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SIMPLE RAPID CORROSION TESTS WITH QUANTITATIVE IMAGE ANALYSIS FOR MATERIALS PRESERVATION

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Executive Summary

Corrosion testing is routinely applied in conservation and preservation laboratories, because many materials used in storage and exhibitions emit volatile components that can corrode metal artifacts, especially lead, copper, and silver. This corrosion not only damages artifacts, but can also lead to loss of historical information (such as nuances of surface details, designs, deliberate patinas, and inscriptions). Most museums rely on a simple exposure test with visual assessment, dating back to the 1970s and similar to what was used in industry at the time, called the “Oddy test.” Over the years many publications have highlighted problems with accuracy, reproducibility, subjectivity, and the length of time required (30 days) for this type of test. Professional corrosion studies and industry scientists now use alternative methods that are faster and more quantitative. However, the Oddy test remains firmly entrenched in conservation practice, mainly because it is simple to carry out, needs only inexpensive and easily-available equipment and supplies, and requires no corrosion science expertise. Yet, the required four-week period is often cited as a problem, because exhibition designers and suppliers frequently need to know much more quickly than that if purchases should go forward; thus the test is often abbreviated to two weeks, decreasing reliability.

The rapid corrosion test described in this project appears to be successful in screening for materials that are likely to be very damaging if used in conjunction with a particular metal. This information is available in a 24-hour period for lead and copper, and within four days for silver. Materials that pass this screening test could be selected for follow-up testing via other means that require more time or expensive equipment, while the materials that are clearly damaging to metals can be eliminated from consideration very quickly. The rapid test also appears to be a very useful screening tool for corrosion inhibitors in metals conservation. The 24-hour test period was successful in showing which corrosion inhibitors work well to protect metal. This test would allow for the rapid screening of many possible inhibitors, in a variety of concentrations, and with replication. The solutions producing the best results could then be set aside for more detailed study and experimentation by a variety of other means.

The research conducted during this project also indicates that both the rapid tests and the traditional Oddy tests can be improved by incorporating Reflectance Transformation Imaging (RTI) for corrosion assessment and permanent documentation of results. RTI is commonly employed in museums and conservation laboratories, is very fast to accomplish, and this step can easily be added. An RTI image can be viewed at many different light positions and enhancement conditions, to provide the best possible view of the rapid corrosion test plate or an Oddy test coupon array. Adding in image analysis is also a very fast step. The enhancement capabilities of image analysis software can aid qualitative judgements, and quantitative data can also be obtained if desired.
**Overall Project Goals**

Corrosion testing is routinely applied in conservation laboratories of most museums, because many materials used in storage and exhibitions emit volatile components that can corrode metal artifacts, especially silver, lead, and copper. This corrosion not only damages artifacts, but can also lead to loss of historical information (such as nuances of surface details, designs, deliberate patinas, and inscriptions) (Wilthew, 1993). Some typical sources of volatiles are known and eliminated from museum use, but given the wide range of interior materials (wood products, sealants, textiles, floor tiles, plastics, inks, adhesives, paints and enamels, varnishes, cleaning products, etc.) and constant appearance of new commercial products and formulations, most museums test all products that will be used.

Most museums rely on a simple exposure test with visual assessment, originally described in the conservation literature in the 1970's, similar to what was used in industry at that time (Oddy 1973, 1975). In conservation it is called “the Oddy test” after Andrew Oddy, who first introduced this approach to the conservation field. There are clear advantages to this test, which is why it has remained in use for so long, despite some problems, difficulties, and reservations, that have been expressed about it over the years. The main advantage is that it is relatively simple and inexpensive to conduct, making routine testing available for cultural institutions that lack the facilities, expertise, or funds to carry out other more complicated or expensive types of tests.

Many publications have highlighted problems with accuracy, reproducibility, subjectivity, and time required (one month) for this type of test (Crume 1985; Shepard *et al.* 1985; Beale 1991; Strahan and Boulton 1991; Green and Thickett 1992, 1993, 1995; Lee and Thickett 1996; Reedy *et al.*, 1998; Wang *et al.*, 2011). By the mid-1980's, corrosion scientists working for industry had often replaced similar tests with others, often rapid, quantitative electrochemical tests (Siebert 1985; Silverman 1994), and these are now standard in professional corrosion studies and in materials testing for industry.

However, the main test in museums today remains the Oddy test (Bamberger *et al.*, 1999; Robinet and Thicket, 2003). Although problems have been noted and alternative procedures have been proposed over the years, it remains firmly entrenched in conservation practice. This acceptance continues because it is simple to carry out, requires only easily-available equipment and supplies, and requires no corrosion science expertise (Bamberger, 2012). Yet, the required four-week period is often cited as a problem, because exhibition designers and suppliers frequently need to know much sooner than that if purchases should go forward; thus the test is often abbreviated to two weeks, decreasing reliability. It has also been noted that it can be difficult to interpret visual qualitative results when trying to read the surface of highly reflective metals, and when control coupons generally include some amount of tarnish or corrosion due to exposure to 100% RH and high temperatures over a period of one month. And, while the desirability for quantitative data is often recognized, so is the need to rely upon methods that do not require specialist personnel, expensive equipment, or inordinate analysis time.

Therefore, we decided to experiment with alternative methods that retain much of the simplicity of the Oddy test while adding speed (results available in closer to one day rather than one month), and which might be able to provide quantitative data, utilizing image capture and...
The first goal was to see if it would be possible to adapt for the conservation field a new, innovative approach recently described in industry for rapidly inducing and quantitatively determining the amount of tarnish or corrosion on metals. This rapid test was chosen for experimentation because it would adapt a new industry test that matches the simplicity of Oddy tests (not requiring highly-trained specialists or expensive equipment). Yet, it provides much more rapid results than the Oddy test, potentially allowing a large number of tests to be run simultaneously, facilitating replication and thus improving validity of results. We decided to couple experiments with this test with image capture methodology now familiar to cultural heritage institutions (Reflectance Transformation Imaging, RTI) and standard image analysis protocols that could provide quantitative data. This piggy-backs on new image capture and analysis techniques already being incorporated into many conservation laboratories.

The second goal was to see if it would be possible to improve the qualitative assessments and permanent documentation methods of Oddy tests, as well as open up the possibility of obtaining quantitative data, by incorporating RTI and image analysis into the Oddy test procedure.

The new rapid test that we experimented with is based on an innovative approach recently reported in the corrosion industry literature (White et al., 2012). It was designed as a rapid, high-throughput corrosion testing method that uses a microfluidic approach (test solutions of 0.2 ml) with as many as 88 simultaneous corrosion tests carried out on a single 100 x 75 x 10 mm metal plate. The advantage of a microfluidic approach such as this is that shallow solutions (with a decreased path length for oxygen diffusion) produce rapid corrosion appearance on metals compared to standard immersion tests in the same solutions (White et al., 2009, 2012). Testing of all 88 samples requires only about one day, and about one additional day should be needed for sample preparation and image capture and analysis. White et al. found good reproducibility of the technique over multiple repetitions and multiple plates, with good comparability with other corrosion tests being used in industry, including 28-day tests. This test, however, was designed for testing of corrosion inhibitors, so we needed to see if it would also work with extraction solutions of exhibition and storage materials, similar to the extractions that are already used in electrochemical testing. We also look at the potential of this rapid test for use as a fast screening test for corrosion inhibitors in the conservation field.

Two corrosion indicators are considered most useful for interpreting tests: (1) a precipitate of the corrosion product which forms on the surface of the wells; and (2) a more subtle tarnishing or pitting attack on the surface, which has the effect of darkening the shiny, polished metal surface. White et al. noted that imaging corrosion was difficult, since the two main corrosion indicators could not be assessed easily in one photographic image. They used a relatively complicated photographic and image processing approach to interpret results. In our work, Reflectance Transformation Imaging was instead used to obtain the best possible images for assessing corrosion products and pitting attack. This is an image capture technique using ordinary photographic equipment, and that is rapidly becoming an important part of the repertoire of conservation laboratories (Cultural Heritage Imaging, n.d.; Smithsonian Museum, n.d.; Mudge et al., 2006, 2010; Artal-Isbrand et al., 2011, 2013; Earl et al., 2011; Duffy et al., 2013). Digital image analysis (Reedy 2006, 2012; Reedy and Kamboj, 2008; Reedy et al., 2014) using commonly-available software was then used to obtain quantitative data from that image.
Regardless of the development of other possibilities, we recognize that many conservation laboratories will prefer to continue with Oddy testing because this approach has been used for many years in the conservation field, and there is a high level of comfortableness about the technique in spite of continuing questions regarding reproducibility and the qualitative assessments. In that case, the RTI image capture coupled with digital image analysis can provide additional data to enhance confidence in the standard Oddy test, as well as providing fast but high quality permanent documentation of results.

Methods and Materials

Building the Rapid Corrosion Testing Apparatus
For our test system, we used 9.0 cm x 6.5 cm metal sheets as the corrosion surface. Tests were run using lead, copper, and silver, as these are the metals typically used for Oddy testing in museums. These are also the museum metals most sensitive to environmentally-induced tarnish or corrosion. This differs from the tests run by White et al. (2012), who used an aluminum alloy of slightly larger size (10 x 7.5 cm). For most tests, thin metal sheets were used (1.6 – 2.4 mm thick, similar to the 2.5 mm-thick metal sheets used in the original tests by White et al. (We obtained unalloyed copper sheet from T. B. Hagstoz, fine silver sheet from Rio Grande, and lead sheet from Rotometals). We also tried thinner metal films (0.1 mm, from Goodfellow), as these are often specified for Oddy tests, but the results were unsatisfactory (see section on Assessing the Results, below). Metal sheets were first abraded to remove any tarnish, polished and thoroughly cleaned and degreased, then stored in a desiccator containing self-indicating silica gel until use. These metal sheets are encased in a sandwich of hard polycarbonate material with a block of pliant material between the upper polycarbonate sheet and the metal.

The pliant material is a polydimethylsiloxane block (PMSS Sylgard® 184, from Dow Corning) that is cast to a thickness of about 10 mm. The Sylgard® 184 is mixed with an elastomer curing agent 10-1, stirred well to remove bubbles, and then poured into a mold. Our mold created PDMS blocks of 9.5 x 7.0 cm, just slightly larger than the metal sheets, so the metal would be completely covered. After about one hour it becomes clear and bubble free. It sets completely within about 48 hours at room temperature, although this can be accelerated in a low-temperature oven.

Holes of 6 mm diameter are cut into the PDMS block on a grid design; using a cork borer (the material is too soft to use a drill). While White et al. (2012) used 88 holes for a larger metal sheet in order to have a high-throughput method, we used only 24 holes. This allowed more spacing between holes, as well as a somewhat smaller metal sheet, and since we are not carrying out intensive high-throughput testing this was sufficient for our needs. The PDMS block is brought into contact with the metal and securely clamped into place between two thick polycarbonate sheets. The top one has an array of holes 5 mm in diameter matching the placement of those of the underlying PDMS. To help control the placement of drilled and cork-bored holes, a measured template was made out of cardboard and superimposed on the surfaces.

The polycarbonate sheet (12.7 mm thick) was obtained as a single 12 x 12 inch sheet. It was cut using a table saw into six pieces of 14.75 x 9.75 cm dimensions, to form the top and bottom part of the sandwich for three assemblies (one each for lead, copper, and silver). Holes were cut using
a drill press; six holes in both the top and bottom sheets for bolts that would be used to clamp the assembly together and tightened with wingnuts; and 24 5-mm diameter holes in the top sheet matching the placement of the cork-bored holes in the PDMS sheet (Figure 1). The metal test plates are then placed onto the polycarbonate base (Figure 2).

The slightly smaller holes of the outer polycarbonate sheet help to direct fluids into the holes of the PDMS block. The main purpose of the pliant PDMS block is to help create a tight seal to hold those fluids in place against the metal for the duration of the corrosion test. The advantage of this microfluidic approach is that shallow solutions (with a decreased path length for oxygen diffusion) produce a more rapid corrosion appearance on metals compared to standard immersion tests in the same solutions (White et al., 2009, 2012). Since a satisfactory test requires that there be no leakage or cross-contamination from one well to another during the test, it is also
important that the assembly be clamped tightly together. We found that to do this required use of pliers to tighten the wingnuts as much as possible (Figure 3).

![Figure 3. Completed rapid test assemblies.](image)

**Sample Preparation Methods**

A wide range of materials were selected to include in experiments, using the AIC Wiki Oddy Tests: Material Databases (AIC n.d.) to find materials that were likely to perform over a range of Pass, Temporary Use, or Fail results. Some additional materials were added that would be known failures (such as 100% wool cloth and crepe rubber from Thailand). The main goal was not to begin to use this new test to make judgements about whether materials should be used in storage and exhibition environments, but to see if consistent corrosion results could be obtained by this new test.

We prepared aqueous extractions following a modification (Corrosion Testing Laboratories, Inc., 1991) of an ASTM standard (ASTM, 2011), previously found to work well for extracting problematic components of typical exhibition and storage materials (Reedy *et al*., 1998). This and very similar protocols are routinely used for extraction in a variety of industry electrochemical and other corrosion tests (Waddell, 2008; ASTM, 2015; Krantz, 2015). For extraction, samples must be prepared to maximize the surface area. For free flowing particulate solids, or cloth-like materials, no further preparation is required. For non-free flowing particular solids, each sample is pulverized, cut, or broken into smaller pieces so that no piece is larger than 6.3 mm in diameter.

Fifty (50 ± 0.1) grams of the sample are placed in a borosilicate glass flask to which 200 ml of solvent (water in this case) are added. The aqueous mixture is heated rapidly on a hotplate to boiling, and maintained at boiling temperature for 30 minutes using minimum heat necessary to avoid excess evaporation of the sample. Stirring may be necessary to avoid “bumping”. The solution is then removed from the heat and allowed to cool for 15 minutes before filtering through a Büchner funnel containing a prewashed, ashless, rapid-filtering paper (Whatman 41 or equivalent). The entire solution is then transferred and filtering continues until the filtrate stops flowing. The flask is washed thoroughly, using a minimum of ten small washes and keeping the total filtrate within 250 ml. The filtrate is transferred to a volumetric flask, allowed to cool before 38°C, and then diluted to exactly 250 ml. The extracted solution is now ready for testing. Since we only used very small amounts of solution in the tests, the amount of sample and water were often correspondingly reduced.
Results and Discussion: Rapid Corrosion Tests

Extractions
It is possible that aqueous extractions do not pull out all components that may be problematic in an off-gassing environment, and that solutions held against metal will not obtain results matching those in a natural museum environment where the material may not be touching an object, only the off-gassed components. Nonetheless, tests involving extractions (generally electrochemical tests) have been used in industry for a long time now to identify potentially corroding materials that should not be used near metals. And, of course the Oddy tests depend upon conditions that are never actually duplicated in the museum environment either (in the case of Oddy tests, elevated temperatures and exposure to 100% RH for one month). So, the point is not to duplicate actual exposure conditions, as that can only be done through controlled long-term tests in actual service conditions, but to rapidly screen for materials that indicate the potential to be problematic.

A good area for future research would be to experiment with alternative extraction methods. The protocol above is also sometimes used with methanol instead of water as the solvent. In that case, instead of boiling, the sample-methanol mixture is held at ambient conditions for 24 hours. A reflux condenser is required to avoid excess evaporation of the solvent. However, previous experiments with extractions of Oddy test materials that compared extractions using water, methanol, and a 50-50 solution of water and methanol found that water extraction consistently produced the highest corrosion rates for electrochemical testing, regardless of which metal was used in the test (lead, copper, or silver) (Reedy et al., 1998). Therefore water extraction appears to be the most likely way to identify the worst possible corrosion that might be encountered.

Aqueous extractions are also the chosen technique for researchers using electrochemical testing (linear polarization resistance measurements) to study the corrosive effects of woods and preservative-treated woods used in contact with various metals (Zelinka et al., 2007, 2008; Zelinka and Stone, 2011). In this case a cold-water extraction is used. Wood is ground into sawdust, then steeped in distilled water (on a 1:10 weight ratio basis) for one week. The sawdust is then removed with a Büchner funnel. Electrochemical tests performed on these extractions were found to correlate well with long-term exposure tests of metals used in conjunction with preservative-treated wood, but the extracts produced higher corrosion rates for untreated wood than were found in long-term exposure tests (Zelinka and Stone, 2011), and research into that issue is ongoing. As part of that wood-metal research, different solution concentrations were tested; given that we had difficulty obtaining corrosion reactions on silver for all but the most damaging materials during the prescribed 24-hour test period (see below), further research with the rapid corrosion test method might also focus on varying solution concentrations.

We also tried this test method as a potential screening tool for rapid tests of potential corrosion inhibitors that might be used in conservation, focusing on copper in those experiments. In this case, the concern is not the extent to which all of the potentially damaging components are extracted, but the extent to which an added inhibitor can protect the metal against corrosion. Our initial experiments indicate that this rapid test might be a good tool for quick screening for corrosion inhibitor performance. For example, artificial salt water resulted in a high amount of corrosion in test wells over a 24 hour period. Artificial salt water solutions with 3% BTA
(benzotriazole, widely used in conservation as a corrosion inhibitor for copper and copper alloys) showed no corrosion at all, indicating a highly effective corrosion inhibitor. In contrast, those with 3% solutions of tannic acid (used in conservation as a corrosion inhibitor for iron but which has been proposed for use with copper) (Kusmierek and Chrzescijanska, 2013) were no different than the salt water alone.

Running the Test
All sample solutions were tested with three to four replicates on a metal plate. The placement of solutions was decided using a random number table, so that all replicates of a particular solution would be dispersed throughout the plate, rather than localized in one particular area, to spread out any accidental or uncontrolled experimental differences that might occur (such as one side of a plate being tighter and less apt to create leakage, mistakes in surface preparation making one area more conducive to corrosion, more evaporation on one edge of the plate, etc.). The locations of each sample replicate were noted on a separate numbered grid so that there could be no confusion later when examining results. The upper left corner of the grid was marked on the metal plate, on the bottom side not exposed to sample solutions, and the upper left corner was also marked on the PDMS block and top polycarbonate sheet, to ensure no confusion as to which wells should receive which solutions and for recording results after disassembly.

Sample solutions were pipetted through the holes to deposit test solutions onto the surface of the metal. Hence it is very important when setting up the assembly to ensure that the holes in the top polycarbonate sheet are well aligned with the holes in the PDMS pliant block. Following the protocol of White et al., (2012) we placed solution volumes of 200 μl into each well. According to the published protocol, the corrosion experiments should be allowed to proceed for 24 hours at room temperature; holes are loosely covered with a plastic film to prevent solution evaporation while allowing diffusion of air. The assembly is then inverted, solutions discarded, and wells washed with deionized water. The plate is allowed to dry for 12 hours in a desiccator at room temperature before imaging.

We ended up experimenting with varying both the amount of solution deposited onto the surface of the metal, and the time allowed for the test to proceed. These variations turned out to be necessary due to the varying reactivity of the metals used for our tests. Clear results can be obtained on lead using the standard 24 hour test period. However, we found that silver requires more time if we wish to see any results other than those for materials highly corrosive to silver. In our first experiments so few of the solutions affected the silver that it was difficult to determine which wells were reacting, without superimposing a template to show the location of the 24 test wells. We found that allowing the test to continue for as long as four days produced more readable results. We then increased the amount of test solution slightly to ensure that no test wells would encounter significant evaporation. The results were also clearer on copper when allowed to proceed for this extended period of time, although it could also be done for an interim period shorter than four days but longer than 24 hours. However, four days was too long for lead, as then even deionized water alone created extensive surface corrosion products.

We also tried using 0.1 mm metal films, as those are used in many Oddy test protocols. However, we found that those were problematic. It was more difficult to get a tight seal, probably due to inherent springiness in the films. This lead to two phenomena: more leakage
from some of the wells; and more appearance of crevice corrosion around the wells. This latter problem occurred as the film became a bit indented around the edges of the holes when the wing nuts were tightened, leading to liquid pooling up in those indentations and concentrating more corrosion there.

Sheet metal is not without surface problems. The relatively soft metals used for conservation tests tend to scratch if they are reused and corrosion cleaned off. It requires a significant amount of time on surface preparation to completely remove these scratches to the point that they are no longer clearly visible in the RTI viewer, which strongly enhances any surface features. However, as we began to conceive of the rapid tests as a quick screening tool, we decided to forego efforts to try to remove these scratches, as they did not appear to affect results in any significant way, and the RTI Viewer enhances surface texture so well that otherwise a great deal of time must go into surface preparation to prevent seeing them.

**RTI for Image Capture**

*White et al. (2012)* noted that imaging corrosion on metal plates was difficult, as it may consist of both a precipitate of the corrosion product forming on the surface of the wells, and a more subtle pitting attack or tarnish, which darkens the shiny, polished metal surface. They therefore captured two images, using two different photographic set-ups with a four-globe copy stand. The first photograph was with side lighting, and the second was taken from above with the metal plate in a cubic diffuse lightbox with a hole at the top for the camera lens. In order to assess the range of corrosion in the wells, they then undertook several steps using Adobe Photoshop to mask off the well areas and to enhance the visibility of corrosion phenomena, creating a black background and white corrosion circles for image analysis. They then used in-house software that analyzed the average brightness of the pixels in a corrosion circle minus the average brightness of background pixels (from a ring around the well circle, of unknown size, of metal plate not exposed to test solutions). Brightness values were then ranked from 0 (darkest, least corrosion) to 100 (brightest, most corrosion). Each plate was photographed at two rotations, 0 and 180 degrees, and the resulting 0-100 ranking combined and averaged.

We chose to employ Reflectance Transformation Imaging (RTI) for several reasons. RTI is a computational photographic method that is becoming more and more widely used in cultural heritage institutions worldwide (Cultural Heritage Imaging n.d.; Newman 2015). It is an inexpensive method that requires only a few simple items besides a camera, yet can capture the surface shape and color of an object, and enables interactive re-lighting of the object from any direction. The open-source software also permits mathematical enhancement of the surface shape and color attributes; this enhancement in RTI often reveals surface information not visible under direct empirical examination of the object. There is also much active research into RTI, leading to periodic improvements in methods and software. We hypothesized that corrosion phenomena should be readily visible on the metal plates using RTI.

For the RTI images, we captured 36 photographs with a small lamp moving at points along a dome around the images at a standard distance from the metal plate, following recommended protocols (Cultural Heritage Imaging, 2013a). The camera remained stationary on a tripod, facing downwards at a table below, where the metal plate was placed along with two small black reflective spheres, a color target, and a scale bar. The photographic process took about ten
minutes, as did the processing of the images with the RTI Builder software (Cultural Heritage Imaging, 2013b). We could then view the image in RTI Viewer (Cultural Heritage Imaging, 2013c) from any light angle and under a variety of enhancement conditions.

The ability to closely examine the metal plate and all of the wells in this manner served to be a useful way to qualitatively assess the differences between the wells receiving each solution, and between the wells and the surface of the metal plate between wells. The RTI image also serves as a good permanent source of documentation of the results of an experiment, one which can be reviewed from any angle or viewing condition later if desired. We photographed each plate separately (lead, copper, or silver), and included a scale in case of future needs to calibrate measurements in image analysis. We also included a marker (a small piece of paper with an X) to indicate the upper left corner of our numbered grid that contained the key to which solutions had been pipetted into which wells so that there would never be any future confusion. The scale and marker are cropped out along with the reflective spheres for the RTI image, but remain in the original image captures for reference if needed.

After much experimentation, we found that image analysis could proceed most efficiently by capturing one photograph in the RTI viewer that seems to show the corrosion/tarnish for all of the wells the best. For image analysis, it is best to find a position where all of the areas of interest have relatively even background lighting (so not strongly washed out in some areas or brighter on one side), while also enhancing the view of corrosion. In some cases this might require two separate photographs, sometimes one that focuses on one side of the metal plate and one that focuses on the other side; or one that best shows surface corrosion products and one that best shows surface darkening/pitting. However, we found that one image was sufficient with the metal plates that we viewed. (For example, for the lead, copper, and silver plates that we viewed, an RTI Viewer setting of x = -.78, y = 0.62, Specular Enhancement, Diffuse Color = 90, Specularity = 10, and Highlight Size = 100 worked well for most specimens.)

At a chosen position, the RTI viewer permits snapping a photograph of that view. Simultaneously, an xml file will automatically be created that records the RTI viewing positions. It is therefore easy to recreate the image if needed, or to select a different viewing position/condition to use for future image analyses.

**Image Analysis Protocols**

For image analysis, we used Image-Pro Premier (by Media Cybernetics, [www.mediacy.com/](http://www.mediacy.com/)), which was introduced in 2012 (Reedy et al., 2014). This software was chosen because it is a comprehensive analysis package in wide use in a variety of different fields, we are very familiar with its use, and there is strong technical support available if needed. It is quite likely that other image analysis software packages could also be employed, or that other uses of Image-Pro Premier might identify alternative preferred protocols.

However, one feature of the Image-Pro Premier product that we find especially useful in being able to conduct fast,repeatable quantitative analyses of area percentages of various components or phases (in this case, of corroded versus uncorroded metal) is the Smart Segmentation procedure. This tool separates, or segments, areas of interest (such as corrosion) based on their differences from the background and other areas of interest (such as different corrosion phenomena) using a multi-parameter separation algorithm that examines all color channels.
(RGB, YIQ, and HIS), background correction channels, and morphological and convolution filter channels for the combination of variables that best distinguish the background and the area(s) of interest. It allows one to very quickly click on and define the reference spots to use for background and for one or more defined area(s) of interest in an image; the reference areas are then used to create segmentation masks to measure the total area percentage comprising the area(s) of interest.

The classification to a phase (such as background uncorroded metal versus corrosion) is done on a pixel level, with the mean value of every reference area (areas of interest and background area) calculated for every active channel (which can include color channels, as well as morphologically processed or filtered images). A Minimum Distance classification is used to classify pixels on the image: the weighted multi-dimensional Euclidian distance is calculated from the value of every pixel on the image to the mean values of objects of interest and background objects. A pixel is then assigned to the class of the closest reference area.

This process results in a segmentation recipe, which is full list of the combination of discriminating variables and the classification function used to assign pixels to a class. A reliable segmentation recipe will tend to incorporate many variables from among the color, background, and morphology choices. This recipe can be saved, and reused later if analyzing another similar object. It is often the case that a recipe defined for a particular metal can be reused over and over again on other image analysis work using that same metal, provided the photographic conditions and RTI image parameters are similar enough. But if the saved recipe from a previous analysis does not seem to work well, it will need to be altered to fit the new example, or a completely new segmentation recipe created.

In order to be able to adequately mark background and corrosion to construct a segmentation recipe, it is usually necessary to do some preliminary “pre-processing” of the image. We also do this in Image-Pro Premier, which has many fast tools available. The tools we found most useful for the images discussed here (lead, copper, and silver rapid test plates and Oddy test coupons) include: Subtract Bright Background, which makes the background illumination more uniform by creating an approximation of the background as a separate image based on bright polarity and feature width, then subtracting this approximation from the original image; Convert to Gray Scale, which often makes the features of interest stand out better from the background; Invert Gray Scale image, which creates a reversed, or negative, image, sometimes making the phase of interest stand out better; Adjust Best Fit, which resets black/white levels by averaging the upper and lower levels of all channels, again sometimes making certain features of interest more visible; and Pseudocolor, which can sometimes better highlight certain features of an image. A pseudocolored image is a gray-scale image with accompanying red, green, and blue values, where differences in color reflect differences in intensity.

As an example of the application of image analysis using Image-Pro Premier tools, in the case of the rapid corrosion test on lead, a procedure that worked well was to first apply Subtract Bright Background, then convert to gray scale. At this point, the differences between uncorroded background, darkening in the test wells due to tarnish, and white surface corrosion products were readily apparent. Once could stop there if only interested in making qualitative judgements. For quantitative analysis, applying the Smart Segmentation tool resulted in a segmentation recipe that incorporates 11 variables. For the test well outlined below in Figure 4, this recipe was used
to determine that the well is covered by 61% darkened area, 13% corrosion products, and only 26% uncorroded metal. The two corrosion phenomena can be combined to form a single summary Corrosion Factor (74 in this case).

Our original idea was that we would try to develop a satisfactory “protocol” for image analysis of metal test plates and Oddy test coupons. After much experimentation, we concluded that the type of metal and nature of the specimens would require some variation/adjustments in procedures. Therefore, we present three protocols in this section, one for the lead test plates, one for copper, and one for silver. In the next section we present three slightly different protocols, one for Oddy test lead coupons, one for copper, and one for silver.

With the lead test plates, two corrosion phenomena can be observed, the formation of white surface corrosion products, and darkening of the metal due to tarnishing. Since these tests are designed to identify problematic corrosion-enhancing materials, not to study various corrosion phenomena, we combined the two into one quantitative measure for image analysis. With the copper test plates, tarnish and corrosion products may appear in several colors; again, these were combined for quantitative analysis for the purposes of these experiments. For both metals, while a few of the wells, where no corrosion occurred, are relatively invisible in RTI, the outlines of most of the wells are clearly visible. It may be enough for most users to stop when the most enhanced image is available, and make a qualitative assessment comparing each test well with the surrounding metal plate. Materials that are definitely harmful when used near lead, copper, or silver are clearly apparent. However, the quantitative assessment may be useful if trying to determine if a material that causes corrosion could still be acceptable for temporary uses (by...
seeing where they fit on the scale of no visible corrosion to clearly visible corrosion, for example).

For silver, even after a test period of four days, many of the wells show little or no tarnish. Once again the extractions from materials that are clearly damaging to silver stand out, with severe tarnish visible. Some wells show visible tarnish, but to a lesser extent. While some of these materials may be considered useful for temporary use, the distinction between “pass” and “temporary” or “temporary” and “fail” may be subtle. With the silver test, it may be better to use this as a screening test for materials that just should not be used around silver. For example, in the test illustrated in the section on silver below, the aqueous extraction from 100% wool cloth shows close to 100% tarnish in all three replicates; a decided fail, as expected. An extraction of Thai crepe rubber shows more subtle, but still quite visible, tarnish. A range of textiles in addition to the wool were also tested. Two of these textiles also produce clearly visible tarnish. In contrast, the other textiles do not. Even without quantitative analysis, it should be apparent that the two problematic textiles should be eliminated as possible choices to use in the vicinity of silver, while the others could be investigated further by other techniques if being considered for use.

1. **Image Analysis Protocols For Rapid Test Plates, Lead:**

   A. *After opening image file (Figure 5A) in Image-Pro Premier, correct for uneven background intensities and lighting in different areas of the plate (to better distinguish corrosion from uncorroded metal).* Under Process tab, select Subtract Bright Background (Figure 5B).

   ![Figure 5A (top): Original image taken from RTI Viewer; and 5B (bottom), image after Bright Background Subtraction.](image-url)
B. Convert to gray scale: Adjust Tab > Setting to 12 bpp Mono. Apply (Figure 6). If only qualitative assessment is desired, it can be done after this step.

![Gray scale image; background metal is gray, corrosion products are white, and metal darkened by tarnish is black.](image)

C. Use Smart Segmentation to develop a recipe for measuring % area covered by corrosion products and % area of metal darkened by tarnish: Create a segmentation recipe by marking the background (grey metal area), corrosion products (white), and darkened metal (black). Several representative areas of the uncorroded plate outside of the corrosion test wells can be used to define the background.

D. Define a Region of Interest (ROI) and measure % area of a test well covered by corrosion products and % area of a test well metal darkened by tarnish: Under Select, use the circle tool to outline the perimeter of a well. To use the circle tool, start at the center of the circle and move outwards until the circle is about the correct size. Then hit “enter” and when two squares appear, they can be used to resize and move the circle as needed. When done, click outside of the ROI to set it in place. Once an ROI is defined, in Smart Segmentation, open the appropriate saved recipe, click on Count, and open the measurement table to view data. Record the resulting data, or save the data to an Excel or Txt file.

Note on Measurements settings: Under Measurement Types, select (1) Object Class = Name; (2) Region: Area uncalibrated; and (3) Region: Percent Area (%). Check that the automatic “split particles” with count is turned off.

The ROI circle can now be moved by clicking and dragging to each of the corrosion wells, one at a time, and the measurement steps above repeated, until all corrosion wells have been measured. This keeps all ROIs the same size and prevents having to re-draw them over and over.

The area % covered by corrosion products and area % darkened can be combined into one Corrosion Factor. If there are replicates, the worst example can be used for the corrosion assessment; or, all replicates can be averaged.

An example can be seen in Figure 7 below. The ROI (green outline, right column, third circle down from the top) shows the effects on the lead of an extraction of 100%
wool cloth. Image analysis shows that 13% of the area in the well is covered by surface corrosion products, and 61% of the area is darkened by tarnish. If the two corrosion indicators are combined, this gives a Corrosion Factor of 74.

Figure 7. ROI (Region of Interest) highlighted for analysis.

2. **Image Analysis Protocols for Rapid Test Plates, Copper:**

   A. *After opening the image file in Image-Pro Premier, under Adjust, select Best Fit. If only qualitative assessment is desired, it can be done after this step* (Figure 8).

   Figure 8. Copper image from RTI Viewer after Best Fit adjustment.

   B. *Use Smart Segmentation to develop a recipe for measuring % area covered by tarnish and corrosion products of several colors:* Create a segmentation recipe by marking the background metal area versus the various colored corrosion products. Several representative areas of the uncorroded plate outside of the corrosion test wells can be used to define the background.

   C. *Define a Region of Interest (ROI) and measure % area of a test well covered by the various colored tarnish and corrosion products:* Under Select, use the circle tool to
outline the perimeter of a well. To use the circle tool, start at the center of the circle and move outwards until the circle is about the correct size. Then hit “enter” and when two squares appear, you can use them to resize and move the circle as needed. When done, click outside of the ROI to set it in place. Once an ROI is defined, in Smart Segmentation, open the appropriate saved recipe, click on Count, and open the measurement table to view data. Record the resulting data, or save the data to an Excel or Txt file.

Note on Measurements settings: Under Measurement Types, select (1) Object Class = Name; (2) Region: Area uncalibrated; and (3) Region: Percent Area (%). Check that the automatic “split particles” with count is turned off.

The ROI circle can now by moved by clicking and dragging to each of the corrosion wells, one at a time, and the measurement steps above repeated, until all corrosion tests have been measured. This keeps all ROIs the same size and prevents having to re-draw them over and over.

3. **Image Analysis Protocols for Rapid Test Plates, Silver:**

   A. **After opening the image file in Image-Pro Premier, Convert to gray scale:** Adjust Tab > Setting to 12 bpp Mono. Apply. **If only qualitative assessment is desired, it can be done after this step. It may be easier to qualitatively compare the test wells with an inverted image:** Adjust > Invert Display (Figure 9).

   ![Figure 9. Silver image from RTI, converted to gray scale, then inverted.](image)

   B. **Use Smart Segmentation to develop a recipe for measuring % area covered by tarnish:** Create a segmentation recipe by marking the background and tarnish. Several representative areas of the uncorroded plate outside of the corrosion test wells can be used to define the background.

   C. **Define a Region of Interest (ROI) and measure % area of a test well covered by tarnish:** Under Select, use the circle tool to outline the perimeter of a well. To use the
circle tool, start at the center of the circle and move outwards until the circle is about the correct size. Then hit “enter” and when two squares appear, you can use them to resize and move the circle as needed. When done, click outside of the ROI to set it in place. Once an ROI is defined, in Smart Segmentation, open the appropriate saved recipe, click on Count, and open the measurement table to view data. Record the resulting data, or save the data to an Excel or Txt file.

Note on Measurements settings: Under Measurement Types, select (1) Object Class = Name; (2) Region: Area uncalibrated; and (3) Region: Percent Area (%). Check that the automatic “split particles” with count is turned off.

The ROI circle can now be moved by clicking and dragging to each of the corrosion wells, one at a time, and the measurement steps above repeated, until all corrosion tests have been measured. This keeps all ROIs the same size and prevents having to re-draw them over and over.

Results and Discussion: Applying Image Analysis to Oddy Tests

Oddy tests were run using both sheet metal coupons, and metal foils, using the same materials selected for the rapid corrosion tests, following standard protocols (Schiro, n.d.). In the RTI Viewer, surface details are enhanced. Hence for sheet metal coupons, some surface scratches may be visible. However, the metal foils, which are often used for Oddy tests, do not work at all for either qualitative assessment or quantitative image analysis. They tend to be quite filled with surface wrinkles, and rarely lie flat. In addition, many Oddy test protocols call for metal foils to be bent over a glass beaker. The two halves of the thin foil coupon can never be completely flattened out again. The result is that it is not possible to find a single position in the RTI Viewer that adequately shows the surface of the entire coupon. Instead, one side will tend to be in shadow while the other is lit. We therefore found it very difficult to make even a qualitative judgement about the foil coupons in the RTI Viewer or in any image captured from it. In contrast, there was no difficulty in working with the coupons cut out from sheet metal. This does lead to the question of whether or not it may be more difficult to evaluate foil Oddy test coupons by eye, given the many surface irregularities and variations that will cause light to reflect in a more complex manner off of the surface. The protocols below, then, use sheet metal coupons rather than thin foil coupons.

RTI for Image Capture

We used the same RTI image capture procedure as was used for the rapid test metal plates. In this case, all coupons of a single metal (lead, copper, or silver) were set out on the table together. A method is needed to ensure that it will be clear later which materials were tested with which coupons. Sometimes we used code numbers stamped on the metal, written on the back, or kept track of in a separate coded grid sheet. A small X was often placed at the top left corner, as with the rapid test plates, to ensure that samples could always be traced back to their location in the code sheet.

As with the rapid test metal sheets, we again captured 36 photographs with a small lamp moving at points along a dome around the images a standard distance from the metal coupon array. The camera remained stationary on a tripod, facing downwards at a table below, where the metal
coupon array was placed along with two small black reflective spheres, a color target, and a scale bar. Since each set of photographs took only ten minutes and the RTI Builder process another ten, it proved to be very efficient and fast since many coupons of a single metal could be documented at once. Hence the RTI work was not an onerous step to add in to the usual Oddy test procedures.

As with the rapid test metal plates, the ability to closely examine each of the coupons, and to compare them to each other and to the controls under a variety of viewing conditions, proved to be a useful way to qualitatively assess the differences between coupons. The RTI image also serves as a good permanent source of documentation of the results of the Oddy tests, much better than a single photograph of these highly reflective metals, and one which can be reviewed from any angle or viewing condition later if desired. A code to which coupons were the controls and identifying the materials that were tested with the others must of course be retained in conjunction with the finished RTI file or any images captured from it.

After much experimentation, we found that, as with the rapid test metal plates, image analysis could proceed most efficiently by capturing one photograph in the RTI Viewer that seems to show the corrosion/tarnish for all of the coupons the best. For image analysis, it is best to find a position where all of the areas of interest have relatively even background lighting (so not strongly washed out in some areas or brighter on one side), while also showing the corrosion well. In some cases it is possible that this may require two separate photographs, sometimes one that focuses on one side of the metal coupon array and one that focuses on the other side; or one that best shows surface corrosion products and one that best shows surface darkening/pitting. However, we found that one image was sufficient with the metal coupons that we viewed for these experiments, and the setting that worked well for the rapid test metal plates also tended to work well for the Oddy test coupon arrays (so for the lead, copper, and silver coupons that we viewed, an RTI Viewer setting of x = -.78, y = 0.62, Specular Enhancement, Diffuse Color = 90, Specularity = 10, and Highlight Size = 100 worked well for most cases).

At a chosen position, the RTI viewer permits snapping a photograph of that view. Simultaneously, an xml file will automatically be created that records the RTI viewing positions. It is therefore easy to recreate the image if needed, or to select a different viewing position/condition to use for future image analyses.

**Image Analysis Protocols**

For image analysis, as with the rapid test metal plates, we used Image-Pro Premier (by Media Cybernetics, [www.mediacy.com](http://www.mediacy.com/)). And, as with the metal plates, after many efforts to try to develop a single protocol for Oddy test coupons, we concluded that variations are needed depending on the type of metal. Therefore, we present three protocols in this section, one for Oddy test lead coupons, one for copper, and one for silver. We use only coupons cut from sheet metal, rather than very thin metal foils.

With the lead test plates, two corrosion phenomena were easily observed, both the formation of white surface corrosion products and a darkening of the metal due to tarnishing. However, with the Oddy test coupons, the darkening is more difficult to see and mark for image analysis; it may require zooming in to compare coupons with the controls. Surface corrosion deposits are easier
to discern and were more common. For the copper coupons, as with the copper rapid test plates, tarnish and corrosion products appear in several colors; again, these were combined for quantitative analysis for the purposes of these experiments. For the silver coupons, tarnished versus untarnished areas are visible, and the differences can be enhanced in the image analysis software.

It may be enough for most users to stop when the most enhanced image is available, and make a qualitative assessment. Materials that are definitely harmful when used near lead or copper are clearly apparent, and it is possible to identify ones that are slightly worse than the controls (and hence might be graded as acceptable for temporary use). However, the quantitative analysis can sometimes be useful to determine that a lightly tarnished surface is indeed worse than the controls.

1. **Image Analysis Protocols for Oddy Test Metal Coupons, Lead:**
   A. *After opening image file in Image-Pro Premier, convert to gray scale (Figure 10A):* Adjust Tab > Setting to 16 bpp Mono. Apply. **If only qualitative assessment is desired, it can be done after this step.** (Uncorroded metal will be gray and corrosion products white). It may be easier to see and compare the corroded versus non-corroded areas and coupons with the gray scale image inverted (then the uncorroded metal is gray, while corrosion products appear black, Figure 10B). However, for marking areas and counting via Smart Segmentation, the uninverted gray scale image seems to produce more satisfactory results.

   ![Figure 10. A (left), RTI image converted to gray scale; and B (right), inverted.](image)

   B. *Use Smart Segmentation to develop a recipe for measuring % area covered by corrosion products:* Create a segmentation recipe using the gray scale image by marking the background (gray metal area) and corrosion products (white). (There may also be darkened areas that need to be discerned by zooming in close.) Uncorroded areas on control coupons can be used to define the background.
C. Define a Region of Interest (ROI) and measure % area of a coupon covered by corrosion products: Under Select, use the rectangle tool to outline coupon. When it is about the correct size, click on “enter” and it can then be resized or adjusted as needed. Coupons are often not all completely perpendicular when set down on the surface for RTI photography, so the adjustment tool in the center of the rectangle can be used to adjust the angle of the ROI as needed. When done, click outside of the ROI to set it in place. Once an ROI is defined, in Smart Segmentation, open the appropriate saved recipe, click on Count (Figure 11), and open the measurement table to view data. Record the resulting data, or save the data to an Excel or Txt file.

![Figure 11. An ROI after counting, with the corroded area (89%) marked in red.]

For example, in the array of lead coupons above, a coupon exposed to cardboard resulted in 89% corrosion (marked in red in Figure 11). Some coupons show as high as 96% corrosion, while the controls never exceeded 7%.

*Note on Measurements settings:* Under Measurement Types, select (1) Object Class = Name; (2) Region: Area uncalibrated; and (3) Region: Percent Area (%). Check that the automatic “split particles” with count is turned off.

The ROI rectangle can now be moved by clicking and dragging it one at a time to each coupon, and the measurement steps above repeated, until all corrosion tests have been measured. The angle of the ROI can be re-adjusted as necessary.

2. **Image Analysis Protocols for Oddy Test Metal Coupons, Copper:**
   
   A. After opening the image file, under Adjust, select Best Fit. If only qualitative assessment is desired, it can be done after this step (Fig. 12).
B. **Use Smart Segmentation to develop a recipe for measuring % area covered by tarnish and corrosion products of several colors:** Create a segmentation recipe by marking the background metal versus the array of colors of corrosion products that may be present. Uncorroded areas on control coupons can be used to define the background. It will likely be necessary to zoom in to several coupons in order to identify and mark all of the corrosion products if there are several colors.

C. **Define a Region of Interest (ROI) and measure % area of a coupon colored by various tarnish and corrosion products:** Under Select, use the rectangle tool to outline coupon. When it is about the correct size, click on “enter” and it can then be resized or adjusted as needed. Coupons are often not all completely perpendicular when set down on the surface for RTI photography, so the adjustment tool in the center of the rectangle can be used to adjust the angle of the ROI as needed. When done, click outside of the ROI to set it in place. Once an ROI is defined, in Smart Segmentation, open the appropriate saved recipe, click on Count, and open the measurement table to view data. Record the resulting data, or save the data to an Excel or Txt file.

   **Note on Measurements settings:** Under Measurement Types, select (1) Object Class = Name; (2) Region: Area uncalibrated; and (3) Region: Percent Area (%). Check that the automatic “split particles” with count is turned off.

   The ROI rectangle can now by moved by clicking and dragging one at a time to each coupon, and the measurement steps above repeated, until all coupons have been measured. The angle of the ROI can be re-adjusted as necessary.

3. **Image Analysis Protocols for Oddy Metal Test Coupons, Silver:**

   A. **After opening the image file in Image-Pro Premier, Convert to gray scale:** Adjust Tab > Setting to 12 bpp Mono. Apply. If only qualitative assessment is desired, it can be done after this step (Figure 13A). It may be easier to qualitatively compare the coupons with a Pseudocolor image (Figure 13B): After converting to gray scale, while still under the Adjust tab, click on Pseudocolor. Tarnish will now appear as blue, and untarnished areas will be green. The red and yellow areas are mainly caused by light reflection from the surface.
B. **Use Smart Segmentation to develop a recipe for measuring % area covered by tarnish:** This seems to work more satisfactorily using the gray scale image rather than the pseudocolor image. Zooming in on several coupons is usually necessary in order to see and adequately mark all tarnish/corrosion product appearances. Create a segmentation recipe by marking the background (gray) and tarnish (black, but sometimes there may also be white or reddish discoloration). Uncorroded areas on control coupons can be used to define the background.

For example, in the array of coupons above, the replicate control coupons range from 0 – 4% tarnish. The coupons visually identifiable as failures can range up to 100% tarnish. Coupons that might be considered acceptable for temporary use can range between 10 – 25% tarnish. In some cases, the results can help to categorize a coupon. For example, visually it was unclear whether one material received a “pass” or a “temporary” grade; the image analysis for both coupons resulted in 3% tarnish, which would be within the scope of the controls.

C. **Define a Region of Interest (ROI) and measure % area of a coupon covered by tarnish:** Under Select, use the rectangle tool to outline coupon. When it is about the correct size, click on “enter” and it can then be resized or adjusted as needed. Coupons are often not all completely perpendicular when set down on the surface for RTI photography, so the adjustment tool in the center of the rectangle can be used to adjust the angle of the ROI as needed. When done, click outside of the ROI to set it in place. Once an ROI is defined, in Smart Segmentation, open the appropriate saved recipe, click on Count, and open the measurement table to view data. Record the resulting data, or save the data to an Excel or Txt file.

   **Note on Measurements settings:** Under Measurement Types, select (1) Object Class = Name; (2) Region: Area uncalibrated; and (3) Region: Percent Area (%). Check that the automatic “split particles” with count is turned off.

The ROI rectangle can now by moved by clicking and dragging one at a time to each coupon, and the measurement steps above repeated, until all coupons have been measured. The angle of the ROI can be re-adjusted as necessary.
Conclusions

While further research is needed regarding several issues that have already been discussed, the rapid tests appear to be successful in screening for materials that are likely to be very damaging to use in conjunction with a particular metal. They will clearly show which materials are damaging, in a 24 hour period for lead and copper, and within four days for silver. Materials that fall between “failure” and “pass” (the “temporary” category) may be more difficult to discern. Hence, this test may be best for a fast screening to eliminate materials that will definitely be damaging to a metal. Those that pass this screening could be selected for follow-up testing via other means that require more time or expensive equipment.

One difficulty is that water held at the surface of the metal (including deionized water) will tend to cause some corrosion over the time period of the test. If the test is held for the standard 24-hour period, that may show up simply as crevice corrosion around the edges of the well; if held for too long for a particular type of metal (such as four days for lead), the entire well can be covered with surface corrosion products. Hence deionized water is not a good “control” in the same way that it is with an Oddy test. Instead, the “control” is a comparison of the test wells with an area of the surrounding metal not exposed to any solutions (White et al., 2012). As a result, interpreting the results and comparing them with Oddy tests will require a difference in thinking and approach. Another issue that needs further research is how to account for the fact that some extractions appear to perform better than deionized water alone, for lead and copper. It may be that there is a qualitative difference in the type of corrosion products that appear, and the effect may differ depending on the length of time of the tests.

Additional research and experimentation could also go into testing various extraction methods found in the literature. It may be that one method may produce better results than the method we used here. In the museum environment, lead is generally used to detect the presence of organic acids, aldehyde, and acidic gases; copper the presence of chloride, oxide, and sulfur compounds; and silver the presence of sulfur compounds and carbonyl sulfides (conservation-wiki.com). An extraction strategy that best brings all of these into the solution might require a different strategy.

Extraction methods are not an issue in tests of corrosion inhibitors. Since corrosion inhibitor testing was the original application that inspired this test design (White et al., 2012) it is not surprising that we found it worked quite well for that use. The 24-hour period was sufficient, and the test allows for rapid screening of many possible inhibitors, in a variety of concentrations, and with replication. The solutions producing the best results could then be set aside for more detailed study and experimentation.

An advantage of coupling both the rapid tests and the Oddy tests with RTI is that the procedure is actually rather fast, and results in excellent permanent documentation. The RTI image can be viewed at many different light positions and enhancement conditions, to provide the best possible view of each of the corrosion wells or test coupons. The enhancement capabilities of image analysis software (such as converting to gray scale, or pseudocolor, etc.) can aid qualitative judgements, especially for examples that fall along the middle of the scale. These operations too can be accomplished very quickly.
While quantitative image analysis takes a bit more time and effort, the additional data may be useful. Adding quantitative information for area percent corrosion is often done in industry and corrosion studies (Oliveira et al., 2000; Choi and Kim 2005; Riberro et al., 2013; Feliciano et al., 2015) and has even been done for conservation applications. For example, Wang et al. (2011) used an in-house software program to calculate area % corrosion on metal films that were used in an alternative to the Oddy test. Grissom et al. (2013) used Adobe Photoshop to determine the area % of tarnish on coated silver coupons exposed to hydrogen sulfide.

The reason that the Oddy test is so popular is its ease of use. The “add-on” component here of RTI documentation provides a variety of alternative ways of viewing and comparing the test coupons, with little additional effort, especially for those laboratories already employing RTI in their routine documentation or examination work. In the same way, the additional effort required for the image analysis step is relatively minor. Yet, it can provide enhancement of qualitative comparisons, and quantitative data on area % corrosion, if desired.

Hence, the rapid test procedure, the application of RTI for viewing enhancement and permanent documentation of rapid test or Oddy test results, and image analysis of selected snapshots from the RTI Viewer all have the potential to improve conservation practice without adding undue time or cost.

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