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# FORENSIC ENGINEERING 8th CONGRESS

Austin, Texas | November 29 – December 2, 2018

## *Forging Forensic Frontiers*

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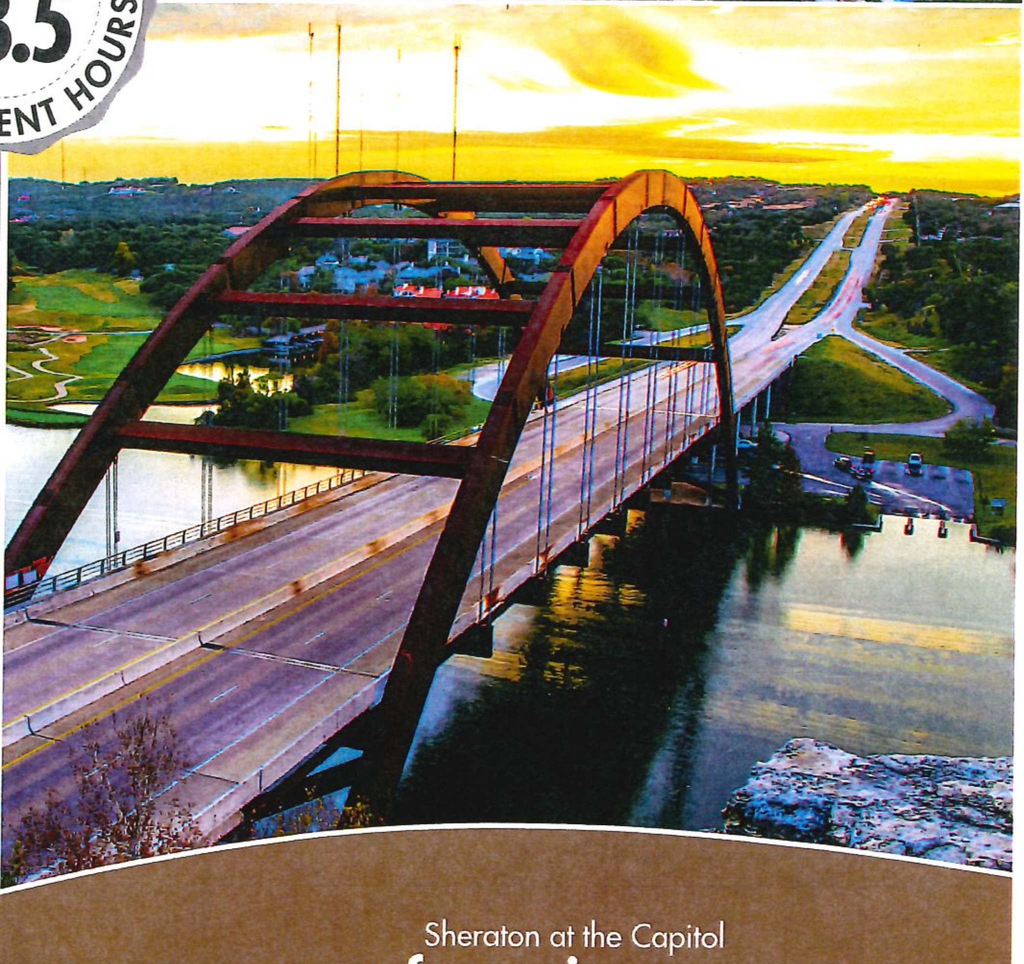

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# FORENSIC ENGINEERING 2018

## *Forging Forensic Frontiers*

PROCEEDINGS OF THE EIGHTH CONGRESS ON FORENSIC ENGINEERING

November 29–December 2, 2018
Austin, Texas

SPONSORED BY
Forensic Engineering Division
of the American Society of Civil Engineers

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# Preface



Forensic Engineering 2018: Forging Forensic Frontiers is a collection of 111 peer-reviewed technical papers presented at the Forensic Engineering 8th Congress, sponsored by the Forensic Engineering Division (FED) of the American Society of Civil Engineers (ASCE). The Congress took place from November 30 to December 2, 2018, at the Sheraton Austin Hotel at the Capitol in Austin, Texas. The goals of the Congress were to bring together leading forensic engineering practitioners, researchers, designers, project and construction managers from around the world to allow attendees to learn about current evaluation techniques and investigative methods. These efforts align with the mission of FED to enhance the forensic engineering profession, develop guidelines for conducting failure investigations, disseminate failure information, promote forensic curriculum in engineering education, share practices to reduce failures, and improve performance of the built environment.

Each paper in this collection was subjected to a double-blind review process, with review comments distributed to authors, author revisions as appropriate, and final review by the proceedings editors. Paper submission began with published calls for abstracts and at least two positive indications from reviewers before invitation to submit full papers. The review process determined whether each paper was applicable, useful, and relevant to forensic engineering; whether the paper had been published previously; whether the methodology was satisfactorily explained; whether the references were verifiable, whether the tables, figures, and photographs complemented the paper; whether the conclusions were clear and justified; whether the elements of the paper related logically to the paper; and whether the writing style, grammar, and formatting were appropriate. Each paper received a minimum of two positive reviews in order to be published. Papers in this collection cover a wide array of forensic topics pertaining to the built environment, with some taking new approaches to historic failure events and others exploring new frontiers in forensic evaluation and analysis methods. The Congress also included papers of local and regional interest, such as assessment of damages from recent Hurricanes Irma, Harvey, and Maria.

Two half-day workshops held on November 29, prior to the official start of the Congress, involved guidance in operation of a forensic engineering practice and conducting forensic engineering investigations. These workshops were sponsored by FED Committees on Forensic Practice and Forensic Investigation, respectively. The morning workshop on *The Practice of Forensic Engineering* was presented by James S. Cohen, Leonard J. Morse-Fortier, Clemens J. Rossell, and Lloyd M. Sonenthal.

The afternoon workshop, *Conducting Failure Investigations*, was presented by Ronald W. Anthony, Richard S. Barrow, Kimball J. Beasley, Jeffrey A. Travis, and Stewart M. Verhulst. The workshop speakers formulated their presentations, in part, on FED sponsored publications Guidelines to Forensic Engineering Practice, 2nd edition, ASCE Press 2012, and Guidelines to Forensic Investigations, 2nd edition, ASCE Press, 2018.

The Congress opened with a featured keynote presentation by accomplished researcher and structural engineer Ahmed Amir Khalil, PhD, P.E. His presentation *High Fidelity Numerical Simulations in Forensic Analysis and Urban Search and Rescue* focused on the use and challenges of high-fidelity numerical modeling in forensic investigations and the use of such to aid in planning for and implementing urban search and rescue operations.

In addition to the presented papers, the Congress also included panel discussions, networking socials, a welcoming reception, an awards luncheon, and committee meetings. Finally, a student paper competition was held that included poster presentations from a number of our future professional forensic engineers.

It has been our pleasure and privilege to be part of this Congress. Happy reading!

Rui Liu, PhD, P.E., M.ASCE
Kent State University
Proceedings Editor-In-Chief

Michael P. Lester, P.E., M. ASCE
Element Analytical, PLLC
Congress Chair

# Acknowledgments

The Steering Committee of the Forensic Engineering 8th Congress expresses its sincere appreciation to the Proceedings Editorial Board, the Executive Committee of FED, its membership, cooperating organizations, ASCE staff, and most especially to the authors, panelists, presenters, peer reviewers, moderators, track chairs, and sponsors for making this Congress a success. Special thanks to our families, without your support this work would not have been made possible.

The guidance, dedication, and commitment of the following individuals contributed to the planning and development of all aspects of the congress venue, program, and activities.

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# Duration of Metal Corrosion: Plumbing and Construction Materials

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## ABSTRACT

The forensic engineer recognizes the importance of metal corrosion as a diagnostic tool when conducting a building investigation. This study advances the scientific community's use of qualitative analysis by reporting the results from three long-term moisture exposure studies. The study was divided into two tasks: 1) creation of a moisture exposure chamber that would allow repeated exposure of study exemplars to fresh water and salt water mists repeatedly over extended periods of time (months), and 2) documentation of the gradual changes that occurred in the specimens as they experienced surface oxidation, discoloration, and the presence of advanced surface corrosion. The study was conducted over three test periods. The first and second test periods were conducted over 244 days and 461 days, respectively. These tests documented qualitative changes to galvanized steel pieces (i.e., corner bead, framing, sill plate, electrical conduit, metal lath, galvanized pipe, and brass fitting). The third study was conducted over 122 days and documented changes to metal components commonly found in the plumbing/building materials for bathrooms and kitchens. These components consisted of stainless steel water supply lines, angle stop valve handles, escutcheon plates, under sink mount brackets, concealed and face cabinet door hinges. The components were exposed to fresh water and seawater using modified methods from ASTM Standard B117. Controlled tests were conducted within an acrylic and polycarbonate test chamber equipped with a recirculating solution system. Frequent time-lapsed photography documented the corrosive effects facilitated by continuous fresh and salt water exposure. The test procedure enabled evaluation between both wetted, humid, and un-wetted (control) specimens. The photographs document qualitatively equivalent exemplars that were compared to "real world" component installations affected by a water loss. These comparisons facilitate determinations of loss duration under conditions of a worst-case, water exposure scenario.

## INTRODUCTION

Many metal components in both residential and commercial structures exhibit profound changes in appearance from corrosion when exposed to conditions of elevated humidity and moisture. A forensic investigation can integrate the appearance of these metal components to provide insight into the conditions that caused their deterioration and the duration of exposure. This observational aspect of a forensic examination introduces new tools that expand the forensic engineer's skill set by extracting as much available information as possible from the structure to derive a comprehensive and complete understanding of the event. The corrosion observed among galvanized metals, nickel-plated metals, brass components and stainless water supply lines could offer practical evidence that is both understood by a jury and can support opinions of the duration of loss following a water exposure event.

Metal corrosion is quantified using numerous methods including the weight loss technique, accelerated testing, electrochemical processes and the percent coverage of corrosion on visible surface areas. This paper focuses on a qualitative analysis featuring a day to day documentation of visible metal degradation of exemplars exposed to a fresh (tap) water fog, salt (sea) water fog and sustained conditions of elevated relative humidity (>95% RH). In conformance with previous metal corrosion research, ASTM standards were used: salt spray apparatus (B117), preparing, cleaning and evaluation of test specimens (G1), exposure of metals by immersion in sodium chloride (G44), exposure and evaluation of metals in seawater (G52), conducting cycling humidity exposure (G60), conducting and evaluating galvanic corrosion in electrolytes (G71) and modified salt spray testing (G85).



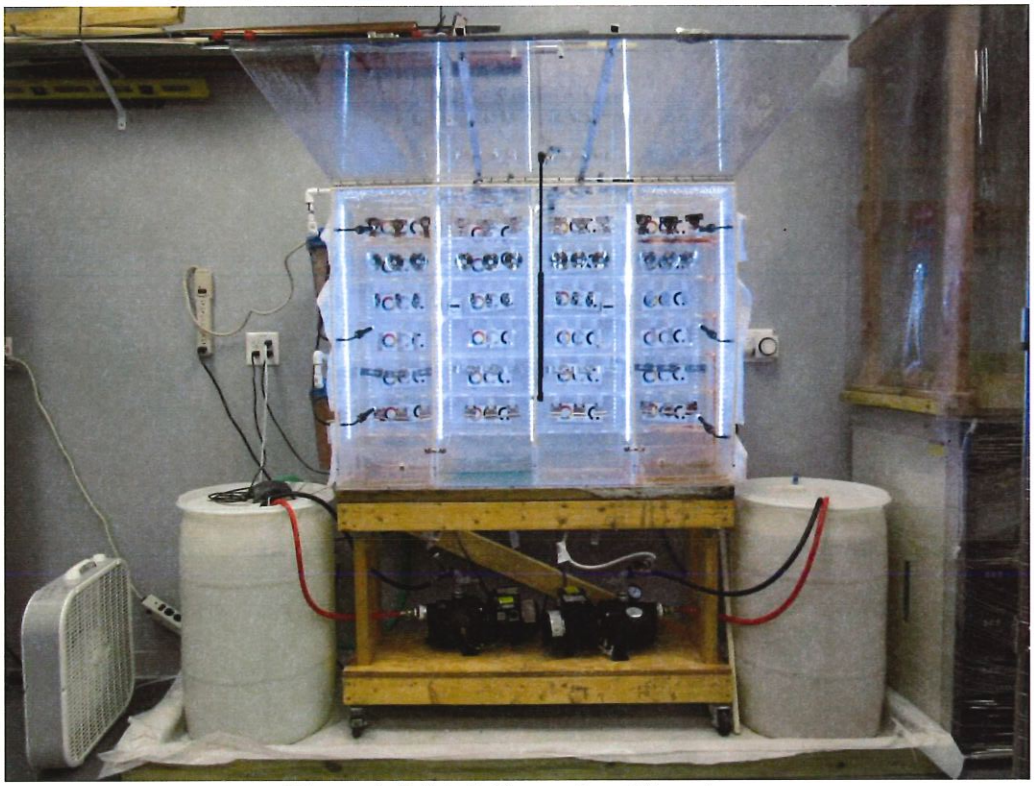

**Photo 1: Metal Corrosion Chamber**

## MATERIALS AND METHODS

An acrylic and polycarbonate test apparatus was constructed that featured four isolated and independently controlled chambers. Within these chambers, shelves supported metal specimens while being exposed to fresh water, salt water, elevated RH, and a control environment at ambient conditions (76ºF and 35% RH). Six shelves were constructed into each chamber in a stacked configuration to serve as mounting points for the exemplars. A secondary benefit of the shelves was to divert water discharged from the foggers away from the specimens suspended above each shelf. This configuration maintained the exposure integrity of each shelf environment by decreasing the possibility of chemical interaction between specimens from one sample to another *via* drainage. To minimize any influences of the testing apparatus on the sample specimen's only non-corrosive plastic components were used to construct the chamber. Fishing line (monofilament) was used to suspend the specimens above the shelves using plastic clips

(**Photo 1**).

Six metal components were evaluated during each of three test periods with some materials tested twice. The first test period evaluated corrosion among electrical conduit, copper tubing, lath, nail guard, corner bead and steel framing. The second test period evaluated corrosion among galvanized water pipe with a threaded brass fitting, electrical conduit, corner bead, lath, steel framing and sill plate. The third test period evaluated corrosion among concealed cabinetry hinges, escutcheon plates, braided supply lines, sink mount brackets, angle stop handles and face-mount cabinet hinges. A fog spray exposed the specimens to fresh or salt water using plastic fogger heads connected to plastic pressurized supply lines.

Each material was tested in triplicate within each exposure environment (*i.e.,* fresh water, elevated humidity, control and salt water). Eighteen specimens were positioned within each exposure environment. The water supply system for the fresh and salt water was re-circulated and featured a 30-gallon tank plumbed to a well pump (Everbilt Model J100A3). The arrangement maintained a near constant water temperature (78 to 80°F) 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 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 25 gallon mixture was formulated using 12.5 cups (<9 pounds) of marine crystals to attain a specific gravity of about 1.021 ($SG_{true} \approx 1.021$). 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 fresh water pH (Etekcity pH-2011, Oakton Instruments 35624-22), salinity (Strom Store RHS-ATC10) and temperature information was recorded periodically. Similarly, tap water was measured periodically to serve as a control. The temperature and humidity (HOBO) were measured continuously for the control and elevated humidity chamber.

### Test Specimen Preparation

Test specimens were prepared with close adherence to ASTM Method (G1). Test specimens that were larger than their respective testing locations were cut to size to fit. An angle grinder was used to cut 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

Three sample sets were examined; the first set was run for 244 days, the second set was run for 461 days and the third set was up to 122 days at the time of this publication. Each sample type was subjected to conditions previously discussed. The first occurrences of gradual changes in appearance appeared quickly based on the observations in this study; white rust (Zinc oxide) appeared within the first few days following free water exposure among all galvanized specimens (**Photos 2, 5, 8, 11, Photographic Appendix**). The subsequent corrosion was regularly documented with visual observations made each day. The photographs provided comparative documentation of the exemplars for use in forensic reports when establishing comparative corrosion and supporting opinions of the duration of moisture exposure (ASTM E860).

An understanding of the surface composition prompted an elemental analysis. The surfaces of all exemplars was examined using Energy Dispersive X-Ray Spectroscopy (EDS) (**Table 1**). The results revealed that most surfaces were comprised of zinc and nickel. A nickel finish was identified on the stainless supply line connector (threaded section); however, the body was composed of brass. A silicate oxide layer ($SiO_x$) was documented on the surface of the face mount cabinet hinge and electrical conduit, presumably to protect from atmospheric water vapor. Silicate oxide layers are often applied on materials used in the food industry to protect from water vapor (Joachim, 2009).

**Table 1: Elemental analysis of metal surfaces**

| | Oxygen | Silicon | Phosphorus | Iron | Nickle | Zinc | Chromium | Copper |
|---|---|---|---|---|---|---|---|---|
| Percent % Content | O | Si | P | Fe | Ni | Zn | Cr | Cu |
| Undermount Sink Bracket* | | | | 3.3 | | **96.5** | | |
| Brass Fitting | | | | | | **42.4** | | **50.8** |
| Sill Plate* | | | | 2.3 | | **94.6** | | |
| Concealed Cabinet Hinge | | | | 6.6 | **84.0** | | | 6.5 |
| Framing* | | | | 3.1 | | **83.4** | | |
| Conduit* | 27.5 | 25.1 | 0.3 | 22.1 | | 5.0 | | |
| Water Pipe* | | | | 2.3 | | **70.9** | | |
| Stainless Supply Collar | | | | **55.3** | | | **28.4** | |
| Corner Bead* | | | | 1.2 | | **93.3** | | |
| Stainless Supply Connector | | | | | **89.0** | 3.2 | | 2.8 |
| Angle Stop Handle | | | | | **90.2** | | 4.8 | 4.8 |
| Escutcheon Plate | | | | 4.8 | **80.4** | | 4.1 | |
| Metal Lath* | | | | | | **88.6** | | |
| Face Mount Cabinet Hinge | 57.4 | 21.0 | | 5.2 | 5.3 | 7.1 | | |

*Galvanized

## Test 1 and 2 Observations

The first observable changes among the test specimens occurred inside the saltwater fogging chamber. Galvanized metal conduit formed a zinc oxide layer on Day 7 and sustained this layer until Day 244 (**Photos 3, 6, 9, 12**). No apparent iron oxide (red discoloration, rust) formed during the study (**Table 2**). Electrical conduit, corner bead, sill plate and framing exhibited varying degrees of corrosion after 244 days (**Photos 4, 7, 19, 13**). Copper specimen corrosion was examined during the 244 Day study and showed only a color change (copper color to black) but never displayed the characteristic blue-green copper patina characterized by the Statue of Liberty in New York City. The general darkening of the copper tubing was accompanied by black and dark green spots.

Galvanized metal lath exhibited rust spots on day 222 of the 461 Day study. Galvanized steel water pipe with a threaded brass fitting was tested in the 461 Day study to observe possible galvanic action between the two dissimilar metals. Brass and galvanized steel are capable of reacting under certain conditions over an extended period (Stewart, 2013). The results showed no apparent reaction between the two metals; however, rust was apparent on the galvanized water pipe threads within the first few days in all test chambers. Galvanized metal corner bead was evaluated during both the 244 and 461 Day studies with rust occurring in the salt water chamber on days 137 and 121, respectively. Galvanized metal sill plate and framing are often interchangeable in a building and are manufactured using identical methods. The separation in this study was based on the manufacture's labeling denoting the application for each material. The sill plate exhibited corrosion on days 195 and 292 during the 244 Day and 461 Day studies, respectively. Galvanized framing exhibited corrosion on day 174 of the 461 Day study (**Table 2**).

**Table 2: Corrosion results from test materials exposed to salt water, fresh water and elevated RH**

| Test Materials | Test 1 (244 Days) | Test 2 (461 Days) | Test 3 (122 days) |
|---|---|---|---|
| Conduit* | No Rust | No Rust | |
| Copper | No Corrosion | | |
| Lath* | Rust Day 244 | Rust Day 222 | |
| Water Pipe* and Brass Fitting | | No Corrosion | |
| Corner Bead* | Rust Day 137 | Rust Day 121 | |
| Sill Plate* | Rust Day 195 | Rust Day 292 | |
| Framing* | | Rust Day 174 | |
| Concealed Cabinet Hinges | | | Rust Day 1 |
| Escutcheon Plate | | | Rust Day 30 |
| Stainless Supply Line | | | No Corrosion |
| Sink Mount Bracket* | | | No Corrosion |
| Angle Stop Handle | | | No Corrosion |
| Face Mount Cabinet Hinge | | | Rust Day 1 |

*Galvanized

### Test 3 Observations

Plumbing and cabinet materials were examined during the third test or 122 Day Study. These materials were concealed cabinet hinge, escutcheon plate, angle stop (shut-off valve) handle, stainless steel water supply line, sink mount bracket and face mount cabinet hinges. In many instances, the primary corrosive influence is elevated humidity inside a kitchen cabinet or bathroom vanity. The results revealed that the occurrence of corrosion induced from fresh water, salt water and elevated RH exposure was directly related to the various metal alloys and fabrication techniques used in the manufacturing process.

The concealed cabinet hinge exhibited corrosion within hours of exposure in the fresh water and salt water chamber (**Photos 17-19**). The elemental analysis of the surface materials identified a thin nickel coating that was insufficient to withstand exposure to liquid water. While nickel and nickel-alloys are corrosion resistant, pores can be present if the coating is applied too thin resulting in the propagation of corrosion with the standard finishing of electrolytic nickel (Heanjia, 2014). The nickel-plated escutcheon plate, identified by EDS analysis, began to corrode on days 30 and 80 in the salt water and fresh water chambers, respectively (**Photos 14-16**). Glossy nickel plating may benefit these components for several reasons: attractive aesthetics, corrosion resistance and ease of cleaning. During testing, the edges of the escutcheon plate began corroding first with propagation occurring over time. The back of the escutcheon plate corroded on day 6 in the salt water mist (**Photo 16**). This finding was attributed to minimal application of the nickel plating during manufacture. The angle stop handle also had a glossy nickel coating that exhibited no corrosion for 122 days with the exception of a white discoloration (**Photos 24-26**). The elemental analysis showed copper (possibly brass) to be the main ingredient for the handle below the nickel coating. The stainless steel water supply line connector showed no apparent discoloration after 122 days of fresh and salt water exposure. Elemental analysis of the threaded connector showed a nickel (Ni) coating over brass (Zn and Cu). The collar and braiding's for the supply line were stainless steel (Fe and Cr). The sink mount brackets showed no apparent rust after 122 days. The galvanized coating (Zn) was slightly discolored with a zinc oxide (ZnO) layer. An interesting finding was the presence of a thin layer of $SiO_x$ identified on the surface of the face mount cabinet hinges during the elemental analysis (**Photos 20-22**). This layer was added by the manufacturer to protect against water vapor in the air. Unexpectedly, the hinges rusted almost immediately (day 1) in the presence of fresh and salt water.

## SUMMARY

Published articles on metal corrosion are primarily quantitative in their analysis (*i.e.*, mm/year, mg/year); this method of documentation does not benefit the forensic engineer tasked to determine the duration of a water loss. Efforts to defend opinions of metal corrosion are difficult to substantiate in the absence of established exemplars and peer-reviewed research. The Daubert standard is a common practice in federal courts for the introduction of scientifically based testimony. Research and published papers are used to substantiate admittance of an expert's opinion. The testing of different materials to corrosive and deteriorating effects of moisture can support scientifically based opinions when the duration of a water loss is a critical factor. Research was conducted on various metal materials (structural, plumbing and cosmetic) found in a building to establish the time when visible corrosion begins and to encourage others to conduct similar studies to guide the opinions of real world circumstances.

## CONCLUSION

The study results provide insight into the time required for corrosion to occur on different metal materials. ASTM methodology offered an understanding of metal oxidation and highlights the benefits of photography to document sequential changes and allow comparison to the corrosion observed during forensic investigation and resulting litigation. Our qualitative analysis resulted in the following conclusions.

1. Exposure testing of various metal components to fresh and salt water and elevated humidity demonstrated an accurate predictive method for the duration necessary to cause visible corrosion.
2. Galvanized metal components exposed to elevated RH exhibited minimal surface discoloration for up to 461 days. The cabinet hinges displayed near unnoticeable spots of corrosion after 122 days of elevated RH.
3. Galvanized metal lath and framing exhibited corrosion along the edges after 461 days of fresh water exposure. The cabinet hinges began corroding after 1 day of fresh water exposure.

4. All galvanized metals showed corrosion at the end of day 461 in the salt water chamber (minus conduit and water pipe). The cabinet hinges and escutcheon plate showed extensive corrosion at the 122-day mark after salt water exposure.
5. Galvanized coatings were resilient to corrosion even in a salt water environment.
6. The nickel coated hinges exhibited corrosion almost immediately when contacted by fresh or salt water. The escutcheon plate exhibited corrosion on the face side after 30 days of salt water exposure.
7. The elemental analysis revealed the galvanized coatings were comprised principally of zinc. The face cabinet hinge and conduit were coated in a silicate oxide layer and all other materials were coated with nickel.
8. The images of metal deterioration over time provided exemplars suitable for characterizing the gradual appearance of oxidized surfaces and rust.
9. The galvanized steel test specimens did not experience corrosion such as the iron oxide (red-orange) on any of the face (unaltered) surfaces before the 137 day mark following exposure to fresh and salt water.
10. Photographs taken after 3 days showed formation of a zinc alloy layer and copper discoloration consistent with zinc oxide (white rust) and copper oxide (black layer), respectively.
11. The hinges used in cabinet manufacturing displayed rust after less than 24 hours of fresh and salt water exposure.
12. The finishes on the escutcheon plate and angle stop handle were composed of nickel despite their bright "chrome" appearance.
13. The findings personified the aggressive nature of salt water when exposed to metal components. This finding can assist in determining the deterioration of materials when in close proximity to sources of salt water.
14. The condition of metal components inside a vanity or cabinetry can provide insight into the environment inside the enclosed spaces.
15. The rate of corrosion varied between the difference materials. The most resilient to corrosion was brass followed by zinc then nickel.

## ACKNOWLEDGEMENTS

Jay Bieber, Research Engineer, University of South Florida, Bob Mulcahy, GHD

## PHOTOGRAPHIC APPENDIX

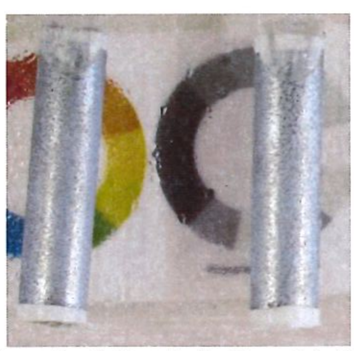

**Photo 2: Electrical Conduit, Day 14, Fresh Water**

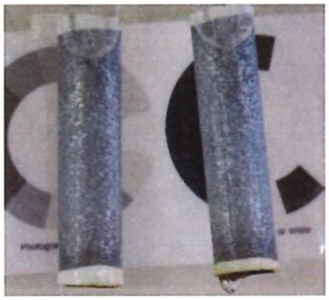
Photo 3: Electrical Conduit, Day 244, Fresh Water

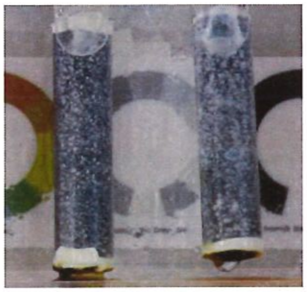
Photo 4: Electrical Conduit, Day 244, Salt Water.

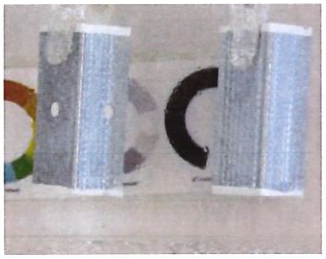
Photo 5: Corner Bead, Day 14 Fresh water

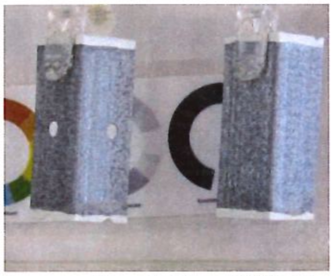
Photo 6: Corner Bead, Day 244, Fresh Water

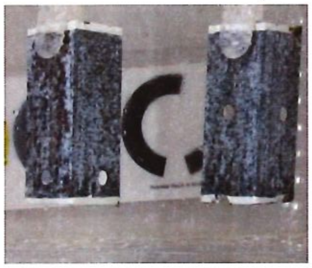
Photo 7: Corner Bead, Day 244, Salt Water.

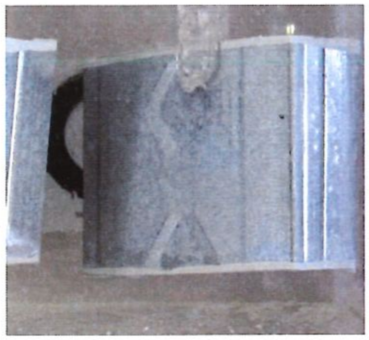

Photo 8: Sill plate, Day 14, Fresh Water

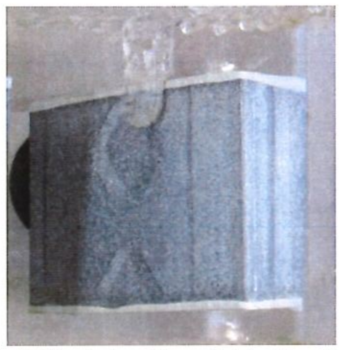

Photo 9: Sill plate, Day 244, Fresh Water.

Photo 10: Sill plate, Day 244 Salt Water

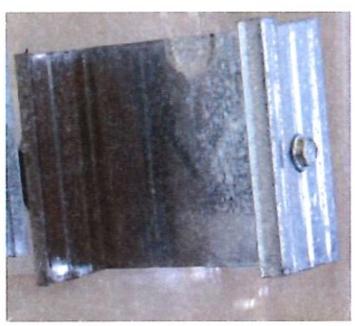

Photo 11: Framing, Day 13, Fresh Water

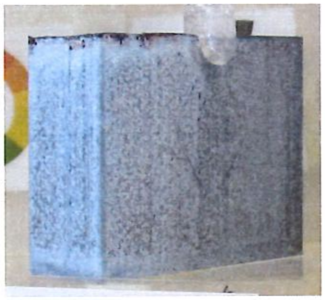

Photo 12: Framing, Day 461, Fresh Water

Photo 13: Framing, Day 461, Salt Water.

Photo 14: Escutcheon plate, Day 14, Fresh water.

Photo 15: Escutcheon plate, Day 122 Fresh water

Photo 16: Escutcheon plate, Day 122, Salt Water

**Photo 17: Concealed cabinet hinge, Day 14, Fresh water**

**Photo 18: Concealed cabinet hinge, Day 122, Fresh water**

**Photo 19: Concealed cabinet hinge, Day 122, Salt water**

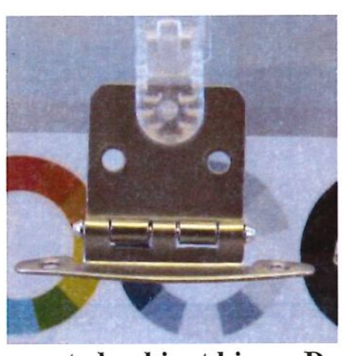

**Photo 20: Face-mounted cabinet hinge, Day 14, Freshwater**

Photo 22: Face-mounted cabinet hinge, Day 122 Freshwater

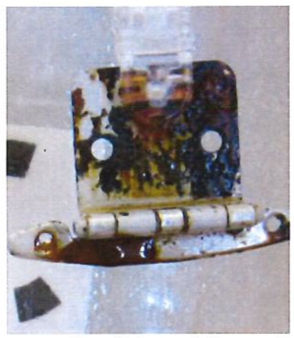

Photo 23 Face-mounted cabinet hinge, Day 122, Saltwater


Photo 24: Angle stop valve, Day 14, Fresh Water


Photo 25: Angle stop valve, Day 122, Fresh Water

**Photo 26: Angle stop valve, Day 122, Salt Water**

## REFERENCES


ASTM Standard B117, 2011, "Standard Practice for Operating Salt Spray (Fog) Apparatus" ASTM International, West Conshohocken, PA, DOI: 10.1520/B0117-11, www.astm.org.

ASTM Standard E860, 2010, "Examination and preparing items that are or may become involved in criminal or civil litigation" ASTM International, West Conshohocken, PA, www.astm.org.

ASTM Standard G1, 2011, "Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens" ASTM International, West Conshohocken, PA, DOI: 10.1520/G0001-11, www.astm.org.

ASTM Standard G44, 2013, "Standard Practice for Exposure of Metals and Alloys by Alternate Immersion in Neutral 3.5% Sodium Chloride Solution" ASTM International, West Conshohocken, PA, DOI: 10.1520/G0044-99, www.astm.org.

ASTM Standard G52, 2011, "Standard Practice for Exposing and Evaluating Metals and Alloys in Surface Seawater" ASTM International, West Conshohocken, PA, DOI: 10.1520/G0052-00, www.astm.org.

ASTM Standard G60, 2013, "Standard Practice for Conducting Cyclic Humidity Exposures" ASTM International, West Conshohocken, PA, DOI: 10.1520/B0060-01, www.astm.org.

ASTM Standard G71, 2014, "Standard Practice for Conducting and Evaluating Galvanic Corrosion Tests in Electrolytes" ASTM International, West Conshohocken, PA, DOI: 10.1520/B0071-81, www.astm.org.

ASTM Standard G85, 2011, "Standard Practice for Modified Salt Spray (Fog) Testing" ASTM International, West Conshohocken, PA, DOI: 10.1520/G0085-11, www.astm.org.

Baboian, Robert. ASTM International. Corrosion Test and Standards. Application and Interpretation. 2nd Edition. Library of Congress. Baltimore, MD. 2005

Cornell University Law School. "Daubert Standard". Legal Information Institute. Ithaca, NY. 1993

Davis, J. R. 2000. Corrosion: Understanding the Basics. Materials Park: ASTM International. NACE/ASTM.

Fundamentals of Metallic Corrosion. Hoboken: Taylor and Francis. 2006

Heanjia Alloys, Heanjia Super-metals Co. Ltd, "Corrosion Resistance of Nickel Finish", Slideshare.net, 2014

Joachim S., Muhammad A., Jero^me D., Dennis K., Martina L., Andreas S., Matthias W., Uwe S., Ulrich S., "Silicon Oxide Barrier Coatings Deposited on Polymer Materials for

Applications in Food Packaging Industry", Plasma Processes and Polymers, 2009
Revie, R. Winston. 2008. Corrosion and Corrosion Control. Hoboken: John Wiley & Sons, Inc.
Roberge, Pierre R. 2008. Corrosion Engineering: Principles and Practice. New York: McGraw-Hill.
Richardson, H. Wayne. "Handbook of Copper Compounds and Applications". New York, NY: CRC Press, Jan 16, 1997.
Schweitzer, Philip A. 2006. Corrosion Engineering Handbook, Second Edition. Boca Raton: CRC Press.
Standard Terminology and Acronyms Relating to Corrosion. Engineering Standard. West Conshohocken: NACE International/ASTM International. 2009
Stuart, D., "Dissimilar Metal Corrosion" PD Hotline Course S118, 2013 https://pdhonline.com/courses/s118/s118content.pdf
Underwriters Laboratories, UL, "Corrosion Control Products", Standard UL 2769, First Edition, 2011
Yildiz, Resit. "Investigation of the cut-edge corrosion of organically-coated galvanized steel after accelerated atmospheric corrosion test". Adana, Turkey. 2012. Sciencedirect.com