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1. REPORT DATE (DD-MM-YYYY) 12-05-2014		2. REPORT TYPE Conference Proceeding (refereed)		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Corrosion Susceptibility of AA5083-H116 in Biologically Active Atmospheric Marine Environments				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER 0601153N	
6. AUTHOR(S) J.S. Lee, R.I. Ray, B.J. Little and W.C. Neil				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 73-4635-03-5	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory Oceanography Division Stennis Space Center, MS 39529-5004				B. PERFORMING ORGANIZATION REPORT NUMBER NRL/PP/7330--13-1878	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research One Liberty Center 875 North Randolph Street, Suite 1425 Arlington, VA 22203-1995				10. SPONSOR/MONITOR'S ACRONYM(S) ONR	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution is unlimited.					
13. SUPPLEMENTARY NOTES <p style="text-align: center; font-size: 2em; color: purple;">20150917423</p>					
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15. SUBJECT TERMS 5083, fungi, atmospheric corrosion, marine					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 11	19a. NAME OF RESPONSIBLE PERSON Jason Lee
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code) (228) 688-4494

**CORROSION SUSCEPTIBILITY OF AA5083-H116 IN BIOLOGICALLY ACTIVE
ATMOSPHERIC MARINE ENVIRONMENTS**

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ABSTRACT

Aluminum alloy (AA) 5083-H116 was exposed to laboratory marine atmospheres with and without fungi. AA5083-H116 coupons were half covered with potato dextrose agar (PDA), a fungal growth media; the remaining coupon areas were left bare and fully exposed to the marine atmosphere. Fungal mycelia were inoculated into the PDA and grew over the entire coupon surface during the 90-day exposure. Overlaid with PDA, AA5083-H116 exhibited shallow crystallographic etching and grain boundary attack. Fungi increased the likelihood and severity of pitting corrosion when compared with abiotic controls. Fungal mycelia were associated with trenching and intergranular pits on the bare surfaces. Al-Si-Mg particles were associated with small (10 μm) pits over the entire coupon surface, regardless of exposure condition.

Key words: aluminum 5083, fungi, atmospheric corrosion, marine

INTRODUCTION

Future ship designs and modernization of existing platforms rely on lightweight aluminum. Aluminum 5XXX series alloys, with magnesium (Mg) as the primary alloying element, have garnered increased attention with their expanded use in Naval vessels. Recent research efforts have focused on the sensitization of these alloys.^{1,2} Sensitization results from the segregation of Mg to grain boundaries, forming the highly anodic β -phase.³⁻⁶ Aluminum alloy (AA)5083 (UNS A95083) has received the vast majority of attention specifically in regards to intergranular corrosion due to sensitization.^{5,7-10} Mizuno and Kelly^{7,8} examined the intergranular corrosion behavior of AA5083-H131 during galvanic coupling to steel. The authors showed that penetration depth in AA5083-H131 was particularly correlated to degree of sensitization (DoS) as measured by the standardized nitric acid test ASTM G67.¹¹ Fatigue and stress corrosion cracking behaviors of sensitized AA5083 have also been evaluated.^{12,13} Pitting of AA5083 under immersed seawater conditions has been

examined, but to a lesser extent than the sensitization studies.¹⁴⁻¹⁶ However, little consideration has been given to the impact of naturally occurring marine environments on the predicted lifetime of AA5083. Specifically, microbiological effects on the corrosion properties of AA5083 have not been demonstrated. In the present study, laboratory tests were designed to answer the following questions related to marine corrosion: 1) Can microorganisms survive/grow on AA5083 surfaces in marine conditions; 2) Can colonization of microorganisms on AA5083 initiate and sustain localized corrosion on boldly exposed surfaces?

METHODS AND MATERIALS

Coupons of as-received AA5083-H116 (1.59 cm dia. x 0.16 cm thick) were mounted in EpoThin™ epoxy (Buehler, Lake Bluff, IL) and polished to 1 μm finish. Mounted coupons were placed face up in square (20 cm x 20 cm x 6 cm) plastic containers. Three containers, lids and two coupons per container were washed with iso-propyl alcohol and air-dried. Difco™ potato dextrose agar (PDA) was prepared according to manufacturer instructions and poured into sterile plastic petri dishes to a depth of 1 mm. After solidification, 1.0 cm x 1.5 cm PDA sections were removed and placed on the mounted coupons covering one half of the AA5083-H116 surface (Figure 1). Care was taken to prevent unintended contamination of the PDA by airborne microorganisms by keeping the lids on the containers when not in use. Fungal species *Aspergillus niger* and *Penicillium oxalicum* were grown on separate PDA plates inoculated from frozen stock specimens. These fungi are known to deteriorate coated and bare A2XXX series aluminum alloys.¹⁷⁻²¹ Both fungi produced mycelia that were transferred to the PDA sections by inoculating loops. One container contained only *A. niger* while the second contained only *P. oxalicum*; the third container was not inoculated with fungi and served as a control. An aerosol of sterile 3.5% NaCl solution was sprayed into each container. Salt loading was not measured. A petri dish filled with sterile 3.5% NaCl was placed in each of the three containers to maintain humidity. The containers were stored in a dark room at 24 °C for 90 days.

After exposure, coupons were photographed, sonicated in soap and water, and acid cleaned in boiling phosphoric acid with dissolved chromium trioxide according to ASTM G1 Designation C.1.1.²² Corrosion morphology was examined by scanning electron microscopy.

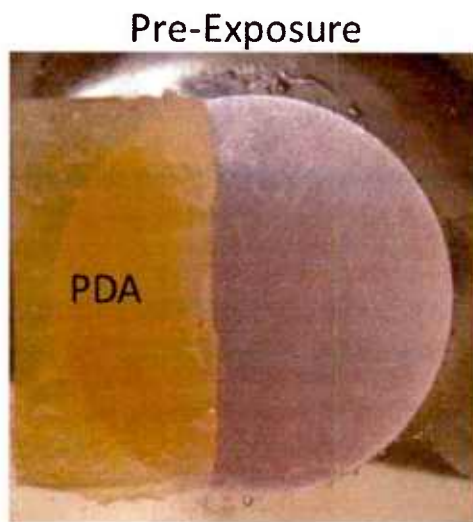


Figure 1. Epoxy mounted AA5083-H116 (1.58 cm dia.) with 1 mm thick potato dextrose agar overlay prior to exposure.

RESULTS & DISCUSSION

Figure 2 shows the representative macroscopic appearance of AA5083-H116 after 90-day exposure to simulated marine atmospheres with and without fungi. Water droplets were visible on all metal and epoxy surfaces after 90 days confirming sufficient humidity was achieved to maintain deliquescence of deposited salt films. After the 90-day exposure, PDA in the control exposure was intact with some shrinkage. Fungal sterility was maintained as evidenced by the lack of observable fungal mycelia or spores in the control PDA. Dark orange spots inside the control PDA corresponded to areas of shallow attack of the AA5083-H116 surface (Figure 3). Prior to solidification, PDA has a pH of 3.5, and has been shown to be corrosive to aluminum 2XXX series alloys.²¹ Fungal mycelia were observed on coupons exposed to either *A. niger* or *P. oxalicum*. Mycelia had grown out of the PDA and had colonized the originally bare AA5083-H116 surfaces. PDA was nearly fully digested when exposed to either fungal species. Spore formation was observed at the initial site of PDA overlay. *A. niger* produced dark brown spores while *P. oxalicum* produced a fuzzy olive green spore mat.

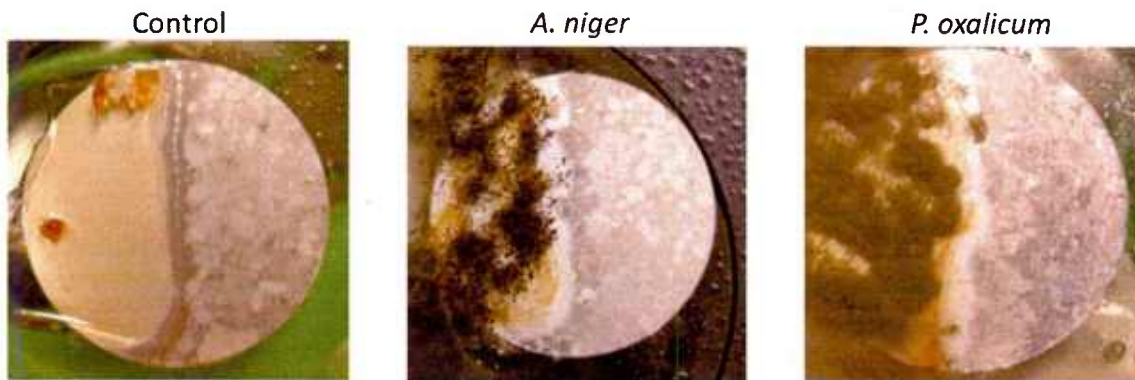


Figure 2. AA5083-H116 coupons after 90-day exposure in marine atmosphere without fungi (control), with *A. niger* and *P. oxalicum*. Fungal mycelium were translucent white in color while spores were brown (*A. niger*) or olive green (*P. oxalicum*). Coupons were 1.59 cm in dia.

Figures 3 and 4 show corrosion morphologies of the control exposure associated with the PDA-covered and bare sides, respectively. Under the PDA (Figure 3), AA5083-H116 was shallowly attacked (20 μm depth) in localized areas. The attack was crystallographic with clearly observable facets. Areas away from the attack had small (10 μm) pits with Al-Si-Mg particles at the bottom. These small particle-associated pits were detected in all exposure conditions, with and without PDA-overlay or fungi. Al-Fe-Mg-Mn-Si particles were also detected. Bare AA5083-H116 (Figure 4) exposed to the marine atmosphere had circular areas, which appeared darker in the SEM, that were covered with Al-Fe-Mg-Mn-Si particles. Circular attack patterns (~ 30 μm dia.) were associated with water droplets and NaCl crystals.

Figures 5 and 6 show the corrosion morphologies of the exposure with *A. niger* associated with the PDA-covered and bare sides, respectively. Under the PDA (Figure 5), preferential attack of the grain boundaries was observed. In each replicate, multiple isolated pits were detected under the PDA overlays. Pits had a crystallographic morphology but were deeper (200 μm) than the shallow attack observed in the control exposure. Bare AA5083-H116 (Figure 6) exposed to the marine atmosphere with *A. niger* had circular attack patterns associated with water droplets and NaCl crystals. Surface regions associated with mycelia exhibited dark, long, thin, branched shapes. Pitting was also observed on the bare surface adjacent to the PDA. Pits had ruptured covers and the pitting morphology was intergranular with small regions of crystallographic attack.

Figures 7 and 8 show the corrosion morphologies of the exposure with *P. oxalicum* associated with the PDA covered and bare sides, respectively. Under the PDA (Figure 7), preferential attack of the grain boundaries was observed. Shallow isolated pits were observed under

the PDA overlays. Pits had a crystallographic morphology and were intermediate in depth (40 μm) compared to the control and *A. niger* exposures. Bare AA5083-H116 (Figure 8) exposed to the marine atmosphere with *P. oxalicum* had circular attack patterns associated with water droplets and salt crystals. Trenches were associated with mycelia. Trenches were shallow (<5 μm) and were not crystallographic, but rather had small circular 1 μm pits at the trench bottom. Extensive pitting with intergranular corrosion morphology was also observed in association with *P. oxalicum* mycelia.

Comparison of corrosion morphology as a function of exposure condition demonstrated noticeable trends. AA5083-H116 exposed under PDA resulted in crystallographic pitting with or without fungi present. Fungi increased the depth of crystallographic attack and resulted in preferential grain boundary dissolution. Exposure of bare AA5083-H116 to humid marine atmosphere resulted in circular attack patterns (30 μm dia.) presumably due to water droplet formation and elevated NaCl concentration. In the presence of fungi, intergranular pitting was observed. In addition, trenches with small (1 μm dia.) pits were associated with fungal mycelia. Pits (10 μm dia.) with Al-Si-Mg particles at the bottom were observed over all AA5083-H116 surfaces, regardless of exposure condition.

These experiments represent the first noted microbiologically influenced corrosion (MIC) of AA5083-H116. The results presented here are the first phase of a larger examination regarding MIC of 5XXX aluminum alloys and should be considered qualitative. Continued examination of these exposure specimens is ongoing and further discussion of the results will be detailed in subsequent publications.

CONCLUSIONS

AA5083-H116 was exposed to simulated laboratory marine atmospheres with and without fungi. Observations suggest AA5083-H116 is resistant to significant attack in salt atmospheres; however, the presence of fungi increases the likelihood of pitting. Small pits (10 μm) were associated with Al-Si-Mg particles for all exposures in both bare and PDA-covered surfaces. Crystallographic attack was observed in all exposures conditions under the PDA overlay. In the presence of *A. niger*, pits under the PDA were significantly deeper and more numerous compared with the other exposures. Mycelia from *A. niger* and *P. oxalicum* were associated with trenching and intergranular pits on the bare surfaces. Crystallographic pitting was observed in control exposures only when covered by PDA.

ACKNOWLEDGEMENTS

This work was supported by NRL Base funding. NRL Publication NRL/PP/7330—13-1878.

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Control – PDA Side

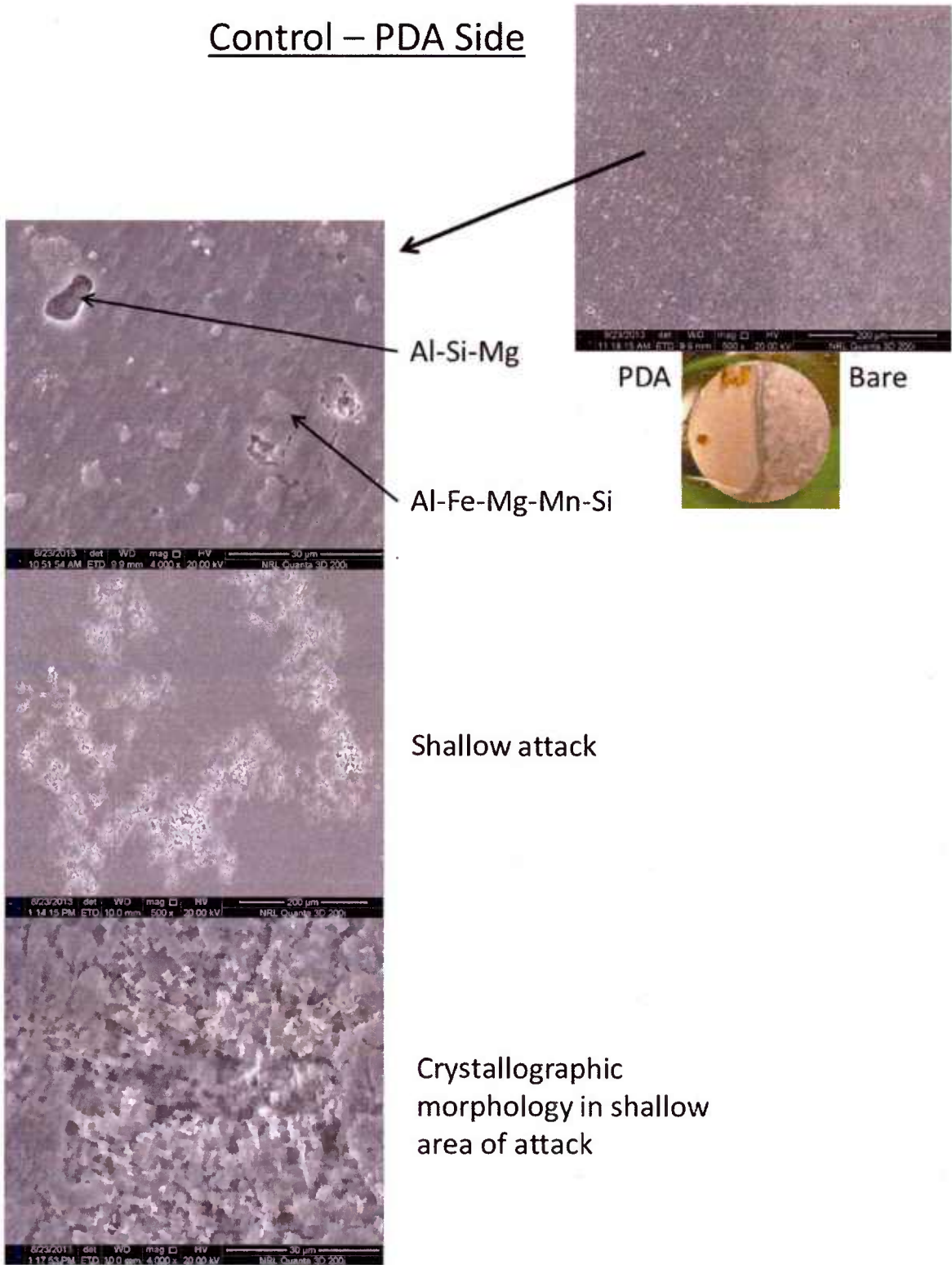


Figure 3. AA5083-H116 surface under PDA after 90-day exposure in marine atmosphere without fungi (control).

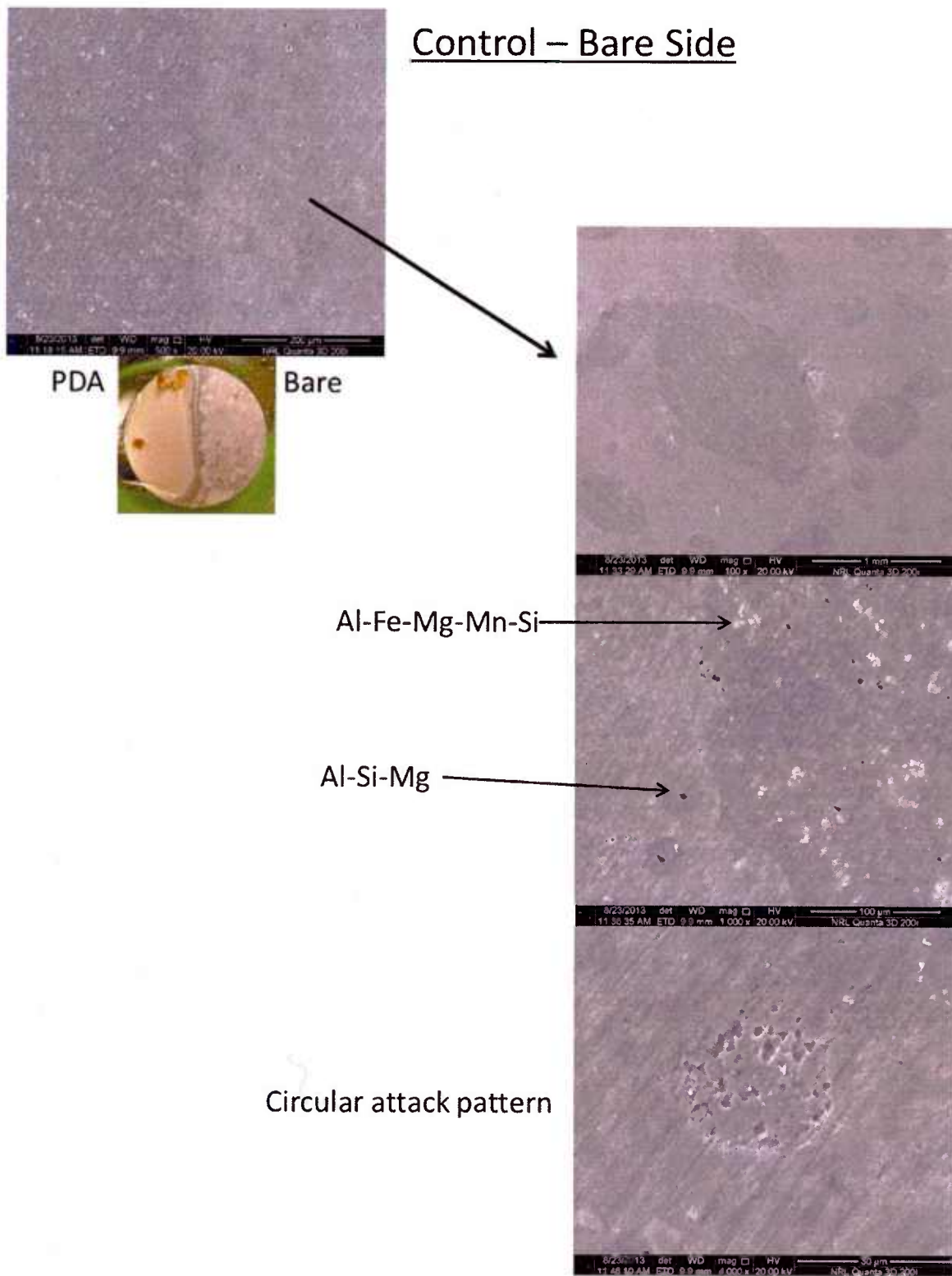


Figure 4. Bare AA5083-H116 coupons adjacent to PDA overlay after 90-day exposure in marine atmosphere without fungi (control).

A. niger – PDA Side

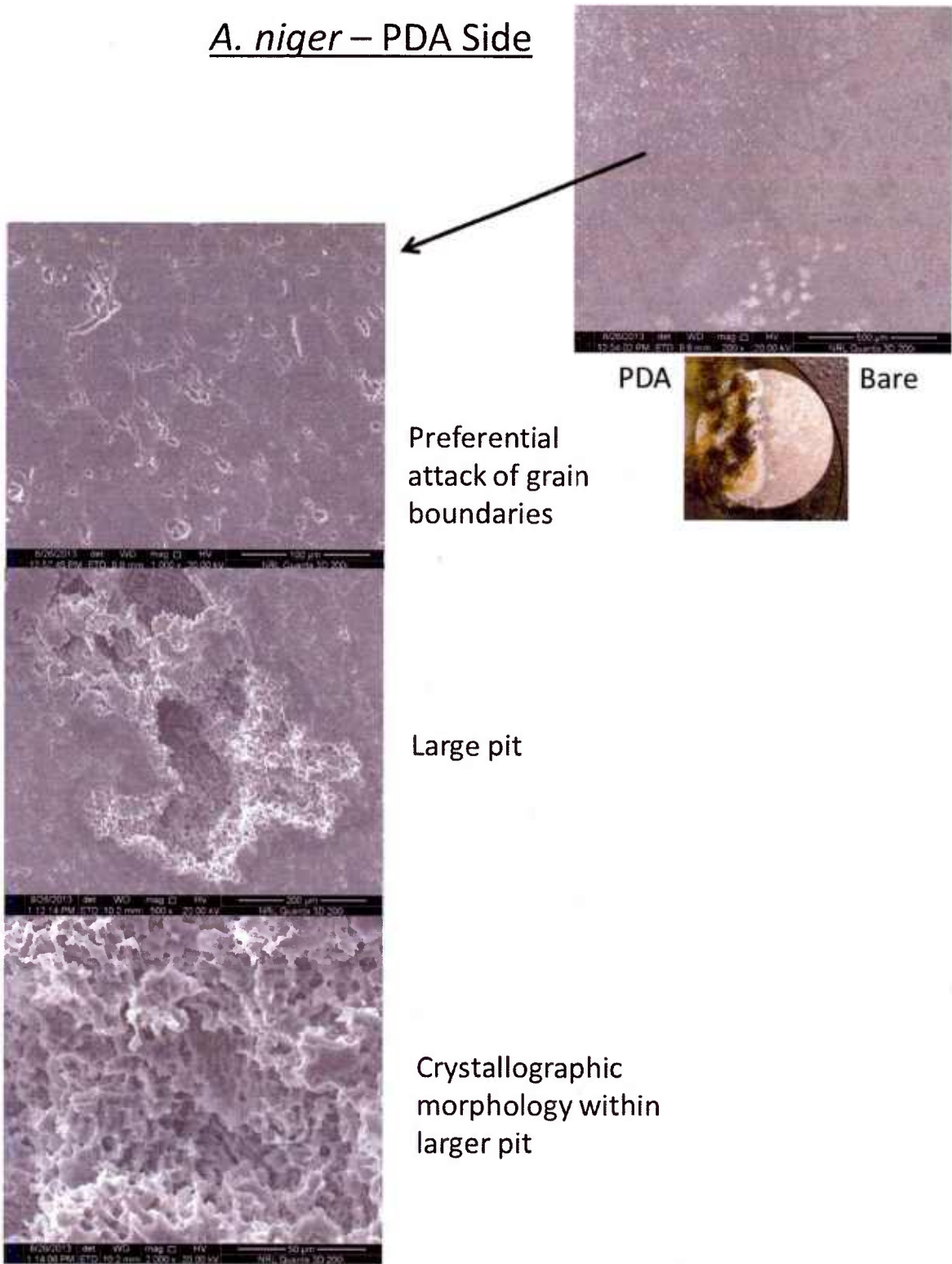


Figure 5. AA5083-H116 surface under PDA after 90-day exposure in marine atmosphere with *A. niger*.

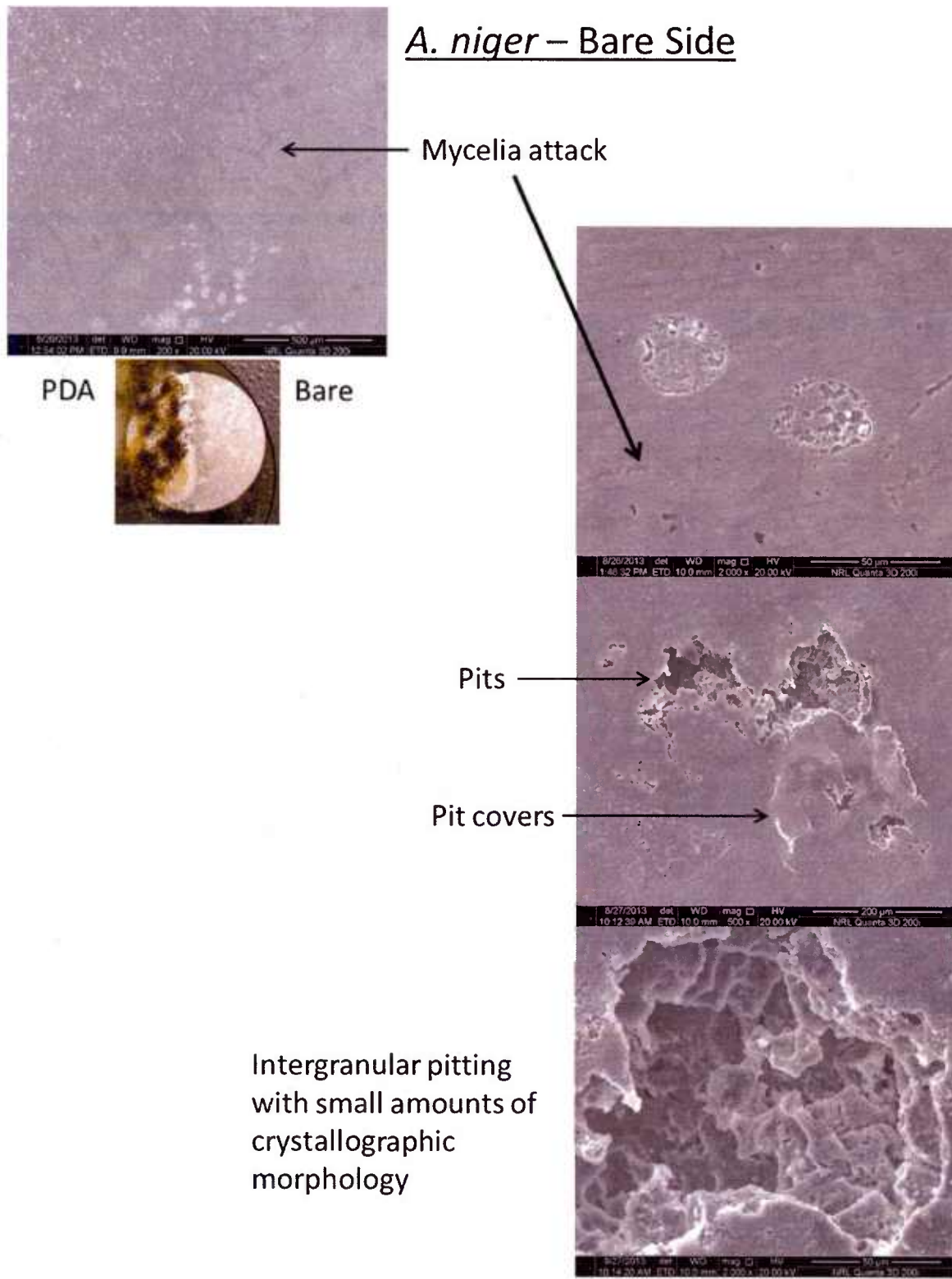
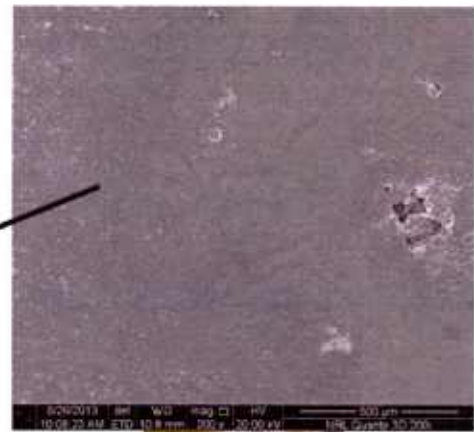
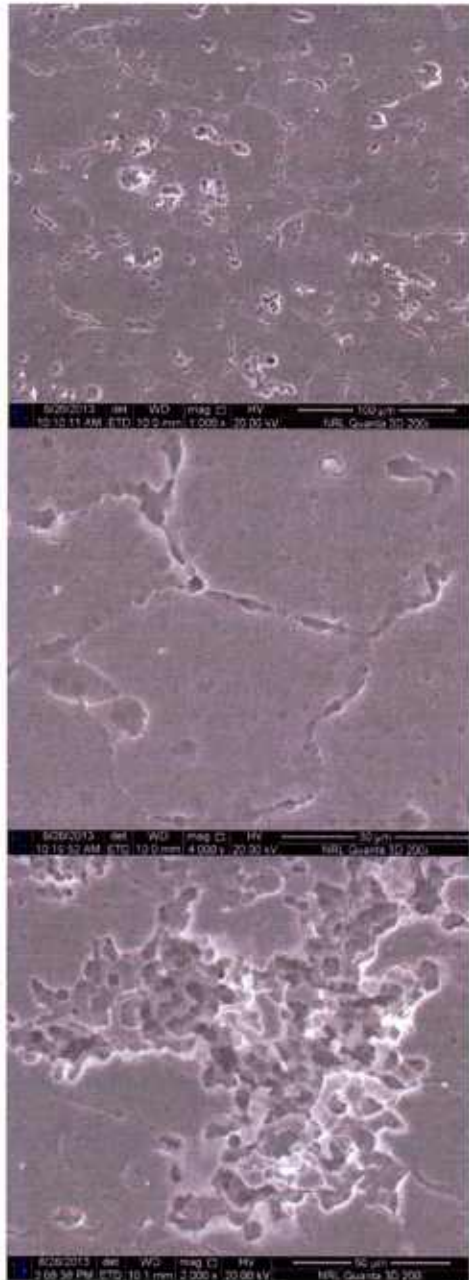


Figure 6. Bare AA5083-H116 coupons adjacent to PDA overlay after 90-day exposure in marine atmosphere with *A. niger*.

P. oxalicum – PDA Side



PDA

Bare



Preferential
attack of grain
boundaries

Shallow crystallographic attack

Figure 7. AA5083-H116 surface under PDA after 90-day exposure in marine atmosphere with *P. oxalicum*.

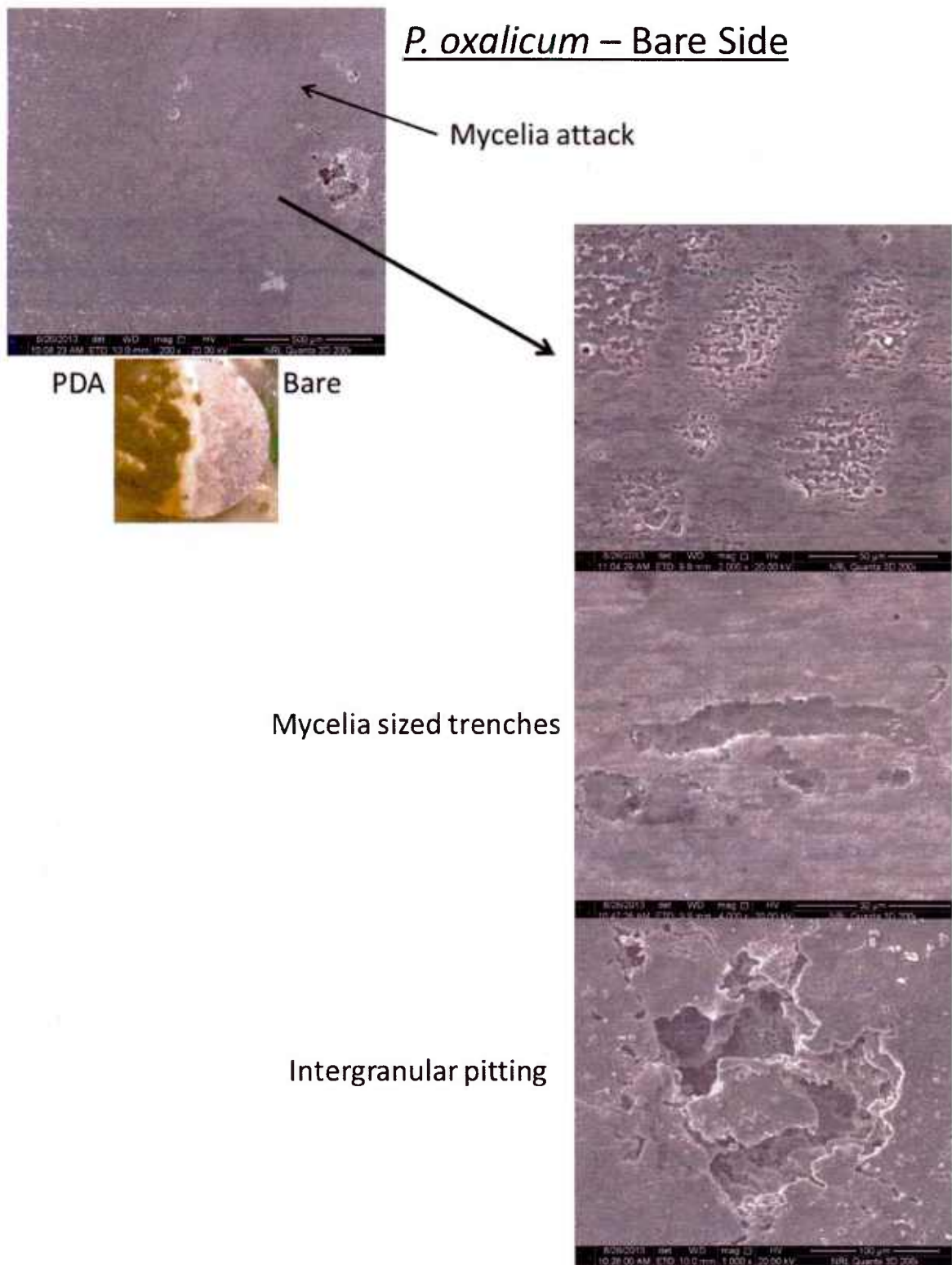


Figure 8. Bare AA5083-H116 coupons adjacent to PDA overlay after 90-day exposure in marine atmosphere with *P. oxalicum*.