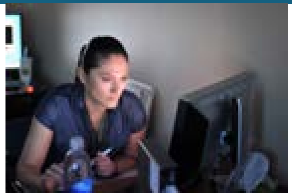
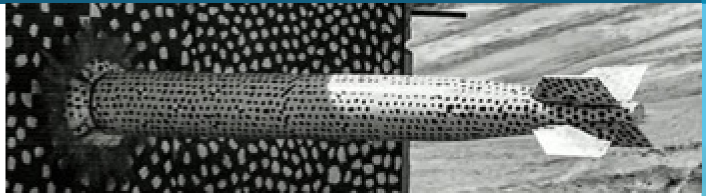
Deep Dive into Marine Energy Composites and Manufacturing





Webinar Series: March-April 2021

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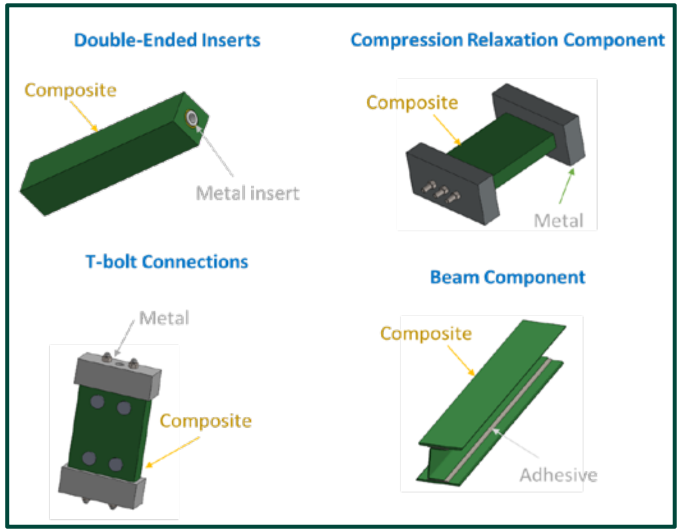
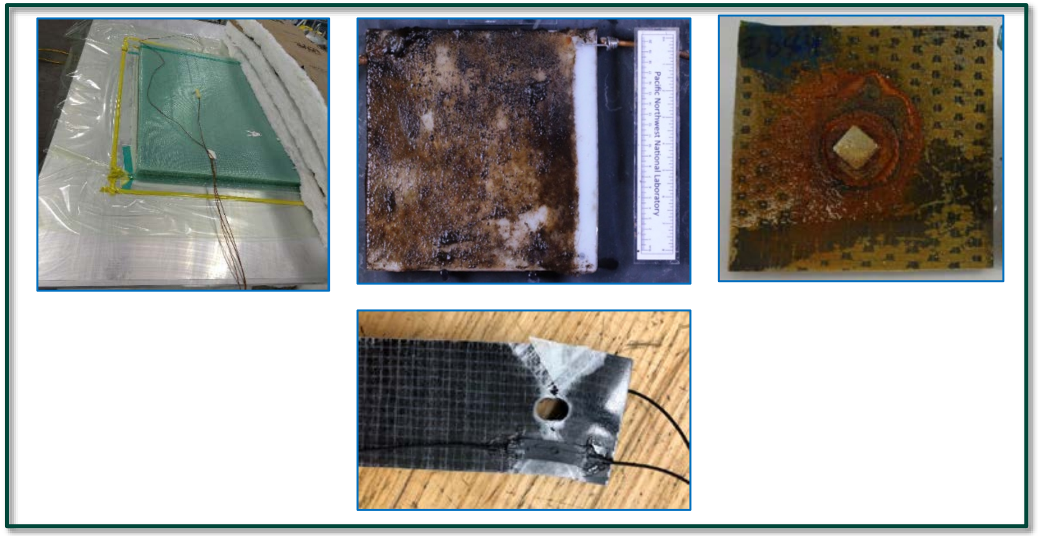
Event Series Listed In WPTO R&D Deep Dive Webinar Series

- Crevice Corrosion in Seawater Using CFRP/Hybrid Composite as Part of a Novel Crevice Former, **March 19, 1-2 pm ET**
- Summary of Marine and Hydrokinetic (MHK) Composites Testing at Montana State University, **March 26, 1-2 pm ET**
- Leveraging the Advantages of Additive Manufacturing to Produce Advanced Composite Structures for Marine Energy Systems, **April 9, 1-2 pm ET**
- Marine Energy Composites & Manufacturing Workshop, **April 16, 10-2 pm ET**

https://www.energy.gov/eere/water/water-power-technologies-office-rd-deep-dive-webinar-series





FLORIDA ATLANTIC UNIVERSITY

Crevice Corrosion in Seawater Using CFRP Composite as Part of a Novel Crevice Former

F. Presuel-Moreno*, B. A. Hernandez-Sanchez**,
*Center for Marine Materials
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Florida Atlantic University
101 North Beach, Dania Beach, FL
** Sandia National Laboratories
Advanced Materials Laboratory
1001 University Blvd SE
Albuquerque, NM

Sandia National Laboratories

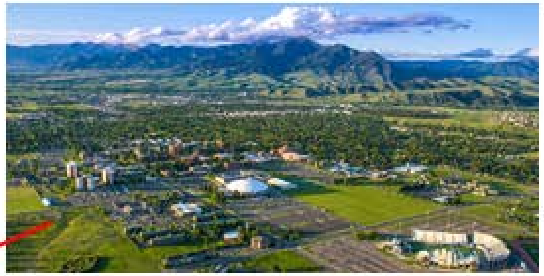
Materials Team

MONTANA STATE UNIVERSITY

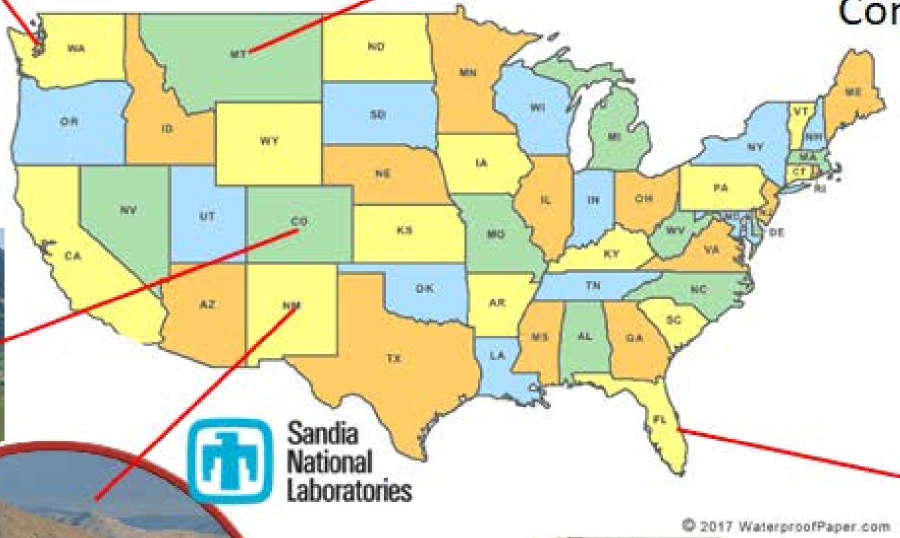
George Bonheyo:
Biofouling

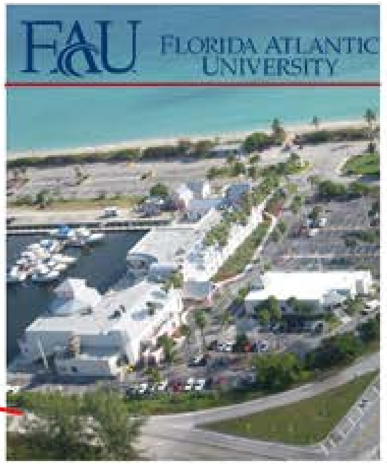
Marine Science Laboratory

Pacific Northwest NATIONAL LABORATORY



David Miller:
Composite Performance





Scott Hughes:
Substructure
Testing

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories

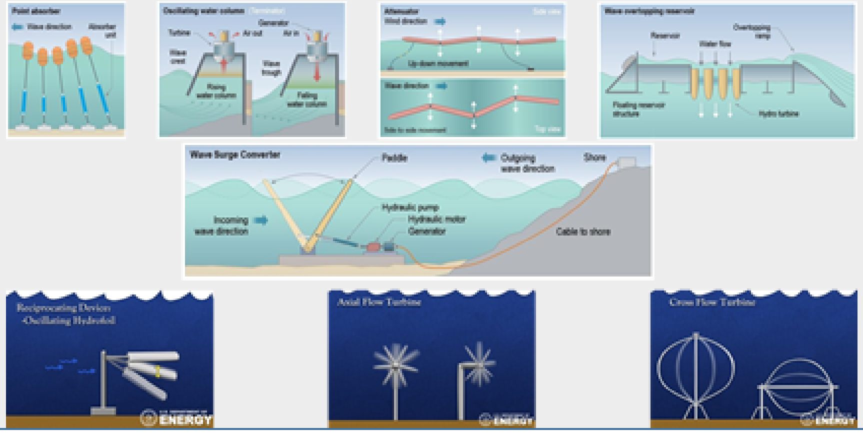
Francisco
Presuel-
Moreno:
Corrosion

Bernadette A. Hernandez-Sanchez: (PI)
Materials Chemistry
Budi Gunawan: Loads & FBG Sensors

Materials Challenges for Marine Renewables

Proper structural/component materials and coatings are critical to reducing engineering barriers, COE, and commercialization time.

Design Challenge: Several Design Configurations & Operational Conditions



Coating & Environmental Challenges

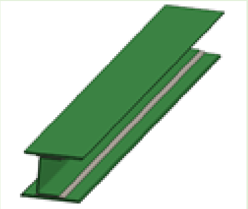
Corrosion

Courtesy of Resolute Marine Energy

Biofouling

http://www.racerocks.ca/

Joined Materials

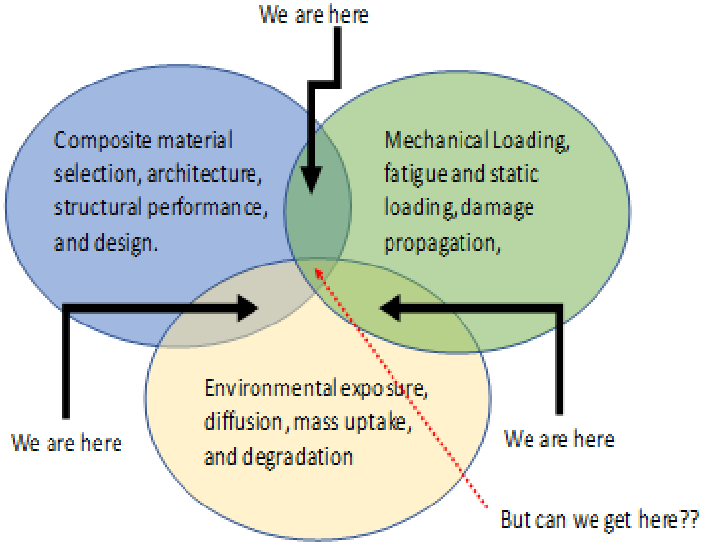


Adhesive joint beams

Significant Periodic Loading:

- Interaction with PTO & Control System
- Site Conditions
- IEC Design Standard (Fatigue/Ultimate)

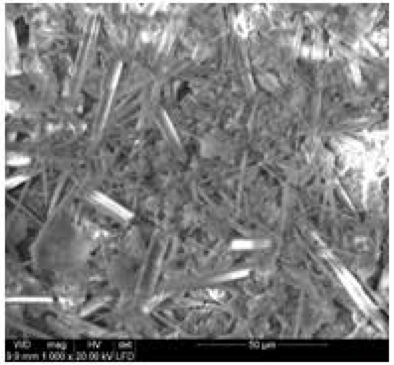
Composites Research Needed



Hernandez-Sanchez et al 13th EWTEC Proceedings

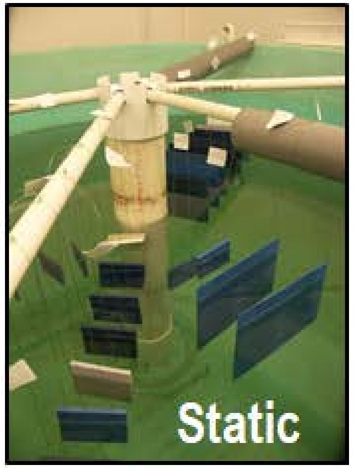
Environmental Effects on Composites

Corrosion can occur on metals connected to carbon fiber composite materials (i.e., CF composite to metal interconnects).



Calcareous deposit from corrosion study CF/VE8084 + anode

Corrosion Studies on Connections



Biofouling Studies on Composites & Coatings

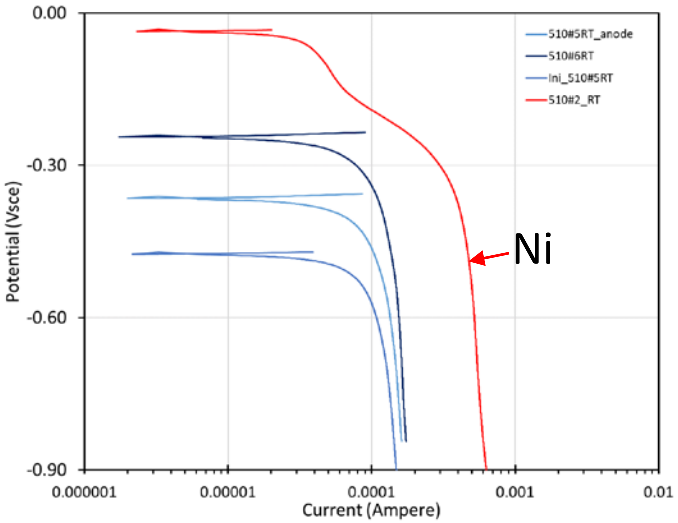
MRE relevant Velocities 0.1 m/S and 2.6 m/s

0-22 month Exposures

Corrosion can occur on metals connected to carbon fiber (CF) composites. A special case is crevice corrosion for bolted CF composite immersed in seawater.

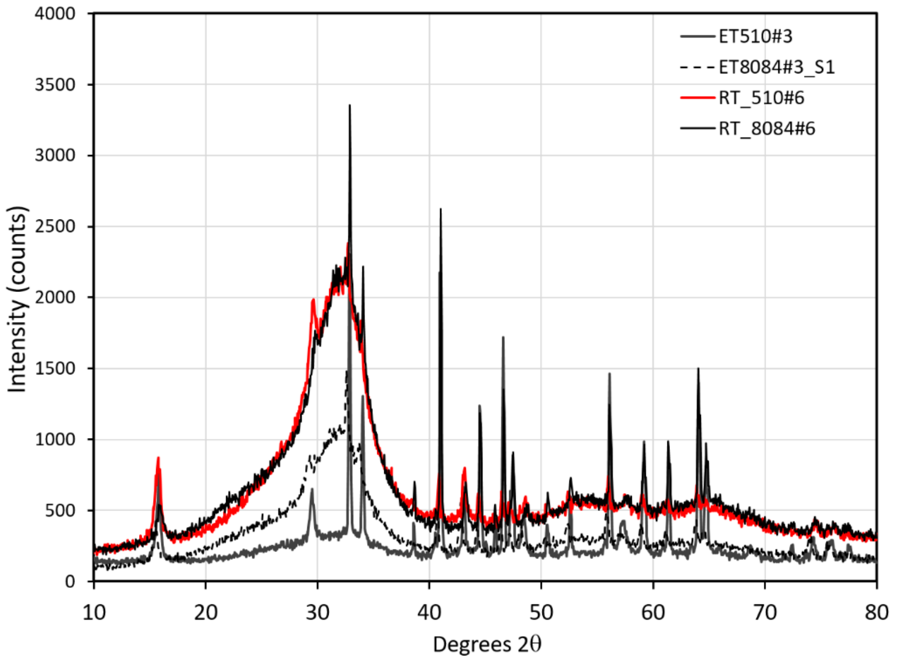
A portion of a carbon fiber composite mast is shown, with metal couplings attached to it.

Cathodic Polarization Scans on CFRP after immersion in seawater interconnected to Al anode



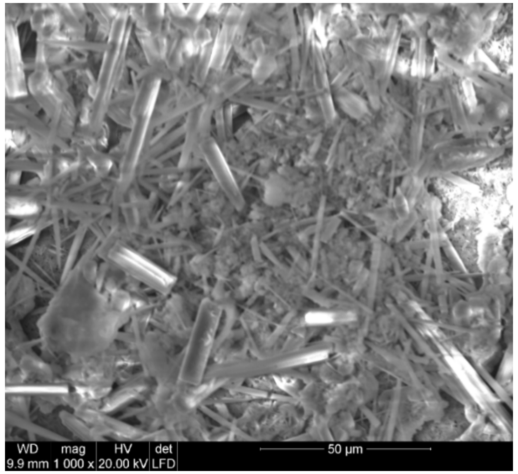
Evidence of cathodic kinetics reduced due to calcareous deposits formed on samples connected to anodes. Smaller i_L

XRD on sections after exposure for 6 months

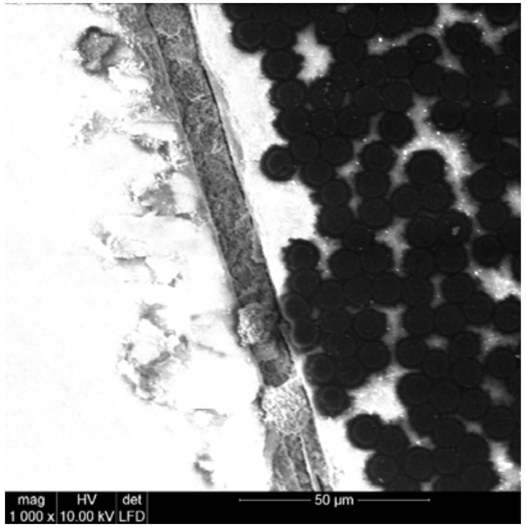


SEM Images of ET CF/VE8084 connected to sacrificial anode

Top view



Cross section view



Experimental

Materials Systems

* CF/VE
** Hybrid Composite

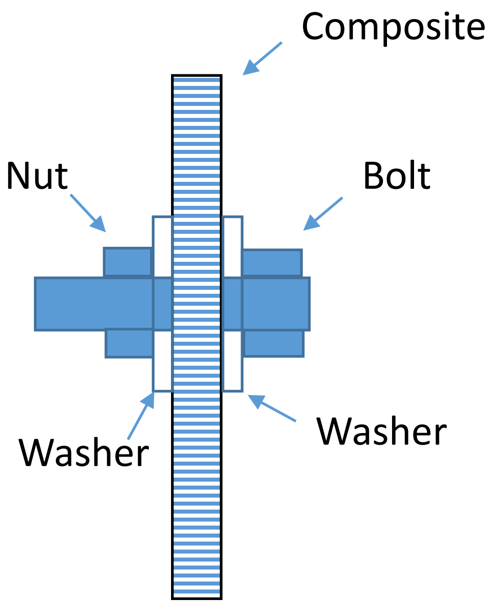
Environmental conditions

- Sea Water /RT
- Sea Water 100°F

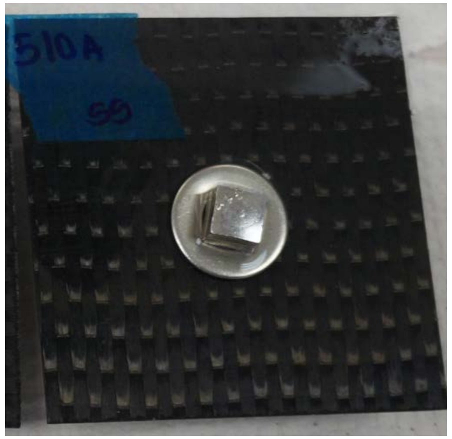
Metal Hardware

Stainless Steel (18% Cr)
Monel (NiCu alloy)
Ti alloy

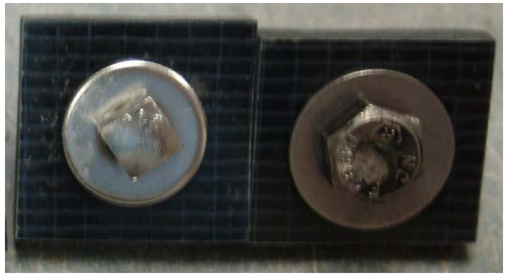
CF/VE panels 1.8 mm thick (6/8 plies unidirectional)
Hybrid (both carbon and glass fiber) 7.5 mm thick
Immersion started November 8, 2018



Crevice assembly using composite as the plate
9.4 mm diameter drilled at the center
Torque: 20 lb-in (2.26 N.m)



CFRP 7.5 cm × 7.5 cm



Hybrid 3.5 cm × 3.5 cm

Number of samples prepared indicating immersion tank

	CF/VE RT	CF/VE ET	Hybrid ET
Stainless Steel	6	6	2
Monel	6	6	1
Ti alloy	6	6	1

Number of samples dis-assembled

	CF/VE RT	CF/VE ET	Hybrid ET
Stainless Steel	4	4	2
Monel	4	4	1
Ti alloy	3	3	1

Number of days at which samples were removed from immersion and dis-assembled

	CF/VE RT	CF/VE ET	Hybrid ET
Stainless Steel	302, 365, 799, 806	273, 323, 652, 729	316, 708
Monel	309, 365, 799, 806	288, 330, 659, 739	704
Ti alloy	330, 448, 806	316, 448, 806	713

Visual inspection at 55, 98, 197, 273, and 600+ (remaining specimens) days.

Samples removed from immersion and dis-assembled starting at day 273, last set at day 806. Stereo microscope and selected samples observed on SEM.

Location where crevice corrosion could develop

The specimen as shown in Figure can lead to the following crevice geometries:

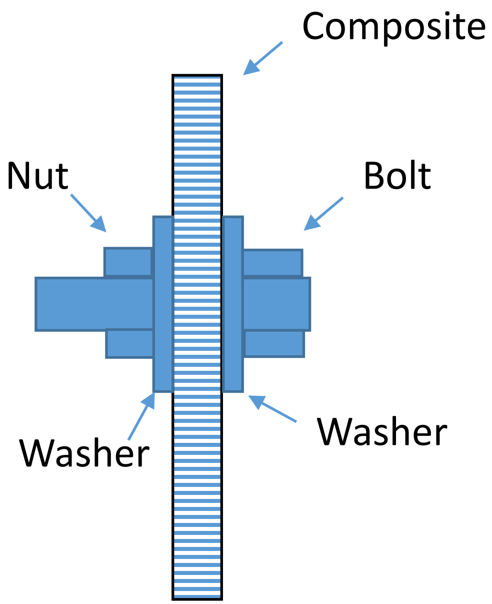
C1: Between the washer/smooth side of the carbon fiber

C2: Between the washer/rough side of the carbon fiber

C3: Between the nut and the washer

C4: Between the bolt head and the washer

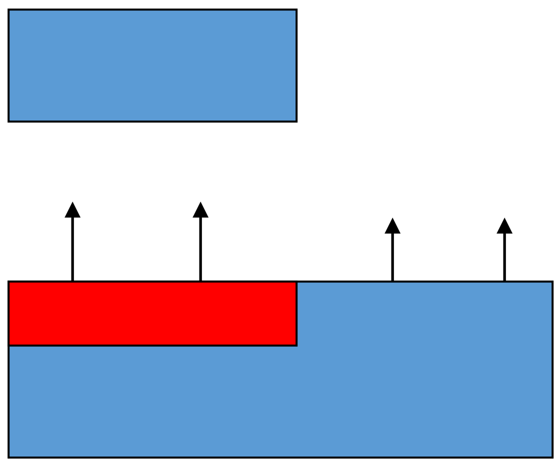
C5: Between the threads of the bolt and the matching threads of the nut.



Crevice assembly using composite as the plate

These tight occluded regions are sites prone for crevice corrosion to occur. In here the focus is on C1 and C2 geometries, as it corresponds to the composite to metal contact. However, a few examples for C3, C4 and C5 geometries are included.

Differential aeration cell - Fundamentals

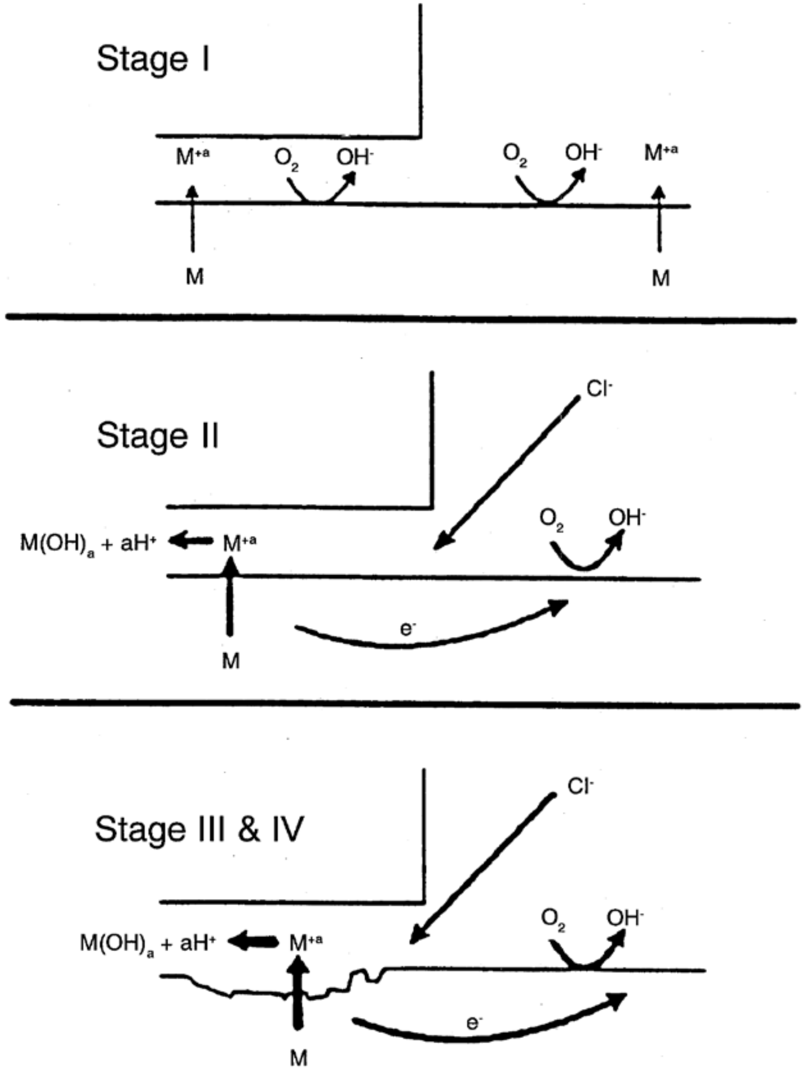


Red –indicates anode

The oxygen reduction reaction occurs at drastically different rates inside the crevice where oxygen is depleted.

- oxygen depleted inside
- ferrous ion hydrolyze
- Fe activates inside, remains passive outside.
- Corrosion rate inside becomes large with anode (inside) and cathode (oxygen reduction outside)
- *At first corrosion is actually worse on the outside because of ready supply of O_2*

Crevice Corrosion - Fundamentals

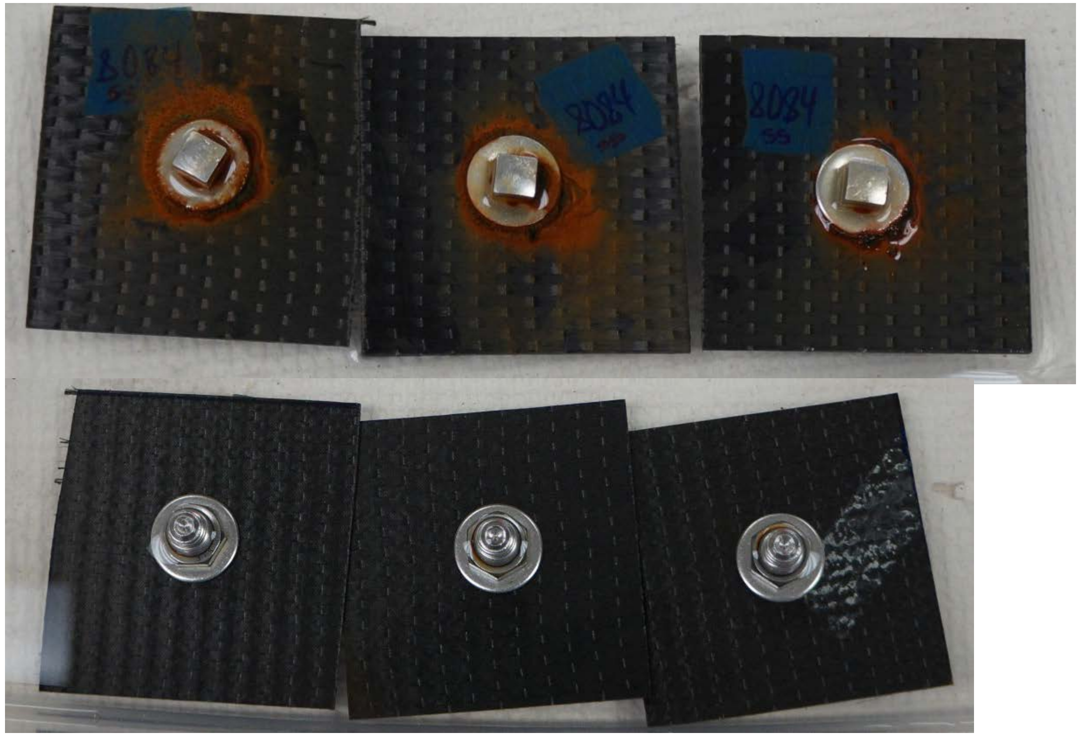


- Oxygen is readily depleted in crevice
- Anode and cathode become separated
- Metal ions hydrolyze, and chloride migrates to maintain electro-neutrality
- Severe crevice chemistry depassivates metal inside crevice, active corrosion occurs

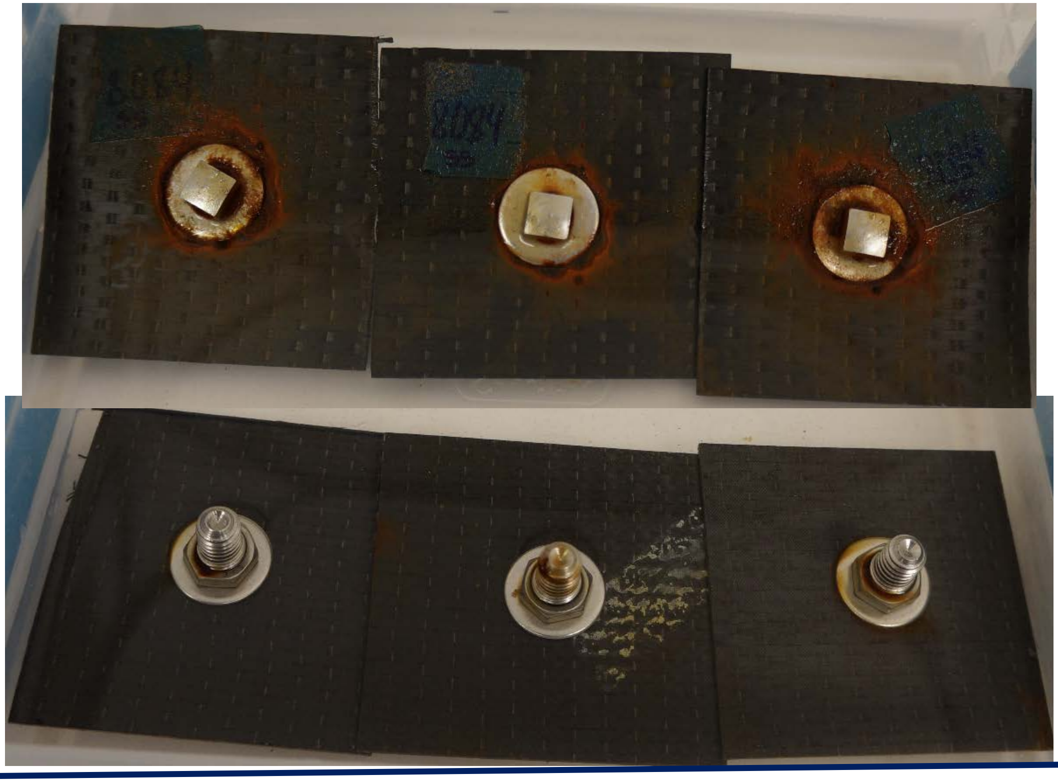
Stainless Steel/CFRP composite fastened samples

Room Temperature

Observations after 55 days of immersion



Observations after 273 days of immersion



Elevated Temperature

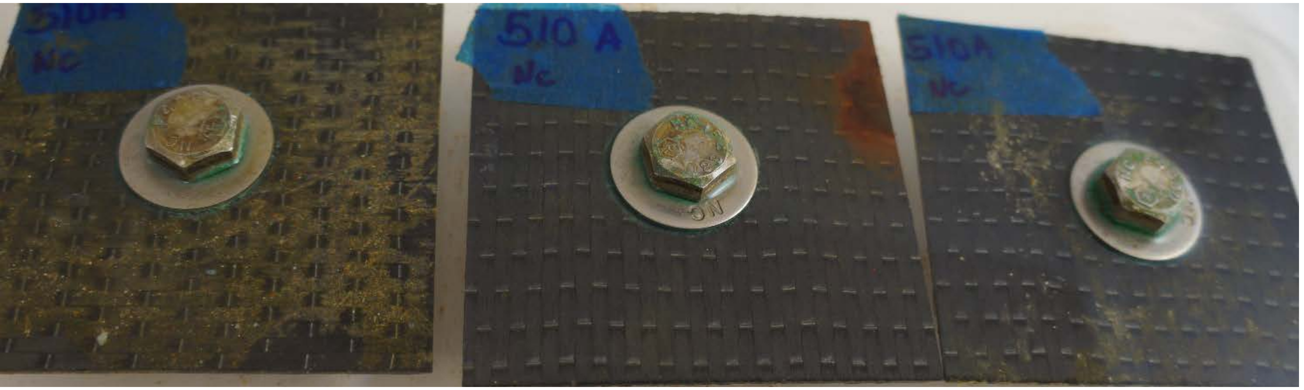
after 55 days of immersion

after 273 days of immersion

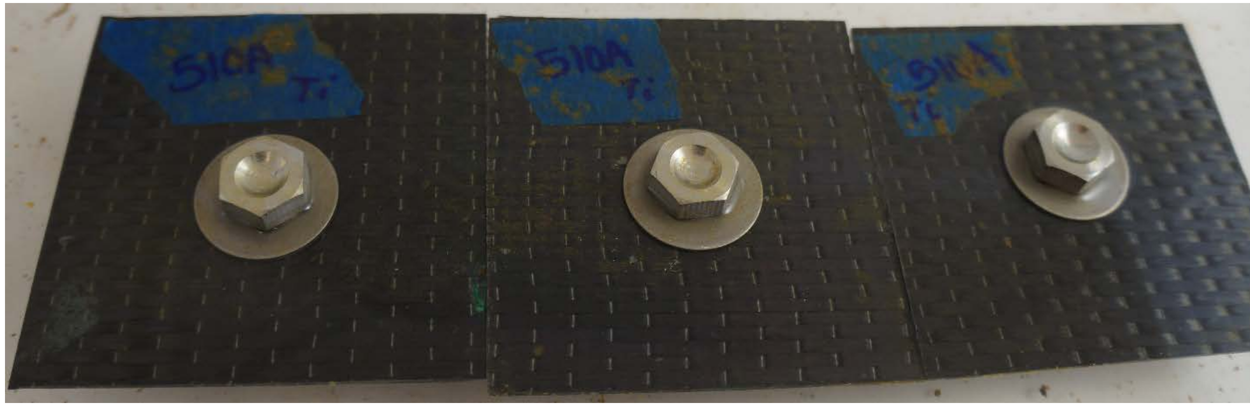
Elevated Temperature

Monel or Ti /CFRP composite fastened samples

Monel, immersed for 55 days



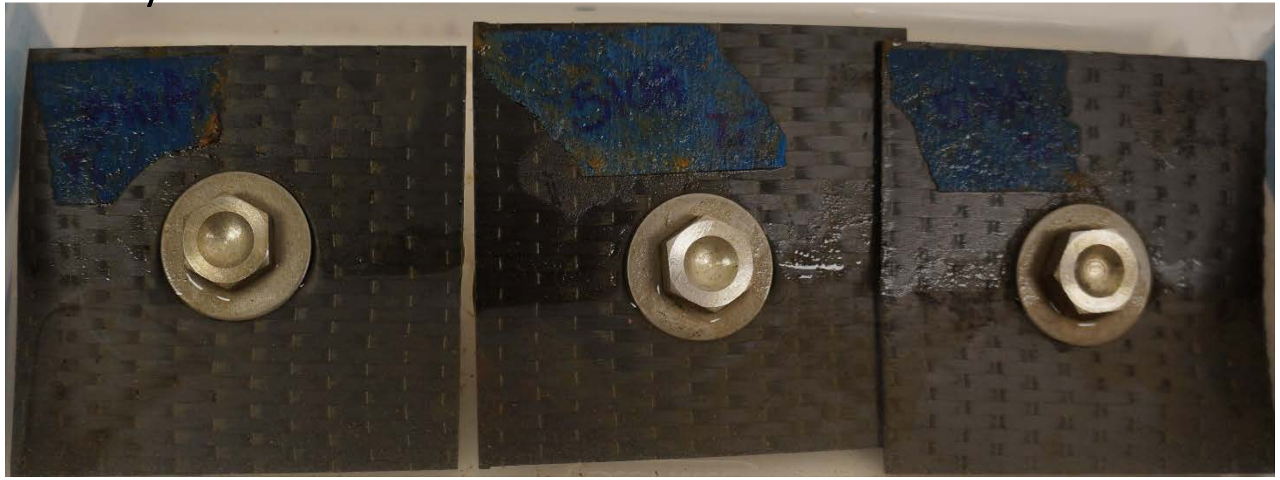
Ti, immersed for 55 days



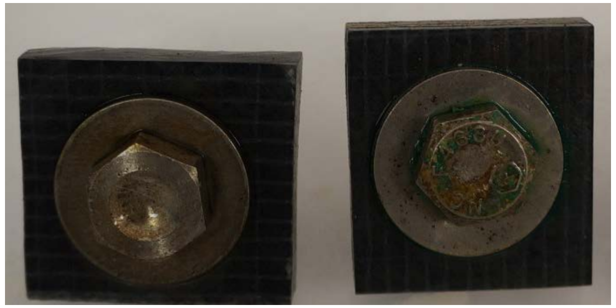
immersed for 273 days

Monel

Ti

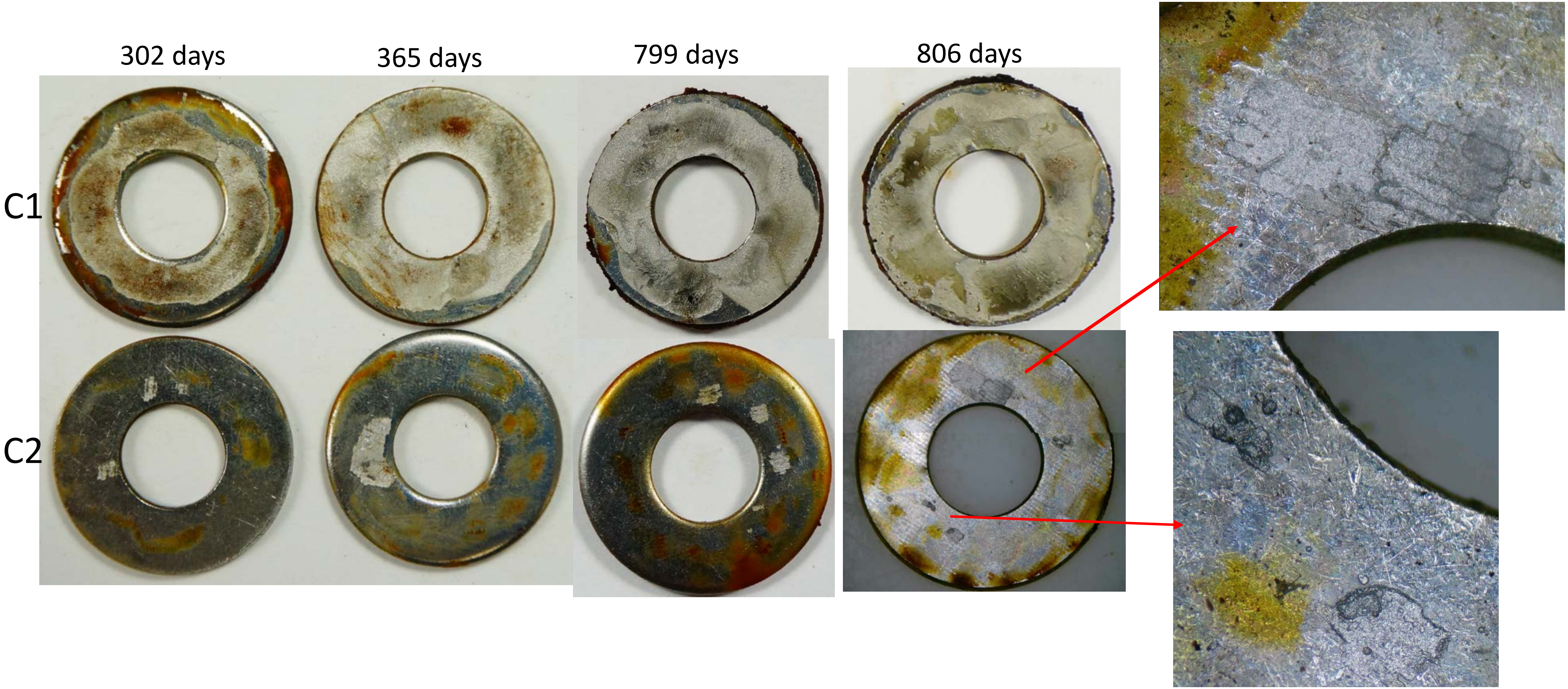


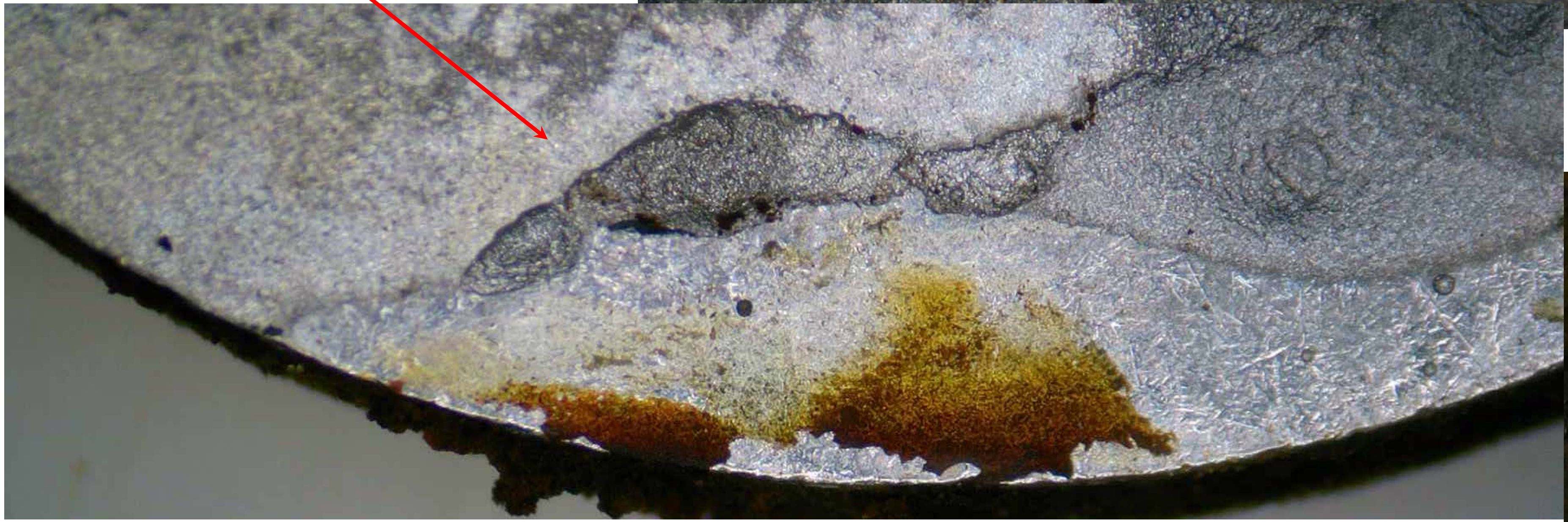
Left
Hybrid- Monel
Right
Hybrid - Ti



Room temperature immersed in Seawater

Stainless Steel Washers in contact with the CFRP composite, top row smooth side, bottom row rough side



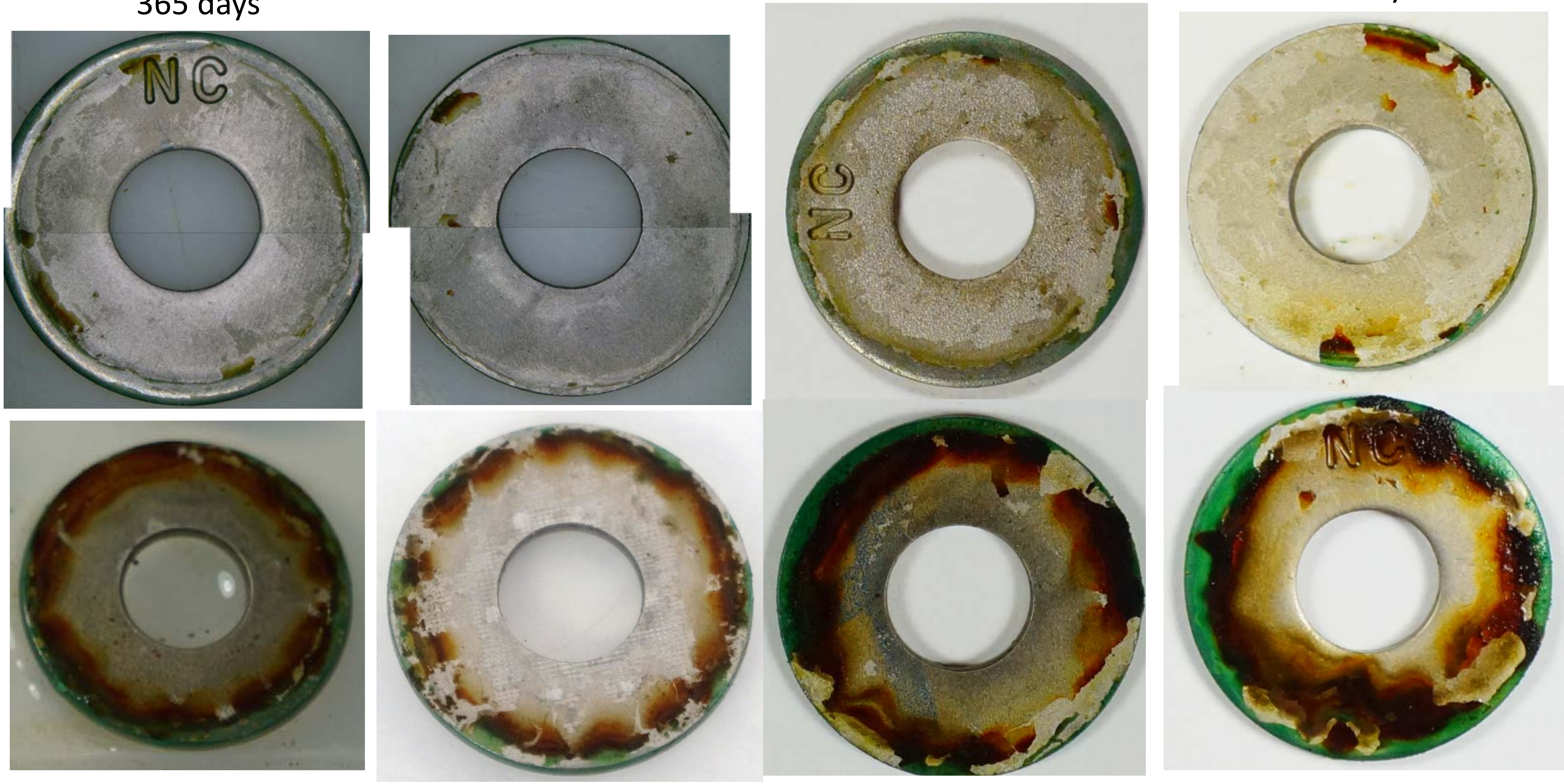


806 days
Washer in contact with smooth composite

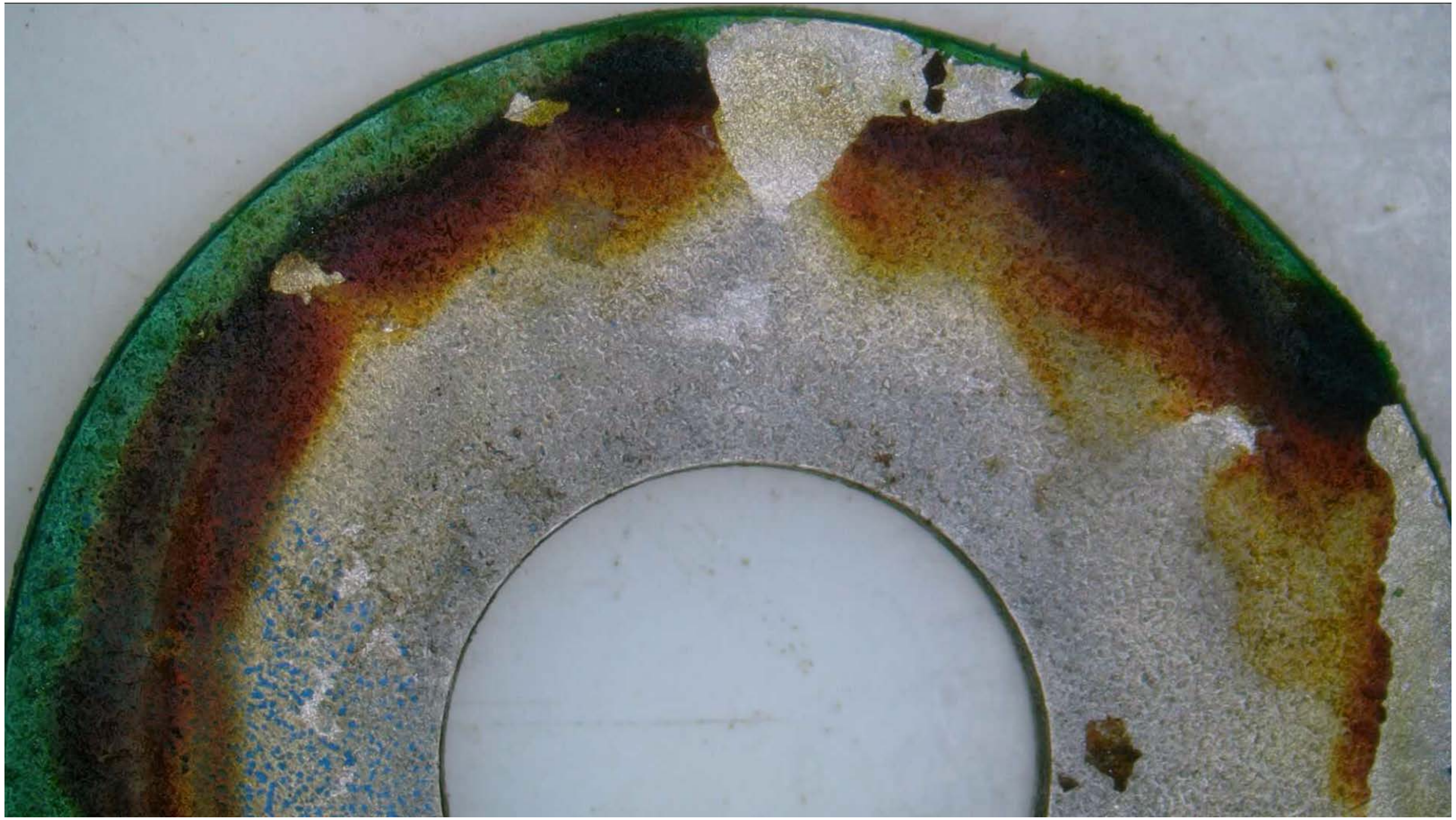
Room temperature immersed in Seawater

Monel washer surfaces in contact with the CFRP composite, top row smooth side, bottom row rough side

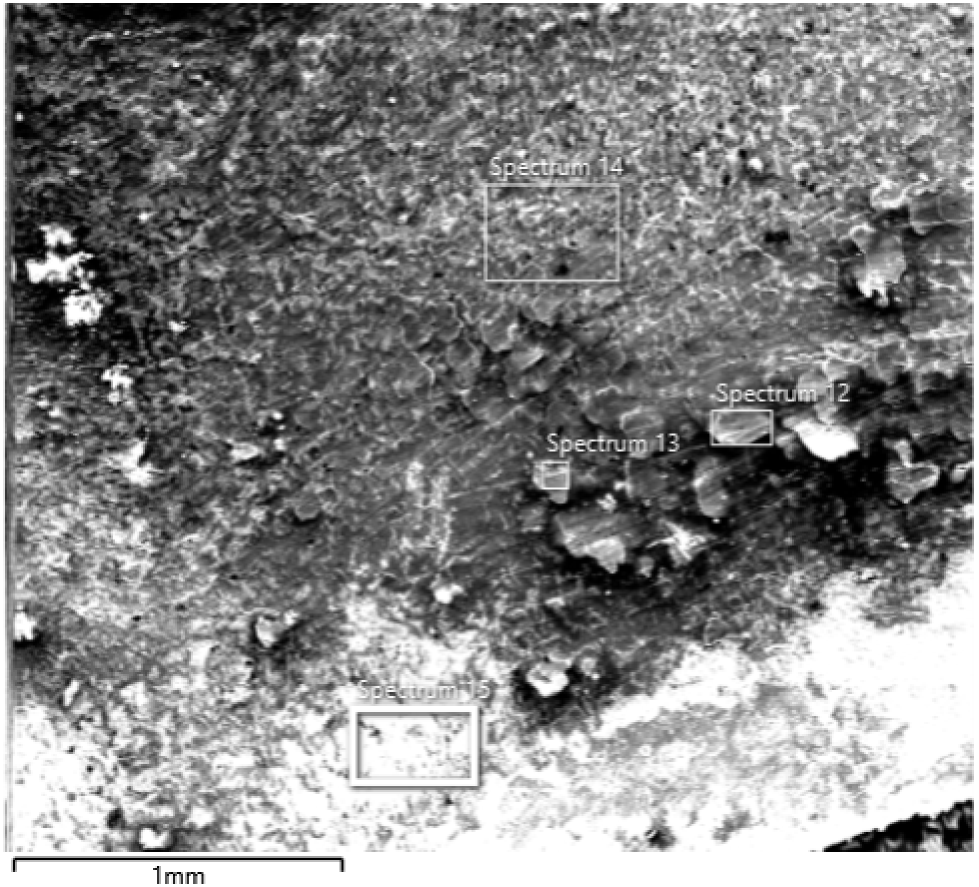
365 days | 309 days | 799 days | 806 days

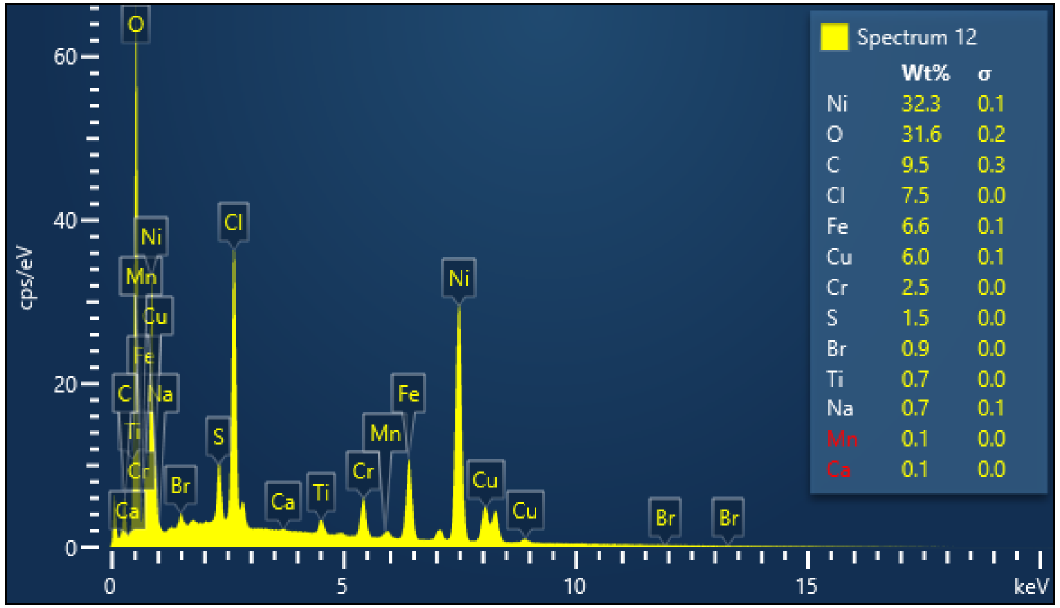


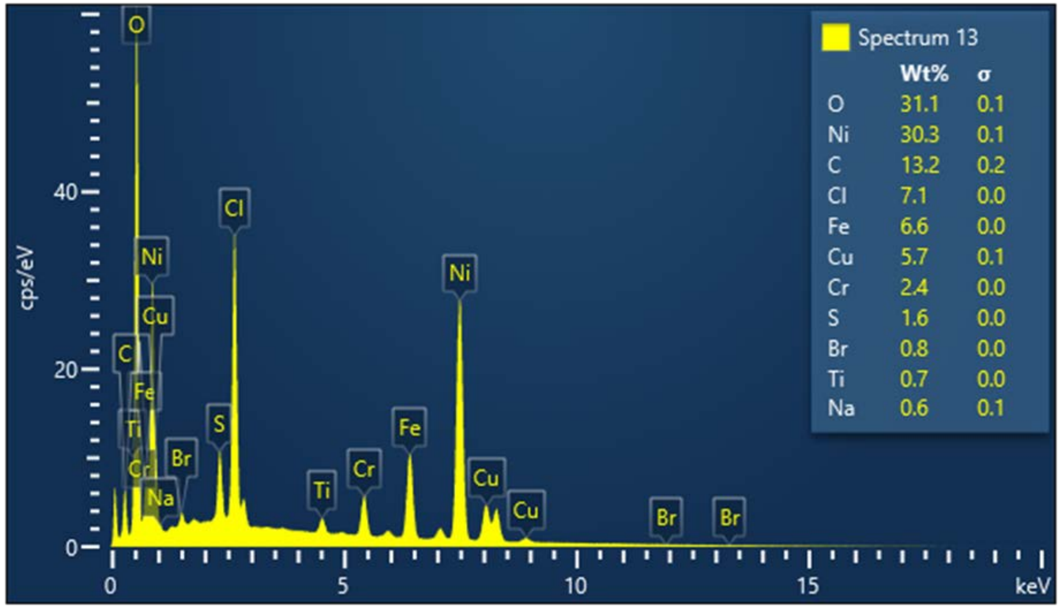
799 days, on the left in contact with smooth CFRP composite, below in contact with rougher CFRP composite surface



Electron Image 5







Room temperature immersed in Seawater

Ti washer surfaces in contact with the CFRP composite, top row smooth side, bottom row rough side

330 days 448 days

806 days

Elevated Temperature – Stainless Steel

Stainless Steel Washers in contact with the CFRP composite, top row smooth side, bottom row rough side

273 days

8084-2019

323 days

510-2019

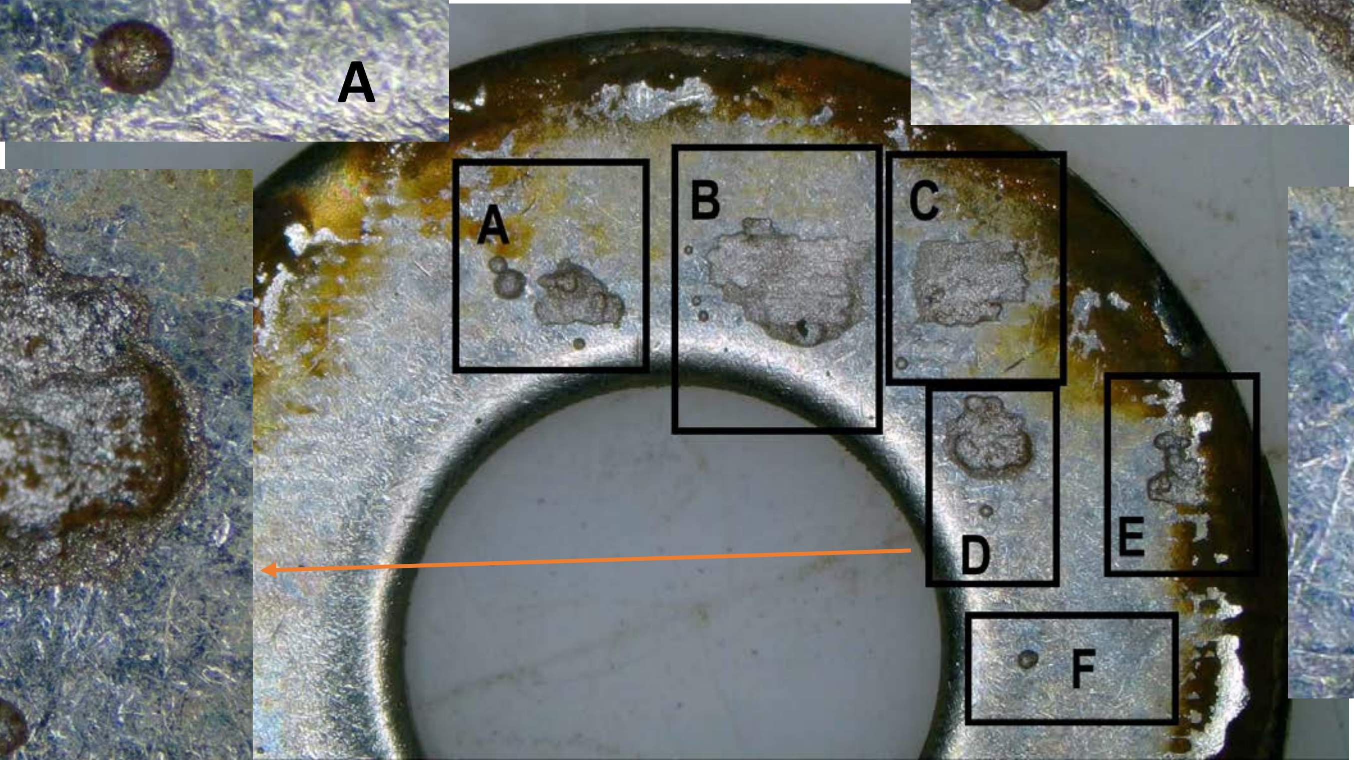
729 days

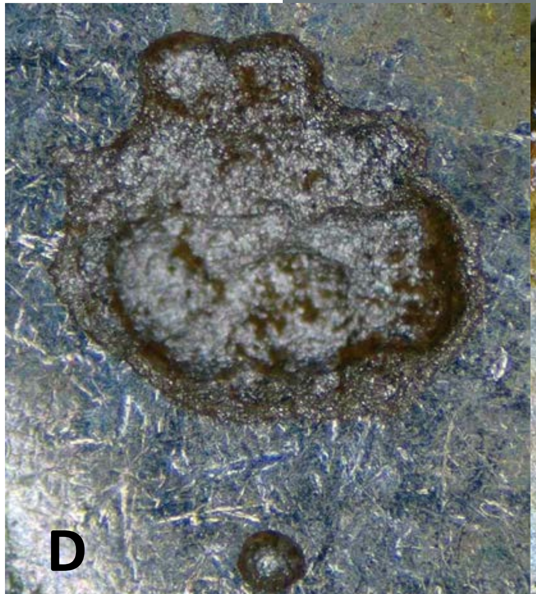
8084-2020

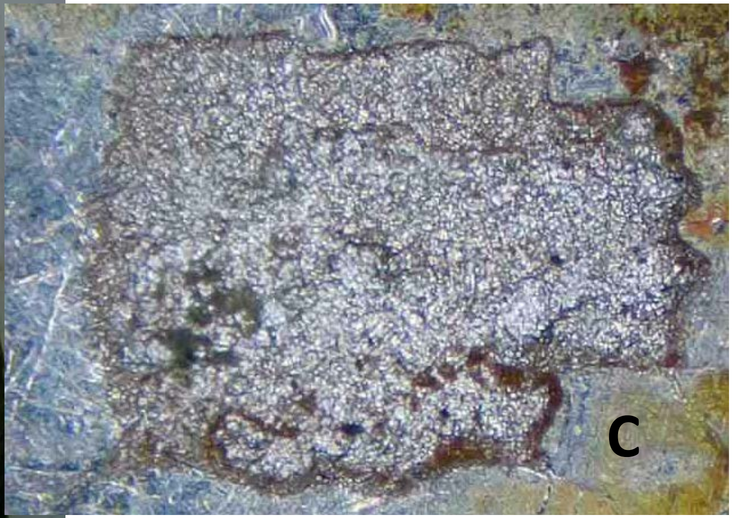
652 days

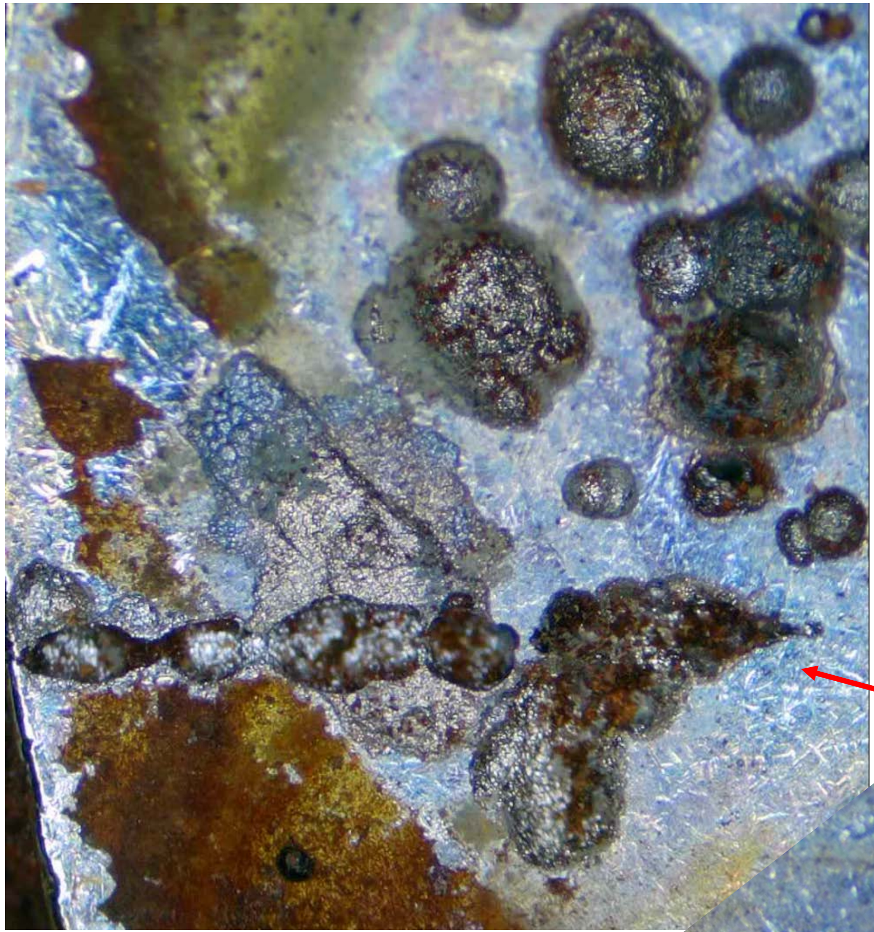
510-2020

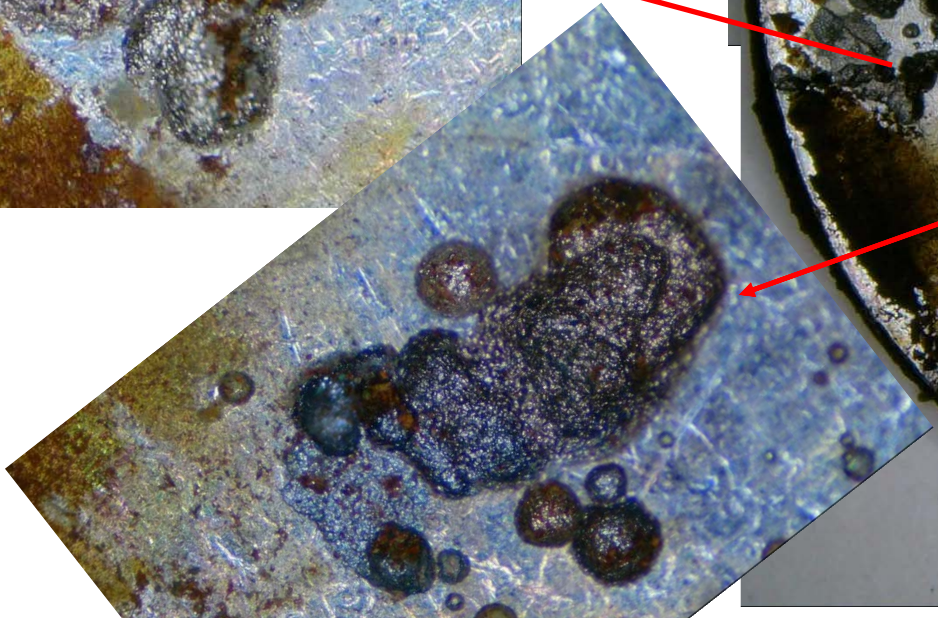
323 days



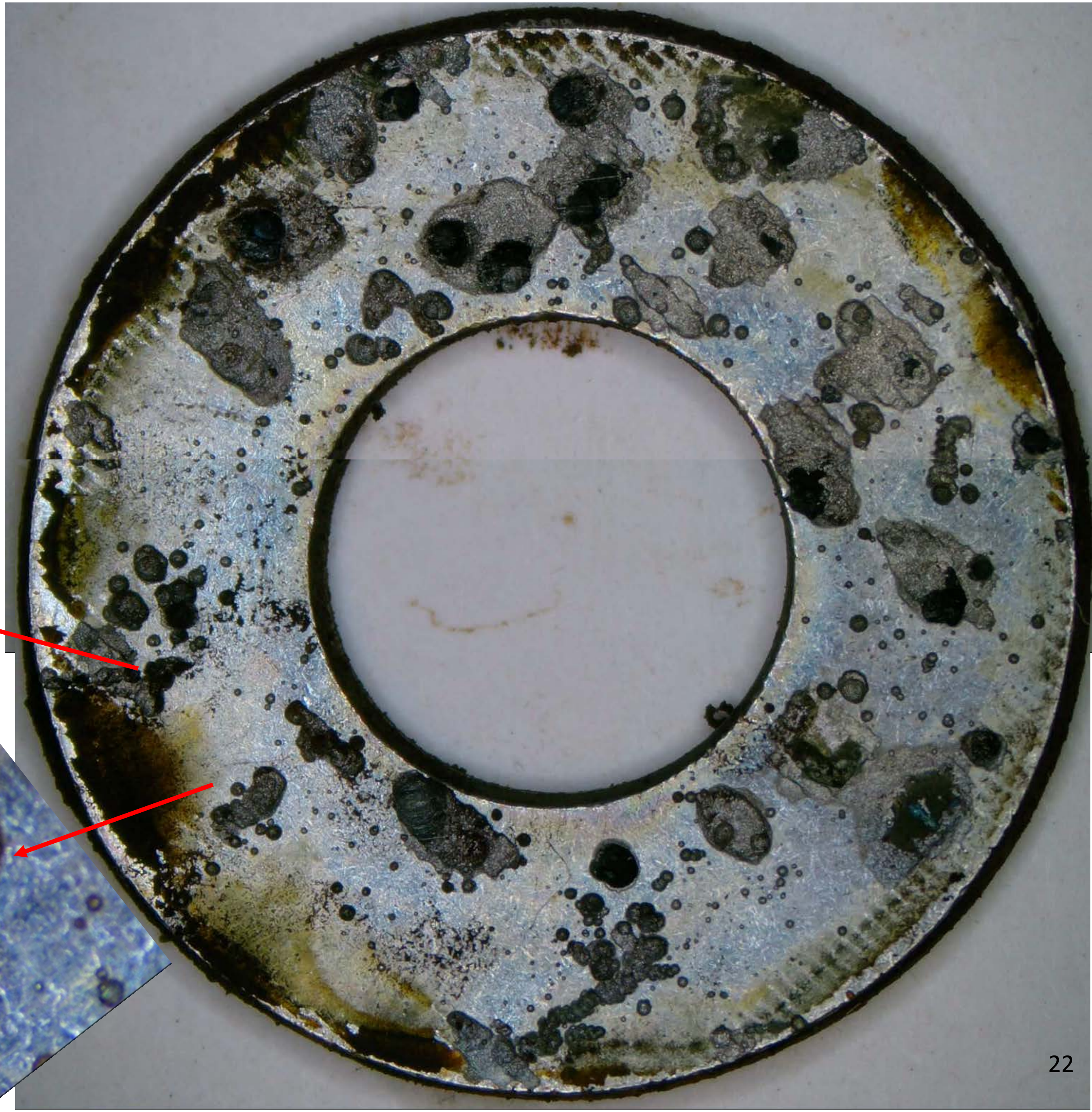








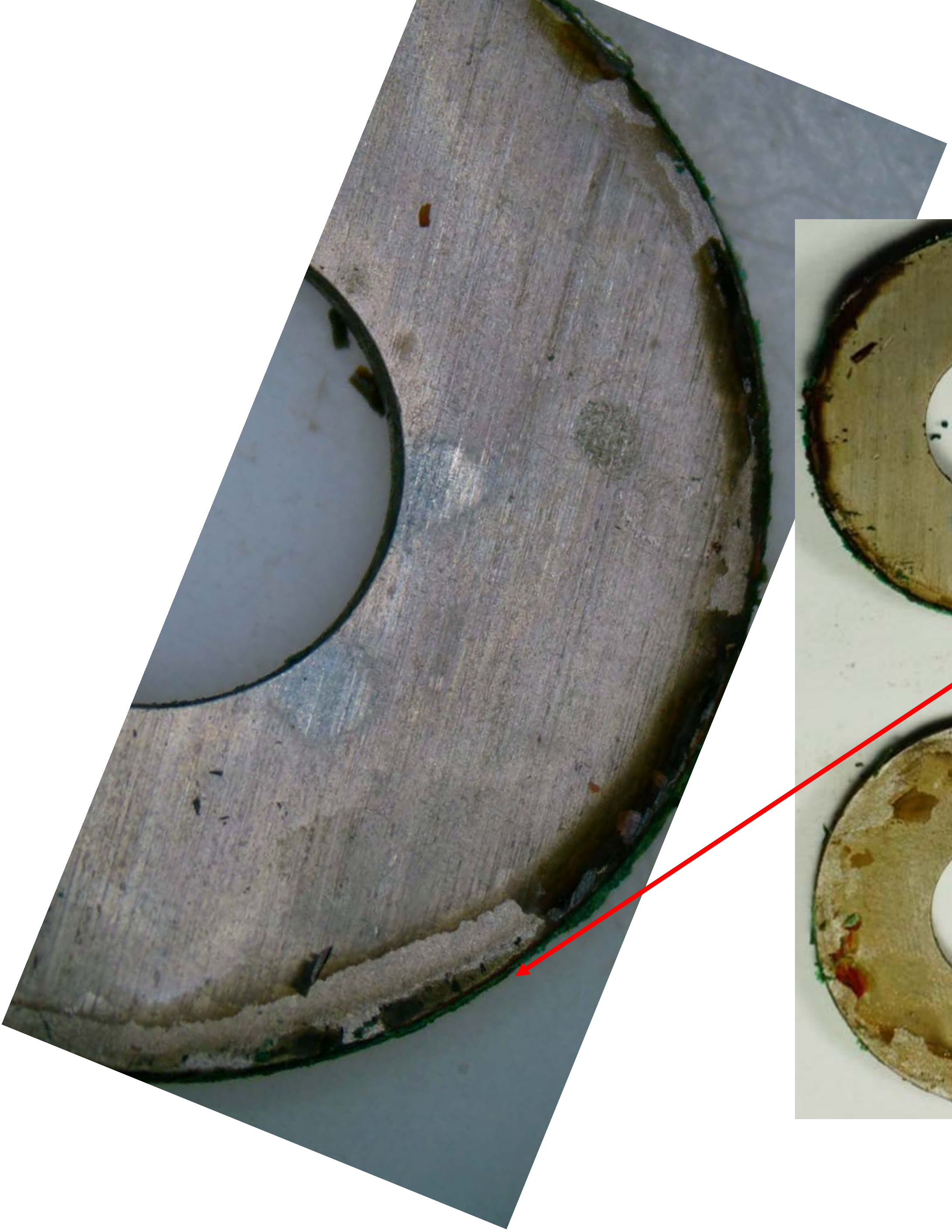
652 days

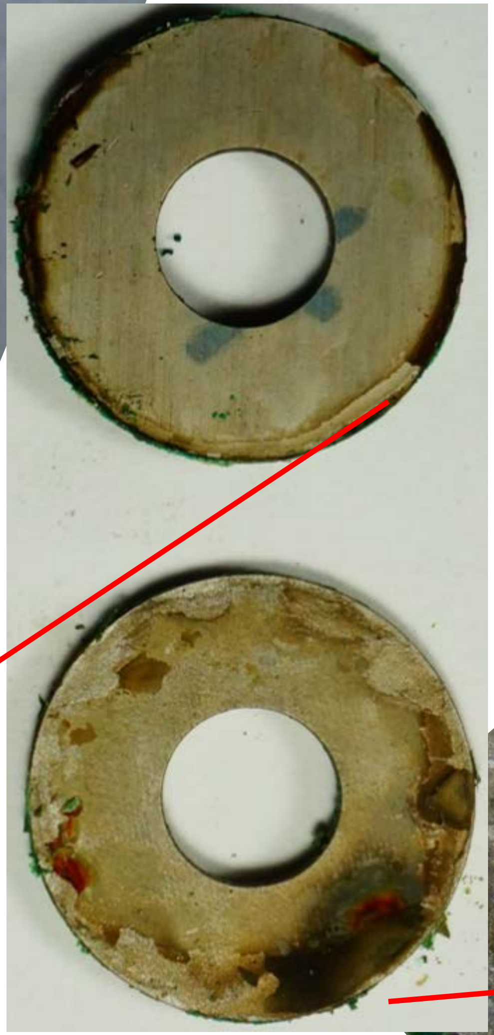


Elevated Temperature

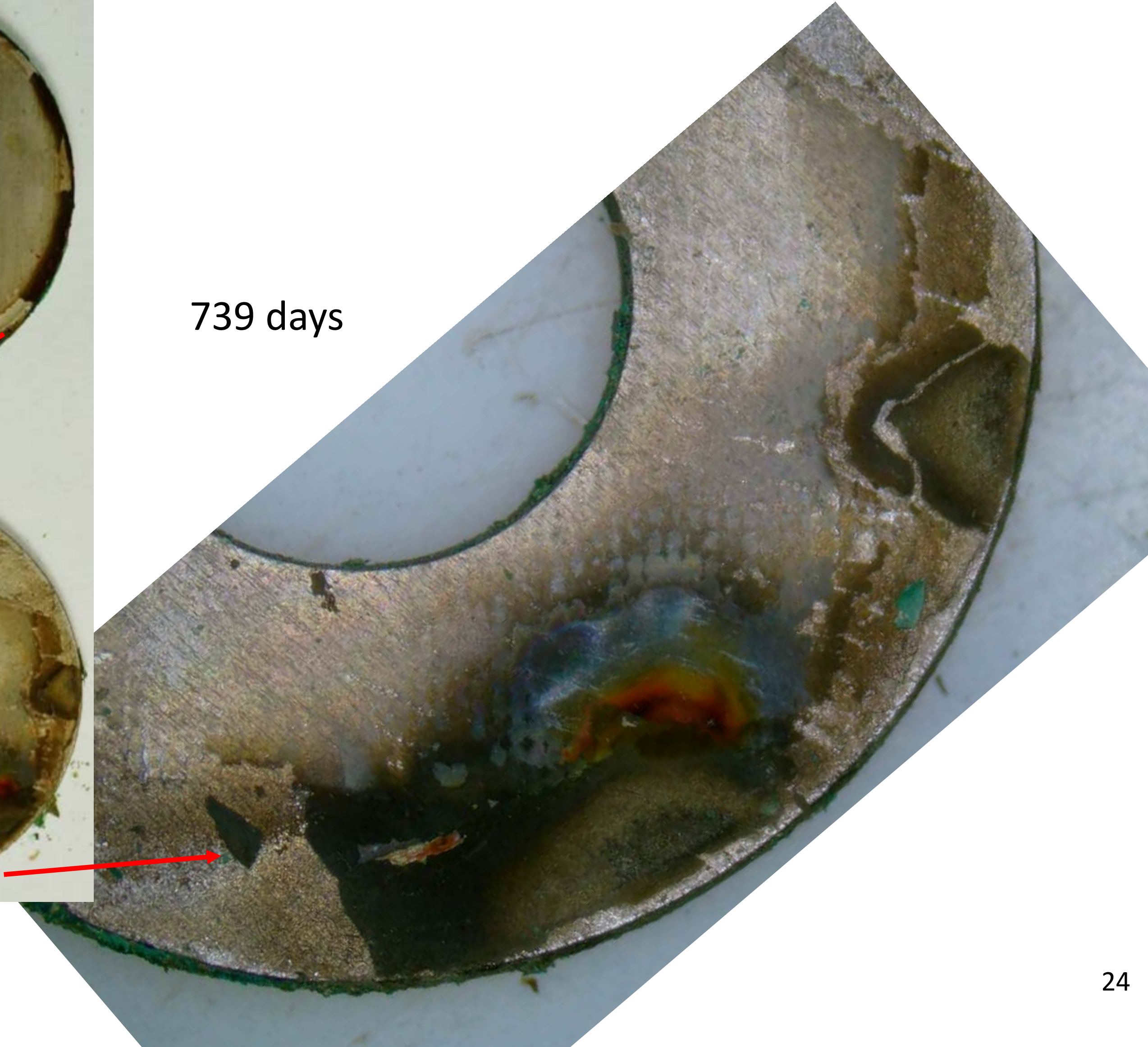
Monel Washers in contact with the CFRP composite, top row smooth side, bottom row rough side

288 days | 330 days | 659 days | 739 days





739 days



Elevated Temperature

Titanium washers in contact with the CFRP composite, top row - smooth side, bottom row - rough side

316 days

448 days

806 days

Elevated Temperature

Washers in contact with the Hybrid composite, top row - smooth side, bottom row - rough side

316 days 708 days

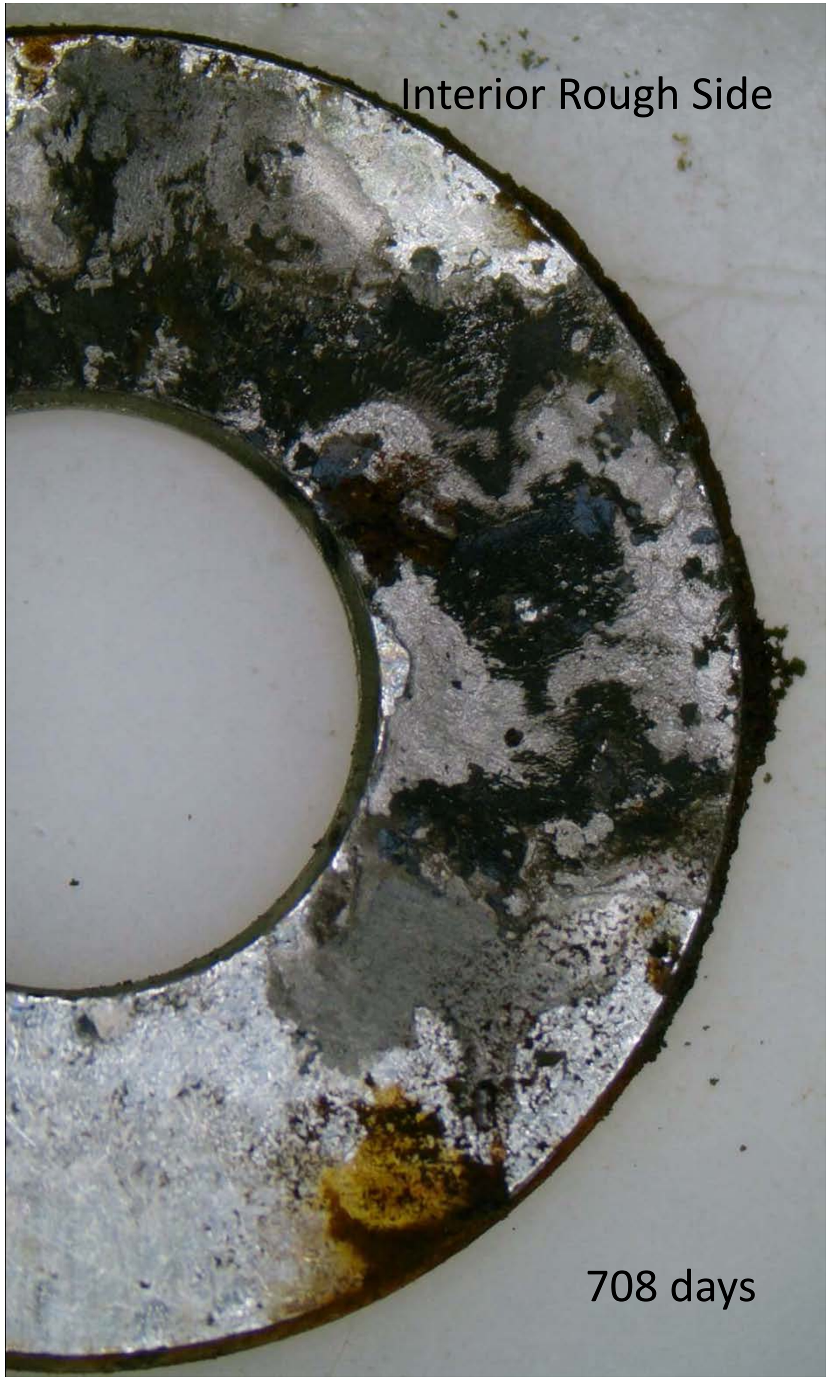
Stainless Steel

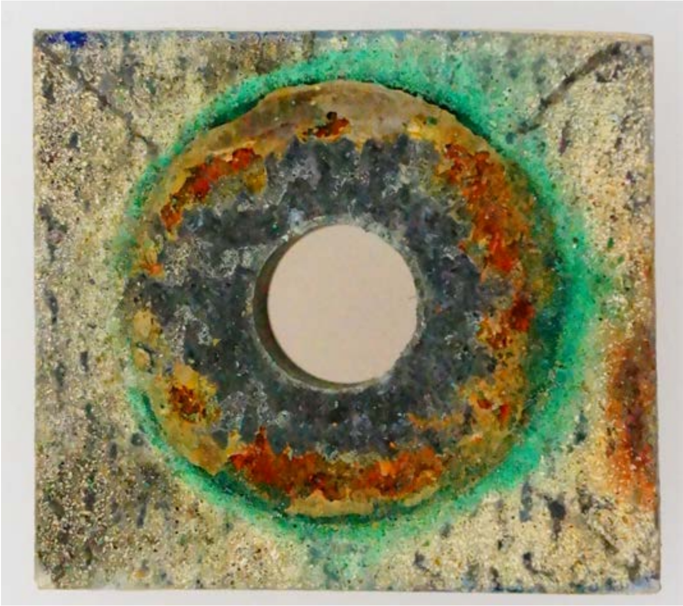
704 days

Monel

713 days

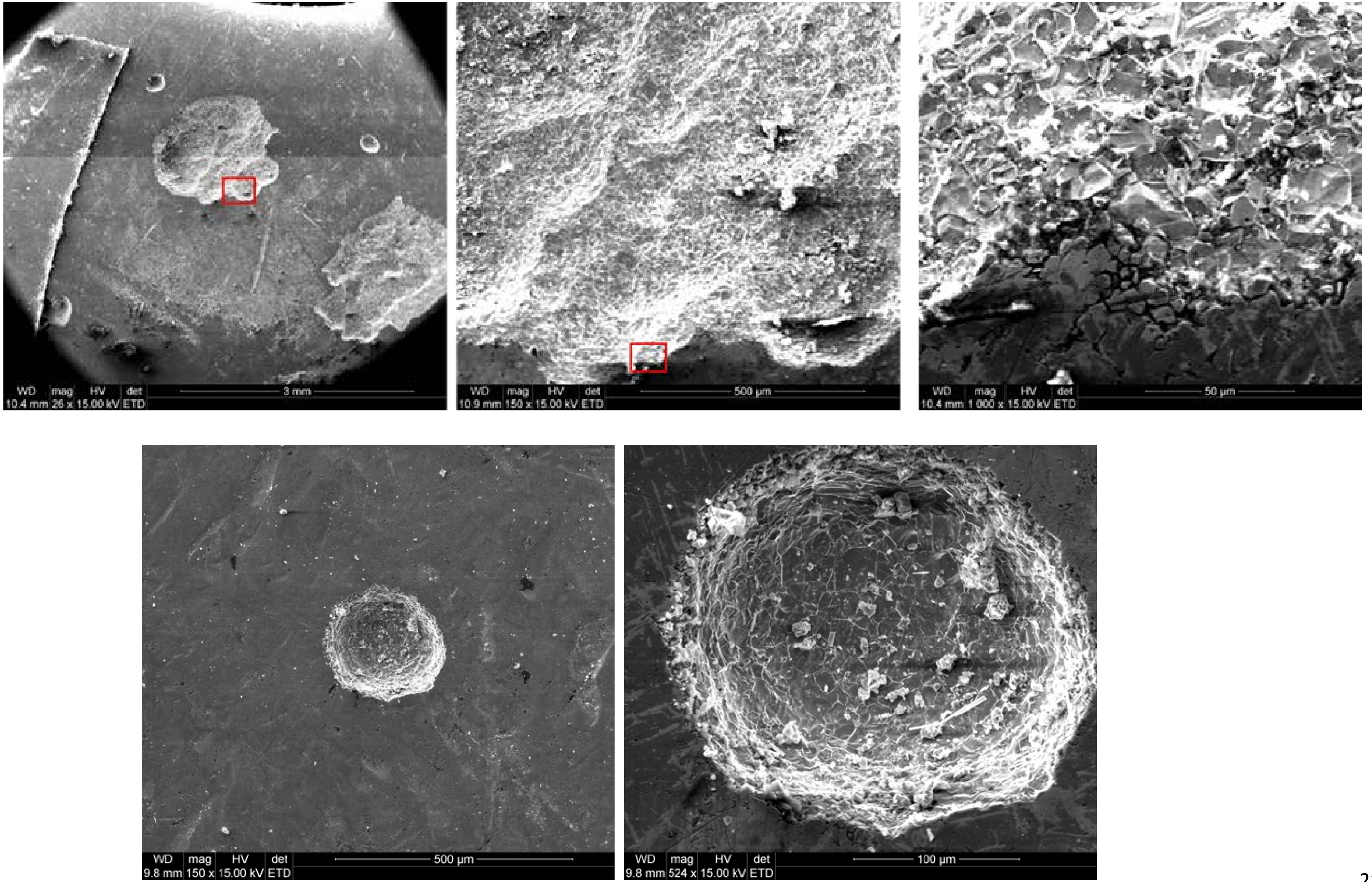
Titanium





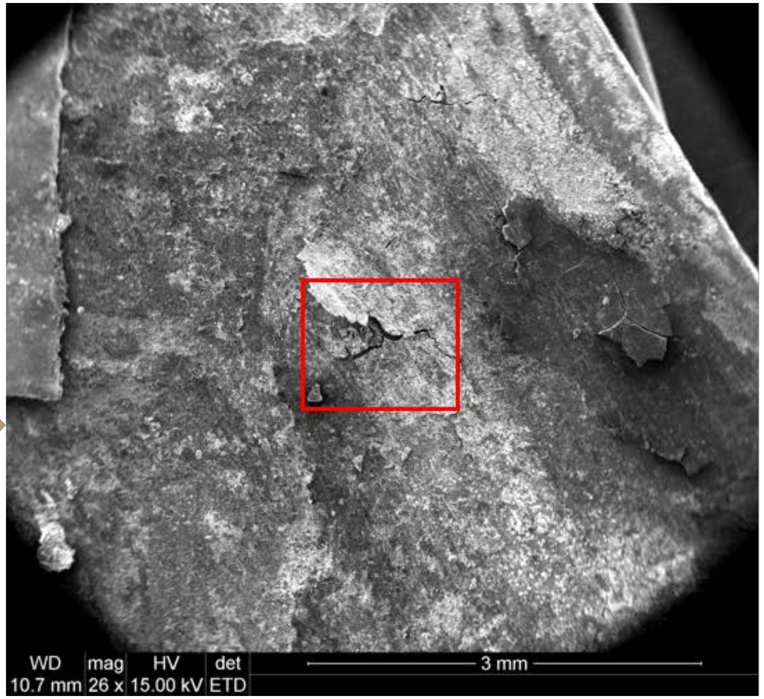
Composite corresponds to samples fastened with Monel

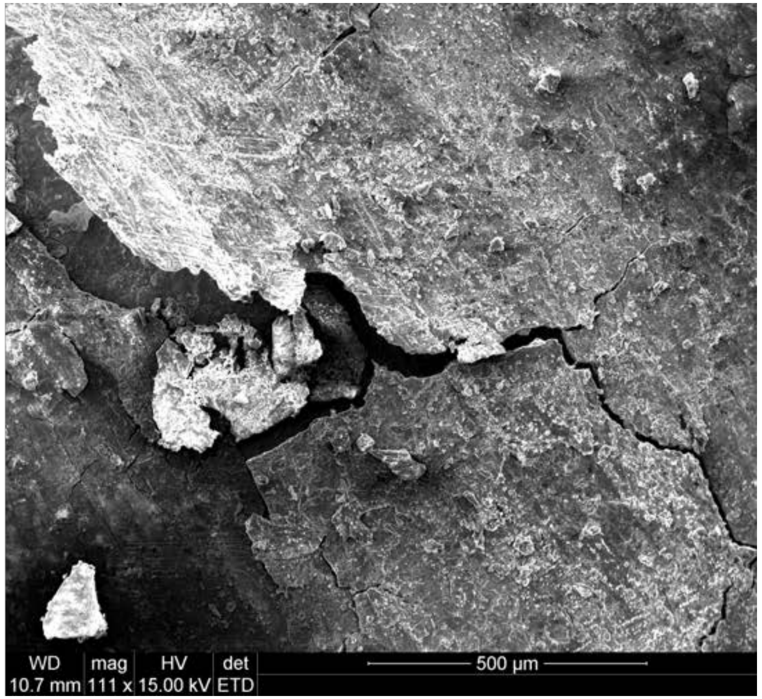
SEM observations

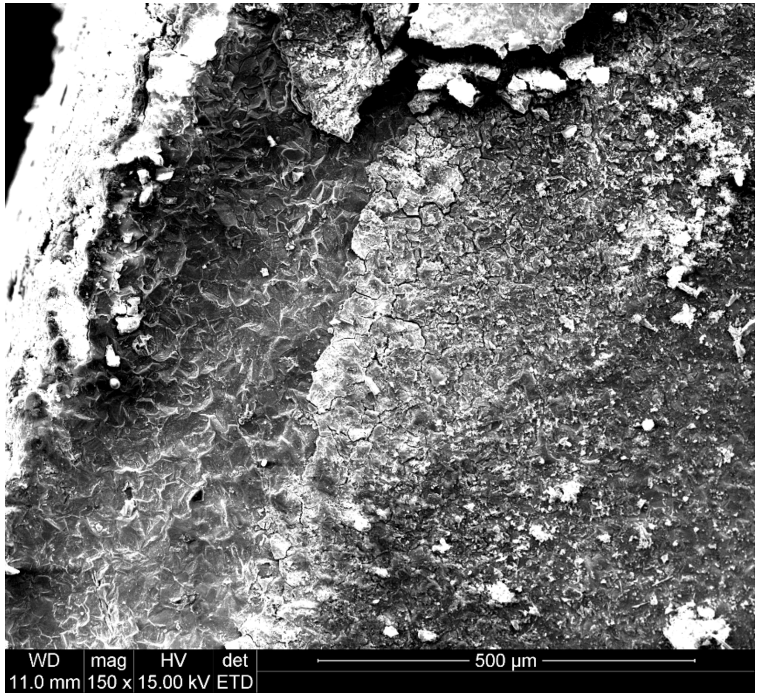


323 days

Monel


WD mag HV det
10.7 mm 26 x 15.00 kV ETD
3 mm


WD mag HV det
10.7 mm 111 x 15.00 kV ETD
500 µm


WD mag HV det
11.0 mm 150 x 15.00 kV ETD
500 µm

Elevated Temperature – Stainless Steel

Stainless Steel Washers in contact seawater, top row bolt, bottom row nut side

Elevated Temperature – Monel

Stainless Steel Washers in contact seawater, top row bolt, bottom row nut side

Elevated Temperature

Washers in contact with the Hybrid composite, top row – bolt side, bottom row –nut side

316 days

708 days

Stainless Steel

704 days

Monel

713 days

Titanium

Example of a C3 site (crevice corrosion between nut and washer surfaces)

Nut side in contact with washer

Washer in contact with nut




Example of a C
(crevice corros
between nut a
washer surface

ated Temperature –
nless Steel (652 days)

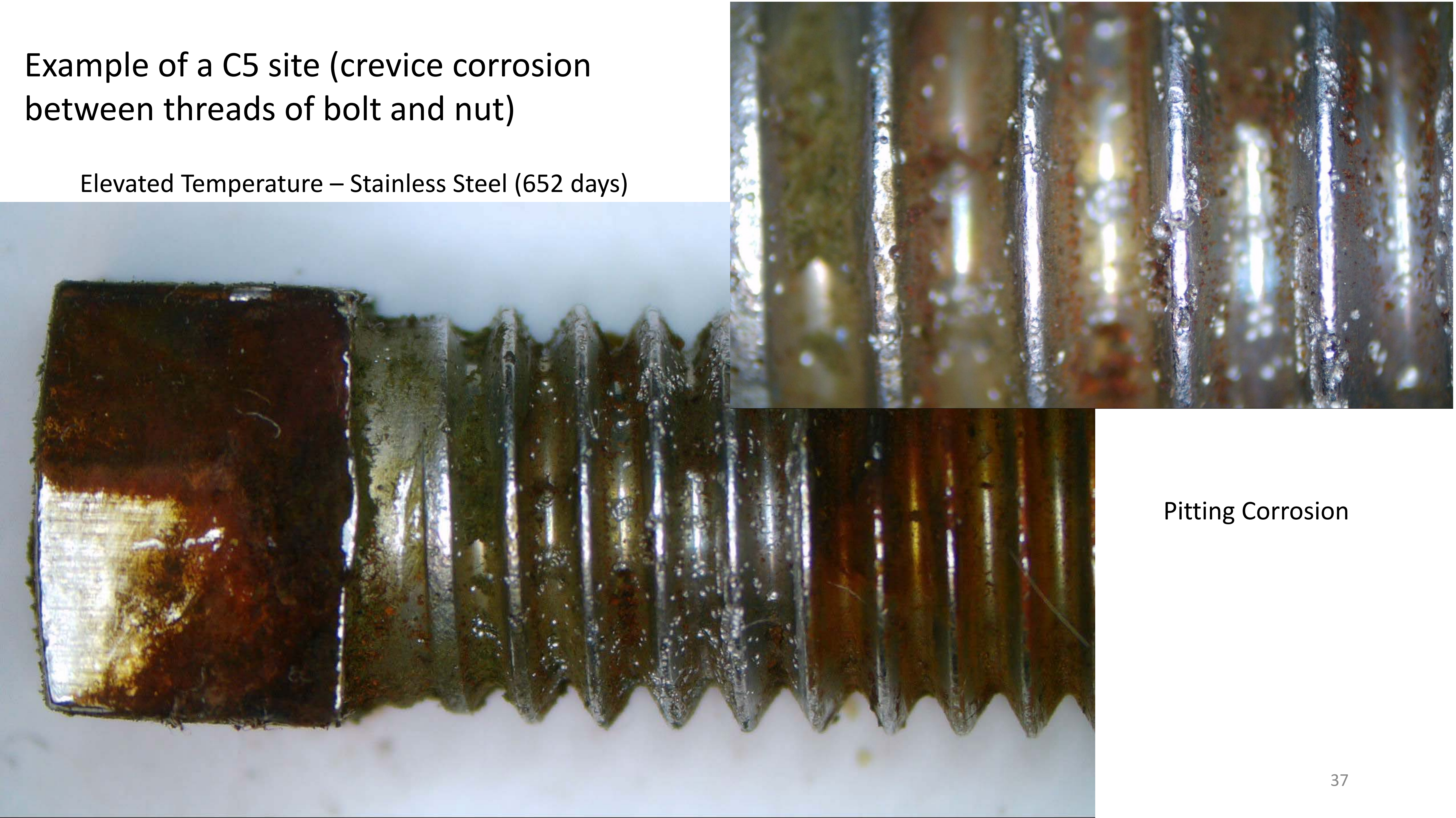
Example of a C3 site (crevice corrosion between nut and washer surfaces)

Example of a C4 site (crevice corrosion between bolt and washer surfaces)

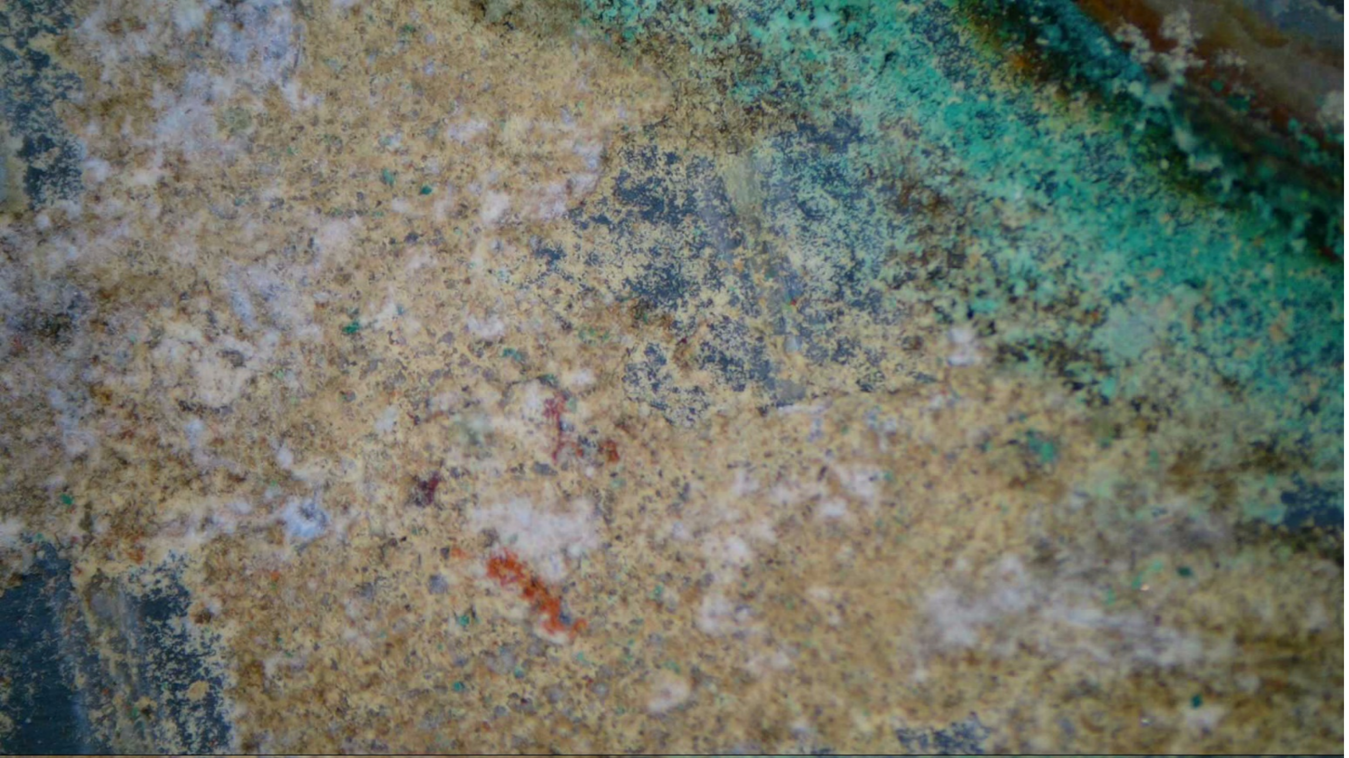
739 days

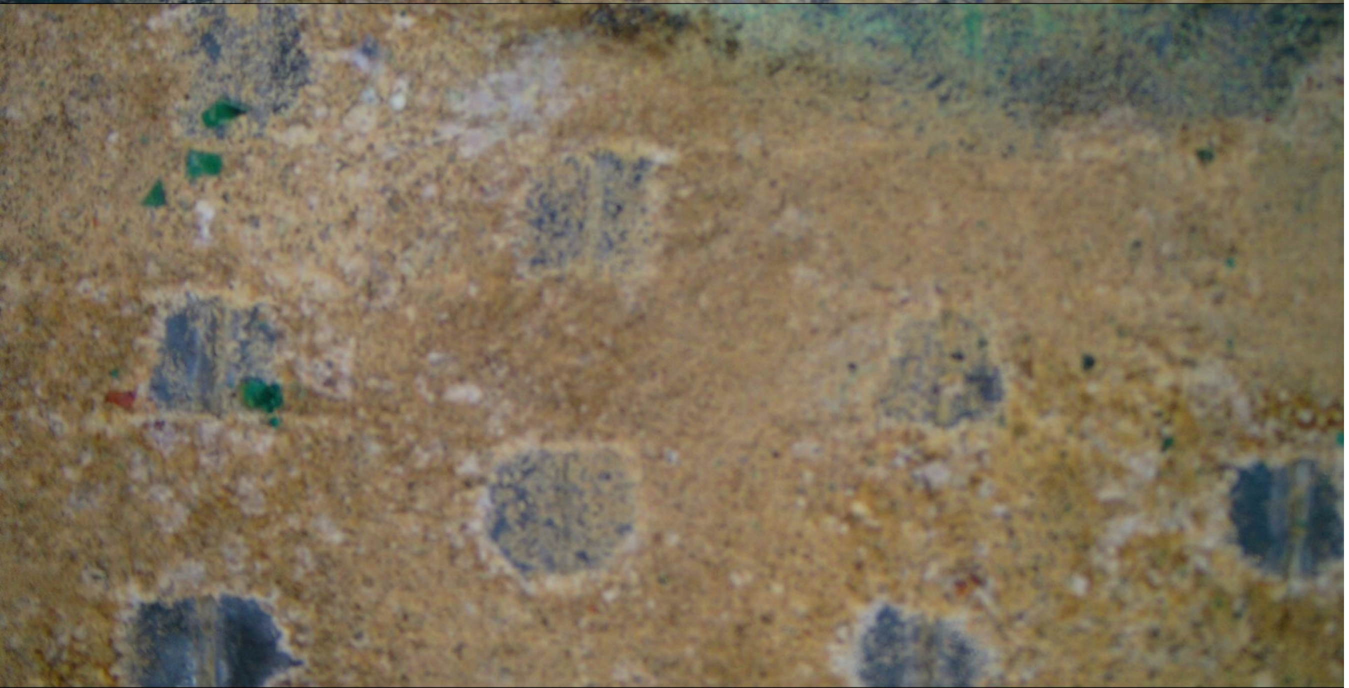
Example of a C5 site (crevice corrosion between threads of bolt and nut)

Elevated Temperature – Stainless Steel (652 days)

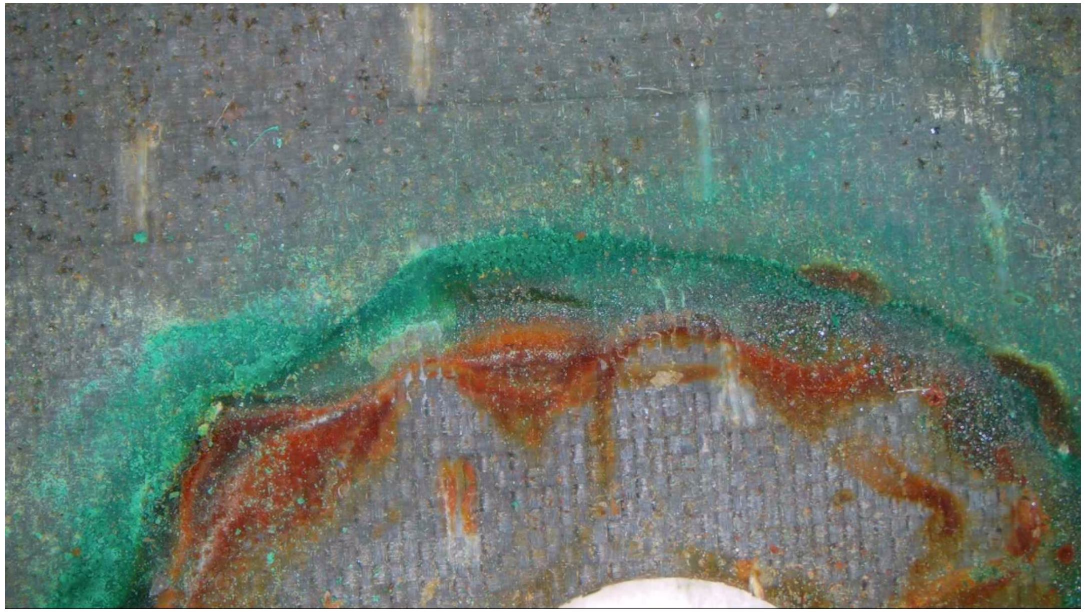


Pitting Corrosion





On the left two close-up images of the composite surface on the bolt side, with calcareous deposits. Below, the composite surface on the nut side. Note the washer inprint and that there are almost no calcareous deposits. Possibly due to the rougher surface of the composite.



Conclusions

Crevice Corrosion of type C1 and C2 were observed on Monel and Stainless steel washers.

Crevice corrosion appears to be more pronounced on samples exposed in the elevated temperature seawater

C1 corrosion occurred with large surface coverage on stainless steel, and most corrosion products leached out.

C2 corrosion occurred as different sizes of pits on stainless steel and as brown corrosion products that flaked easily on Monel washers.

No corrosion took place on the Titanium washers within the time monitored

Thank You,
Questions?

Acknowledgments

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