

TECHNICAL GUIDE FOR INACCESSIBLE STRUCTURAL VOID COATINGS AND TREATMENTS

A National Shipbuilding Research Program Surface Preparation Panel Project
NSRP Subcontract No. 2015-438

June, 2016

Approved for public release; distribution is unlimited.
Category B Data – Government Purpose Rights.

GENERAL DYNAMICS
Bath Iron Works



Executive Summary

Inaccessible voids are commonly found within a ship's structure or structural appendages. Their size, and configuration/geometry, can vary widely among various ship designs. While inaccessible voids are most frequently found in the hull structure below the waterline, they may also occur above the waterline. By definition, inaccessible structural voids are bounded by permanent, welded structure, and have no manhole accesses, and therefore cannot be completely coated for corrosion protection using traditional blasting and painting methods. The most common examples are rudders, bilge keel and skeg voids, and peak voids at the bows of ships.

In addition to any residual pre-construction primer, the legacy corrosion prevention method for inaccessible structural voids has been to coat them with a petroleum solvent based compound meeting Military Specification MIL-PRF-16173, Grade 1. Alternative methods that have been proposed, approved, and used on a case basis by various shipbuilders include the use of vapor phase corrosion inhibitors (VCIs) as defined by Commercial Item Description CID A-A-59441 or other specifications, and/or purging the voids with an inert gas (typically argon or nitrogen).

Little information is available with respect to corrosion performance of corrosion control technologies within inaccessible voids. Ideally, the corrosion protection method(s) used in inaccessible voids should last for the design life of the ship (e.g., 30-40 years), barring any incident that results in flooding the void with water. To better understand the degree to which each can protect the uncoated steel surfaces, a series of benchtop tests evaluated 72 different combinations of steel condition, environmental exposure, and corrosion prevention measure. The testing scope represented conditions that may be encountered on ship structural voids constructed of welded steel.

In addition to corrosion protection, other factors influence selection of corrosion control approach in inaccessible voids. These include intense cost-reduction efforts, efforts to reduce the environmental impact and hazardous waste treatment associated with the MIL-PRF-16173 corrosion preventive compounds, and newer ship and hull form designs (e.g. wave-piercing hulls) that are resulting in voids with unusual sizes and geometries and complex internal stiffening.

This document presents information on the design, production, and repair considerations to facilitate appropriate technology selection. It also provides data on the relative corrosion performance of the various methods in several simulated void environments, based on testing conducted to date as a part of this project.

Table of Contents

Executive Summary	1
Table of Contents	2
Acknowledgements	3
Conclusions	4
Recommendations	5
Background	6
Preservation Requirements and Desirable Properties	9
Performance	9
Design and Production	9
In-Service/Repair	9
Cost	10
Characteristics and Use of Void Preservation Methods	11
Residual Pre-Construction Primers	11
MIL-PRF-16173 Grade 1, Class I or II Corrosion Preventive Compounds	11
Vapor Phase Corrosion Inhibitors	13
Inert Gasses	15
Inert Gas and VCI's	16
Prior Navy Experience	19
Benchtop Testing of Inaccessible Void Coatings and Treatments	21
Experimental Approach	21
Steel Test Panel Conditions	21
Environmental Exposure Conditions	22
Corrosion Control Methods	24
Test Panel Evaluation	26
Results	26
Atmospheric with Condensation	26
Atmospheric without Condensation	29
Seawater Immersion	31
Discussion	33
References	38
Appendix A – Representative Products List	39

Acknowledgements

The authors would like to acknowledge the support of the National Shipbuilding Research Program Surface Preparation and Coatings Panel and the Naval Sea Systems Command (NAVSEA) for their contributions to this project. The support of the NAVSEA Technical Warrant for coatings has provided the foundation on which all of our efforts were based. The project team is indebted to representatives of GD-NASSCO, GD-Bath Iron Works, HII-Ingalls Shipbuilding, and BAE Southeast Systems who shared their experience with inaccessible void corrosion control technologies. The support and assistance of the NSRP Project Technical Representative, Mr. Steve Cogswell (BAE Southeast Systems) has also been essential for project team. Finally, we appreciate the comments provided during panel meetings and on draft versions of this report by all of the NSRP shipyards.

Conclusions

1. Rusting of bare steel before treating an inaccessible void negatively impacts the efficacy of the all corrosion preventive technologies tested. In some cases the corrosion rates of pre-rusted surfaces were more than ten times that of surfaces that were corrosion-free prior to treatment.
2. In the atmospheric conditions (condensing and non-condensing) on un-rusted test coupons, less than 0.2 mils of corrosion occurred on the test coupons after 6 months regardless of treatment method.
3. In immersion condition such as may exist when a void is breached, MIL-PRF-16173 coatings provide significantly more corrosion protection than VCI or inert gas methods, especially on surfaces with pre-construction primer. The testing timeframe was limited to six months; it is unknown how long the coatings would protect the surfaces.
4. One of the approved MIL-PRF-16173 products performed significantly better than the other approved product.
5. The MIL-PRF-16173 product applied by simulating “float coat” and “fill and drain” procedures performed similarly regardless of application method.

Recommendations

1. The benchtop test data should be validated with in-service experience. This may include field observations of inaccessible voids or data on the failure rate of inaccessible voids.
2. The Navy should consider the following criteria when selecting inaccessible void treatments:
 - a. For inaccessible voids not subject to flooding: residual pre-construction primer alone may be adequate, but must be in good condition, without extensive rusting, and the void must be dry when sealed up (no standing water). VCI and/or inert gas should provide adequate supplemental protection.
 - b. For inaccessible voids where boundaries are exposed to the sea, weather or standing water, consider the likelihood and consequence of the void being breached when selecting preservation methods.
 - i. For inaccessible voids likely to be subject to flooding and/or extended seawater exposure at some point during the ships service: Use MIL-PRF-16173 preservative. This will protect for some period of time once flooded. Design and venting details should be implemented which will reasonably ensure all internal surfaces have been coated.
 - ii. For inaccessible voids not likely to be subject to flooding and/or extended seawater exposure at some point during the ships service: The combination of residual pre-construction primer, VCI and inert gas purging should provide adequate protection unless breached.
3. Shipyards should implement build strategies which minimize the amount of corrosion that occurs during shipbuilding. Corrosion which occurs on inaccessible void surfaces should be removed (and ideally touched up with pre-construction primer) prior to closing the void.
4. Validate the observed difference in performance of MIL-PRF-16173 products. If the performance differences are significant, a test method which discriminates among the products should be developed and incorporated into the specification.
5. If MIL-PRF-16173 products are to be used, additional study should be performed to optimize use and reuse of these materials in order to reduce cost and waste.

Background

The term “inaccessible void” as used in ship specifications, and in this report, refers to volumes within the ship that are fully enclosed by welded-shut ship structure, with no means for human entry after initial construction via manhole or any other type of removable access. Naval shipbuilding specifications for coating often applied the ambiguous adjective “small” for these voids when stating the preservation requirements, and some later somewhat arbitrarily further defined them by adding “less than 2 cubic feet” (<0.057 cubic meters). However, for the purposes of this report, inaccessible voids of any size are considered.

Certain types of inaccessible structural voids rarely or never require preservation treatments in Navy ship specifications, due to experience and the low risk of any significant corrosion in these voids over the life of the ship. This has been stated in most Navy ship specifications in this manner: “Preservative treatment is not required within small inaccessible voids of welded watertight and airtight construction where boundaries are not exposed to the sea, weather or standing water.” In addition, the interior of pipe used as structural stanchions, and pipe and tube used for non-structural ship outfitting items such as lifeline stanchions and handrails are not preserved. These items are not considered in this effort.

Inaccessible voids that are designed specifically for buoyancy or acoustic purposes, and filled with foams accordingly, are not considered in this report. In addition, this report and the associated testing that was performed, focuses on steel structure, although many of the same discussion points can be extended to aluminum structures if necessary.

The surfaces of steel structural plates, shapes, and stiffeners within inaccessible voids will frequently have thin (<1.0 mil), weld-through pre-construction primer (PCP) on them. This primer will have been removed or burned off in weld joint regions, and may have been disturbed or damaged in other small spots due to handling and other shipbuilding activities. As a result, the percentage of the surface area within the void that retains the PCP can vary widely according to the void size, configuration, and internal structural complexity.

In addition to any residual pre-construction primer, the legacy corrosion prevention method for inaccessible structural voids has been to coat them with a petroleum solvent based compound meeting Military Specification MIL-PRF-16173, Grade 1. Alternative methods that have been proposed, approved, and used on a case basis by various shipbuilders include the use of vapor phase corrosion inhibitors (VCIs) as defined by Commercial Item Description CID A-A-59441 or other specifications, and/or purging the voids with an inert gas (typically argon or nitrogen).

There are several factors that can drive the need for alternative types of corrosion control approaches in inaccessible voids. These include intense cost-reduction efforts, efforts to reduce the environmental impact and hazardous waste treatment associated with the MIL-PRF-16173 corrosion preventive compounds, and newer ship and hull form designs (e.g. wave-piercing hulls) that are resulting in voids with unusual sizes and geometries and complex internal stiffening.

Although not currently reflected in any Navy shipbuilding requirements, large voids may be able to have a significant portion of their surfaces blasted and coated with either an epoxy primer, or even a complete multi-coat coating system during initial construction prior to welding the final closure plates, but the areas surrounding the closure weld joints will not be able to be coated. However, this would be highly dependent on the individual void configuration and the shipyards' structural assembly and erection process. Figure 1, a commercial tugboat skeg assembly, is an example of where this approach would be feasible.



Figure 1. Skeg Void Assembly for a Commercial Tugboat¹.

Even if partial coating were attempted prior to closing the void, the consequences of corrosion on the remaining uncoated surface may be as significant as if the entire inaccessible structure was left uncoated. Furthermore, removal of blast grit may also be problematic in voids with very complex internal stiffening and segmented compartments. Very small, unusually shaped voids, such as long, narrow voids with cross-sectional dimensions of only a couple inches at unique deck/bulkhead structural joints, may not have either residual PCP or any ability to be partially coated.

Ideally, the corrosion protection method(s) used in inaccessible voids should last the design life of the ship (e.g., 30-40 years or more), barring any incident that results in flooding the void with water. It is assumed here, as a part of general good shipbuilding practices, that no voids are closed knowingly with standing water in them. The corrosion environment and risk inside of voids varies with their location: those above the waterline, or that have no boundaries exposed to seawater or a water-filled tank can be expected to have a rather benign environment with fairly stable temperature gradients and little risk of accidental water entry or flooding. They may only experience minor condensation from the moisture in the air when the void was closed up. On the other hand, voids with one or more boundaries exposed to seawater, standing water, or a water-

¹ Used with permission of BAE Southeast Shipyards

filled tank are prone to temperature gradients which can promote condensation and subsequently, corrosion.

Cracking or mechanical damage that occurs during service, allowing the ingress of seawater or other contaminants, will of course significantly increase the corrosion in the void during the period of time that it goes either undetected or not repaired. While it would be desirable for the initial preservation method to provide some degree of short-term corrosion protection during flooding, this condition represents a design excursion and is generally not reflected in the initial design requirements.

Preservation Requirements and Desirable Properties

The requirements and desired characteristics of an inaccessible void preservation method are fairly simple to describe, and can be broken down into the following areas:

Performance

- Required: Able to protect bare steel from general corrosion and pitting caused by occasional cyclic condensation, for the service life of the ship. Average annual corrosion rate target should be <2-4 mils per year (mpy).
 - For example, using <25% thickness loss structural steel repair criteria from reference (c), for a notional 0.50-inch thick plate and a 30 year ship design life, any localized (e.g., pitting) average corrosion rate over the 30 years should be less than ~4 mpy to avoid repairs.
- Desired: Provide some degree of short-term corrosion protection to bare steel immersed in seawater until the time that repairs can be made, in the event of unexpected flooding of the void due to cracking or mechanical damage.

Design and Production

- Required: Method selected must be able to treat/affect almost all surfaces within the void, with a corresponding ability to reasonably verify that effective treatment has been achieved.
 - Void structural design details may be needed to accommodate the preservation method selected, according to the void geometry and complexity. Vents, drains and avoidance of fluid traps (for fill and drain methods) must be provided.
 - Verification methods vary with approach: monitoring of venting gas oxygen content, expulsion of air and liquid preservative through an upper vent, recording of weight of VCI powder used for volume of void treated, etc.
- Desired: the preservation method selected should not require any special production schedule disruptions or delays as compared to the use of MIL-PRF-16173 preservatives.
- Desired: the preservation method should not create an extraordinary safety risk to shipyard personnel nor require more costly or cumbersome safety measures by the shipyard compared to the use of MIL-PRF-16173 preservatives.
- Desired: The hazardous materials used and waste generated should be no more than that encountered with the use of MIL-PRF-16173 preservatives.

In-Service/Repair

- Required: Method must allow for repair of the structure by welding when necessary without creating unacceptable risks.
 - Underwater hull appendages with inaccessible voids frequently must have emergent repairs performed by underwater welders working in an enclosed habitat, and has special challenges. The treatment method will be subject to the heat of

welding and grinding unless they can be effectively removed prior to repair. Coating products such as the MIL-PRF-16173 preservative film will liquefy and run off of the surface and down the inside of the void. Hazardous fumes or other potential health effects of the treatment method on underwater welding personnel should be able to be managed through the use of protective equipment and control measures. Current Navy underwater hull husbandry practice requires inerting the interior of a void to be repaired underwater with nitrogen until the oxygen content inside the void is 8% or less.

- Desired: Ability to periodically test or inspect for the continued presence/efficacy of the treatment method during the life of the ship, and renew it if necessary.
 - For voids located on the underwater hull, this action would notionally be performed in drydock, using the existing vent and drain plugs in the void.
- Desired: In the event of a crack or other breach of the void boundary, the preservation method should be minimally harmful to the environment, and should not cause any human safety issues, depending on whether the boundary breached is to the sea, or to an interior area of the ship.

Cost

- Desired: the total installed cost (materials, labor, storage and handling, disposal, etc.) of the preservation method should be no more than that incurred by the use of MIL-PRF-16173 preservatives.

Characteristics and Use of Void Preservation Methods

A summary of the important characteristics of the various preservation methods, and their more common design, production, and sustainability/repair factors is provided below.

Residual Pre-Construction Primers

Pre-Construction Primers (PCP), also known as “shop primers”, are generally applied to steel plates and structural shapes in an automated finishing line at the shipyard, in which the steel is blasted to the required surface profile using centrifugal blasting and then immediately coated. In some cases, the steel may be provided from the steel supplier with the PCP already applied. The majority of the products used as PCP’s are inorganic zinc-silicate coatings that are applied to a dry film thickness (DFT) typically between 0.5-1.0 mils (12.7-25.4 microns). PCP’s are designed to be able to be welded-through by a variety of welding methods during the assembly of ship structures. The coatings are intended to provide short-term (approximately 6-9 months) atmospheric corrosion protection during ship construction. Typical products currently used are listed in Appendix A.

Residual PCP can be considered the default corrosion protection system in inaccessible voids, if no other steps are taken. Virtually all steel surfaces within the void except for weld joint areas, cut edges, or spots that have been ground for various reasons will have this coating on them. Depending on the shipyard storage and fabrication facilities, the local corrosion severity of the environment, and the time of exposure during shipbuilding before the voids are closed up, the PCP will have been weathered to some degree during the construction period.

MIL-PRF-16173 Grade 1, Class I or II Corrosion Preventive Compounds

Materials

For the products used in inaccessible voids, the specification classifies them as follows:

Grade 1: Hard film, (175 degrees Fahrenheit (°F) 80 degrees Celsius (°C) minimum flow point of solvent deposited film)

Class I – High VOC – VOC exceeding 2.8 lbs/gal

Class II – Low VOC – VOC not exceeding 2.8 lbs/gal

The specification describes the materials as “...solvent-dispersed corrosion preventive compounds that deposit thin, easily removable films after evaporation of solvent”. On test coupons prepared for qualification to the specification, the compounds are to form continuous, unbroken films a maximum of 4 mils (100 microns) thick upon evaporation of the solvent. To qualify to the specification, specimens treated with Grade 1 products shall pass a 14 day ASTM B117 (reference (o)) salt spray exposure test and a 600 hour accelerated weathering test, in each case showing no more than a “trace” (3 small dots) of corrosion. In addition, after 1200 hours of exposure to the accelerated weathering test, no rust is permitted to have broken through the coating surface.

Production Considerations

These preservatives are commonly applied to voids in one of two methods, “fill and drain”, or “float coating”. In the fill and drain method, the void is filled with the coating and then allowed to drain, resulting in coverage of the interior surfaces. The excess coating drained from the void can be used to fill subsequent voids, provided that the material is still within its shelf life limits. In the float coat method, a calculated amount of the product is placed into the void space and water is slowly added. As the preservative is lighter than the water, it floats on top. The water is added until the preservative starts to come out of a vent hole at the high point of the void, after which the water and preservative are then slowly drained. The preservative displaces the water as the water is drained, coating the surfaces.

The water drained from the void must be collected and treated, and the excess preservative material must be collected and recycled or disposed. It should be apparent that the float coat method can require much less preservative material than the fill and drain method, trading off the extra costs and effort of treating the drained fluids. However, the differences in the amount of material used are not a significant factor if the material can be re-used. Additional factors include:

- Dealing with material shelf life, moving the material around the shipyard, and use of hazardous spill retention booms all add to the cost of this method.
- Temperature can impact product viscosity, which can affect applicability and product waste. Heating the material to decrease its viscosity adds cost and complexity to the process.
- If float coating, products must be evaluated for applicability. Not all qualified products will float on water; refer to Appendix A.
- Voids should be ventilated following application and prior to plugging to remove any solvent vapors, although this can be very difficult considering the small diameter ports, or holes, used for filling and venting.

Design Considerations

The design considerations for both application methods of the MIL-PRF-16173 preservative are similar, and pertain to the structural details in the void:

- Placement of the low point drain must be considered. The preservative, or water, may pool below the drain and not be able to be removed.
- Dual-purpose venting and drain holes, or snipes, may need to be provided in stiffening elements to eliminate air pocket traps that could prevent coverage of the surface, and to allow drainage of the fluid to prevent pooling. The number and size of the internal snipes and rat holes can affect the speed of the process, as the materials are viscous and flow through the holes can be slow.
- Placement of the high point vent must be considered. Any surface area above the high point vent may not be able to be coated and will be left unprotected.
- The orientation of the structural element containing the void to be treated during construction may be different than the final installed orientation on the ship. For instance, components such as removable hinged ramps may be positioned vertically by the shipyard

using cranes or other jigs to facilitate using gravity to fill and drain the preservative. Placement of the fluid passage/venting rat holes and snipes in the internal stiffening structure must take this into account.

Sustainability/Repair Considerations

- If water enters the void through a crack or other means, the coating will provide some degree of corrosion protection for a limited period.
- Inspection during the ship life cycle to assess continued corrosion protection is generally not practical or required. Remote visual inspection (RVI) technology may be able to be used in relatively simple voids, provided that some type of insertion plug or port is provided.
- Prior to any repair hot work, the coatings must be removed, as flash points are relatively low and can lead to fire.
 - For voids that may require underwater weld repairs, these coatings cannot be readily removed. Divers will purge the void with nitrogen in these cases, to prevent combustion, reference (d). In the section on underwater welding, NSTM Chapter 074, Volume 1 (reference i) notes that “...Internal voids that have been exposed to sea water as a result of the repair process shall be preserved against corrosion using MIL-C-16173 Grade 3 preservative.” However, when repairs are made underwater, re-treating the void with preservative by either the fill and drain or float coat method is impractical. Common underwater hull husbandry practice is to leave the void, e.g. a rudder, filled with residual nitrogen to provide some degree of corrosion protection, although the process is not currently controlled to the degree described for inerting during new construction discussed below.

NOTE: The characteristics and qualification requirements with respect to corrosion prevention for the soft film Grade 3 preservatives are less than those for the hard film Grade 1 preservative. The Grade 1 preservative can have a thickness up to 4 mils maximum compared to 1 mil maximum for Grade 3, and has salt spray and accelerated weathering performance requirements that do not apply to Grade 3 products. The intended use section of the specification also describes a higher degree of corrosion protection provided by the Grade 1 products compared to Grade 3.

Vapor Phase Corrosion Inhibitors

Materials

As a class of materials, VCI's can be simply described as per the intended use paragraph of Commercial Item Description (CID) A-A-59441:

“VCI products are ... chemical compounds that actively diffuse invisible corrosion inhibiting vapors into their surrounding atmosphere. The molecules of these vapors adsorb to metal surfaces inside the enclosed volume to form an active layer of protection against corrosion that causes no change to the character of metal surfaces. The VCI layer later completely evaporates from all metal surfaces when they are exposed to the atmosphere and the VCI diffusion source is removed.”

For the purposes of treating inaccessible voids, the appropriate product form is a powder supplied in bulk form (A-A-59441 Type V). Compliance with the limited performance requirements of specification MIL-I-22110 is often also cited by VCI powder product manufacturers. In general, the products must not produce any contact corrosion with the types of metals that they are intended to protect, and typically are intended to provide 24-36 months or more corrosion protection of bare metals from residual humidity and occasional condensation in a fully sealed or enclosed void. The amount of material to be used is dependent on the volume of the void to be protected, with manufacturer recommendations typically on the order of 0.5 ounces/ft³ or less. The specifications for the materials also have generic but ambiguous safety requirements, such as being “non-toxic”, not posing any hazards to personnel entering treated spaces following treatment, and being “environmentally safe”. Specific to A-A-59411, VCI compounds are not to contain: a) amines and nitrites or nitrates in combination, b) phosphates, or c) silicones.

Production Considerations

Introducing VCI powder into a void can be accomplished by pouring the powder in through a funnel, or blowing, fogging, or dusting through a tube. Under some conditions, VCI powders may tend to clump or cake and not flow well. Complex or very long voids may benefit from the use of more than one access plug to introduce the product. The powders do tend to have a very noticeable ammonia odor. Proper respiratory protection and dust hazard prevention is required when handling the powder. When blowing the powder into a void with several open vent ports, personnel in the area of a remote exhaust port may require Personal Protective Equipment (PPE) as well as those adding the powder through a port. Caution signs should also be posted in the area of the vent (exhaust) ports.

Design Considerations

Complex geometries should not affect performance. By the nature of its behavior, the VCI is intended to diffuse throughout the void, its internal support structures and other hard to reach areas. Once sealed, the vapor transport reaches an equilibrium providing long term protection.

Sustainability/Repair Considerations

The use of VCI powders will generally allow for weld repairs to be made without any special removal procedures. Depending on the void location and whether the repairs are being conducted waterborne, a void may easily have the VCI powder inserted again after repairs.

There is no practical way to positively determine if the VCI in a void is still providing corrosion protection or needs to be renewed. As with the corrosion preventive compound, indirect assessment may be possible via RVI technology to determine if there is extensive corrosion in a void, but would be limited to relatively simple voids with some type of insertion plug or port. However, adding fresh VCI materials on a periodic basis should be fairly simple.

If a void treated with VCI is below the waterline and/or exposed to water surrounding the structure, a crack or other breach may result in flooding the void. VCI's will provide little, if any corrosion protection for a flooded void structure.

Inert Gasses

Materials

Preservation using inert gasses is generally performed using either nitrogen or argon, which will not react with steels in the temperature ranges encountered in tanks or voids. For this type of application, the gasses would most likely be supplied in compressed gas cylinders. Commercial purity available for nitrogen can be >90% for “low purity”, or greater than 99.9% for “high purity”. Compressed argon purity is commonly at >99.9%. “Purging” or “inerting” are commonly used industry terms for displacing an existing atmosphere (air) with an inert gas.

In addition to corrosion prevention and preservation applications, purging with an inert gas is frequently done to reduce or eliminate a hazardous or combustible atmosphere from a vessel, tank, or apparatus. When inerting is performed for this purpose, the maximum oxygen concentration specified may vary with the applicable controlling regulations or documents. The National Fire Protection Association (NFPA) defines inerting as maintaining “...the oxygen content of the atmosphere of the space at or below 6%, or 50 percent of the amount required to support combustion, whichever is less.” (Reference k) Navy requirements contained in the NSTM’s are more stringent, at either 1% maximum (reference (l)) or 3% maximum (reference (m)) oxygen.

The goal of inert gas purging for corrosion control is to reduce the oxygen level in the space to a level that will eliminate or severely minimize corrosion. The natural oxygen level in air is approximately 21%. Depending on the industry and application, various target levels of maximum oxygen content are used for corrosion control. Section 631 of the DDG-51 Class ship specifications required a maximum oxygen content of 8% for certain voids purged with argon or nitrogen as an alternative to the use of MIL-PRF-16173 preservative. Reference (g) also cited an 8% maximum oxygen level for corrosion control, but noted that 1% maximum will provide better protection. Reference (n) defines an inert condition as an oxygen content of 5% or less by volume. Several commercial inerting service providers for the marine or pipeline industry cite an oxygen content of 1% or less.

Production Considerations

In displacement purging, the amount of inert gas used is contingent on the volume of the void. The quantity required may be on the order of 120% of the void volume. The inert gas is pumped into the void via a low point port, and the oxygen level is monitored at a high point vent until it reaches a set target level. While a void, or its boundaries, may be briefly subjected to pressure during tightness testing, it should never be left pressurized with the inert gas during service. Internal void complexity can greatly affect the time required to reach the threshold level, and may also require more than one upper vent to be monitored to assure that no un-purged pockets or traps remain.

Design Considerations

Upper and lower pluggable ports must be provided in the void structure. In complex voids, snipes or access holes or cuts in internal structural divider plating may be useful to allow the gas to flow freely and avoid air pockets.

Sustainability/Repair Considerations

The use of inert gas purging will generally allow for weld repairs to be made without any special removal procedures. Depending on the void location and whether the repairs are being conducted waterborne, a void may easily be able to be inerted again after repairs.

There is no practical way to positively determine if the inert gas in a void is still providing corrosion protection or needs to be renewed. Indirect assessment may be possible via RVI technology to determine if there is extensive corrosion in a void, but would be limited to relatively simple voids with some type of insertion plug or port. However, additional purging with inert gas on a periodic basis should be fairly simple.

Any breach that compromises airtightness of the void will eliminate corrosion protection by allowing the inert gas out and oxygen into the void. If the breach is exposed to water surrounding the structure and the void becomes flooded, the corrosion will be more severe than if the breach simply allows oxygen into the void. In either case, corrosion protection cannot be re-established until the void is repaired.

Inert Gas and VCI's

The use of inert gas and VCI powder in combination can potentially provide corrosion protection performance advantages over either of the two methods used alone. Inert gas purging will drive out entrained moisture in the air, reducing the chance that condensation could occur within the void in service, and the diffusion of the VCI chemical throughout the void volume can compensate for difficulties in purging all of the air from a void with complex internal stiffening.

Materials

Materials are as previously described under the individual sections for VCI's and for inert gas purging.

Production Considerations

Production considerations for this hybrid preservation scheme are very similar to those previously described for each method. However, as illustrated in Figure 2, there are pros and cons in the alternatives for the sequence of events.

When VCI powders are used after a void has been inerted, there is some time that will elapse between securing the inert gas, plugging the lower ports, and introducing the VCI into the void.

During this time, natural diffusion may allow some higher-oxygen air back into the void. Based on the densities of the gasses at normal temperatures and pressures shown below, this is much less likely to occur when argon is used as the inert gas, as argon is heavier than air.

Air =	0.075 lb/ft ³
Argon =	0.104 lb/ft ³
Nitrogen =	0.073 lb/ft ³

NTP - Normal Temperature and Pressure - is defined as air at 20°C (68°F) and 1 atm (101.325 kN/m², 101.325 kPa, 14.7 psia, 0 psig, 29.92 in Hg, 760 torr).

Design Considerations

Design considerations are the same as those previously described under the individual sections for VCI's and for inert gas purging.

Sustainability/Repair Considerations

Sustainability/repair considerations are the same as those previously described under the individual sections for VCI's and for inert gas purging.

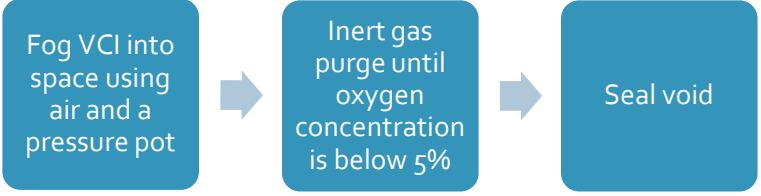
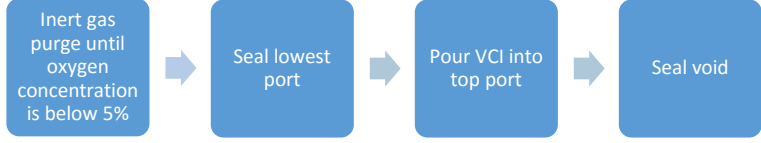
Process	Considerations
 <pre> graph LR A[Fog VCI into space using air and a pressure pot] --> B[Inert gas purge until oxygen concentration is below 5%] B --> C[Seal void] </pre>	Advantages • Good VCI distribution • Easy to inject VCI • Minimizes time from inerting to sealing Disadvantages • May blow VCI out of void, requiring replacement and safety considerations
 <pre> graph LR A[Inert gas purge until oxygen concentration is below 5%] --> B[Fog VCI into space using inert gas and a pressure pot] B --> C[Seal void] </pre>	Advantages • Good VCI distribution • Easy to inject VCI Disadvantages • May blow VCI out of void, requiring replacement and safety considerations • Fogging process must be performed with inert gas to avoid introducing significant oxygen into the void
 <pre> graph LR A[Inert gas purge until oxygen concentration is below 5%] --> B[Seal lowest port] B --> C[Pour VCI into top port] C --> D[Seal void] </pre>	Advantages • Eliminates risk of powder leaving void Disadvantages • VCI distribution will only occur in vapor phase • Can be challenging to get large volumes of VCI into small holes due to clumping • Time between inerting and sealing isn't minimized

Figure 2. Alternative Processes for Inert Gas Purge & VCI Treatment

Prior Navy Experience

The Navy has had varying degrees of experience with each of the preservation methods described herein. They have the most extensive experience with the MIL-PRF-16173 preservative, and the least accumulated in-service experience is with the VCI or inert gas methods. Table 1 summarizes most of the Navy experience with these treatments.

In-service performance history with these treatments tends to be limited, since by definition, they are not able to be periodically inspected as a part of structural health monitoring programs like those defined in CCAMM, reference (c). Adequate corrosion protection performance is implied through the lack of widespread or recurring reports of structural deterioration during normal service. There have been some opportunities to collect performance indicators for the MIL-PRF-16173 preservative as a result of mechanical damage incidents or casualties that result in repairs being required, which are summarized below. Otherwise, there is not yet sufficient service experience, or direct or indirect evidence, to assess the performance of the inert gas or VCI methods used to date.

Inaccessible voids in rudders, bilge keels and skeg voids are the only ones where there have been performance indications with the MIL-PRF-16173 preservative. In DDG-51 class rudders, which have a widespread history of cracking and flooding, significant internal corrosion has been reported by divers inside some rudders during repair efforts, but no correlation to the length of time that the rudder had been flooded was readily available. In contrast, repair work performed on an aircraft carrier bilge keel that had been found to be flooded due to cracking reported that there was very little corrosion detected.

LCU-1610 class bow ramp and skeg voids were preserved with the MIL-PRF-16173 material, and corrosion in these voids has been a significant maintenance issue on these landing craft. The bow ramp voids in particular are subject to a great deal of mechanical damage that can result in cracking and flooding, and many of the ramps have been replaced due to internal corrosion. The ramps are constructed using a box-grid latticework of internal stiffening structure with vent holes between the internal cells. The ramp is designed such that a portion of it free floods when deployed. When plating has been removed from these ramps in order to accomplish repairs, it was observed that the preservative had not uniformly covered all of the internal surfaces.

It is noted that the Navy also had a requirement for the use of a hot application petrolatum corrosion preventive compound, MIL-C-11796 (reference (j)), for use in filling propulsion shaft strut and stern tube bearing voids, but those voids are not considered under the scope of this guide.

Table 1 – Historical Navy Void Preservation Methods

Void Type	Below & contacting water?	MIL-PRF-16173 Preservative¹	Inert gas	Inert gas & VCI	PCP Only
Rudders	Yes	All ²	DDG51 Cl. U/W repairs	DDG1000 Cl.	
Bilge keels	Yes	All ²		DDG1000 Cl.	
Skegs	Yes	All ²		DDG1000 Cl.	
General small, inaccessible	Yes	All ²		DDG1000 Cl.	
General small, inaccessible³	No				All ²
General small, inaccessible, above WL	No	LPD17 Cl. ⁴	LPD17 Cl. ⁴		All ²
Bow Ramps	Yes ⁵	LCU1610 Cl.			
Masker emitter air box	Yes & No		DDG51 Cl.		
Chain Locker canning plate	No		DDG51 Cl.		

Notes:

1: MIL-PRF-16173 Grade 1 applied over any residual PCP.

2: All ship classes, unless otherwise noted.

3: Per ship specifications: Voids "...of welded watertight, and airtight construction, where boundaries are not exposed to the sea or to standing water."

4: LPD17 Class specifications allow either MIL-PRF-16173 preservative or inert gas for these voids.

5: Ramps lowered into water during loading/unloading.

Benchtop Testing of Inaccessible Void Coatings and Treatments

Little information is available with respect to corrosion performance of corrosion control technologies within inaccessible voids. Ideally, the corrosion protection method(s) used in inaccessible voids should last for the design life of the ship (e.g., 30-40 years), barring any incident that results in flooding the void with water. The corrosion environment and risk inside of voids varies with their location: those above the waterline, or that have no boundaries exposed to seawater or a water-filled tank can be expected to have a rather benign environment with fairly stable temperature gradients and little risk of accidental water entry or flooding. They may only experience minor condensation from the moisture in the air when the void was closed up. Conversely, voids with one or more boundaries exposed to seawater, standing water, or a water-filled tank are prone to temperature gradients which can promote condensation and subsequently, corrosion. This corrosion concern increases significantly if a crack develops in a void below the waterline, allowing ingress of seawater and other contaminants.

To better understand the degree to which each can protect the uncoated steel surfaces, a series of benchtop tests of alternative protection schemes were conducted in simulated service conditions. The testing scope is intended to represent conditions that may be encountered on ship structural voids constructed of welded steel that are not foam filled (e.g., for buoyancy or acoustic reasons).

Experimental Approach

The test matrix involved exposing duplicate test panels in each of 72 different combinations of steel condition, environmental exposure, and corrosion prevention measure. Table 2 shows the overall test matrix. After 6 months of exposure testing, the corrosion on the panels was evaluated. Details on each of the variables and the evaluation methods are presented in this section.

Steel Test Panel Conditions

Four sets of replicate 1-in by 3-in by 1/16-in AISI 1010 carbon steel test were abrasive blasted with aluminum oxide (2-3 mil surface profile) and pre-weighed. Two sets of panels were coated with Interplate 937, a zinc silicate pre-construction primer (PCP) using conventional spray methods. The average dry film thickness (DFT) was 0.48 mils (within the desired 0.4 to 0.7 mils range) with a standard deviation of 0.14 mils. The remaining sets were left without PCP.

Two sets of test panels (one bare set and one set with PCP) were weathered outside in rural New Jersey for a period of seven (7) days during which they were sprayed with ASTM D1141 seawater² twice (to simulate steel exposed outside at as shipyard prior to assembly). Additional witness coupons were also exposed to quantify the extent of rusting which occurred on the bare steel panels.

² ASTM D1141 - 98(2013), *Standard Practice for the Preparation of Substitute Ocean Water*, ASTM International, West Conshohocken, PA, 2013.

These procedure resulted in the four surface conditions shown in Table 2 – bare steel, pre-rusted bare steel, PCP coated steel, and weathered PCP coated steel.

Table 2 – Experimental Test Matrix

Panel Surface Condition	Immersion						Atmospheric (~85% RH)						Atmospheric (~85% RH With Condensation)					
	Tectyl 891D Fill & Drain	Tectyl 891D Float Coat	Esgard PL-1	VCI	Control (Uncoated)	Inert Gas Purge	Tectyl 891D Fill & Drain	Tectyl 891D Float Coat	Esgard PL-1	VCI	Control (Uncoated)	Inert Gas Purge*	Tectyl 891D Fill & Drain	Tectyl 891D Float Coat	Esgard PL-1	VCI	Control (Uncoated)	Inert Gas Purge*
Clean, bare steel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Pre-rusted bare steel	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Pre-construction Primed (PCP)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Weathered PCP	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2

*Inert gas purge atmospheric conditions varies from the other test conditions. Specifically, the relative humidity in the atmospheric exposure was low (nominally 40%) and the condensing situation was exposure in a 100% RH environment with ASTM seawater as the moisture source.

Environmental Exposure Conditions

The test panels were exposed in one of (3) environments, each representing different potential conditions within a void – atmospheric with condensation, atmospheric without condensation and immersion. Lascar EL-USB-2 data loggers were placed in each container to log temperature, relative humidity and dew point throughout the exposure period. Figure 3 shows the test setups for each environment.

Atmospheric exposure with condensation on the panel surfaces is intended to simulate closed conditions in a void with boundaries that are at temperatures below the dew point, resulting in condensation. This may occur in a void with one surface exposed to the seawater. These test panels were in contact with thermoelectric coolers, lowering their surface temperature below the dew point to facilitate condensation on the panel surfaces. Figure 4 demonstrates the condensation formed as a result of contact with the thermoelectric coolers.

Atmospheric exposure without condensation on the panel surfaces is intended to simulate closed conditions in a void with boundaries that are at temperatures above the dew point. For the

atmospheric exposure evaluation, test panels were exposed in 10-quart air tight containers (representing an inaccessible void) maintained at a relative humidity of approximately 80-85% (using a solution of glycerol and water)³ for a period of six (6) months.

The immersion condition was intended to simulating a crack leading to a flooding event or residual water in the void. For the immersion test, two (2) of each panel condition were immersed in artificial seawater for a period of six (6) months. The seawater was not aerated.



Figure 3. Immersion (left) and Atmospheric with and without Condensation (right) Testing

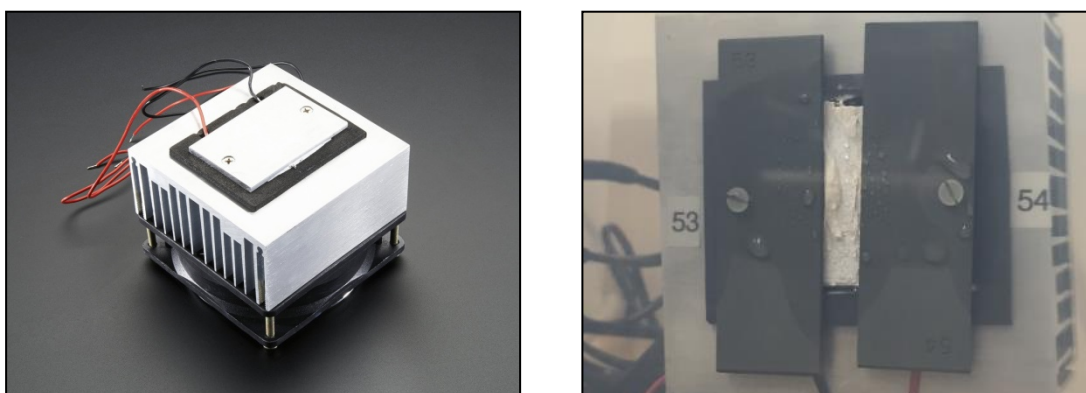


Figure 4. Thermoelectric Cooler (left) and Condensation Formed on Test Panels (right)

To better understand the effect of purging with an inert gas, duplicate test panels were exposed in two (2) containers, which were purged with nitrogen such that the O₂ level was maintained at less than 5%. As listed in Table 2, one container housed coupons immersed in a bath of ASTM seawater and coupons in the vapor space above the seawater. This simulates a condition in which a void with some collected water (whether by condensation or leakage) is inerted prior to sealing. The other container housed coupons at ambient conditions. Figure 5 and Figure 6 and show the inerted containers. Maxtec Handi+ Oxygen Analyzers were used to monitor and maintain O₂ levels. Lascar EL-USB-2 data loggers were also placed in each container to log temperature, relative humidity and dew point throughout the exposure period.

³ Forney, C. and Brandl, D, "Control of Humidity in Small Controlled-environmental Chambers using Glycerol-Water Solutions," HortTechnology, January-March 1992, vol. 2 no. 1, pp. 52-54



Figure 5. Inerted Container and Oxygen Monitor

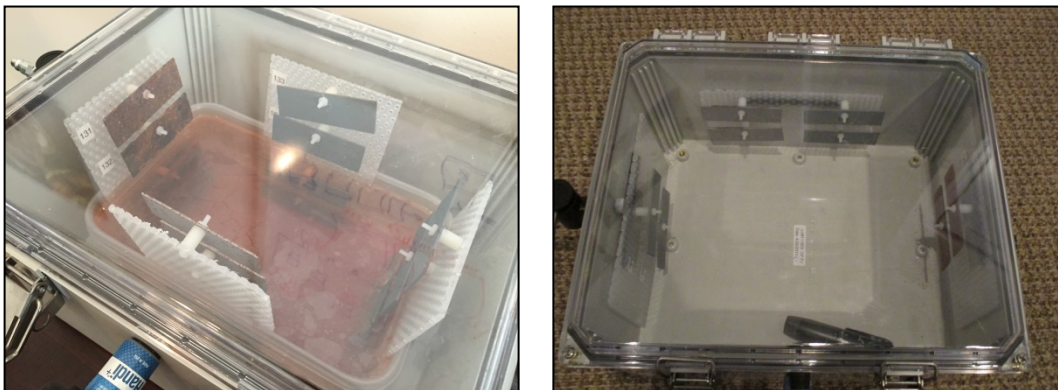


Figure 6. Environments within Inerted Containers (Immersion / Atmospheric on Left and Ambient on Right)

Corrosion Control Methods

MIL-PRF-16173, Grade 1 Corrosion Preventative Compounds

Several products are listed on the qualified products list (QPL) for coatings meeting MIL-PRF-16173, Class 1, Grade 1. These are listed in Table 3.

Table 3 – Coatings Meeting MIL-PRF-16173, Class 1, Grade 1

Product	Manufacturer
Cortec VpCI-368M	Cortec Corporation
Esgard PL-1	Esgard
Nox-Rust 501	Daubert Chemical
Nox-Rust 501LS	Daubert Chemical
Tectyl 891D	Daubert Chemical

According a Daubert Sales representative, the Nox-Rust and Tectyl products are essentially the same, but Tectyl 891D is more readily available. The Cortec VpCI-368M was not readily available for testing. For these reasons, only Esgard PL-1 and Tectyl 891D were evaluated.

MIL-PRF-16173, Class 1, Grade 1 coatings can be applied using one of two methods:

1. Fill and Drain – coating is pumped into a void and subsequently drained. The void geometry, and the drain and air escape vent locations will affect surface coverage. Time is allotted to ventilate any gases and the void is sealed.
2. Float Coat – a specified amount of coating is added to the void (dependent upon void volume) and water is pumped in to float the coating throughout the void, thus coating the interior surfaces. The water is subsequently drained and discarded. Time is allotted to ventilate any gases and the void is sealed. The locations of the drain and air escape vents may also affect surface coverage. Coating in this manner involves water, which could potentially affect coating performance.

To evaluate the corrosion performance of MIL-PRF-16173 coatings, sets of test panels were coated with either Tectyl 891D (Tectyl) or Esgard PL-1 (Esgard) using representations of each of the aforementioned application methods. To represent the fill and drain method, each panel was dipped into its respective coating and allowed to dry for a period of 24-hours. For the float coat method, panels were placed into a container in which water had been added to an appropriate amount of Tectyl.⁴ The panels were then dipped past the coating into the water and pulled back up through the coating to cover the entire panel surface. These panels were also allowed to dry for 24-hours to cure prior to exposure. Figure 7 shows representations of the fill and drain and float coat methods respectively.

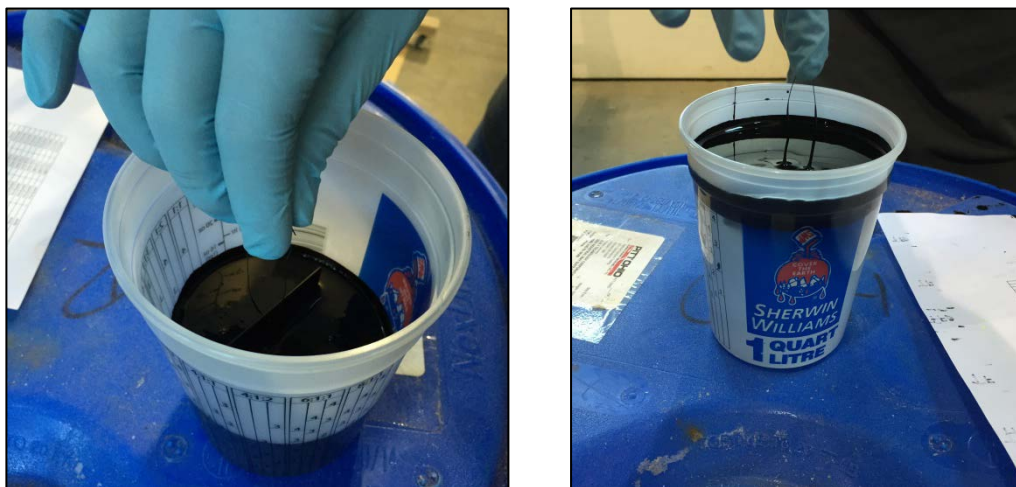


Figure 7. Representations of the Fill and Drain (left) and Float Coat (right) Methods

Vapor Phase Corrosion Inhibitors

VCI powder product manufacturers cite compliance with the performance requirements of specification MIL-I-22110 or commercial item description A-A-59441 Type V. The Navy has previously used a powder supplied in bulk form to the requirement of A-A-59441 Type V for protecting inaccessible voids. Zerust® ActivPowder™ – 10F was selected for testing as it is

⁴ Esgard PL-1 did not float and therefore was applied using only the fill and drain method.

represented to meet the requirements of CID A-A-59441/5. The VCI is designed to diffuse rapidly to protect against flash rust and to provide long term corrosion protection. It is designed to provide at least 3 years of corrosion protection in water-tight enclosures and up to 15 years in vacuum or gas-tight enclosures. In the VCI test conditions, the uncoated coupons were exposed in the aforementioned containers with nominally 2.8 grams of VCI powder (300 g/m^3), as recommended in the CID for enclosed spaces. The powder was simply placed in the bottom of the test enclosure.

Inert Gas

Dry inert gasses (such as argon or nitrogen) are sometimes used in lieu of coatings or VCIs (or in conjunction with VCIs) for corrosion protection. Purging with inert gases lowers the oxygen concentration within the void, decreasing the propensity for corrosion. Specifications for this treatment generally require the oxygen (O_2) level in the void be lowered to 5-8% or less. To better understand the effect of purging with an inert gas, test panels were exposed in containers which were purged with nitrogen such that the O_2 level was maintained at less than 5%. As listed in Table 2, one container housed coupons immersed in a bath of ASTM seawater and coupons in the vapor space above the seawater. This simulates a condition in which a void with some collected water (whether by condensation or leakage) is inerted prior to sealing. The other container housed coupons at ambient conditions.

Test Panel Evaluation

After the six-month exposure period, the panels were removed, visually evaluated for surface corrosion and photographed. Pre-construction primer was removed from the coated panels using a commercial paint stripper. All panels were abrasive blast cleaned with glass bead media to remove corrosion and residual coating. Each test panel was then solvent wiped and weighed to determine metal loss.

For pre-rusted coupons without PCP, the metal loss incurred during the pre-exposure period was measured with replicate witness panels. Depending on the pre-exposure period, pre-exposure metal loss ranged from 0.14 to 0.37 mils. The co-efficient of variation for the weight loss on any given set of pre-exposed test panels was less than 30%. This metal loss was subtracted from the total weight loss to calculate the corrosion during the simulated void exposure period.

Results

Atmospheric with Condensation

Figure 8 shows the average temperature, relatively humidity and dew point data (error bars show two standard deviations—which accounts for 95% of the data) for panels exposed to atmospheric conditions with condensation. The data for the inerted enclosures are included for comparison purposes. The panels exposed in the vapor space of the inerted enclosure with the seawater bath (refer to the left image in Figure 6) experienced similar conditions to the panels to which thermoelectric coolers were attached. Specifically, the relative humidity values in this

environment were typically over 100% and condensation was often visible on the top of the enclosure.

Figure 9 and Figure 10 show the visual corrosion observations and average metal loss data (with error bars depicting one standard deviation) for test panels exposed to atmospheric conditions with condensation. The visual corrosion is consistent with the metal loss data. Negligible corrosion was measured on the panels which were not pre-rusted despite some visual rust spots on some of the panels. Corrosion is most evident on the pre-rusted panels; corrosion loss is much as an order of magnitude higher for the pre-rusted bare panels versus all other steel conditions. One of the MIL-PRF-16173 coatings protected the pre-rusted panels from corrosion nearly as well as the panels which were not pre-rusted. The VCI and other MIL-PRF-16173 coatings provided some corrosion control benefit versus the control pre-rusted surface.

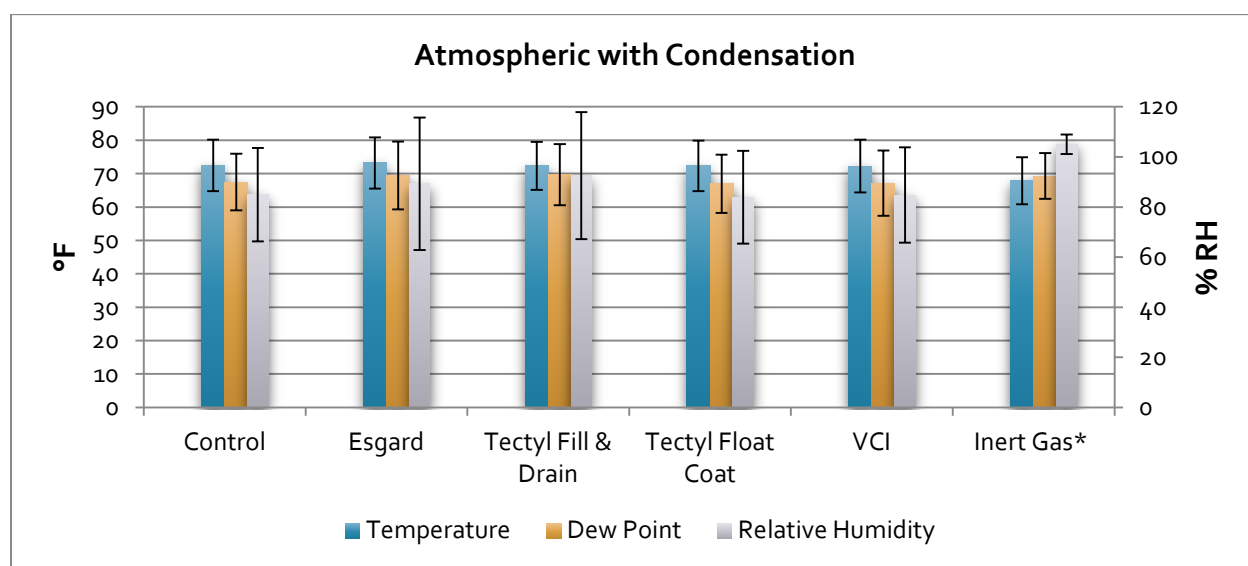


Figure 8. Average Temperature, Relative Humidity and Dew Point Data for Condensation Environment

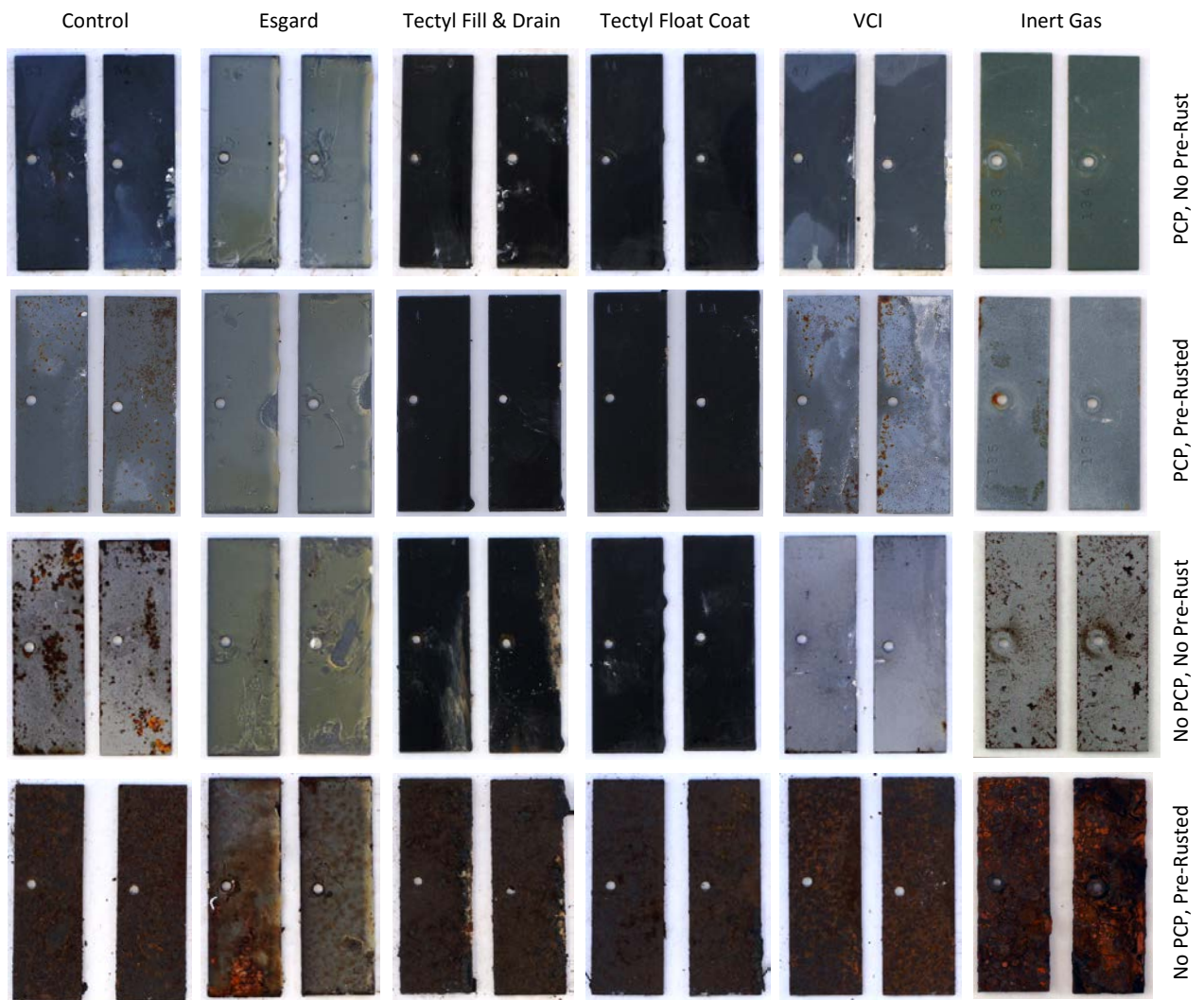


Figure 9. Corrosion Observed After 6-Months Exposure to Atmospheric Conditions with Condensation

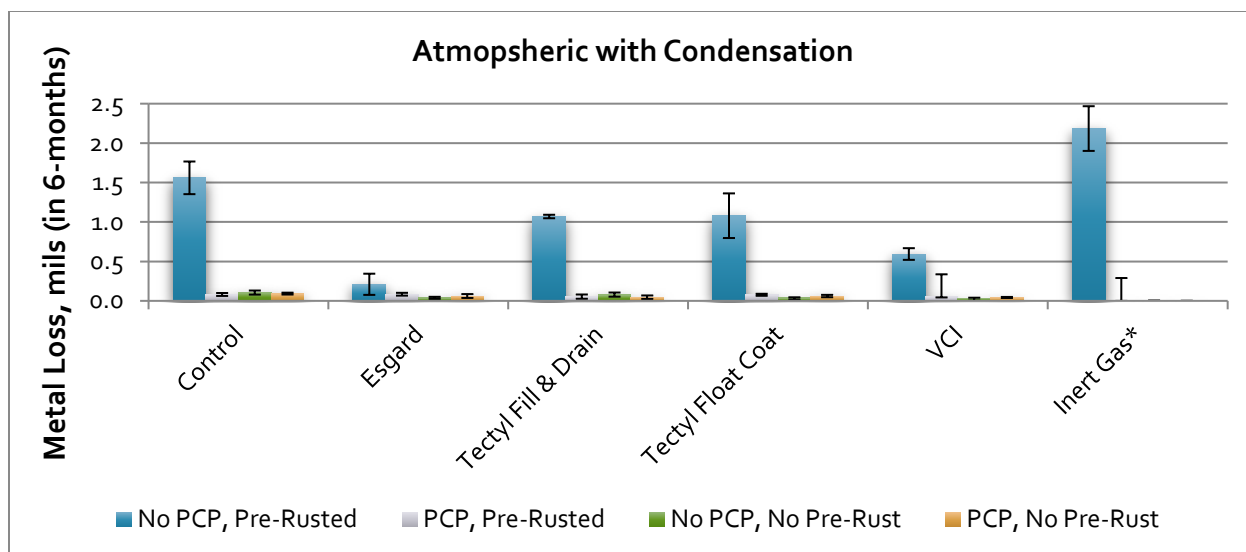


Figure 10. Metal Loss Data for Panels Exposed to Atmospheric Conditions with Surface Condensation

Atmospheric without Condensation

Figure 11 shows the average temperature, relative humidity and dew point data (error bars show two standard deviations—which accounts for 95% of the data) for panels exposed to atmospheric conditions without condensation. The data for the inerted enclosures are included for comparison purposes. The inerted enclosure without the seawater bath (refer to the right image in Figure 6) experienced much lower humidity values due to the introduction of dry nitrogen.

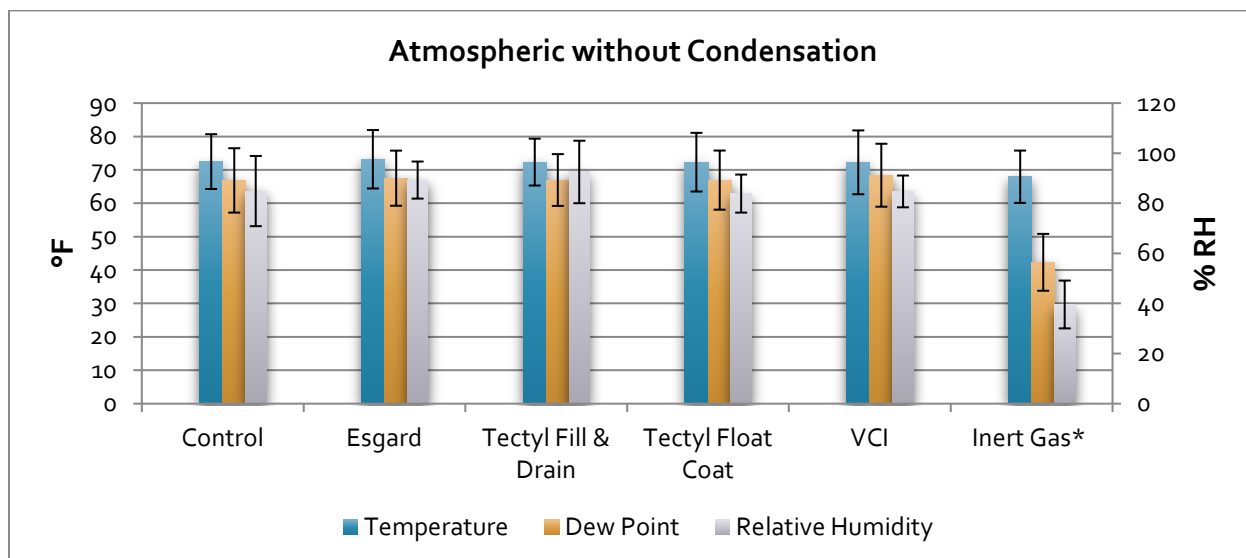


Figure 11. Average Temperature, Relative Humidity and Dew Point Data for Atmospheric Environment

Figure 12 and Figure 13 show the visual corrosion observations and average metal loss data (with error bars depicting one standard deviation) for test panels exposed to atmospheric conditions without condensation. Data for panels exposed in the inerted container at ambient conditions was included for comparison purposes. This represents a void in which dry inert gas was introduced, dropping the ambient nominal relative humidity. The visual corrosion is consistent with the metal loss data. Negligible corrosion was measured on the panels which were not pre-rusted despite some visual rust spots on some of the panels. Corrosion is most evident on the pre-rusted panels; corrosion loss is much as five times higher for the pre-rusted bare panels versus all other steel conditions. Inert gas purge and one of the MIL-PRF-16173 coatings protected the pre-rusted panels from corrosion when compared to the control. The VCI and other MIL-PRF-16173 coatings did not provide any corrosion control benefit versus the control pre-rusted surface.

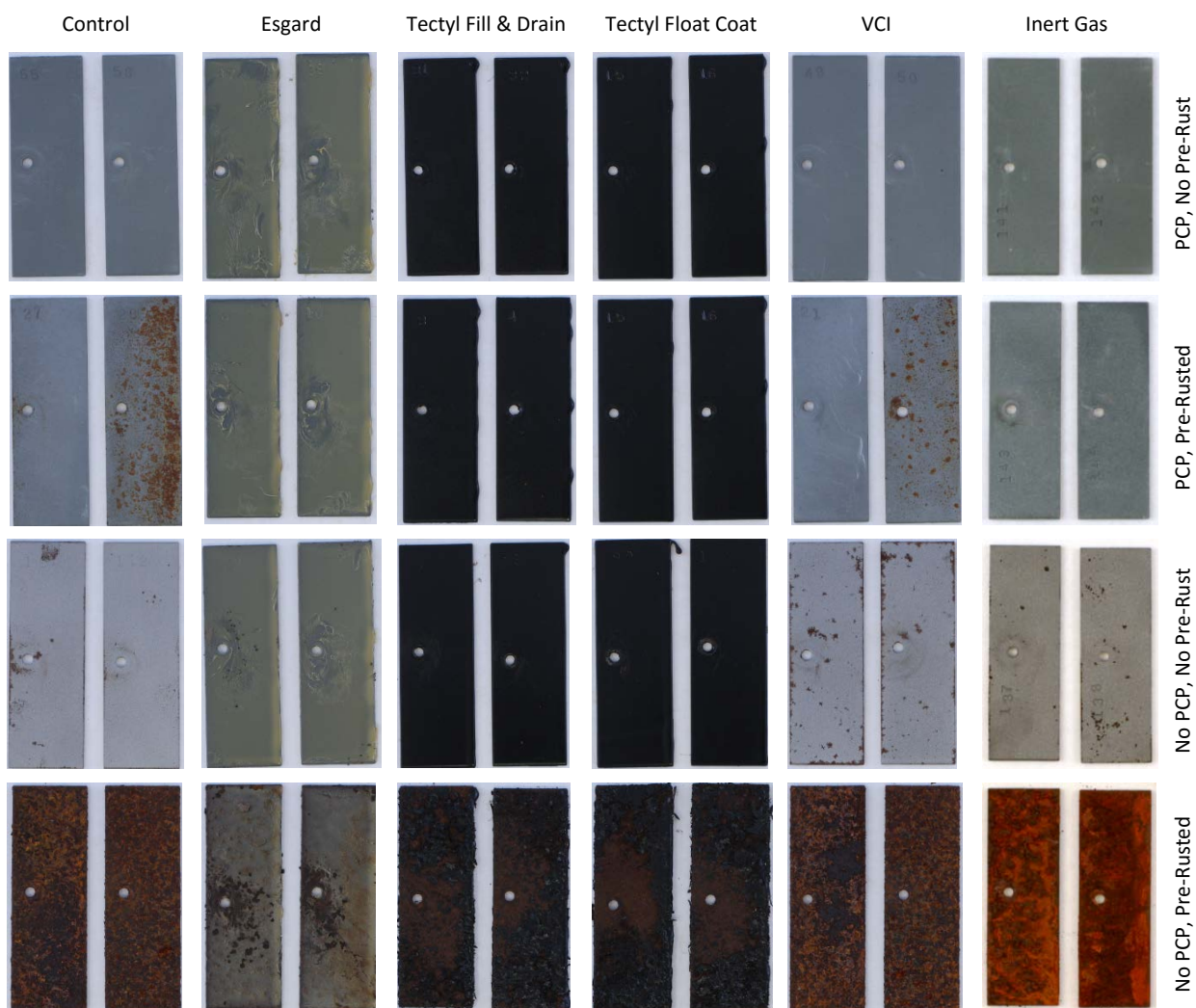


Figure 12. Corrosion Observed After 6-Months Exposure to Atmospheric Conditions without Condensation

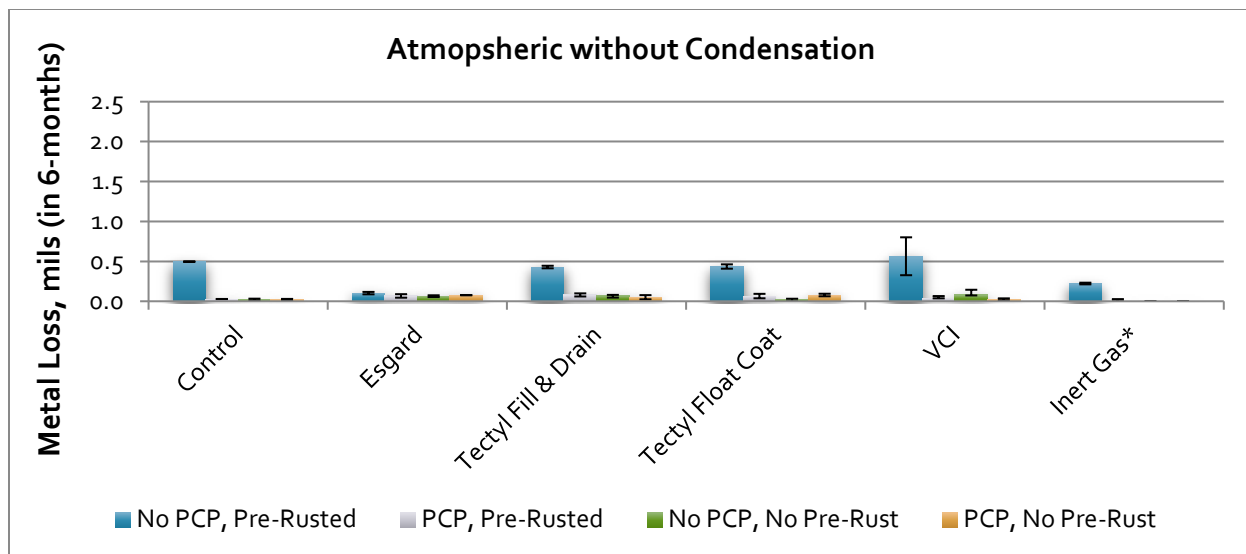


Figure 13. Metal Loss Data for Panels Exposed to Atmospheric Conditions

Seawater Immersion

Seawater immersion is intended to represent a void which has been breached. However, note that the inerted test condition remained inerted which would likely not be the case if the void was breached; therefore this data is not particularly relevant to a ship life cycle. No temperature data was logged for the immersion environments, but the baths were maintained indoor at ambient room temperature of nominally 70°F.

Figure 14 and Figure 15 show the visual corrosion observations and average metal loss data (with error bars depicting one standard deviation) for test panels exposed in ASTM seawater immersion. The visual corrosion is consistent with the metal loss data. Corrosion is most evident on the pre-rusted panels, however in immersion exposure significant corrosion was observed on panels with all other initial conditions. All of the MIL-PRF-16173 coatings provided corrosion protection in the immersion condition whereas the panels with VCI treatment corroded comparably to the control. As in the other test conditions, one of the MIL-PRF-16173 coatings outperformed the others.

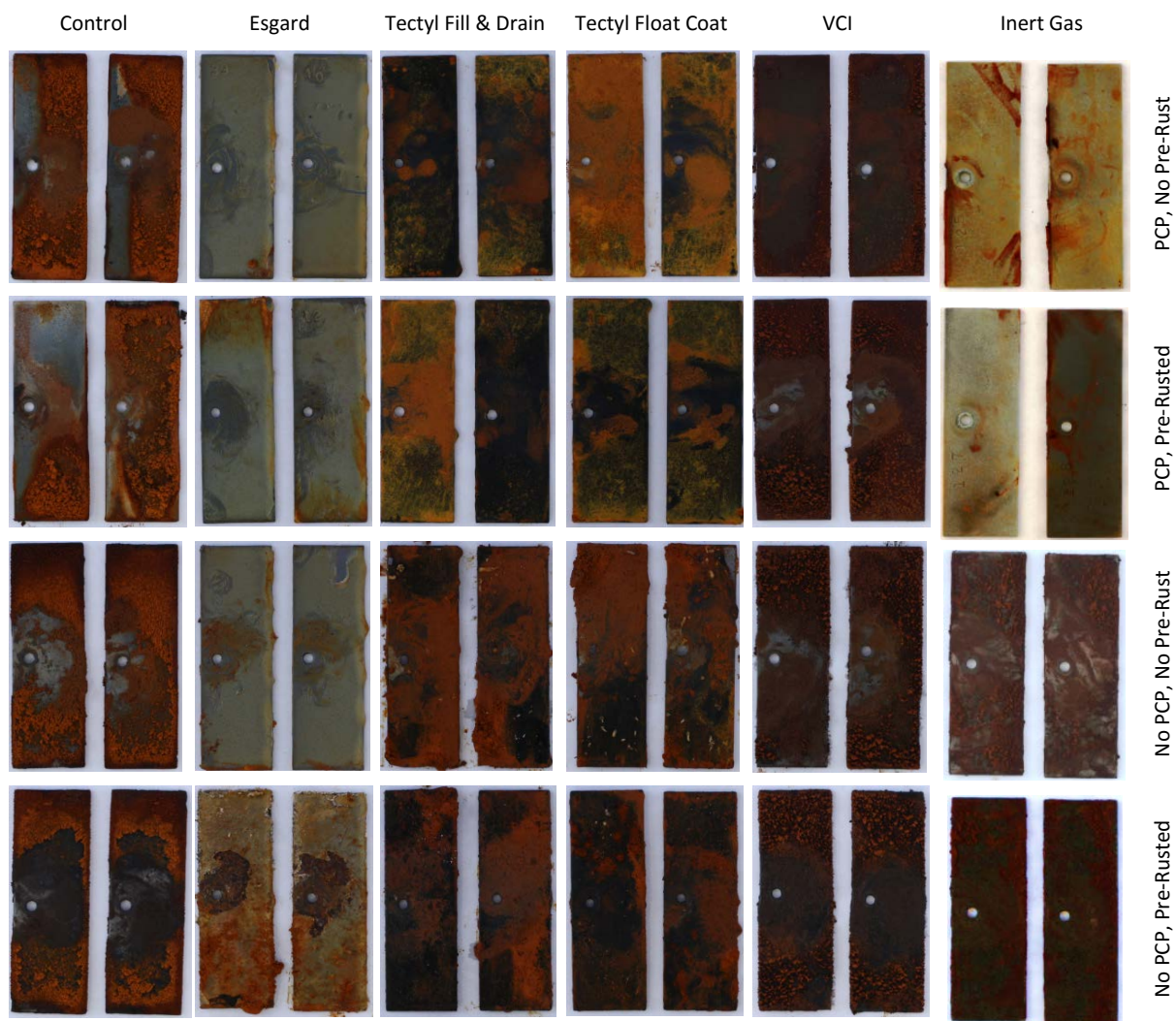


Figure 14. Corrosion Observed After 6-Months Exposure to ASTM Seawater Immersion

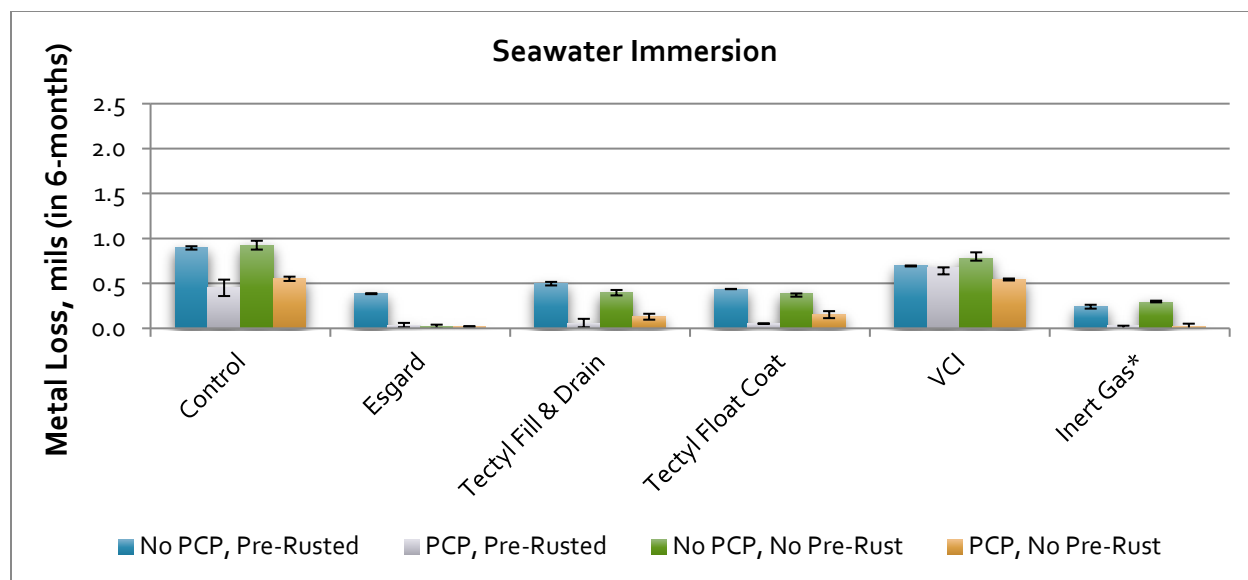


Figure 15. Metal Loss Data for Panels Immersed in ASTM Seawater

Discussion

Figure 16 shows an interaction plot for the various parameters evaluated in the benchtop testing. The values plotted are the mean corrosion rates for all test panels of similar parameters. The plots are organized such that the interaction of one parameter and each of the other categories is shown. Essentially, plots with parallel lines suggest no interaction of the two parameters depicted. Irregularities in the graphs suggest an interaction between the parameters depicted on the graph. The plots clearly reinforce some of the observations depicted in the results section. For example, the first two lines show that all of the corrosion control technologies are less effective over pre-rusted test panels without PCP. However, the second column of panels from the left show that one of the treatments is markedly better over the pre-rusted steel surface. Similarly, the far right column shows that the control and VCI treatments are negatively impacted by the presence of surface moisture (i.e., condensation or immersion).

Figure 17 shows the average metal loss data (with one standard deviation error bars) for test panels with all treatments grouped by steel surface conditions and test environment. These data reinforce the observation that once the bare steel begins to corrode, all treatments are less effective. This is most significant in the condensing exposure. The data suggest that procedures should be implemented to remove corrosion from inaccessible void surfaces prior to closing them up. Applying supplemental PCP would also be helpful.

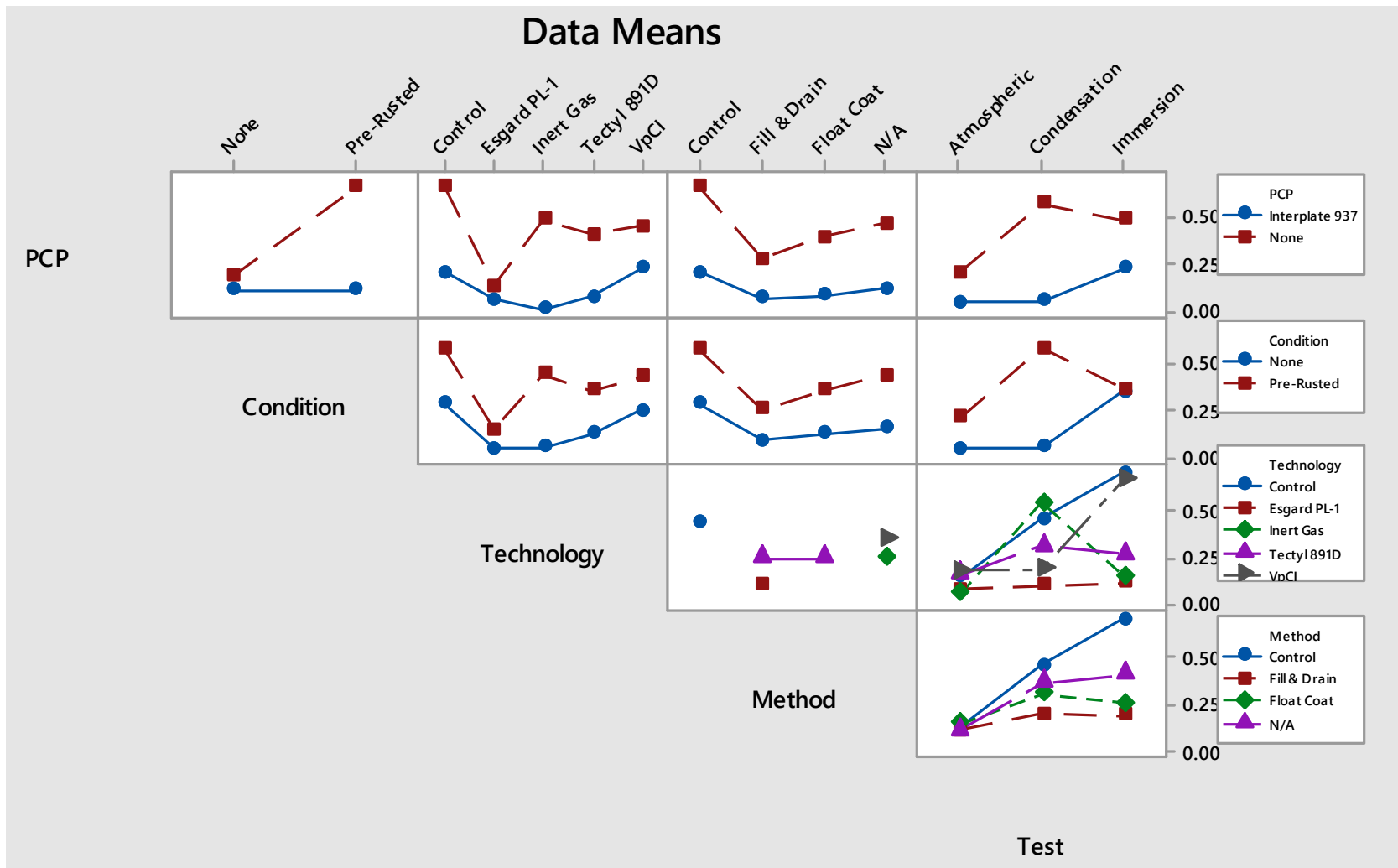


Figure 16. Interaction plot showing the mean corrosion loss as a function of various test condition combinations.

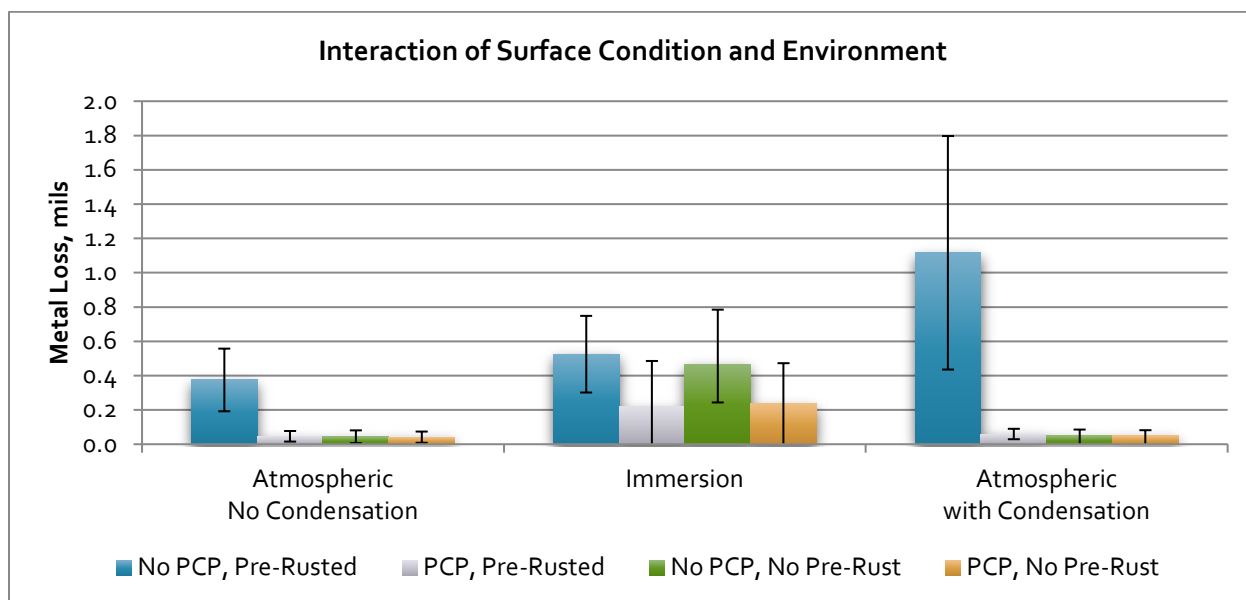


Figure 17: Impact of PCP on Corrosion

Figure 18 and Figure 19 show cumulative probability distributions of atmospheric corrosion rate data (condensing and non-condensing) for all steel surface conditions except the bare, pre-rusted steel. Each prevention technology and the control panels are represented by a different line. While statistically significant differences may exist, all corrosion prevention technologies and the control (untreated) panels predominately had less than 0.2 mils of corrosion during the 6-month test period.

Figure 20 shows a similar plot of the same conditions (i.e., not including bare, pre-rusted panels), in the seawater immersion environment (failure event). The data suggest a clear benefit of MIL-PRF-16173 coatings – roughly 0.5 mils less corrosion over the 6-month timeframe. The data also suggest that there is no difference between VCI and the untreated control panels. It is worth noting that all metal loss values are low relative to what would typically be seen in aerated seawater (6-8 MPY).⁵ This may be due to the fact that the test environments were not aerated or refreshed and may in part be due to the use of artificial seawater.

Visual analysis and metal loss data did not support the use of one application method over another (fill and drain vs. float coat), but did support the use of Esgard product versus the Tectyl product.

The combination of VCI and inert gas was not tested, but is becoming more prevalent in shipyards. Additional testing with this condition should be conducted and compared against the data in this testing.

⁵ H. Möller, E.T. Boshoff, and H. Froneman, “The corrosion behavior of a low carbon steel in natural and synthetic seawaters”, The Journal of the South African Institute of Mining and Metallurgy, Volume 106, August 2006.

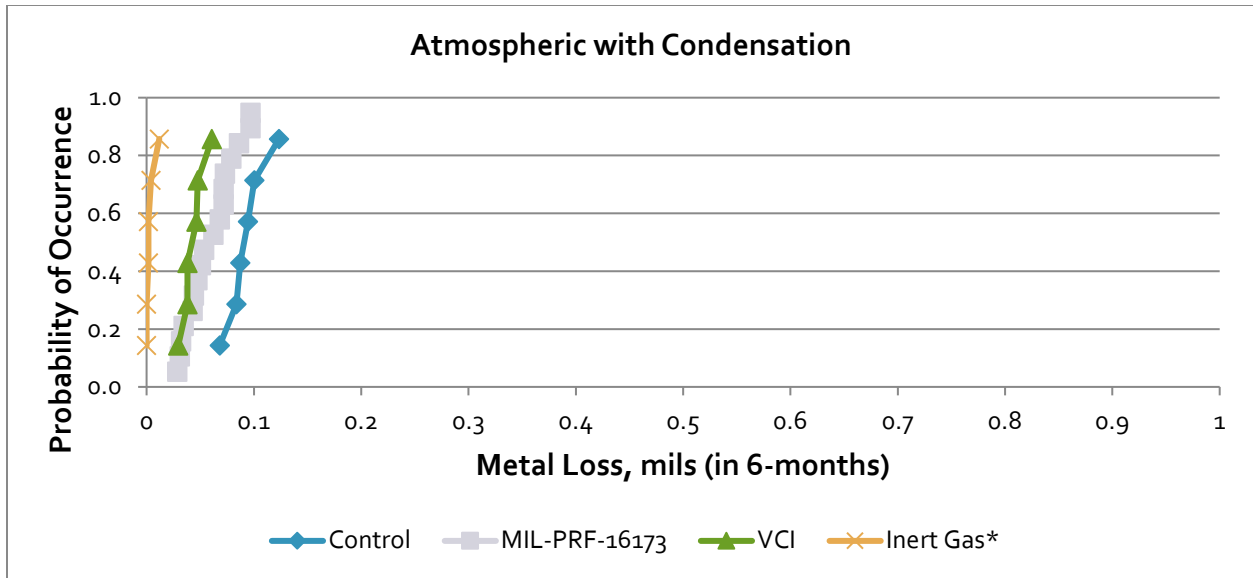


Figure 18: Metal Loss Data in Atmospheric with Condensation Exposure

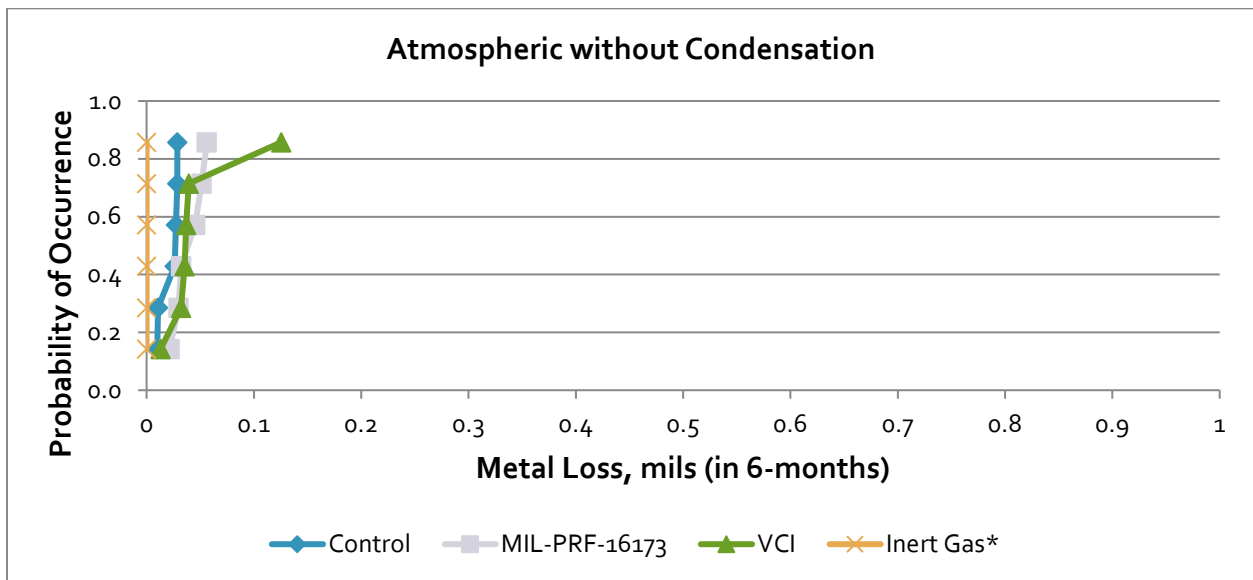


Figure 19: Metal Loss Data in Atmospheric without Condensation Exposure

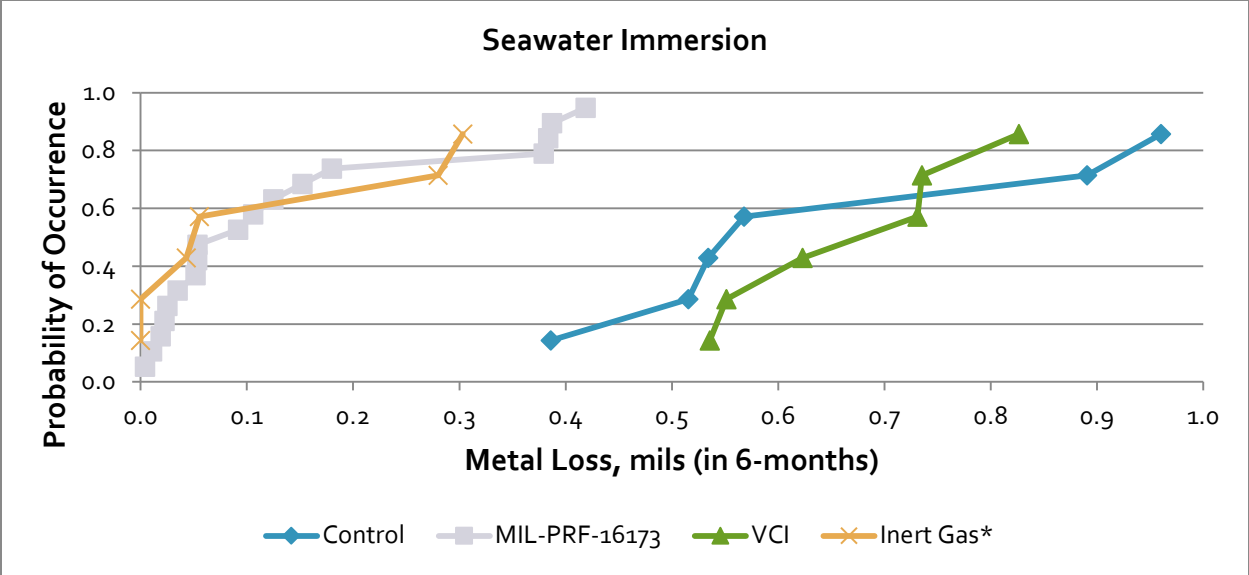


Figure 20: Metal Loss Data in Seawater Immersion

References

- a. MIL-PRF-16173E(SH), w/ Interim Amendment #1, "Corrosion Preventive Compound, Solvent Cutback, Cold-Application", 7 Sept 2006
- b. CID A-A-59441, "Vapor Corrosion Inhibitors", 16 Jan 2004 (with Specification Sheet A-A-59441/5)
- c. Navy Technical Manual T9630-AB-MMD-010, "Corrosion Control Assessment And Maintenance Manual (CCAMM)", Rev. 3, 30 June 2015
- d. E-mail, T. McCue (NAVSEA 00C) to N. Clayton (Elzly Technology), Subject: RE: NSRP Inaccessible Void Project, 20 Mar 2015
- e. MIL-I-22110C, "Inhibitors, Corrosion, Volatile, Crystalline Powder", 26 Sept 1985
- f. NACE Standard Test Method TM0208-2013, "Laboratory Test to Evaluate the Vapor-Inhibiting Ability of Volatile Corrosion Inhibitor Materials for Temporary Protection of Ferrous Metal Surfaces", 2013
- g. "Corrosion Protection of Cargo Tanks", Chevron Shipping Company, Tanker Structure Co-Operative Forum 2000 Shipbuilders Meeting, Tokyo, October 2000
- h. NACE TM 0208-2013, Laboratory Test to Evaluate the Vapor-Inhibiting Ability of Volatile Corrosion Inhibitor Materials for Temporary Protection of Ferrous Metal Surfaces, NACE International, Houston Texas.
- i. Naval Ships' Technical Manual (NSTM) Chapter 074, Volume 1, "Welding and Allied Processes", Rev. 5, 31 Jan 2003.
- j. MIL-C-11796C, "Corrosion Preventive Compound, Petrolatum, Hot Application", 26 Apr 2000 (Inactive for new design as of 22 Jan 2013).
- k. National Fire Protection Association (NFPA) 306: "Standard For The Control Of Gas Hazards On Vessels", 2014 edition.
- l. Naval Ships' Technical Manual (NSTM) Chapter 074, Volume 3, "Gas Free Engineering", Rev. 5, 1 Sep 2009.
- m. Naval Ships' Technical Manual (NSTM) Chapter 542, "Gasoline and JP-5 Fuel Systems", Rev. 5, 1 Jul 2010.
- n. American Bureau of Shipping (ABS), "Guide for Inert Gas System for Ballast Tanks". May 2012.
- o. ASTM B117, "Standard Practice for Operating Salt Spray (Fog) Apparatus".

Appendix A – Representative Products List

Inorganic Zinc Silicate Pre-Construction Primers (Partial List)

International Paint

- Interplate 997
- Interplate 937

PPG Coatings

- Sigmaweld 199

MIL-PRF-16173 Grade 1 Corrosion Preventive Compounds (from QPD a/o January 2016)

Grade 1: Hard film, (175 degrees Fahrenheit (°F) 80 degrees Celsius (°C) minimum flow point of solvent deposited film)

Class I: High VOC - VOC exceeding 2.8 pounds per gallon (lbs/gal) (340 grams/liter)

Class II: Low VOC - VOC not exceeding 2.8 lbs/gal (340 grams/liter)

Esgard Inc.

- Esgard PL-1 – Class I & II [Density 9.6 lb/gal; SG 1.18]

Daubert Chemical Co.

- Nox-Rust 501 – Class I & II [Density 7.6 lb/gal; SG 0.88]
- Nox-Rust 501LS – Class I [Density 7.34 lb/gal; SG 0.88]
- Tectyl 891D Class I - Class I [Density 7.3 lb/gal; SG 0.89]
- Tectyl 891D Class II – Class II [Density 7.6 lb/gal; SG 0.91]

Cortec Corp.

- VpCI-368M – Class I [Density 7.1-7.5 lb/gal; SG not reported]

For the purposes of evaluating these products for float-coat application, product data sheets and MSDS's indicate that all products except for Esgard PL-1 are less dense than water and/or have a specific gravity (SG) of less than 1.0. In addition, they all are reported to have negligible solubility in water.

Vapor Phase Corrosion Inhibitors

Northern Technologies Corp.

- Zerust ActivPowder-10F (Claims conformance to MIL-I-22110C although not listed on QPD. Also claims conformance to NACE Standard Test Method TM 0208-2013, reference (h), and CID A-A-59441/5.)

Cortec Corp. (All claim conformance to MIL-I-22110C although not listed on the QPD)

- VmCI-307 Powder
- VpCI-309, -309 SF Powder

- VpCI-609/609S Powder (Also claims conformance to NACE Standard Test Method TM 0208-2008.)

Inert Gasses

- Compressed Argon Gas (Ar) >99.998%
- Compressed Nitrogen Gas (N₂) High Purity > 99.998%; Low Purity > 90%