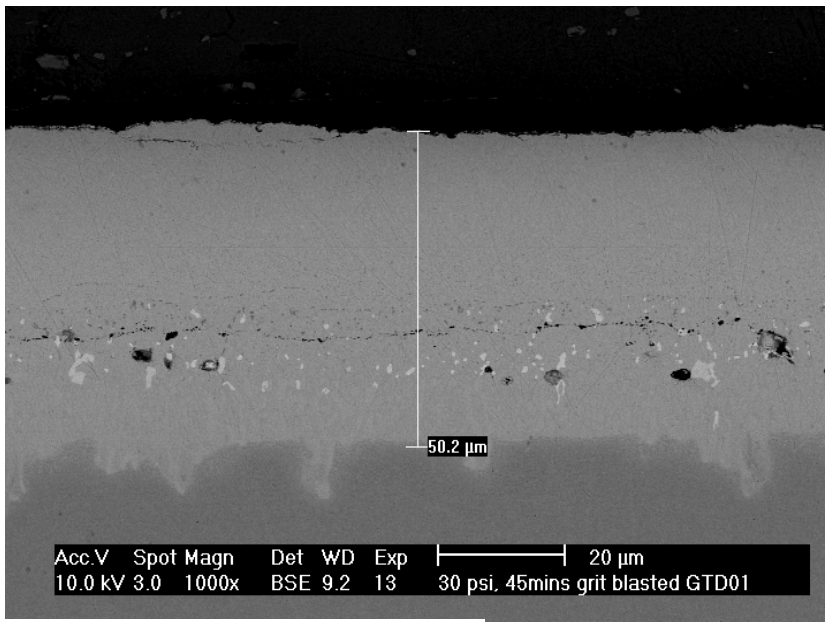
$$R_a = \frac{1}{L}\int_0^L |\, y(x) \,|\, dx$$

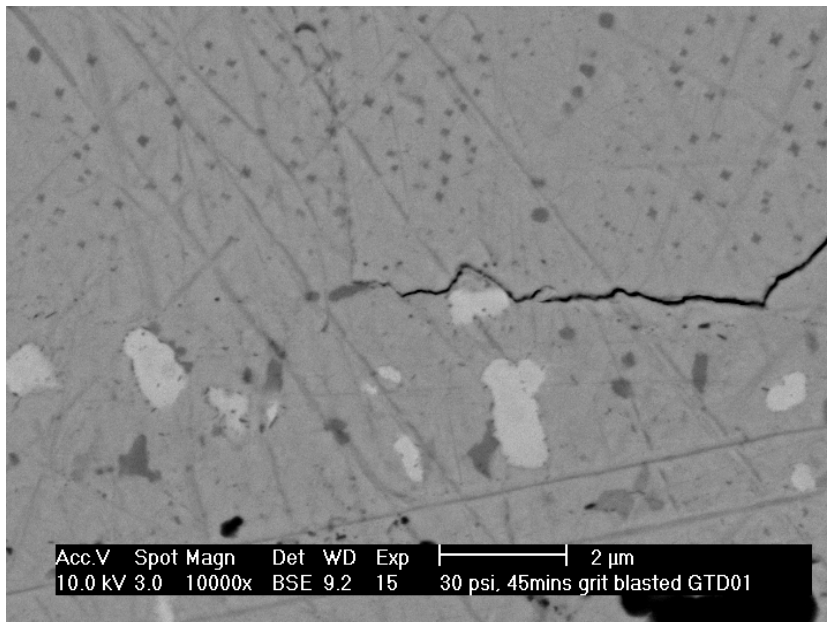


GTD111+Pt Aluminide – grit blasted at 30psi for 45 minutes









GTD111+CoNiCrAlY – grit blasted at 30psi for 45 minutes