Corrosion testing techniques and evaluation practices used in industry

There are endless options for surface finishes and conditions for metal products. Chemical coatings, films and paints are commonly applied to metal parts. The many surface preparation and coating options range from; blasting and polishing, to pickling, passivation and plating. But remember, application of any type of coating adds another level of complexity to the finishing process. So how do you know if your coating, plating or application is going to hold up over time and exposure to the elements before going into production? Environmental simulation, and/or accelerated corrosion testing, is the perfect technique to determine durability of your products.

By Michael Porfiliio, Director, of Quality, Stainless Foundry & Engineering, Inc., USA

Corrosion costs

The products of corrosion that are at times an aesthetic annoyance cannot be compared to the potential catastrophic failure to many corrosion modes. There are numerous hidden costs of corrosion to structures, equipment, bridges, proactive coatings, specialty materials, cathodes, anodes, or other manufactured parts are just some of the items that suffer the effects of corrosion.

The price of corrosion damage is staggering. A 2016 global study by NACE International puts the global cost of corrosion is estimated to be $2.5 USD trillion, which is equivalent to 3.4% of the global Gross Domestic Product (GDP) in 2013 [1]. By using available corrosion control practices, it is estimated that a savings of 15% to 35% of the cost of corrosion could be realized; between $375 to $875 billion USD annually on a on a global basis could be saved [1]. See table 1.0 below.

The coatings industry is experiencing pressure from environmentalist groups, corporate sustainability programs and individuals to produce "greener" products. These greener offerings in the long run will in general will be the future of coating processing but at what cost if they don't perform. Environmentally friendlier coatings generally have less corrosion resistance over the lifetime of the coating or finish. This has left the industry, in some situations, struggling to come up with new alternative friendlier counterparts that have long term performance reducing costs and offering sustainability.

Salt spray and humidity testing

Tests such as neutral salt spray testing (NSS) and humidity testing can help a manufacturer or end user determine the effectiveness and reliability of their coating/finishing process. By examining test specimens throughout the duration of the test, obviously surface effects are noticeable sometimes within a single day or two, preventing expensive and time consuming rework and recalls. The comparison to an unfinished or control specimens will help to determine the best surface finish for the intended application. At times no surface finish will be acceptable and a new material

Table 1.0 Cost of Corrosion Figures

Global Cost of Corrosion (CoC) by Sector (Billion USD) – NACE Impact Study[1]						
Economic Regions	Agriculture CoC USD billion	Industry COC USD billion	Services COC USD billion	Total COC USD billion	Total GDP USD billion	COC % GDP
United States	2.0	303.2	146.0	451.3	16,720	2.7%
India	17.7	20.3	32.3	70.3	1,670	4.2%
European Region	3.5	401	297	701.5	18,331	3.8%
Arab World	13.3	34.2	92.6	140.1	2,789	5.0%
China	56.2	192.5	146.2	394.9	9,330	4.2%
Russia	5.4	37.2	41.9	84.5	2,113	4.0%
Japan	0.6	45.9	5.1	51.6	5,002	1.0%
Four Asian Tigers + Macau	1.5	29.9	27.3	58.6	2,302	2.5%
Rest of the World	52.4	382.5	117.6	552.5	16,057	3.4%
Global	**152.7**	**1446.7**	**906.0**	**2505.4**	**74,314**	**3.4%**

selection may be the only remedy.
There are many specifications and standards written to direct how testing, and equally important, to evaluate the results of your tests. The most common specifications for performing a NSS test are ASTM B117 and ISO 9227, which outline the test conditions required for the neutral salt spray testing.
These specifications unify the testing parameters across the globe in the efforts to evaluate the effectiveness of paints, coatings and finishes.
These specifications unify the test parameters worldwide in order to evaluate the effectiveness of paints, coatings and finishes. In this test, an atmosphere of 5% solution of Sodium Chloride is atomized and introduced at a constant rate throughout a sealed chamber. Test specimens are inclined and placed in the polyethylene lined cabinet so that the test is parallel to the primary direction of flow of the sodium chloride mist. The mist wets the surface, and the excess solution runs off into the bottom of the cabinet.
Humidity testing is another measurement of the effectiveness of the corrosion resistance properties of a metal part. This test can be performed in many ways. The first takes place in an unused NSS cabinet by sampling turning off the salt solution flow and plugging the drain. The second test takes place in an environmental simulation cabinet specifically designed for this type of test. The requirements for this test can be specified by a manufacturer's specification or in an ASTM specification publication such as ASTM D2247 and ISO 16961. These types of tests assist in evaluating primarily paints and their tendencies to bubble and blister. Acceptance criteria's for the test results are generally customer specified.

Free iron detection tests and evaluations

The above two types of evaluations (NSS and environmental), cabinet corrosion testing can also be very effective as free iron detection tests. Free iron testing is an excellent predictor of corrosion resistance properties and surface finish success. Locations on a casting or finished part, which are rich in free iron, can become epicenters for corrosion while in service or inventory. In most cases, free iron tests can be done via salt spray testing in about two hours or in a humidity chamber in about 24 hours.
These different combinations of test media and hours of exposure have led to a host of different conclusions for manufacturers and end users. The most important element is the cost effectiveness of coating and surface finishes vs. corrosion resistance.
In addition to these two cabinet style tests, another procedure that can effectively detect free iron is a potassium ferricyanide – nitric acid (Ferroxyl) test, in accordance with MIL-STD-735 and ASTM A380. The Ferroxyl test will illuminate even the lowest levels of iron contamination. In this test a reaction with the chemicals in the test solution yields a chemical reaction in the form of a bluish coloration, demonstrating the presence of free iron. It is a very sensitive test.
Once the testing has begun, the challenge becomes the evaluation of the constantly changing surfaces of interest. Sometimes it is helpful to add a point of certain failure to the test specimen, or scribe, to see how bad a failure becomes if it should occur via damage or deficiency of the coating. There are many evaluation procedures such as ASTM D610, D714 and D1654 that oversee the evaluation of the test specimens. These specifications use numerical values to evaluate the severity of the corrosion, blistering and/or creep.
These laboratory type tests have one goal in common: to assist the surface preparation industries, evaluate the efficacy of their coating material and/or process. Corrosion testing can assist industries from epoxy powder coating companies to chemical coating operations to zinc/cadmium/chrome plating providers, and everyone in between.
The ultimate goal in applying a coating or perform surface treatments is to protect surfaces providing the highest quality product with the least amount of overhead in order to yield maximum profit.

Accelerated corrosion testing concepts

Accelerated corrosion testing allows base material verification prior to final application of surface treatments such as plating or polishing. Unwanted corrosion in stainless steels and other related alloys is of significant concern and consideration in their engineering and function. Rough surface finish, elevated temperatures and corrosive environments encountered in service can accelerated corrosion and lead to early failure in materials as well as stained surface finishes.
Encountered different forms of corrosion are commonly encountered in service, and many can be strongly influenced by the heat treatment process. Fortunately, there are many types of standardized test methods and evaluations, which seek to qualify materials and quantify the rates corrosion that a metal alloy may experience. Some examples are noted below.
Pitting corrosion is a localized form of corrosion found in stainless steels and other related alloys, which does not typically experience uniform corrosion. Pitting corrosion is typically caused by the breakdown of the passive surface layer and results in small zones of corroded "pits". These pits can act as sites of crack initiation and are detrimental to a materials performance and appearance.
Intergranular corrosion (IGC) in stainless steel generally is associated with a precipitated inter-metallic phase found at the grain boundaries of a material. For example chromium carbide precipitation at the grain boundaries of an alloy can deplete the surrounding areas of corrosion inhibiting chromium. In the

Table 2.0 Intergranular Corrosion Coupon Cast Stainless Steel

Tested Corrosion Coupon	Corrosion Test Comments
	Intergranular corrosion coupon tested in accordance with ASTM A262, Practice B (120 hour boiled in ferric sulfate – sulfuric acid). Sample exhibits an acceptable mass loss of 0.7574 grams and a mass loss rate of 89.9 mils/yr.

Table 3.0 Corrosion Testing of a Sensitized Stainless Steel Sample

Microstructure Evaluation	Corrosion Test Comment
	An example of a microstructure that has been sensitized and etched In accordance with ASTM A262, Practice A. The material is ASTM A351, grade CF3M (AISI 316L). The above image shows a representative section of a cast test bar microstructure. The structure of the sample revealed steps between the austenite matrix and the isolated ferrite pools, and most closely resembles ASTM A262, Figure 4. No grain boundary ditching or sigma phase is present making this microstructure acceptable.

presence of a corrosive environment, these grain boundaries are preferentially attacked and are subsequently weakened.
Stress corrosion cracking (SCC) is another form of corrosion that can cause normally ductile materials to fail prematurely in a brittle manner. When a material is both stressed (especially at elevated temperatures) and also exposed to a corrosive environment, the grain boundaries can be attacked and the materials mechanical properties can be compromised. SCC is very alloy specific in that certain alloys may only experience SCC in the presence of specific chemical environments. Austenitic stainless steels in particular are susceptible to SCC in the presence of chlorides.
Sensitizing heat treatments in stainless steel can aggravate problems associated with intergranular corrosion (sensitization is a process in which the material is heated to a temperature in which chromium carbides for example can precipitate out of solution at a grain boundaries and create a chromium depleted region which adversely effects corrosion resistance). Austenitic stainless steels are susceptible to sensitization after heating to roughly 500°C to 800°C. The addition of carbide stabilizing elements such as niobium or titanium can help to ameliorate the problem, however, processes such as welding a susceptible material can still detrimentally affect its microstructural integrity. See table 3.0 below for an example.
There are many standardized methods for testing a materials susceptibly to one of the three forms of corrosion addressed (pitting, SCC and IGC). See table 4.0 for some examples of test methods used for material acceptance.
A common test for pitting corrosion is the ASTM G48 test. How it works: A sample coupon is polished, dimensioned and weighed before testing. A sample is then placed in a ferric-chloride solution for a specified time period. The sample is reweighed after testing and visually examined for signs of pitting corrosion. This test can also quantify the mass loss rate of certain materials and can be very useful in ranking a materials ability to resist this form of corrosion in service.
ASTM A262, Practice E is a common test for intergranular corrosion (IGC). If two samples are polished for testing using one as a control sample. One of the two samples is boiled in a copper/copper sulfate sulfuric acid solution for a specified period of time while the other sample is placed in a desiccator.
After the proper exposure, the two samples undergo a U-bend test, with the apex of the bend being examined by magnification to look for evidence of intergranular fissures. The presence of these fissures or ditching indicates that the materials susceptibility to intergranular corrosion and can be used to determine if a sensitizing heat treatment has affected the material susceptibility to intergranular corrosion. See table 3.0 below for examples of failed corrosion bend samples.
The ASTM G36 test is commonly applied test to look for susceptibility to stress corrosion cracking (SCC). In this method, samples are polished and bolted into a U-bend configuration. The samples are boiled in a magnesium chloride solution for a specified period of time, and the apex of the bend is under magnification evaluated to look for evidence of cracking formations. The presence of cracks indicates susceptibility to stress corrosion cracking.
As there are many different types of corrosion and common methods of testing to their applications areas of interest. See Table 5.0 below for a sampling of the options commonly available.
Although corrosion can be determined to the service life of many stainless steels and related alloys, there are fortunately many methods available to help predict a materials expected performance. The American Society for Testing and Materials International (ASTM international) has standardized many of these methods, which are part of the standard toolkit designed to help

Table 4.0 Corrosion Testing Bend Samples IAW ASTM A262, Practice E

Failed Bend Sample	Failed Bend Samples of Boiled and Un-boiled Conditions
	
ASTM A 262, Practice E failed bend coupon. There are inclusions and fissures in the apex of the bend sample.	A pair of failed bend samples tested in accordance with ASTM A262, Practice E. Both the boiled and un-boiled samples failed prematurly with no ductility.

Table 5.0 Common Corrosion and Environmental Testing Methods

ASTM Test Method	Applicable Forms and Alloys	Relevant Type of corrosion
ASTM B117	Cast and Wrought stainless steels, painted items, plated and coated materials, etc.	Surface corrosion, rust and oxidization
ASTM G85, Annex A1 through 5A	Cast or wrought metals but primarily steels and aluminum alloys	Corrosion on plating / coatings, aluminum, sea water, SO2, paints and steel components
ASTM A262, Practice B	Cast and wrought austenitic stainless steels	Intergranular corrosion
ASTM A262, Practice C	Cast and wrought austenitic stainless steels	Intergranular corrosion
ASTM A262, Practice E	Cast and wrought austenitic stainless steels	Intergranular corrosion
ASTM G28, Method A	Wrought nickel rich chromium bearing alloys	Intergranular corrosion
ASTM G28, Method B	Wrought nickel rich chromium bearing alloys	Intergranular corrosion
ASTM A923, Method A	Cast and wrought duplex austenitic / ferritic stainless steels	Detecting detrimental intermetallics phases
ASTM A923, Method C	Cast and wrought duplex austenitic / ferritic stainless steels	Detecting detrimental intermetallics phases
ASTM A262, Practice A	Cast and wrought austenitic stainless steels	Detection of Sigma phase in the microstructure
ASTM A923, Method B	Cast and wrought duplex austenitic / ferritic stainless steels	Detecting detrimental intermetallics phases utilizing Charpy V-notch impact testing
ASTM G36	Wrought, cast, welded stainless steel and related alloys	Stress corrosion cracking
ASTM G48, Method A	Stainless steels, nickel based and chromium bearing alloys	Pitting corrosion
ASTM G48, Method B	Stainless steels, nickel based and chromium bearing alloys	Pitting corrosion

minimize the costly effects of corrosion in metals.

Corrosion societies and technical committees

There are a few organizations in the Unites States to assist manufacturers in matters pertaining to corrosion. The most prominent is the National Association of corrosion Engineering International (NACE International) which is based out of Houston, Texas. This organization focuses on corrosion on numerous grades of steels, heat treatments and surface treatments. Most of the specified material types are austenitic stainless steels, duplex stainless steels and nickel based alloys as dependent upon the sour gas and corrosive environments. NACE International works with its individual members as well as manufacturing organizations.

More support can be found for manufacturers from ASTM. ASTM has hundreds of committees and sub-committees on technical topics from testing, to materials specifications, to manufacturing practices and test parameters. Technical committee G01 was formed in 1964 meeting twice per year and has more than 350 members. The committee has many manufacturing members to drive the process for the specifications contained in the corrosion testing volume 3.02 of the ASTM family of standards.

On a global level, there is the World Corrosion Organization (WCO), which is based out of the European Union (EU) and discusses attends meetings, and drafts many of the NACE International type material codes and testing protocols. The mission of the WCO is to alert and make industry aware of the problems and solutions applicable to corrosion while identifying best practices to deal with and prevent corrosion; facilitate corrosion related control through the industry, and normalize world corrosion standards. As the ISO and other EU states begin to solidify their stances of corrosion and its byproducts the WCO is making a unified approach.

Final thoughts

The application of corrosion tests can be a complicated subject. If you know your specific goals, the usefulness of the process can be informative and value added. To have a solid concept of the product life and usefulness before elemental degradation is key to the selection of materials, coatings, and/or manufacturing processes. Better, more reliable products can be achieved through proper testing selection.

Referenced works

1. NACE International – International Measures of prevention, Application and Economics of Corrosion technologies Study, 3/01/2016

About Michael Porfilio

Michael has been in and servicing the foundry industry since 1985. His background is in the fields of Metallurgy, Quality Management, Sales and Marketing as well as Operations Management. He currently is a Certified Nuclear Quality Systems Auditor and NDT Level III. He is employed at Stainless Foundry & Engineering, Inc. as the Director of Quality.