Barrier Properties and Galvanic Corrosion Resistance

Electrochemical Impedance Spectroscopy (EIS) was used to evaluate the barrier properties of the Gentoo coating. Aluminum alloy UNSA92024 coupons were coated with MIL-PRF-85285D grey polyurethane (1.0 mil thick) and tested with and without the addition of Gentoo. Initial testing (i.e. "dry") of the samples showed similar impedance across the full frequency range (Figure 4). After exposure to ASTM B117 salt fog conditions for 336 hours, the samples were retested. The polyurethane only sample showed a significantly larger reduction in impedance (~two decades) compared to the Gentoo, indicating significantly better barrier properties for the coupon.

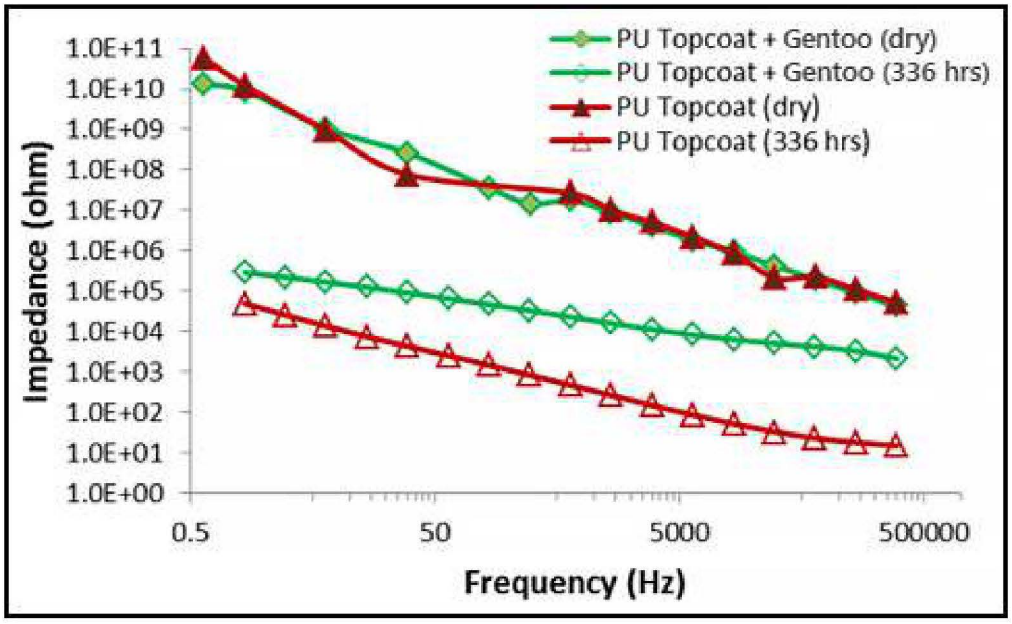

Figure 4

Electrochemical Impedance Spectroscopy (EIS) testing: MIL-PRF-85285D Polyurethane coated UNSA92024 aluminum alloy.

Galvanic corrosion around cathodic fasteners mated to anodic aluminum alloy structures is a common problem in the aircraft community. It is known that galvanic corrosion of aluminum is controlled by the available cathodic current, and that a reduction in available current should result in less corrosion damage. As an assessment of the possible galvanic protection attributes of Gentoo, polarization testing was conducted on a bare 316 stainless steel flat coupon and compared to a similar coupon with Gentoo applied. Results from the tests are observed in Figure 5. The addition of Gentoo resulted in an approximate two-order of magnitude reduction in cathodic current density compared to the bare 316 stainless steel coupon.

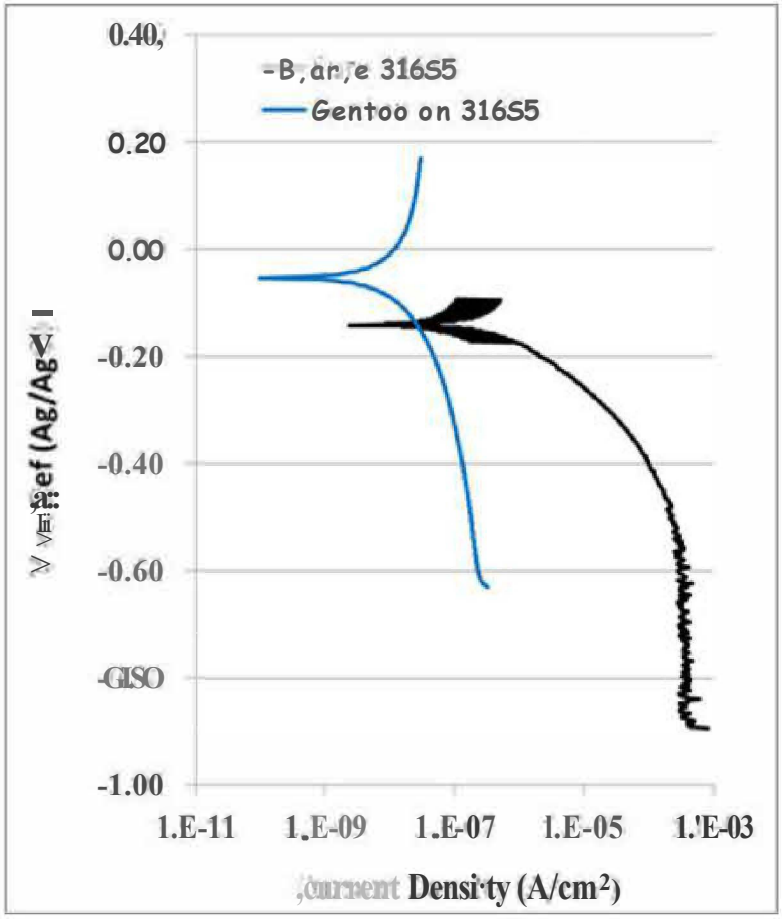

Figure 5

Polarization test results for a bare 316 stainless steel substrate compared to a similar substrate with Gentoo.

Fastener Assembly Galvanic Corrosion Testing

As a further assessment, several 316 stainless steel screws and washer assemblies were prepared bare, and separately coated with Gentoo. The fasteners were attached to primed and topcoated aluminum alloy 7075-T6 (UNS A97075) coupons and exposed to accelerated corrosion conditions for galvanic corrosion assessment. Specifically, the fastener assemblies consisted of ¼-20 x 1 inch full-thread screws and corresponding mated flat washers (Figure 6), with and without Gentoo. Select screws and washers were also cadmium plated per ASTM F1941 FE/CD SA. The 7075-T6 aluminum coupons were approximately 1 x1 .375 x0.032 inch and a ¼-20 drill and tapped hole was created in the middle region of each one for mated fastener attachment. All aluminum panels were initially deoxidized with Alumiprep 33 and treated with PreKoke, a non-chromate adhesion promoter for paints. Following

the pretreatment, a MIL-PRF-23377 epoxy primer and MIL-PRF-85285D grey polyurethane topcoat from PRC Desoto were applied to the surface. The coated coupons were hand-scribed to expose fresh, bare metal prior to fastener attachment. During galvanic assembly, nylon spacers and 18-8 stainless steel nuts were used on the backside of the aluminum coupons and torqued to 25 in-lbs. Each distinct assembly type was tested in triplicate via placement in ASTM B117 cyclic salt fog conditions.

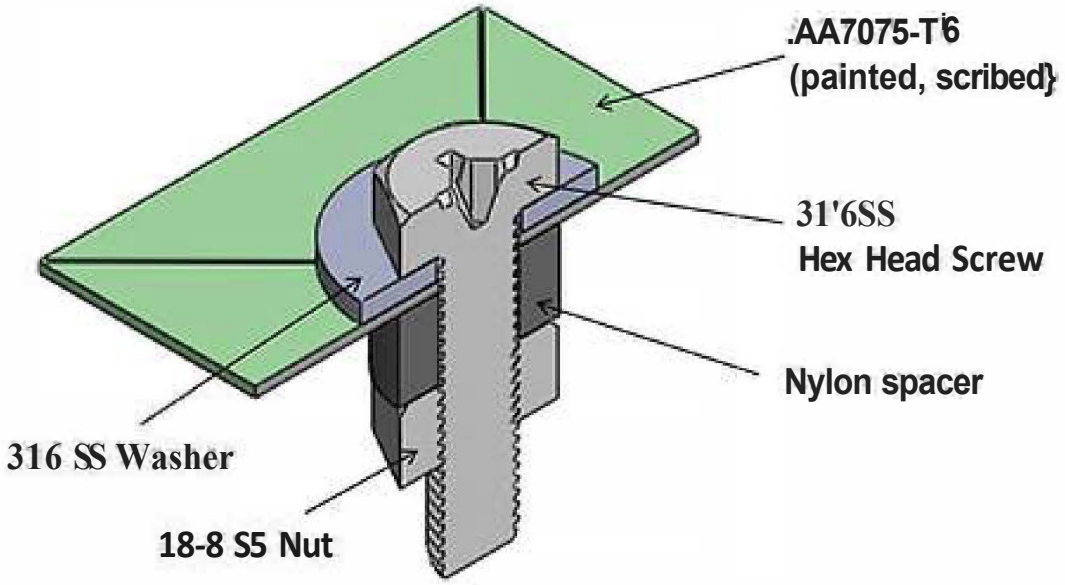

Figure 6

Schematic overview of the galvanic fastener assembly components used for corrosion assessment of Gentoo as applied to 316 stainless steel fasteners.

Bare B7 steel fastener and cadmium (Cd) plated B7 steel fastener assemblies were used for galvanic coupling with the scribed, painted aluminum panels. Control and Gentoo coated fastener assemblies were used. After 648 hours of B117 exposure, significant amounts of corrosion product was evident with the bare B7 steel fastener assemblies, while significantly less corrosion was evident after 1340 hours of salt spray with the cadmium plated B7 steel fasteners. The test assemblies were removed from B117, solvent stripped and cleaned using ASTM G1 guidelines and evaluated for weight loss and pit depth measurements due to corrosion. The parts were solvent stripped by first using a Rust-Oleum Aircraft Paint Remover soak at 49°C, followed by immersion in a 60-70% nitric acid stripping solution and rinsed with ethanol to remove any residue. Improved corrosion resistance from Gentoo treatment of

fasteners and painted panels were demonstrated visually, by corrosion based weight loss and pit depth measurements of the stripped aluminum panels on both the bare B7 and cadmium plated B7 fastener assemblies. The barrier effect of the Gentoo appears to be potentiated when combined with electrochemically deposited layers, such as Cd plating. Results are displayed in Figure 7.

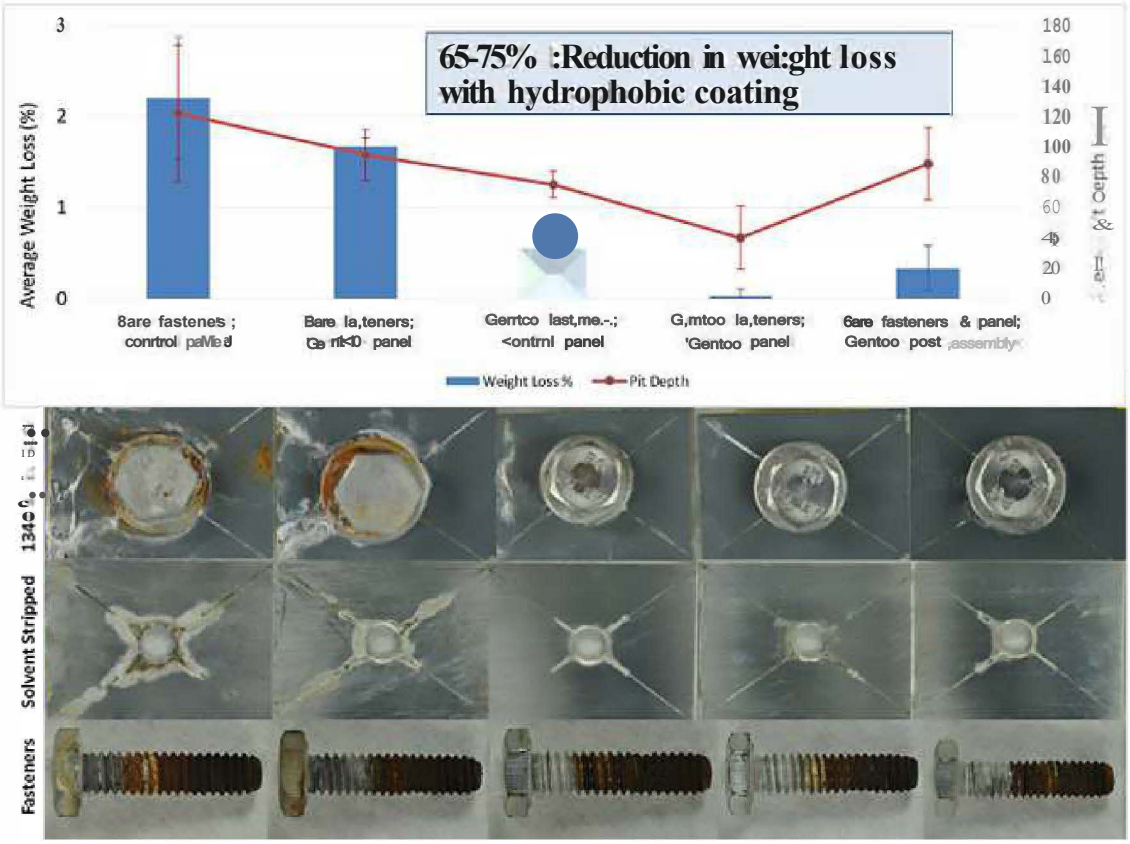

Figure 7

Galvanic Fastener Assembly Test Images of Cadmium plated B7 HSS bolts after 1340 hours of Salt Spray (top row images) and solvent stripped using ASTM G1, coated 7076-T6 aluminum panels (middle row) measured for weight loss and pit depth (accompanied graphs), and side images of representative fasteners (bottom row)

In the following sections, continuous salt fog corrosion resistance, chipping resistance combined with salt fog corrosion resistance, and galvanic and HSS accelerated corrosion resistance and environmental exposure at Kennedy Space Center in Florida results are reported in detail. Performance evaluations focused on **LHE** ZnNi plated 300M (UNS K44220) or 4130 (UNS G41300) high strength steel parts. All HSS threaded parts were 300M, while all HSS flat panels were 4130 alloy. All testing was performed in triplicate. Specific testing procedures are discussed in the results section.

Corrosion Resistance

Accelerated ASTM B117 corrosion testing was performed on **LHE** Zn-Ni plated 4130 HSS painted panels. The flat panels were primed with a MIL-PRF-85582 Class N chrome-free epoxy primer and topcoated with a CA8201/F17925 MIL-PRF-85285 Type I Class H white glossy urethane paint, or a CA8211/F3673 MIL-PRF-85285E Type I grey semi-gloss paint. Control panels included the primer and topcoats only. Gentoo was applied to selected control panels. All panels were "X" scribed according to MIL-PRF-32239 and placed in ASTM B117 salt fog with images taken every 500 h. Figure 8 displays the salt fog exposed panel images for the white and grey topcoat controls and Gentoo treated panels. Significant amounts of red rust are present on all the panels with the onset of rust by 500 h of exposure. The scribe corrosion is rated according to ASTM D1654 for each of the panels and is graphically displayed in Figure 9. For both the white and grey topcoats, the Gentoo treatment significantly reduces the scribe creep.

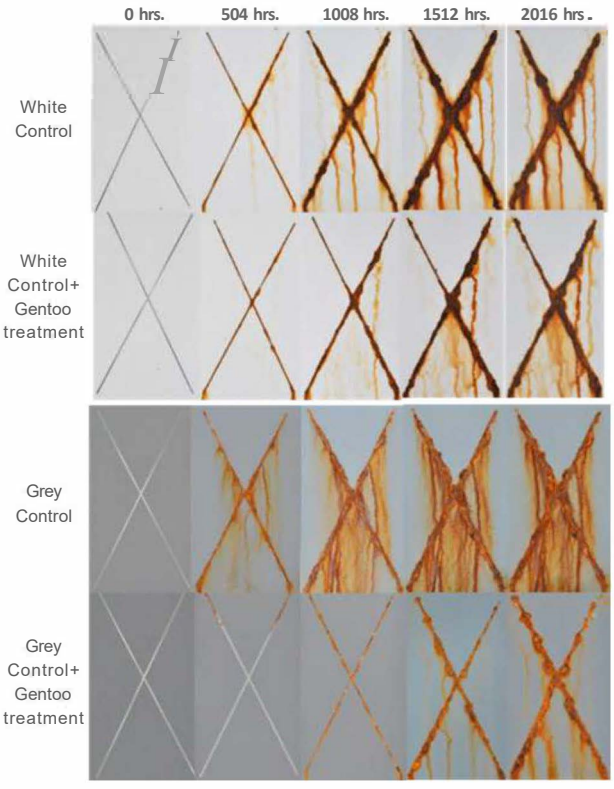

Figure 8

Images of MIL-PRF-32239 scribed **LHE** Zn-Ni 4130 HSS painted panels with either the MIL-PRF-85285 white glossy topcoat or the MIL-PRF-85285 grey semi-gloss topcoat with and without Gentoo following ASTM B117 Salt Fog Exposure

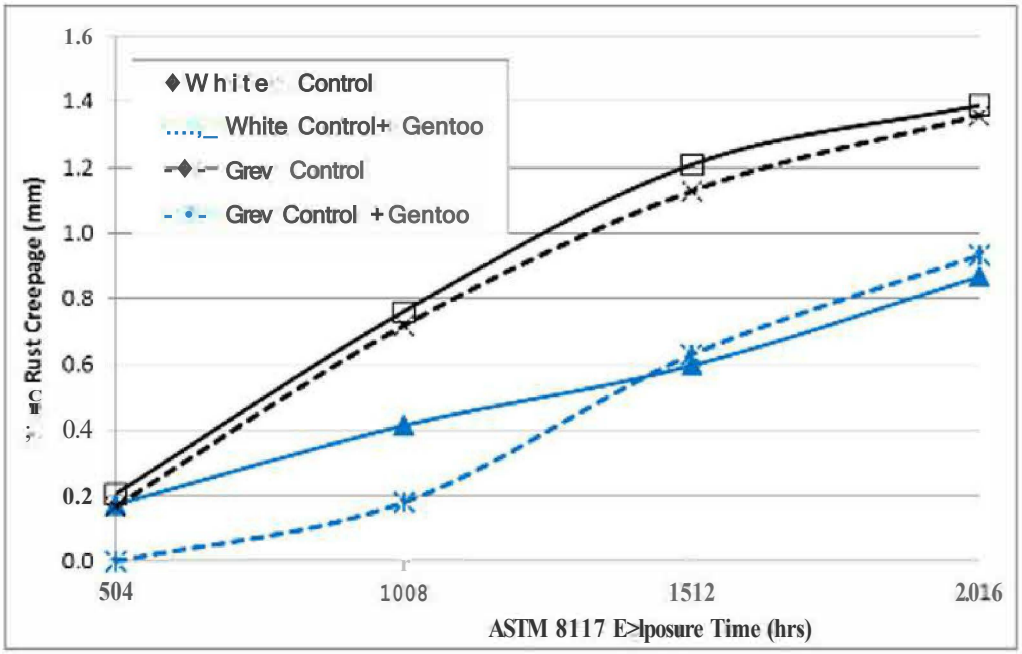

Figure 9

ASTM D1654 Scribe Corrosion Ratings of Scribed, ASTM B117 Salt Fog Exposed painted, LHE Zn-Ni 4130 HSS panels with and without Gentoo

Chipping Resistance Testing

University of Dayton Research Institute (UDRI) employs their CLG-LP-044 laboratory procedure for performing foreign object debris (FOO) testing on 4x6 inch coated panels according to ASTM D 3170 Standard Test Method for Chipping Resistance of Coatings. Cured, coated panels are tested in triplicate by mounting in the target chamber of the Gravelometer and firing one pint of 3/8 - 5/8-inch water eroded alluvial stones at the test panel with an air gun operating at 70 psi. Loose gravel is removed from the panel with an 898 filament tape, and the panel is rated by a visual comparison to transparent standard chips.

UDRI performed chipping resistance testing on Gentoo treated and untreated LHE Zn-Ni 4130 steel panels, as well as on Gentoo treated and control MIL-PRF-23377 epoxy primer with MIL-PRF-85285D grey urethane topcoat painted LHE Zn-Ni 4130 steel panels. No reportable differences were observed in coating chip protection between the Gentoo treated and untreated bare steel panels. After chipping resistance testing, the damaged panels were placed into an ASTM B117 salt fog chamber. After 2136 hours of exposure, the Gentoo treated steel and Gentoo treated primed/topcoated, steel panels demonstrate significant corrosion improvement over the bare steel and painted steel control panels. This Gentoo treatment isproviding added exposure protection as a function of impact over the control panels.

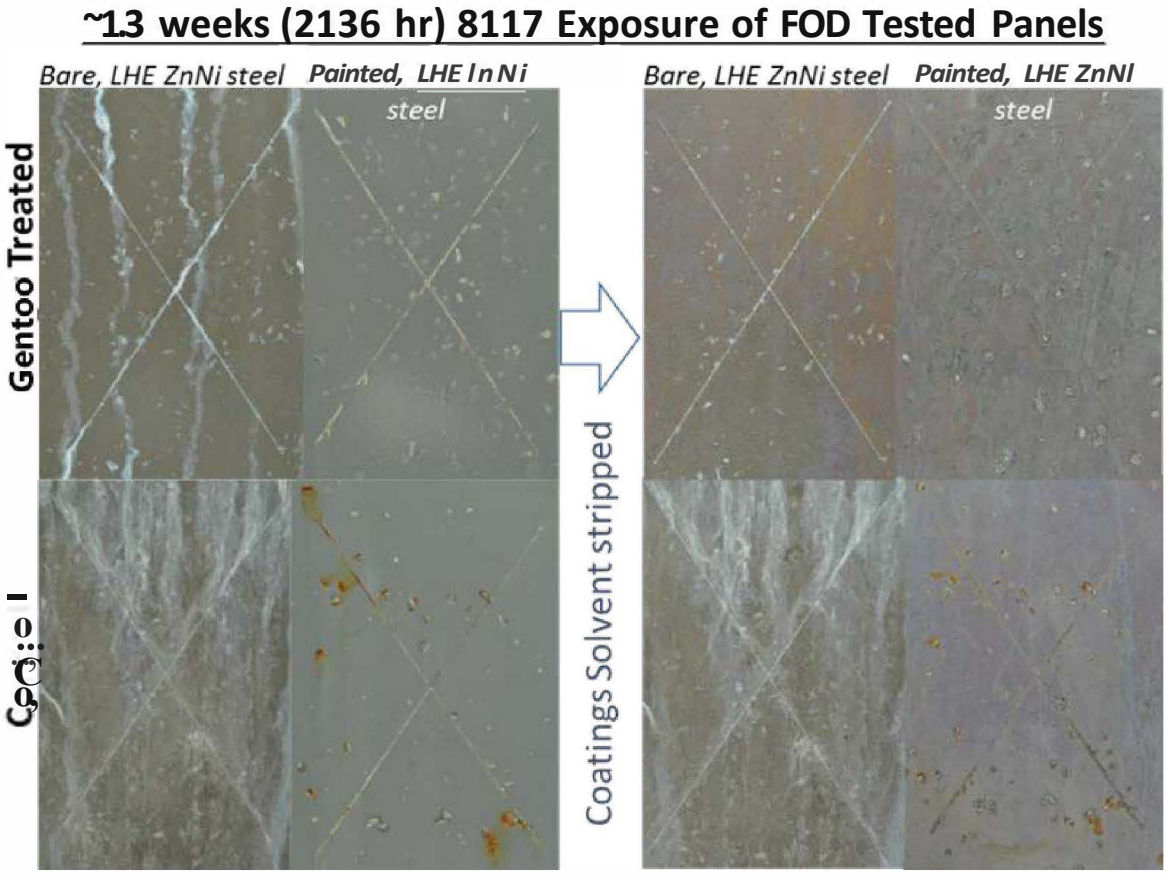

Figure 10

2136 hours of B117 Salt Fog Exposure of FOD Tested Bare and MIL-PRF-23377 primer with MIL-PRF-85285D topcoat painted LHE Zn-Ni plated HSS panels with and without Gentoo

Chipping resistance testing was repeated with LHE ZnNi plated 4130 HSS panels with a MIL-PRF-23377J Type I Class N chrome-free epoxy primer and topcoated with CA8201/F17925 MIL-PRF-85285 Type I Class H white glossy urethane paint with and without Gentoo. Bare LHE Zn Ni 4130 with and Gentoo surface treatment was also included. No significant differences resulted in the chip protection ratings between the surface treated and untreated panels. Panels were placed into ASTM B117 salt fog for 2000 h of exposure. Red rust spots are visible on the painted control panel, while the Gentoo panels remain unchanged (Figure 11).

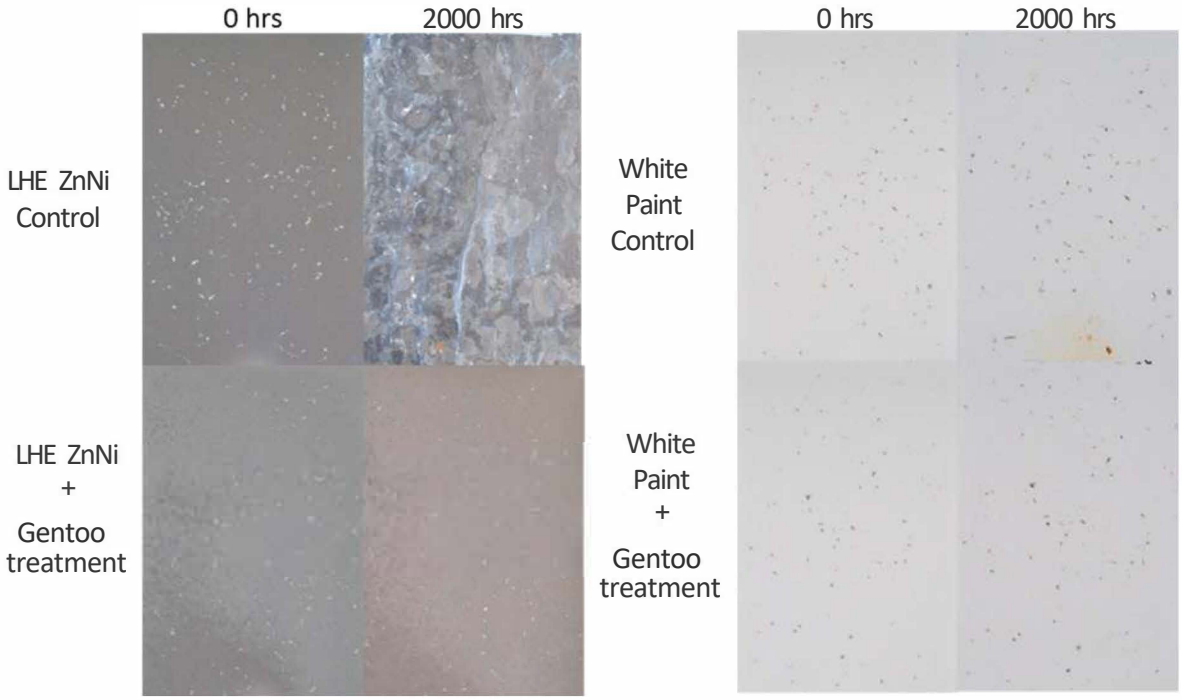

Figure 11

ASTM B117 Exposed, Chipping Resistance Tested LHE Zn Ni plated 4130 HSS bare and painted panels with and without Gentoo