Duration of Exposure (Part 3): Plumbing and Construction Materials

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ABSTRACT

This study advances our understanding of metal corrosion rates among 21 common building, plumbing and electrical components by comparing their qualitative responses to four exposure scenarios: control conditions (24ºC and 50% RH), elevated humidity (>95% RH), freshwater mist, and saltwater mist (seawater @ 35 ppt) over periods ranging from 11 to 18-months. The entire study was conducted over a nine-year period. Changes in surface appearance varied among the components due to their elemental composition. The final study documented changes to galvanized steel pieces (i.e., garbage disposal bracket, electrical outlet cover, electrical junction box, flexible electrical conduit, and electrical conduit strap), steel pieces (i.e., sink fastener and face-mounted hinge), and one brass piece (SharkBite angle stop valve). The elemental composition revealed that the most corrosion resistance over the entire study was among nickel, stainless steel, and galvanized steel components. The least resistance was exhibited among those with a predominance of iron. The study concluded that careful examination of these components could provide insight into the duration of a water loss.

INTRODUCTION

The forensic criminal sciences offer an array of methods to estimate the timeline of a criminal event. The elemental composition of human hair, the growth phases of Blow Fly in a cadaver or the types of tree pollen recovered from clothing offer a window to the occurrence of a criminal event (Carper, 2000; Gennard, 2007; Gun, 2006; Redsicker, 2000). Material failure analysis can also provide a perspective to the forensic engineer by evaluating the visible events that occur during metal corrosion.

In the absence of corrosive chemical agents, metal corrosion (*i.e.,* rust, surface pitting, dulling, oxidation, flacking, blackening and material loss) indicated a moisture source within the environment. Nearly all metal structural, electrical, and plumbing components express visible change when exposed to moisture for increasing periods of time. The studies described herein were undertaken to document the visible changes that occurred to common household metal components so that comparison to components of unknown exposure could be estimated to derive the moisture exposure period. This investigation describes the relationship between the elemental analysis of metal component surfaces and their corrosion resistance.

Traditional approaches to studying metal corrosion were evaluated by the loss in weight technique, accelerated testing, electrochemical processes, and the percentage coverage of corrosion on visible surface areas. This qualitative study offers sequential documentation of metal degradation when exposed to fresh (tap) water, salt (seawater) and elevated relative humidity. In conformance with previous metal corrosion research, we focused our research design on standards for use of a salt spray apparatus (ASTM B117). Preparing, cleaning and evaluation of test specimens used ASTM G1.

MATERIALS AND METHODS

A test apparatus constructed of acrylic and polycarbonate was constructed with four independently controlled isolated chambers (Figure 1). Each chamber was equipped with shelves to support or suspend metal specimens being exposed to fresh water, salt water, elevated RH, and a control environment at ambient conditions (24ºC and 50% RH). The size of the six shelves allowed one or two specimen sets to be positioned on each shelf. The shelves also served to divert accumulated water discharged by the foggers away from specimens positioned below. The configuration of shelves and foggers produced uniform exposure throughout the chamber while limiting the opportunity for the possibility of chemical interaction between specimens from one sample to another via directed drainage. The sample specimens were exposed to non-corrosive plastic components to minimize any influences of the testing apparatus on the sample specimens. Fishing line (monofilament) and plastic clips were used to suspend the specimens above the shelves (Figure 1).

The first two tests evaluated corrosion among galvanized water pipe with a threaded brass fitting, nonflexible electrical conduit, corner bead, lath, framing, sill plate, concealed cabinetry hinges, escutcheon plates, braided supply lines, sink fasteners, angle stop valve handles, and face-mounted hinges (Wells *et al.*, 2015, 2018). A fog spray was used to expose the specimens to fresh or saltwater using plastic fogger heads connected to plastic pressurized supply lines.

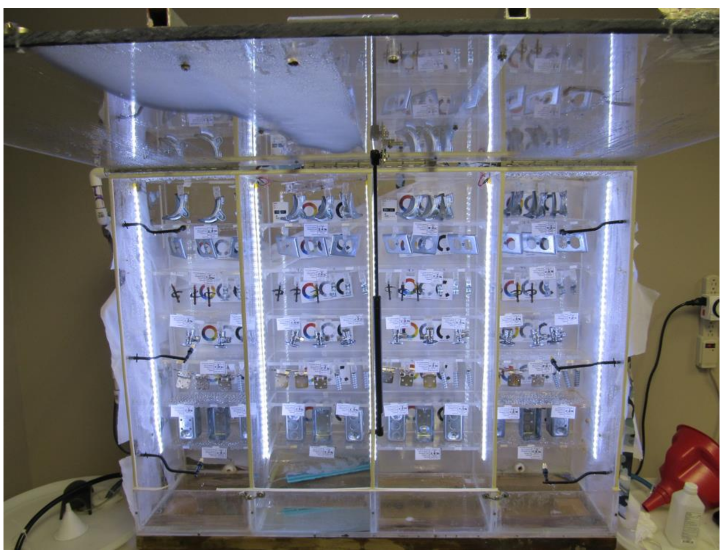

Figure 1. Metal Corrosion Chamber.

Each material was tested in triplicate within each exposure environment. In the most recent test, twenty-one specimens were positioned within each exposure environment. The water supply system for the fresh and salt water was re-circulated to a 113.6 liter (30-gallon) tank plumbed to a well pump (Everbilt Model J100A3). This arrangement maintained a near constant water temperature (25.5ºC to 26.6ºC) using a water recirculation system and by implementing the fogging (wetting) period for 15 minutes "on" followed by a dry period of 45 minutes "off". This wet-dry cycle was effective in maintaining the specimens in a constant saturated state.

Fresh water was provided by the City of Tampa. Salt water was created using a formulation of marine crystals (Coralife Marine Salt) combined with tap water. The 94.6 liter (25-gallon) mixture was formulated using 12.5 cups (< 4.08 kg /9 pounds) of marine crystals to attain a specific gravity of about 1.021 (SG_{true}≈1.021). A filtration system was incorporated that used a 10-micron filter (3M Filtrete, 3WH-STDGR-F02) before the fogger heads to ensure specific water quality and removed any particulates. The salt and freshwater pH (Etekcity pH-2011, Oakton Instruments 35624-22), salinity (Strom Store RHS-ATC10) and temperature information were recorded periodically. Similarly, tap water was measured periodically to serve as a control. The temperature and humidity (HOBO) were measured periodically for the control and elevated humidity chamber.

Test Specimen Preparation

Test specimens were prepared with close adherence to ASTM G1. Test specimens that were larger than their respective testing locations were cut to size to fit. An angle grinder, tin snips and band saw were used to cut 7.62 cm (3-inch) sections of each type of test material that required sizing. One of the most frequently reported modes of failure for galvanized steel materials was on the cut edges (Yildiz, 2012). During the first iteration of the testing, the cut edges were sealed with a metal primer (Rust-Oleum) that extended to approximately three millimeters (mm) onto the sample surface. During the second and third testing iterations, the metal primer was not used on the edges due to the surface faces corroding before the edges during the first test. The test specimens were cleaned with soap and water followed by an acetone rinse to remove any surface contaminates such as fingerprints or manufacturing oils. Oils from fingerprints are known to cause accelerated corrosion (UL, 2011). To minimize the likelihood of this occurring nitrile gloves were worn during specimen handling.

RESULTS

Elevated humidity exhibited little to no visible change among the 21 test components (Table 1). Except for the steel sink bracket**,** most finishes were either dulled or exhibited an oxidized whitish gray finish over the test periods. The sink bracket exhibited surface rust after 30 days.

Freshwater mist exhibited a greater variety of surface responses than humidity (Table 2). Freshwater mists expressed little to no change to the angle stop valves (Figures 14-16), stainless steel supply line or brass fitting except for dulling the brass finish. Galvanized components (framing, conduits, electrical elements) appeared new-like for 13 days but exhibited a mottled appearance that became increasingly darker (Figures 5-7, 11-13, 20-22 and 23-25). The most profound effects were shared by steel components (sink fastener and face-mounted hinge).

Saltwater mist was the most aggressive solution. Most components exhibited a visible change within 30 days of exposure and corrosion within three to six months (Table 3). All steel components (sink bracket and face-mounted hinge) exhibited corrosion almost immediately. Galvanized components exhibited a mottled or blotchy gray to graying effect with a white gray to near black discoloration at the end of the study period.

Composition Comparisons

There was no ambiguity regarding the best performing components. Nickle coating, stainless steel and galvanized steel exhibited the highest competence in preventing the corrosive effects of humidity, fresh and saltwater mists (Table 4). Aesthetic applications of clear polyurethane sealants on steel face-mounted hinge surfaces offered little to no resistance to corrosion following a few days of exposure.

Elemental Analysis

The elemental composition was critical to understanding the corrosive behavior. Elemental analysis of each component's surface was made using an Olympus XRF Handheld Analyzer. The analyses revealed high percentages of surface elements (zinc or nickel) among components with excellent corrosion resistance. The least corrosion resistant components contained a predominance of iron. Elements not tabulated were detected at less than one percent were calcium, cobalt, sulfur, lead, manganese, molybdenum and titanium.

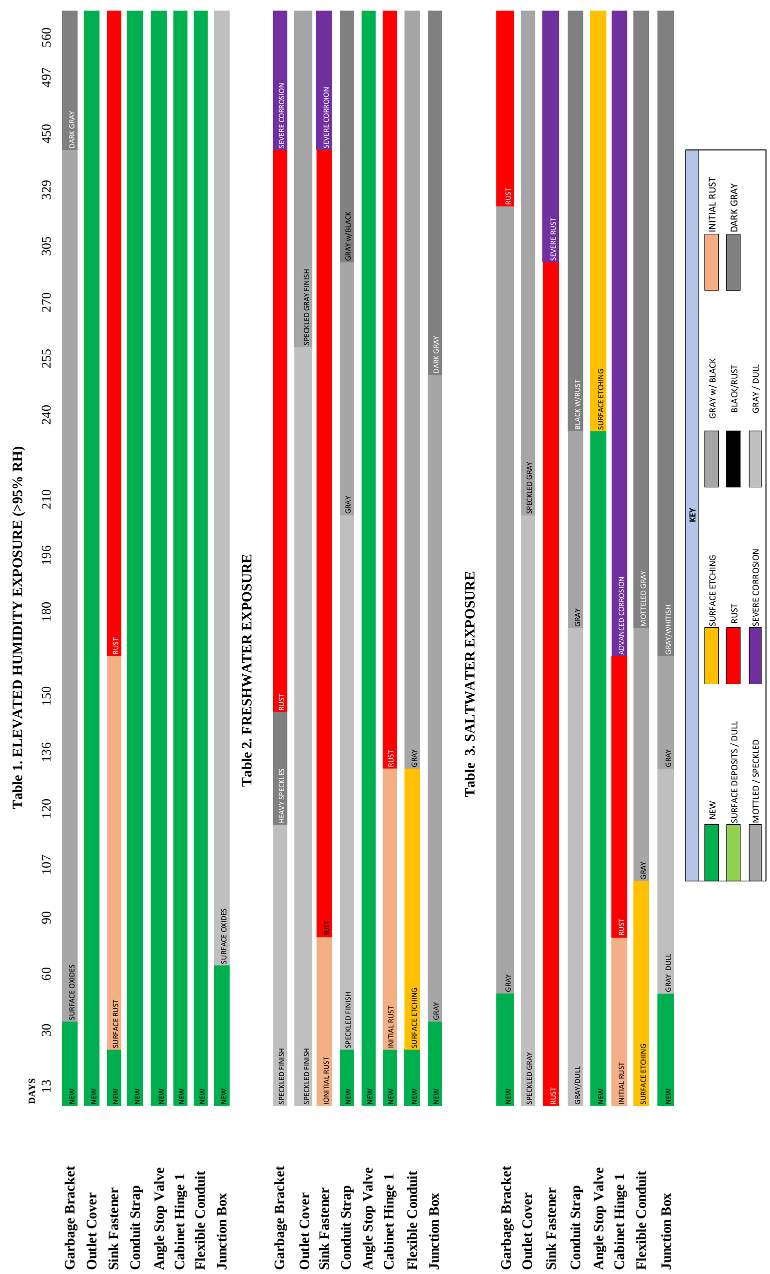

Figure 2. Garbage Disposal Bracket, Day 13, Fresh Water

Figure 3. Garbage Disposal Bracket, Day 200, Fresh Water

Figure 4. Garbage Disposal Bracket, Day 560 Fresh Water.

Figure 5. Outlet Cover, Day 14 Fresh Water.

Figure 6. Outlet Cover, Day 200, Fresh Water.

Figure 7. Outlet Cover Day 560, Salt Water.

Figure 8. Steel Sink Fastener, Day 14, Fresh Water.

Figure 9. Steel Sink Fastener, Day 200, Fresh Water.

Figure 10. Steel Sink Fastener, Day 560 Salt Water.

Figure 11. Electrical Conduit Strap, Day 14, Fresh Water.

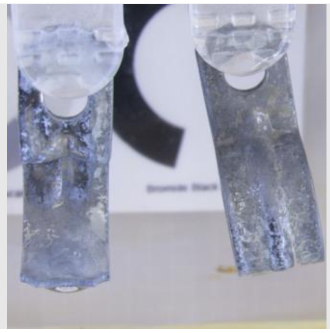

Figure 12. Electrical Conduit Strap, Day 200 Fresh Water.

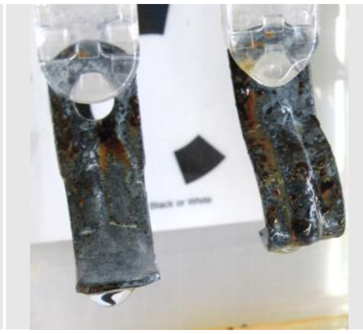

Figure 13. Electrical Conduit Strap, Day 560, Salt Water.

Figure 14. Angle Stop Valve, Day 14, Fresh water.

Figure 15. Angle stop valve, Day 200 Fresh water.

Figure 16. Angel Stop Valve, Day 560, Salt Water.

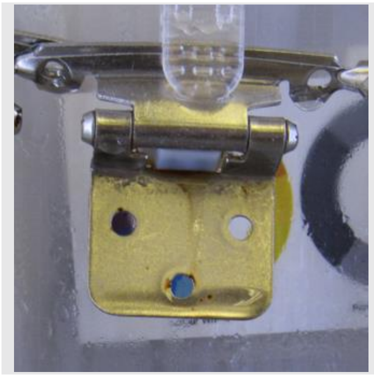

Figure 17. Face-mounted hinge, Day 14, Fresh Water.

Figure 18. Face-mounted hinge, Day 200, Fresh Water.

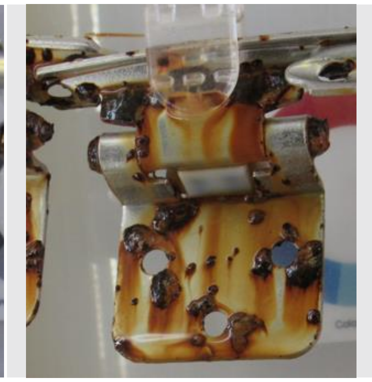

Figure 19. Face-mounted hinge, Day 560, Fresh Water.

Figure 20. Flexible Electrical Conduit, Day 14, Freshwater.

Figure 21. Flexible Electrical Conduit, Day 200 Freshwater.

Figure 22. Flexible Electrical Conduit, Day 560, Saltwater.

Figure 23. Junction Box, Day 14, Fresh Water.

Figure 24. Junction Box, Day 200, Fresh Water

Figure 25. Junction Box, Day 560, Salt Water.

Among the corrosion-resistant galvanized components (*i.e.*, conduit strap, garbage disposal bracket, flexible electrical conduit, electrical outlet box and electrical outlet cover), the principal surface element was zinc at a reported range from 71% to 96%. Lesser elemental components in this group were iron (2 to 27%) and aluminum (1.9 to 2.6%).

The non-galvanized component that exhibited superior corrosion resistance was the angle stop valve angle stop. The predominant elements analyzed from the surface were nickel (13.7%), zinc (16.8%) and copper (64.5%). The predominant surface elements among the least resistant components (*i.e.*, sink fastener, face-mounted hinge) were iron (5-98%), nickel (5-26%) and chromium (0.04% to 0.05%).

Chromium was not a primary element of the angle stop valve surface. This attractive surface was attributed to less expensive nickel. Copper was most prominent in the angle stop valve at 64%. Among the 8 tested components, all contained to some extent iron with silicon on the top surface. Other components contained less frequently detected elements; chromium (5/8) and copper (6/8).

Table 4. Elemental Analysis of plumbing, electrical and cabinet components

	Percentage Elemental Composition (> 1%)						
	Si	Al	Fe	Ni	Zn	Cr	Cu
Sink Fastener (black)	0.09		**98.9***		0.04	0.04	
Concealed Hinge	0.07		**56.1**	28.4		0.03	15.1
Face Mounted Hinge	0.10		**57.0**	26.31		0.05	16.1
Face Mounted Hinge	**20.9****	**1.4**	**5.2**	**5.3**	**7.1**		
Angle Stop Handle	0.05		0.0	**42.8**	10.74	3.50	**42.8**
Escutcheon Plate	0.07		43.9	**54.8**		0.64	
Concealed Hinge	0.22	0.9	6.6	**84.0**			6.5
Supply Line Collar	0.37	0.6		**89.0**	3.2		2.8
Angle Stop Handle				**90.2**		4.8	4.8
Galv. Metal Lath		2.6			**88.6**	4.1	9.1
Galv. Conduit Strap	0.06		26.9		**72.9**	0.06	0.0
Galv. Garbage Bracket	0.22		25.4		**72.8**		
Galv. Flexible Conduit	2.33		17.3		**79.3**		
Galv. Outlet Box	0.33		20.3		**78.0**	0.04	0.0
Galv. Sink Fastener			3.3		**96.5**		
Galv. Water Pipe		2.5	2.3		**70.9**	0.3	
Galv. Sill Plate	0.93		2.3		**94.6**		
Galv. Framing		2.4	3.1		**83.4**		
Galv. Conduit	25.14	1.9	22.1		5.0		
Brass Fitting	0.44	3.0	0.3		42.4		**50.8**
Angle Stop Valve	0.24		0.0	13.7	16.8		**64.5**

* Predominant element in bold **Silicon containing coating by manufacturer

Poor corrosion resistance to the face-mounted hinges was unexpected based on their nickel (26%), and copper (16%) content. However, since their underlying composition was iron (56%), it may have contributed to rapid corrosion.

The 560-day exposure study consisted of eight components. A sequence of three photographs is provided for each on Days 14, 200 and 560 exposed to different sources (Figures 2-26). The photos depict both gradual and abrupt changes in surface features attributed to their metal composition and moisture exposure source. Among these eight components, five were galvanized (*i.e.*, conduit strap, garbage disposal bracket, flexible conduit, electrical outlet box and cover). These exhibited excellent corrosion resistance for 10 months or more following fresh or saltwater exposure. No corrosion was observed following elevated humidity exposure. Among the remaining components (*i.e.*, face-mounted hinge, angle stop valve [Shark Bite®], and sink fastener) the angle stop valve (nickel coated) exhibited little to no change while the sink fastener and face-mounted hinge expressed corrosion within days of exposure.

DISCUSSION

Metal corrosion studies benefit our estimation of water loss duration; however, the authors offer suggestions to refine water loss investigations. First, identify as many metal components as possible near the source that exhibit corrosion. These serve as "prongs in your argument" whether the water loss is brief or long-term. Document these examples as close as possible so that the surface conditions can be easily viewed and described. Second, identify the metal components and their surface elemental composition to allow correlation to corrosion performance (Table 4). Third, integrate the corrosion findings with other materials that also respond to moisture such as nearby walls (gypsum board, sill plate, framing), plywood, particle board and carpet tack strips. They all express changes that correspond to moisture exposure (Moon, 2012, Nehrig *et al*., 2018). Fourth, document the condition of metal components adjacent to the source to serve as "controls". Controls will show that the observed corrosion was not a consequence of normal aging, a preexisting condition, or an unidentified source. Fifth, photograph cabinet contents before your invasive examination. In rare occasions you may identify open containers of bleach or chemicals that may pose a corrosive environment. Fifth, use gloved hands to remove all elements from cabinets and vanities. Once the contents are completely removed you will have a clear understanding of previous water exposure events.

CONCLUSION

Water leaks originate from a variety of sources that are commonly expressed as visible corrosion metal surfaces. Evidence of corrosion depends on (1) water as a liquid or gas contacting the metal surfaces and (2) the duration of exposure. The studies confirmed that the longer the exposure period, the more severe the corrosion. Galvanized steel components with robust zinc coatings (*i.e*., garbage disposal bracket, electrical outlet box, flexible conduit, conduit bracket and outlet cover) exhibited the best resistance (no visible rust) to corrosion. The nickel-coated brass angle stop valve exhibited formidable resistance following 560 days of continuous exposure to both fresh and salt water. Clear-coated steel components (*i.e.,* sink fastener, face-mounted hinge) exhibited the least corrosion resistance. Examination of metal plumbing, electrical and cabinet components provides valuable insight to (1) identifying the source and extent of the moisture, and (2) distinguishing between corrosion caused by water vapor or liquid water.

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