Oddy Test Protocol at the Metropolitan Museum of Art (The Met)
Current Version: 20211201_OT. Details can be found on the AIC wiki's "Oddy test methods chart wiki"

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This method derives aspects of the protocol published by The British Museum,[1] where test tubes are fitted with silicone stoppers holding three metal coupons, and the Met's original three in one jar version,[2] where metals are hung from the rim of a beaker inside of a screw-top jar. In both cases, the corrosion states of the coupons after 28 days of aging at elevated temperatures and humidity in the presence of an unknown material are used to determine the appropriateness of a material for use in close proximity to cultural heritage materials. The Met's previous versions (20160416_OT and 20190226_OT), which are downloadable from the AIC's Oddy test wiki site, incorporated silicone stoppers or nylon coupon holders, respectively, pressed into the neck of screw-top Pyrex™ jars. We observed significant inconsistencies in stopper quality and production time, which lead us to identify replacement options.

The current version (20211201_OT), which is downloadable from the AIC's Oddy test wiki site, uses the 3D printed nylon coupon holders in tandem with reusable water-jet cut stainless steel coupon holders that fit into the neck of screw-top Pyrex™ jars. This new method retains the repeatability improvements made with method 20190226_OT and reduces long-term costs and waste. The need to use one stainless steel and one nylon holder is based on test results the can be found at this link: test results. The data shows an increased sensitivity to sulfides of the silver coupon when using the nylon holder relative to the stainless steel holder. The nylon holders remain available for purchase on Shapeways for those using the Oddy test to evaluate materials intended for use with silver collections. Using one stainless steel and one nylon holder is recommended due to the increased sensitivity of sulfide detection on the silver with nylon holders and the reusability of the stainless steel holders. The Met is working on a reusable holder that does not react with sulfides.

This document includes written instructions and links to video demonstrations of the method. Each change has been labeled as a new version of the test using the following format YEARMODA_OT indicating the year (YEAR), month (MO), and date (DA) the modification was implemented. A list of versions correlating to results being published on the AIC Oddy Test wiki site is available here.

Note: The text contains multiple 'how to' videos demonstrating implementation of various protocol steps

Outline:

[1]Korenberg, C., Keable, M., Phippard, J., Doyle, A. "Refinements Introduced in the Oddy Test Methodology", Studies in Conservation, (August 2017), online article, 1-12.
[2]Bamberger, J. A., Howe, E. G., Wheeler, G., A Variant Oddy Test Procedure for Evaluating Materials Used in Storage and Display Cases, *Studies in Conservation* 44 (1999) 86-90.

[1]Korenberg, C., Keable, M., Phippard, J., Doyle, A. "Refinements Introduced in the Oddy Test Methodology", Studies in Conservation, (August 2017), online article, 1-12.
[2]Bamberger, J. A., Howe, E. G., Wheeler, G., A Variant Oddy Test Procedure for Evaluating Materials Used in Storage and Display Cases, *Studies in Conservation* 44 (1999) 86-90.

I. Personal Protection Equipment (PPE): Nitrile gloves, safety glasses, and a laboratory coat are worn throughout this procedure. Hands are washed with soap and warm water prior to donning gloves to remove oils. Care is taken to always handle the metal coupons (copper [Cu], lead [Pb], or silver [Ag]) with tweezers while wearing clean nitrile gloves, as handling coupons with dirty or oily hands can cause coupon contamination. Out of a small range of gloves, Freeform® SE blue powder-free nitrile gloves performed best in the Met's Oddy test and are worn throughout the procedure.

II. Washing Methods: Outlined below are two different washing methods. The hand washing method was used April 2016 to July 2017. The dishwasher method began in July 2017 and is our current washing method. If you are running hundreds of tests a year, the dishwasher method (section II.A.) can reduce labor costs. The alternative is to hand wash all supplies. Hand washing is an acceptable alternative to the dishwasher method and is described in section II.B. below.

Reuse of test components: New components are always washed before using. New stainless steel holders should be hand washed with Micro-90 Lab Cleaner following the Hand Washing Method before using the first time. Subsequently either the Hand Washing Method or the Dishwasher Method is acceptable. Used components are not always reused. Lids, nylon holders, and o-rings from permanent test jars and lids from temporary test jars can be reused. Lids, nylon holders and o-rings from unsuitable test jars are NOT reused. Nylon holders and O-rings from temporary and unsuitable test jars are NOT reused Lids from temporary test jars are tracked and when a lid has been in a temporary test more than four times, it is no longer reused. Once washed, stainless steel holders can be reused regardless of prior test results. These practices were established to avoid contamination from one test to another. All used materials are separated by type and test result and are saved for potential future use if it is established that cross contamination is not an issue.

A) Dishwasher Method Used June 6, 2017-current (method 20170606_OT)
Using Lancer 815 LX Dishwasher

Glassware: Mechanically remove all materials from jar. Place each jar over a spindle jet. The wash cycle includes the following steps:

Prewash	Rinse for 2 min.* with 60°C water
Wash (base)	Rinse with 96 mL of NaOH in 12 L of water at 40°C for 2 min.*
Rinse A	Rinse for 2 min. with unheated water.
Acid Rinse	Rinse with 96 mL of Phosphoric Acid in 12 L of unheated water for 2 min.
Rinse B	Rinse for 3 min. with unheated water.
Rinse C	Rinse for 3 min. with unheated water.
Purified Water Rinse A	Rinse for 3 min. with unheated 15 MΩ-deionized water.
Purified Water Rinse B	Rinse for 1 min.* with 60°C 15 MΩ-deionized water.

*When water is being heated, it is recycled within the chamber until it reaches temperature making the times listed much shorter than the actual cycle time. After the washer reaches the prescribed temperature, it runs for the programmed amount of time. The full wash cycle requires approximately 1.75 hours. Detergents are not currently used, however, testing is underway to determine if their use improves consistency of results.

Washed glassware placed in a 60°C oven for drying and storage.

Viton™ o-rings, stainless steel/nylon coupon holders, and lids: Place on flat stainless steel mesh rack. Lids are placed upright with threads facing downward and are weighted with a stainless steel mesh screen to inhibit flipping. The wash cycle includes the following steps:

Prewash	Rinse for 2 min.* with 80°C water
Rinse A	Rinse for 5 min. with unheated water.

Rinse B	Rinse for 1 min.* with 80°C water.
Purified Water Rinse A	Rinse for 1 min. with unheated 15 MΩ-deionized water.
Purified Water Rinse B	Rinse for 1 min.* with 60°C 15 MΩ-deionized water.

*When water is being heated, it is recycled within the chamber until it reaches temperature making the times listed much shorter than the actual cycle time. After the washer reaches the prescribed temperature, it runs for the programmed amount of time. The full wash cycle requires approximately 2.5 hours. Detergents are not currently used, however, testing is underway to determine if their use improves consistency of results.

Washed Viton™ o-rings, stainless steel coupon holders, and lids are dried in a 60°C oven. Once dry, they are removed and stored in clean glass beakers.

Vials: KIMAX™ vials are washed by hand.

1. Place dirty vials in a 50 mL Pyrex® beaker, and use a disposable glass pipet to deliver solutions into the vials. Soak vials with Micro 90 Lab cleaner for at least 24 hours (1% solution in tap water). Rinse 3 times with tap water. Soak in room temperature aqueous sodium hydroxide (NaOH) bath with a pH of 12 for at least 15 hours (overnight). Use 10" stainless steel tongs for delivering and retrieving items from the baths. Thick nitrile gloves, safety glasses, and a laboratory coat are required.
    a. **Base bath preparation (yields 0.5 L)**: Add 20 g KOH(s) to 250 mL of deionized H_2O in a 1000 mL beaker with watch glass cover in a ventilated hood with stirring. Once cooled to room temperature, add 230 mL of isopropanol (technical grade is sufficient). Check that the pH reads 12 on the pH indicator strip. Transfer the base bath to a lidded ~500 mL polyethylene or polypropylene container. Keep and use base bath in a secondary lidded polypropylene 12 quart container that's set in a polypropylene drip tray.
2. Rinse with hot tap water then place in a hydrochloric acid (HCl) bath with a pH of 2 for at least 15 hours (overnight). Thick nitrile gloves, safety glasses, and a laboratory coat are required.
    a. **Acid bath preparation (yields 500 mL)**: Slowly add 50 mL HCl (37% w/w; 1.2 g/mL density) to 450 mL of deionized H_2O. Check that the pH reads 2 on the pH indicator strip. Store and use the acid bath in a glass beaker contained in a lidded polypropylene 12 quart container within a secondary polypropylene drip tray.
    b. Rinse three times with hot tap water then rinse three times with 18.2 mΩ-deionized water.
    c. Dry and store in an oven, right side up, at 60°C.

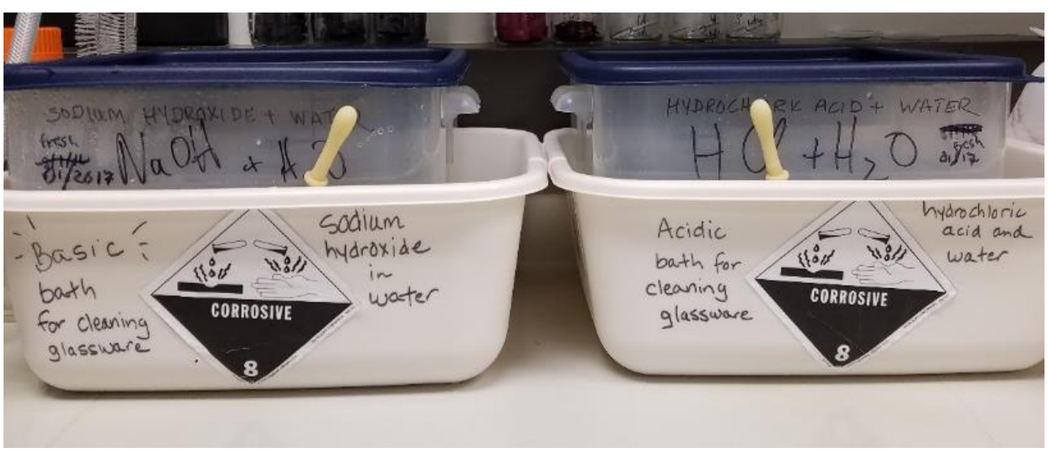


Figure 1: Base and acid baths in secondary containers.

B) Hand-washing Method Used April 2016-May 2017 (method 20160416_OT)

Glassware Preparation:

1. Wash with Micro-90 Lab Cleaner (1% solution in tap water) using a laboratory cleaning brush and tap water.
2. Rinse 3 times with hot tap water.
3. Soak in room temperature aqueous sodium hydroxide (NaOH) bath with a pH of 12 for at least 15 hours (overnight). Use pipets to deliver the solutions into the small vials. Use 10" stainless steel tongs for delivering and retrieving items from the baths. Thick nitrile gloves, safety glasses, and a laboratory coat are required.
    a. **Base bath preparation (yields 7 L)**: Add 3.0 g NaOH (s) to 7.5 L of deionized H_2O. Check that the pH reads 12 on the pH indicator strip. The base bath is contained in a lidded polypropylene 12 quart container within a secondary polypropylene drip container.
4. Rinse with hot tap water then place in a hydrochloric acid (HCl) bath with a pH of 2 for at least 15 hours (overnight). Thick nitrile gloves, safety glasses, and a laboratory coat are required.
    a. **Acid bath preparation (yields 7 L)**: Slowly add ~6 mL HCl (37% w/w; 1.2 g/mL density) to 2 L of deionized H_2O. Add the remaining 5 L of deionized H_2O. Check that the pH reads 2 on the pH indicator strip. The acid bath is contained in a lidded polypropylene 12 quart container within a secondary polypropylene drip container.
5. Rinse three times with hot tap water then rinse three times with 18.2 mΩ-deionized water
6. Dry in an oven, right side up, at 60°C.

Viton™ o-rings, stainless steel holders, and lids:

1. Wash Viton™ o-rings, stainless steel holders, and lids in a Micro-90 Lab Cleaner solution (1% in tap water) by dipping in cleaning solution and rubbing with gloved hands or a clean sponge. Do NOT soak for any length of time in Micro-90 Lab Cleaner solution.
2. Rinse 3 times with hot tap water and 3 times with 18.2 MΩ-deionized water.
3. Store in oven at 60°C.

KIMAX™ Vials: Same as instructions outlined in the dishwashing method section II-A above.

III. Metal Coupon Preparation

1. Measure and cut high purity (99.998% or higher) metals (Ag, and Cu) into coupons measuring 0.8 cm x 2.5 cm. Cut Pb into strips that are 10 cm long by 0.8(x) cm wide, with x being the number of skinny strips you want. Each skinny strip yields 4 coupons. Cutting large strips of lead before sanding and then cutting them down after sanding makes the sanding process quicker and more efficient.
    a. Use a dedicated pair of scissors for each metal.
    b. An in-contact variant of this test is used to assess materials that are expected to be in physical contact with the art. The in-contact test can be run on its own without hanging materials or in addition to the standard protocol in the same jars as the hanging coupons. For the in-contact version, measure and cut the Ag and Cu into 0.8

x 1.25 cm coupons. These in-contact coupons are half the size of the standard ones. Cut the Pb into 10 cm long by 0.8(x) cm wide, with x being the number of skinny strips needed. Each skinny strip yields 8 coupons. Continue with the same sanding and washing techniques as the standard protocol.

2. Copper and Silver Coupon Preparation: Soak copper and silver coupons in a small beaker of acetone and wipe dry with a Kimwipe®. Next, soak the coupons in fresh HPLC grade isopropanol. Remove from beaker and wipe dry with a Kimwipe®. (Click here for video). Collect rinse solutions and disposed of as hazardous waste.
3. Lead Coupon Preparation: Place a 12 inch by 12ch in flat glass plate inside the filtration box, and place the un-sanded 10 cm by 0.8 cm lead strips on top of the glass plate. The strips should be made as flat as possible before sanding. The metal is very soft and flexible, so it folds and creases easily. Any folds or creases will make it more difficult to achieve an even texture after sanding. Cut a 2 in square piece of 3200 grit Micromesh™ sandpaper, and fold it in half twice so that it forms a 1 in square with grit on both sides (Figure 2). To sand, use a gloved finger hold the closer end of one lead strip. While sanding, hold the Micromesh™ between thumb and forefinger close to the fold. Sand from the center of the strip to the end away from the user using even light pressure (Click here for video). We suggest watching the video in 0.25x speed to better observe the sanding technique. Every stroke should be straight and run all the way from the middle of the strip past the far end onto the glass plate. To avoid a curved sanding motion, use your entire arm, not just the wrist, to create straight strokes (Figure 3). Avoid using the tip of the thumb or pressing part of the thumbnail into the Micromesh™. Change the position of the Micromesh™ every 15-20 strokes to an unused portion of the Micromesh™. Figure 4 shows examples of correct and incorrect contact. Correct contact results in thin lines of lead being transferred to the Micromesh™ (left side of Figure 4). The right side of Figure 4 shows a situation where the user's fingers are not close enough to the fold in the sandpaper, and too much contact occurred during each stroke. Practicing the movement on the glass plate before sanding the lead is recommended. Approximately 45 strokes will properly sand a single section of lead. Once the first section is sanded, rotate the strip 180 degrees and sand the second half of the same side, then flip the strip over and sand the other side using the same technique.

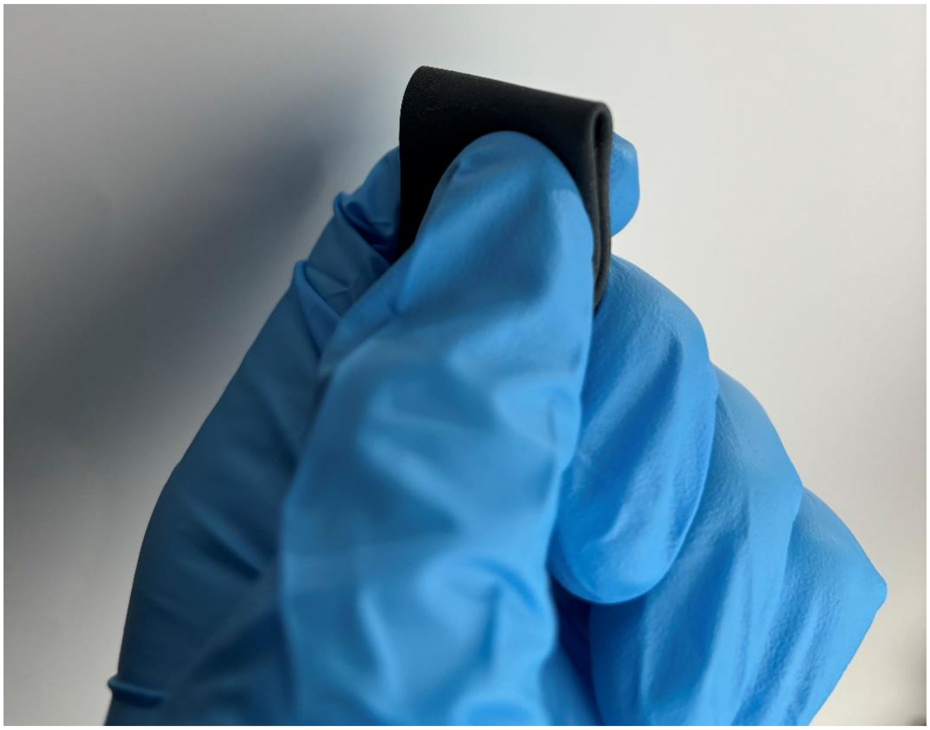


Figure 2: how to properly fold and hold the sandpaper. Thumb and forefinger as close to the fold as possible without touching the lead during sanding.

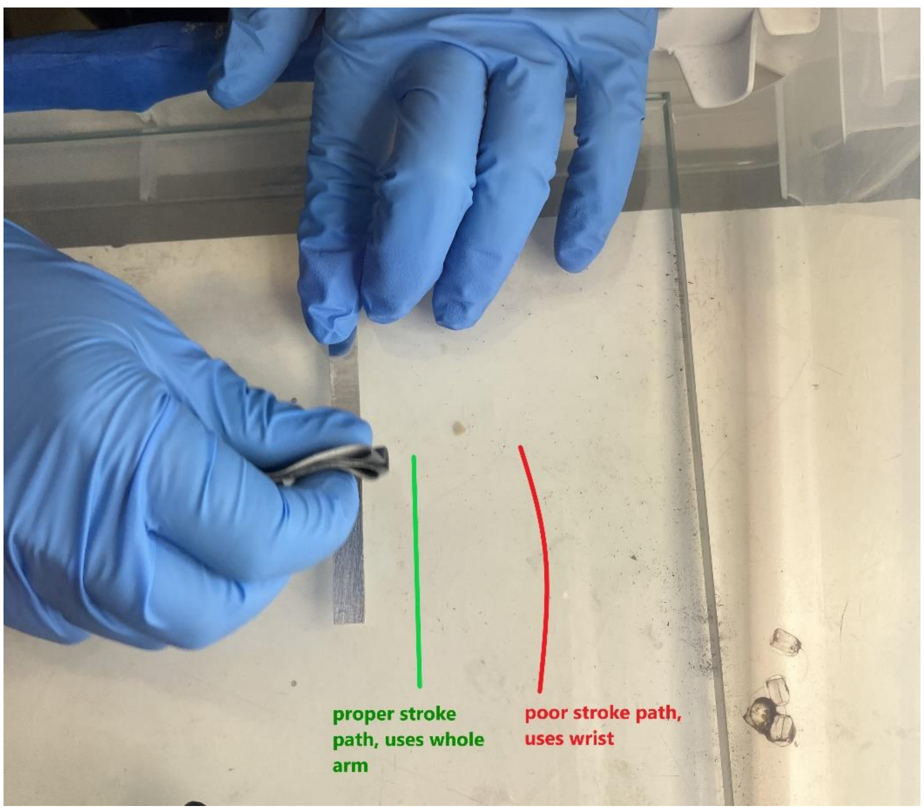


Figure 3: Left: straight stroke path that uses the whole arm for the movement. Right: improper stroke path that uses only the wrist for the movement.

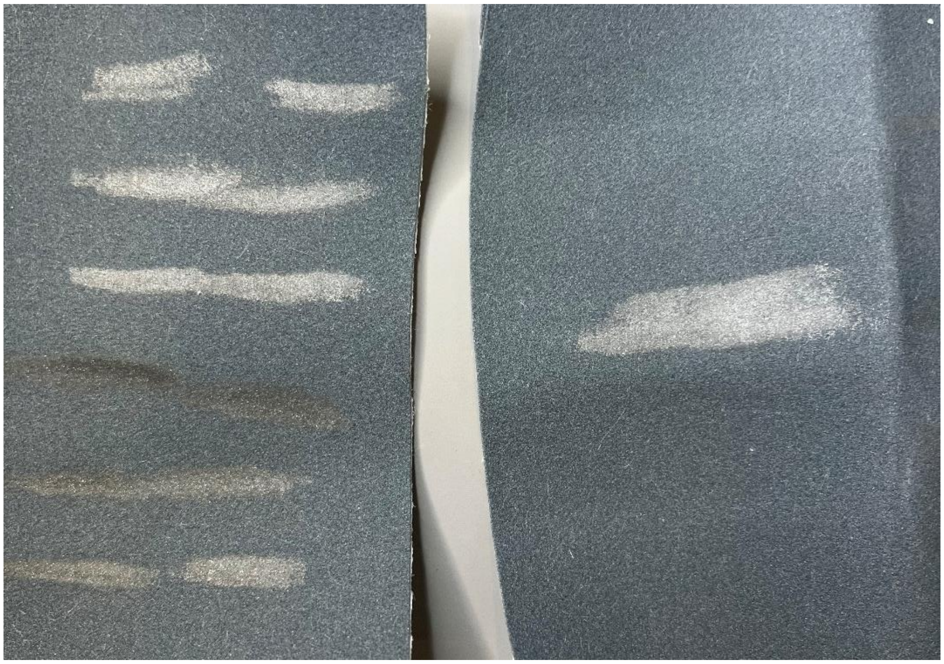
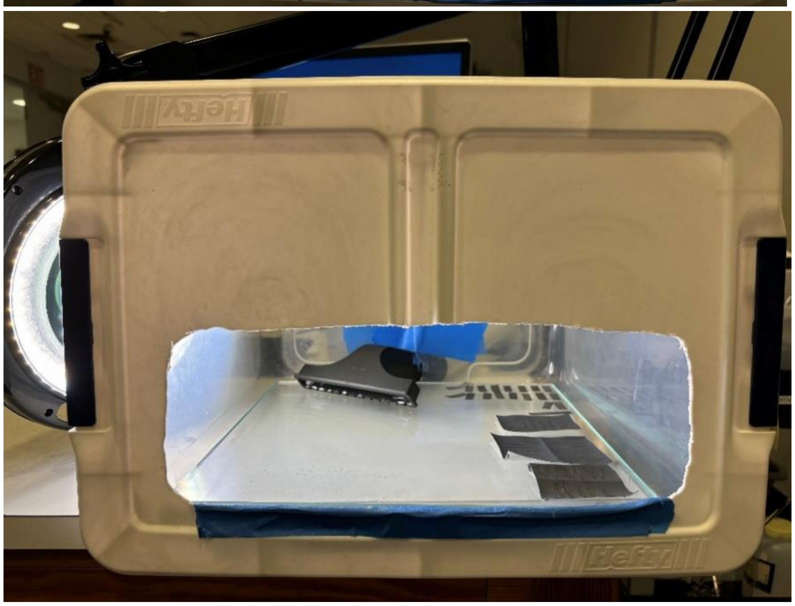


Figure 4: Left: lead residue on sandpaper after using proper sanding technique. Each mark represents ~10-15 strokes of sanding, one on the left and right in 6 different locations on the sandpaper. A correct, small/thin surface area in contact with the lead coupon is shown. Right: lead residue after improper sanding technique. Too large of a surface area in contact with the lead coupon.

a. If the lead strip elongates or stretches longer than 10 cm, too much pressure is being applied while sanding. The goal is to remove the native oxide, leaving a surface with uniform roughness, applying minimal pressure. Hanging large images of over-sanded and correctly sanded lead coupons in the preparation area is recommended for reference. A correctly sanded lead coupon is lighter in shade than the un-sanded lead and has a consistent overall texture with no shiny/reflective patches. See Figures 7, 8, and 9 below for examples of properly sanded lead, spotty under-sanded, and shiny over-sanded lead. The sanding process is completed in a homemade 'filtration box' with ULPA filtered vacuum pulling air out of the back of the box (Figures 5 and 6). Vacuuming may not be necessary, as we have measured and not found a difference between the particulate levels at the face of the box and the surrounding air.



Figures 5 & 6: Top: Top view of filtration box with glass top for viewing and glancing angle light to the left. Bottom: Front view of the filtration box, showing the filtered vacuum that pulls air from the back of the box.

b. Sand lead coupons just before inserting into jars to minimize re-oxidation.

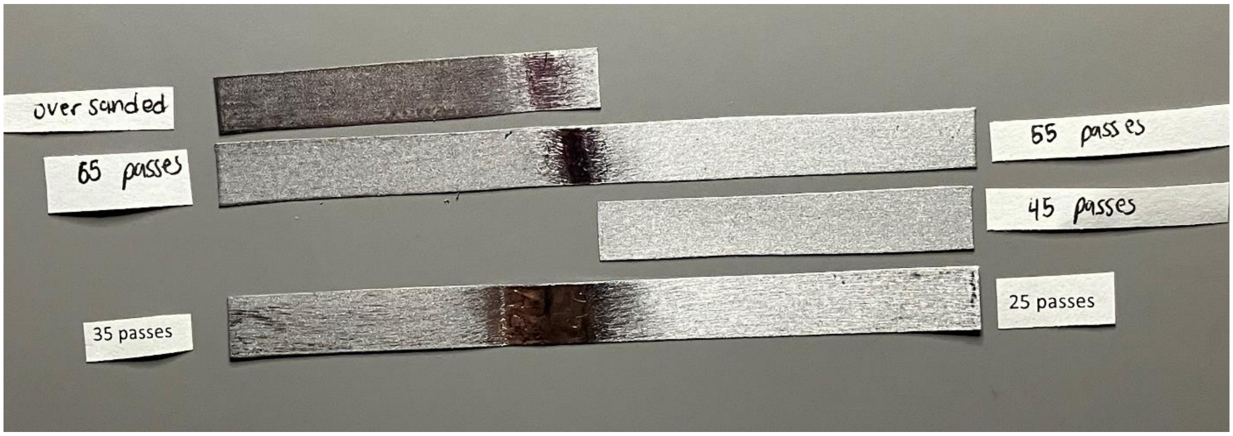
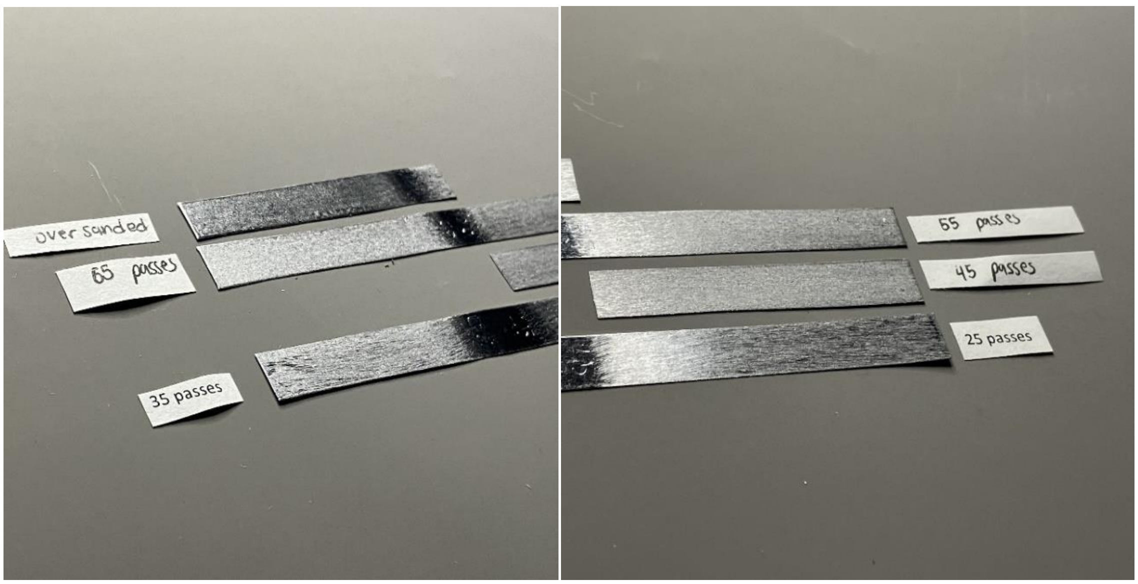


Figure 7: Over-sanded lead coupons, properly sanded lead coupons (45-55 passes), and under-sanded lead coupons (25-35 passes).



Figures 8 & 9: Left: Detail of lead coupons that were over-sanded, sanded with 65 passes (OK), and 35 passes (under-sanded). Right: Detail of lead coupons that were sanded with 55 passes (OK), 45 passes (OK) and 25 passes (under-sanded).

4. After sanding 10 cm long lead strips, rinse each side with a Kimwipe® dipped in acetone. Repeat until the Kimwipe® wipes clean. Next dip a Kimwipe® in isopropanol and wipe each side of the lead strip. Repeat. (Click here for video). Cut the large lead strip into skinny 0.8 cm x 10 cm strips. Cut each 0.8 cm lead strip into four 0.8 cm x 2.5 cm coupons.

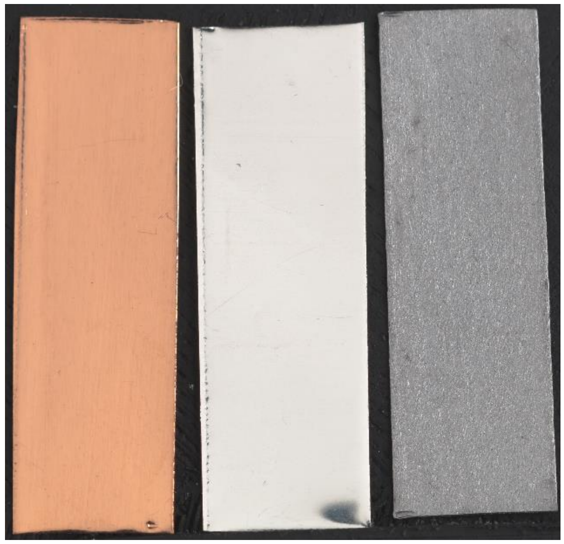


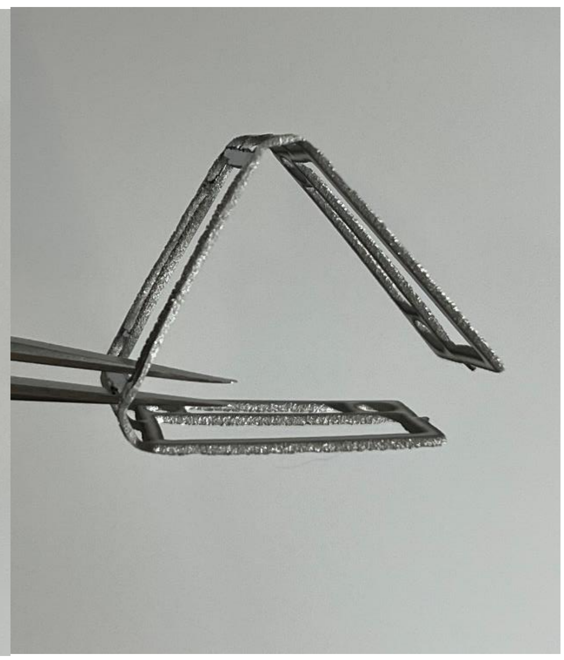
Figure 10: Freshly cut and sanded (lead only) metal coupons.

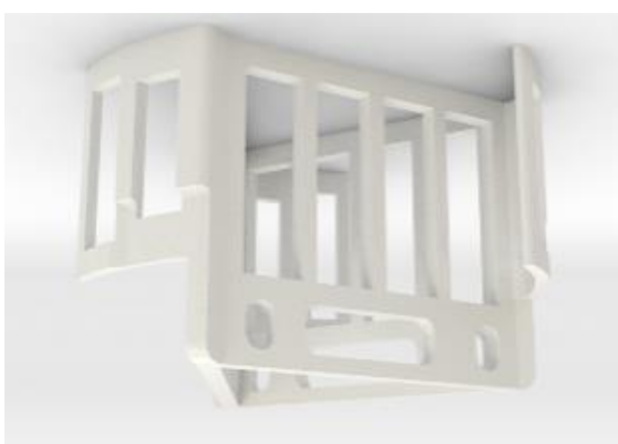
5. After polishing and rinsing, dispose of Kimwipe®, Pb-contaminated gloves, and sandpaper as lead-contaminated hazardous waste. After the coupons have dried, press the coupons flat using two blocks of polished flat stainless steel or glass.
6. All metals are stored immediately upon receipt from the supplier within at least one Corrosion Intercept® Ziploc®-style bag. Before being placed in Corrosion Intercept® bags, the manufacturer's packaging for Copper and Silver are removed and disposed of. The plastic box that the Lead is received in is kept and the rest of the packaging is removed and disposed of. Ideally both sides of the bag are composed of the Intercept material rather than using the style with a transparent window. The lot numbers and Month/Year that the metals were received (found in the packing slip) in are recorded on the Corrosion Intercept® bags.

IV. Jar preparation and assembly

1. Run all tests in duplicate, including controls. Produce one set of controls for each group of tests. In other words, if 15 materials are being tested on Monday, one set of controls is required. A new set of controls is required for the next group of Oddy tests that are prepared on Tuesday.
    a. A best practice but not a requirement is to make one jar out of all new supplies. Used supplies according to the Note in section 2 above are used to make the 2nd jar. o-rings with new or unmarked (permanent) lids for the first jar of each material (this jar is marked A) and permanent o-rings with lids with a history of 'Temporary' results on the second jar of each material (this jar is marked B). Nylon holders should be placed in Jar A with new components and SS holders should be placed in Jar B with 'Temporary' components.
2.
3. To prepare one jar, place a sheet of weighing paper on the scale and tare to zero. Weigh 2g of test sample material on the paper and load into a 100 mL borosilicate jar (Kimble™ KIMAX™ GL 45 Media/Storage Bottles, Product # 02-542A, 100mL) along with a borosilicate mini-test tube (Kimble™ KIMAX™ Reusable Borosilicate Glass Tubes with Plain End, Product #14-925B, 0.7mL) containing 0.5mL 18.2 MΩ-deionized water. Dose 18.2 MΩ water into the mini-test tube using a recently calibrated micropipette.
    a. See Section VIII for a sample preparation guide.
    b. Each control jar contains 0.5 mL of water in the KIMAX™ test tube as well as the metal coupons folded over a coupon holder. No other material is placed in the jar.

4. To a pre-washed stainless steel coupon holder, attach the metal coupons by bending the coupon 5-7 mm from one end and crimping it onto the holder (see Figures 14 and 15). Repeat this step with nylon holders. Insert the coupon holder into the mouth of the jar.
    a. Make sure coupons do not contact each other, the jar, or test material.
    b. For the in-contact variant, using tweezers, on each coupon fold over a 1-2 mm of one corner. Make sure that the test material in the jar lays as flat as possible and place a Cu, Ag, and Pb coupon on top of the material so that the folded triangle flap of each coupon faces up toward the mouth of the jar and the smooth side of the coupons is facing down toward the bottom of the jar. Place the coupons so that smooth side is fully in contact with the sample material and none of the coupons are touching each other or the glass sides of the jar. In control jars, place the coupons on the bottom of the jar in the same orientation as sample jars.





Figures 11, 12, & 13: the triangle configured water-jet cut stainless steel holder from the side (left) and the top (right). Shapeways laser sintered nylon coupon holder (bottom).

5. Insert a Viton o-ring into each lid and lightly screw the lids onto the jars. Tighten lids to a torque of 4 Nm using a torque wrench fitted with the custom socket.

Figures 14 & 15: Left: crimping the Cu coupon onto the holder using tweezers. Right: A coupon holder with Cu, Ag, and Pb coupons attached.

Figures 16, 17, & 19: Left: a coupon holder placed in the neck of a sample jar. Center and Right: A sealed sample jar with hanger, coupons, test material, water and vial.

6. Weigh jars and record values.
7. Place jars in oven leaving as much space between jars as possible for air circulation, with the jars standing upright.

Figures20 & 21: 3D printed torque wrench socket produced to fit GL45 cap and CDI 1502MRMH-QR torque wrench (2.8-16.4 Nm range) used for tightening lids consistently.

8. Leave jars in oven at 60°C for 60 minutes. Remove jars and re-tighten lids to a torque of 4 Nm while warm using a torque wrench fitted with the custom socket.
9. Return jars to the oven and age at 60 ± 1.5 °C for 28 days.

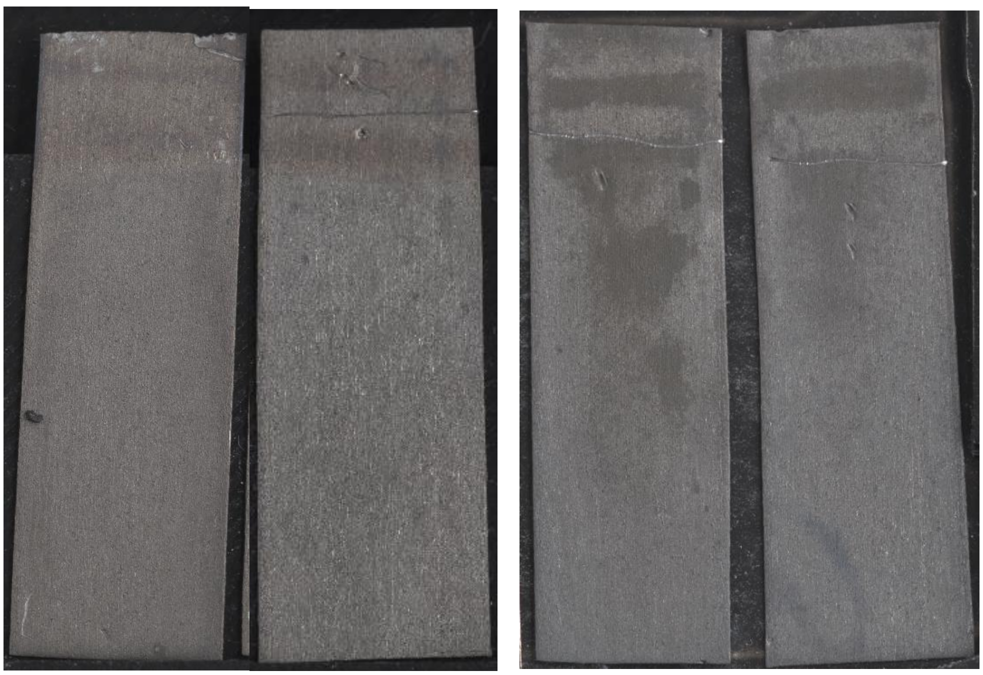
V. Assessment at completion of testing

After 28 days in the oven, remove jars from oven, and allow to cool to room temperature.

2. Record weights of each jar. Compare to the pre-aged weights to determine whether each vessel was sealed during the experiment. A loss greater than 25% of the water mass (25% of 0.5 grams, or a loss of more than 0.13 grams) is considered a system failure, and the experiment is repeated. If both jars were correctly tightened and both lose more than 0.13 grams in similar amounts, this is not considered a failure, as we suspect that the materials in these cases are pressurizing the jars and helping to push volatiles and water past the seals.
3. Open jars and lift the coupon holders out of the jars. Remove coupons from the coupon holders using tweezers.
4. Unfold the coupon where it was crimped over the coupon holder. Scribe the inside of each coupon across the width of the coupon where it met with the holder using a dissection needle. Press the coupons flat using two blocks of polished flat stainless steel, aluminum, or glass. Place the coupons on a fresh piece of aluminum foil or petri dish.
5. Inscribe the letter “C” in the portion of the control coupons that were folded over to avoid mixing samples during coupon evaluation. Assess the controls for corrosion. If they are minimally corroded, proceed. If the coupon corrosion of a given metal in one jar is significantly different from that in the other or if there is significant corrosion, repeat the experiment.

6. Using a spatula, remove the o-ring from the lid. Save and wash o-rings from ‘Permanent’ test jars. Consider sorting and saving ‘Temporary’ and ‘Unsuitable’ o-rings and coupon holders. Also consider sorting out ‘Unsuitable’ lids. It may be that with proper treatment, they can be safely reused. The Met is currently not reusing temporary or unsuitable o-rings and coupon holders, and not reusing unsuitable lids. A line is scratched on the top of lids from jars with a ‘Temporary’ result, and lids with more than 3 lines are no longer used. Lids, nylon hangers, and o-rings from ‘Permanent’ jars are left unmarked and are reused. Used o-rings (Permanent, Temporary, and Unsuitable) o-rings are bagged separately. After accumulating ~50 Permanent O-rings, they are washed and reused.

Lead



Figures 22 & 23: Left: acceptable amount\ of minimal corrosion for control. Right: too much corrosion, observed as darkening, for control.

Copper


Figures 24 & 25 Left: acceptable amount of minimal corrosion for control. Right: too much corrosion, observed as reddening, for control.

Silver


Figures 26 & 27: Left: acceptable amount of minimal corrosion for control. Right: too much corrosion, observed as yellowing, for control. Note: silver control coupons rarely show corrosion.

7. The following ratings are used to assess non-control coupons:
    a. <u>"Permanent" rating</u>: The material tested may be used indefinitely in the presence of art.

        i. Coupons look similar to the controls.
        ii. For silver, remnants of polishing compounds from some manufacturers can develop or appear as white splotches. This stock is generally returned to the manufacturer, however, if it makes it into a test, the white splotches are ignored.
    b. <u>"Temporary" rating</u>: The material is safe for use near but not in contact with art for up to six months.
        i. Copper: Slight reddening, yellowing, or rainbow-like color change
        ii. Silver: Slight yellowing, purpling, or darkening, development of a white/orange haze.
        iii. Lead: Darkening, yellow/olive tarnish, haze from slight crystal formation over the entire coupon, or heavier crystal formation at the interface with the coupon holder.
    c. <u>"Unsuitable" rating</u>: The material should not be used in contact with or near art and another material should be found.
        i. Copper: Severe blackening or matte-textured surface.
        ii. Silver: Severe color change to dark purple, yellow, or black.
        iii. Lead: White fluffy crystal formation.

8. Photos of scored coupons from permanent, temporary, and unsuitable categories and commonly observed corrosion can be downloaded from the following links: Copper Corrosion Library, Silver Corrosion Library, and Lead Corrosion Library

VI. Photographing Oddy Test Coupons

After being evaluated, Oddy test coupons with matching duplicate results and passing control jars are photographed using two different types of lighting: diffuse lighting using a Rosco LitePad HO90 12"x12" (figure 17), and glancing-angle lighting using a Cree XLamp CXA3050 LED with a Mean Well HLG-100H-36A power supply (figure 18). The diffuse lighting allows for proper color representation in the photograph. Glancing-angle lighting allows for the representation of surface texture in the photograph. Coupons are placed on an angled stage in between the Rosco LitePad and the white piece of paper board used to diffuse light. A photograph is taken using the diffuse lighting and another one is taken using the glancing-angle lighting. Photographs are color-corrected and processed in Lightroom.

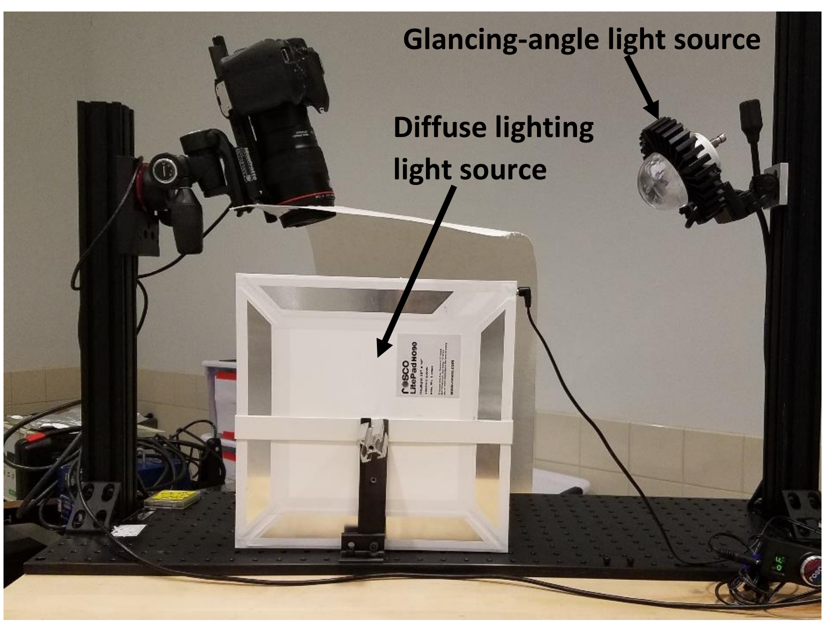


Figure 28: image of the photo stand and its two separate light sources—glancing-angle and diffuse lighting.

Figure 29: image of the coupon stage bolted down on the photo stand. The stage is in between the Rosco LitePad LED and the paper board used to diffuse the lighting.

Diffuse Light: Below are photographs of the coupon photographing stage from various angles lit with the Rosco LitePad LED.

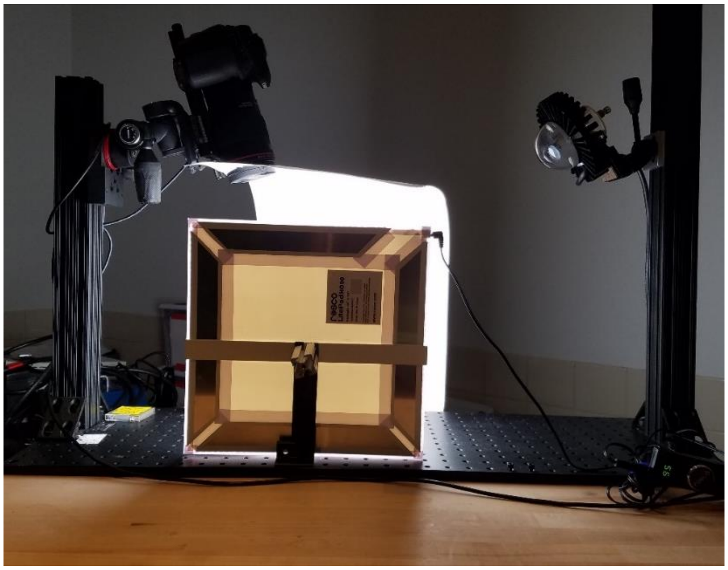


Figure 32: image of the photo stand from behind the Rosco LitePad LED with side angle lighting

Figure 33: image of the photo stand from in front of the camera with side angle lighting

Figure 34: image of the photo stand from the right side of the camera with side angle lighting

Figure 35: image of the photo stand from the left side of the camera with side angle lighting

Glancing-Angle Light: Below are photographs of the coupon photographing stage from various angles lit with the glancing-angle LED light.

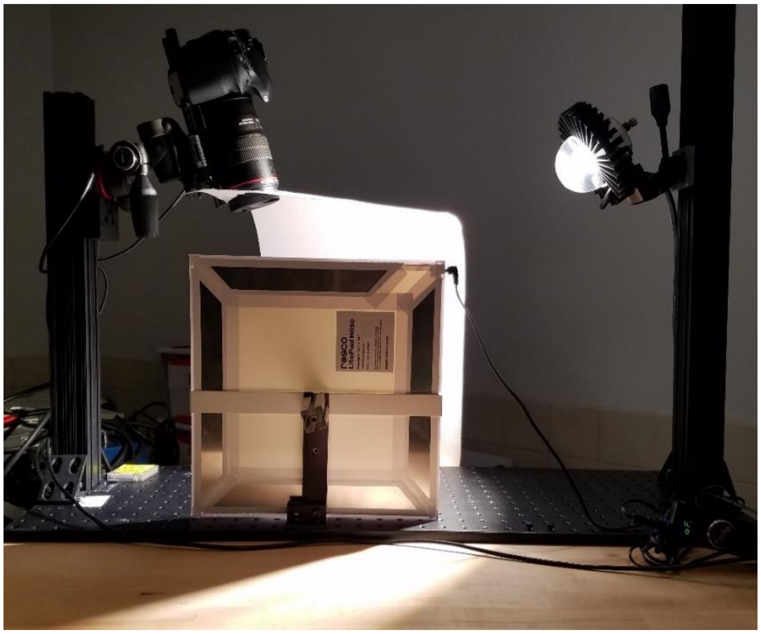


Figure 36: image of the photo stand from behind the Rosco LitePad LED with glancing angle lighting

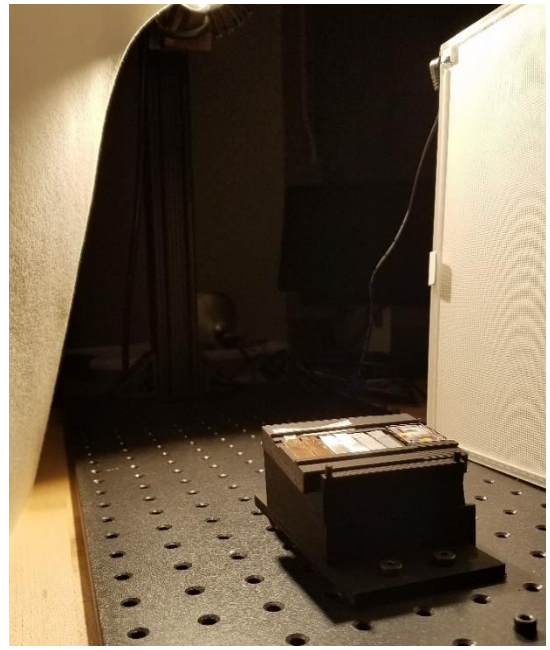


Figure 37: image of the photo stand from in front of the camera with glancing angle lighting

Figure 38: image of the photo stand from in front of the camera with glancing angle lighting

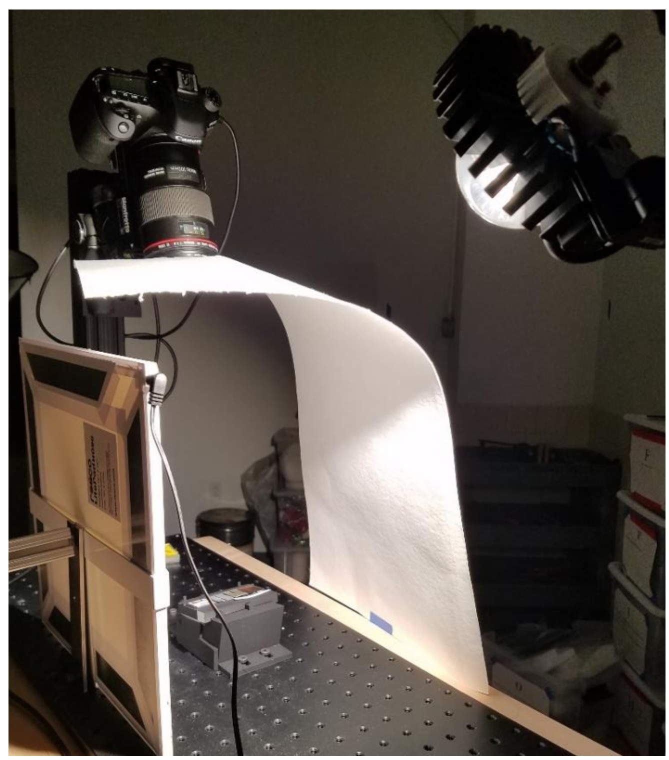


Figure 39: image of the photo stand from the left of the glancing angle light with the light on

VII. Materials and Supplies

- Deionized H_2O (18.2 MΩ) (Millipore Direct 8Water Purification System)
- Freeform® SE blue powder-free examination gloves (Microflex Product FFS-700-S)
    - https://microflexpublic-ansellhealthcare.msappproxy.net/Products/FFS-700.aspx
- Micro-90 Concentrated Lab Cleaner Detergent (Sigma Product # Z281506-1EA)
    - http://www.sigmaaldrich.com/catalog/product/aldrich/z281506?lang=en&region=US
- Shapeways laser sintered nylon coupon holder
    - https://www.shapeways.com/product/62958LYNJ/oddy-test-hanger-triangular?optionId=64267957
- Water-jet stainless steel coupon holders – 'Met Oddy part' in 0.5mm 316 stainless steel
    - Order from Peter Hotkowski of Asterisk Incorporated, 50-3 River Street, Old Saybrook CT 0647, 860-388-3811, peteh@asteriskinc.com
- Kimble™ KIMAX™ GL 45 Media/Storage Bottles (Product # 02-542A) 100mL
    - https://www.fishersci.com/shop/products/kimax-gl-45-media-storage-bottles-15/02542a
- Extra caps: Kimble™ Blue Polypropylene Cap (Product # 02-542-1)
    - https://www.fishersci.com/shop/products/kimble-blue-polypropylene-cap/025421#?keyword=14395c45
- Viton™ o-ring; size 323; Product #V75323; 75 durometer black
    - https://www.globaloring.com/product/v75323/
- Kimble™ KIMAX™ Reusable Borosilicate Glass Tubes with Plain End (Product #14-925B) 0.7mL
    - https://www.fishersci.com/shop/products/kimble-kimax-reusable-borosilicate-glass-tubes-plain-end-17/14925b?searchHijack=true&searchTerm=14925B&searchType=RAPID
- Spatula & Packer Double Ended - SurgicalExcel 81-12191
    - https://www.amazon.com/gp/product/B00HMI3PSM/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1
- Shapeways Oddy Torque_8 Socket
    - https://www.shapeways.com/product/Y5CM86ZA6/oddy-torque-8-socket?key=af3fae4ea2c3226c7951811bd45c0e89&li=shop-inventory
- CDI 1502MRMH-QR torque wrench (2.8-16.4 Nm range)
- Accupet 500-5000 ul Micropipette (Product #AP-5000)5 mL bulk Eppendorf-fit reference tips
    - http://ssibio.com/tips/specialty-tips/macro-volume-tips/4420-00-detail
- MYLAR® A 1 mil (25 micron)
    - http://www.tekra.com/products/films/polyester-films/polyester-pet/mylar
- EMD Millipore 109535 MColorpHast™ pH-indicator strips (non-bleeding), pH 0-14
    - https://www.emdmillipore.com/US/en/product/Papel-pH-1-14%2C0-pH-caixa-com-100-tiras%2C-menor-divis%C3%A3o-1%2C0,MDA_CHEM-109535
- 10" Stainless Steel Tongs
    - https://www.amazon.com/Surgical-Stainless-Steel-Tongs-Inch/dp/B0015AK5JK
- Wooden handled straight point teasing needle, Part Number: 19010. Referred to as dissection needle in text.
    - https://www.fishersci.com/shop/products/shandon-straight-point-teasing-needles/19010#
- Lancer 815 LX Dishwasher
    - http://www.lancer.com/Products/Laboratory/Glassware-Washer-Dryers/-Lancer-Undercounter-Laboratory-Washers/815LXOverview

- Custom Stainless Steel Mesh Screen used to hold down lids: Material: ROUND HOLE STAINLESS PERFORATED SHEET 304 (Part#: 13523); Dimensions: 17.1” x 18.1”
  - https://www.onlinemetals.com
- LancerClean Sodium Hydroxide (NaOH) Detergent – LCD-S
  - http://www.lancer.com/Products/Consumables/Cleaning-Chemicals/LancerCleanDetergent#5574-product-features
- LancerAcid Phosphoric Acid Rinse – LCA-P
  - http://www.lancer.com/Products/Consumables/Cleaning-Chemicals/LancerAcidRinse

Metal Preparation Material

- Micro Mesh Regular 3200
  - http://micro-surface.com/index.php/products-by-type/rolls/micro-mesh-rolls.html
- Acetone HPLC grade
  - https://www.fishersci.com/shop/products/acetone-hplc-fisher-chemical-6/p-215618
- Isopropanol HPLC grade
  - https://www.fishersci.com/shop/products/isopropanol-99-9-hplc-grade-fisher-bioreagents/bp26324#?keyword=isopropanol+%28hplc%29
- Metal Coupons (99.998% Purity) - Alfa Aesar (Pb, Cu) and Fine Metals Corp. (Ag)
  - Pb : Alfa Aesar™ Lead foil, 0.1mm (0.004 in.) thick, Puratronic™, 99.998% (metals basis)
    - https://www.fishersci.com/shop/products/lead-foil-0-1mm-0-004-in-thick-puratronic-99-998-metals-basis-2/aa12051gh?searchHijack=true&searchTerm=AA12051GH&searchType=RAPID
  - Cu : Copper foil, 99.999% (metals basis), unannealed 0.1 mm x 100 mm x 100 mm; Fine Metals Corporation
    - https://finemetalscorp.com/product/copper-foil/
  - Ag : Silver foil, 99.998% (metals basis), annealed, 0.1 mm x 100 mm x 100 mm; Fine Metals Corporation
    - http://www.finemetalscorp.com/View.aspx?page=metals/silver/silverfoil

Photographing Equipment

- Rosco LitePad HO90 (diffuse lighting LED)
  - http://us.rosco.com/en/product/litepad-ho90
- Cree XLamp CXA3050 LED (glancing-angle LED)
  - http://www.cree.com/led-components/products/xlamp-leds-integrated-arrays/xlamp-CXA3050/
- Mean Well HLG-100H-36A Power Supply (for glancing-angle LED)
  - https://www.mouser.com/ProductDetail/MEAN-WELL/HLG-100H-36A?qs=3IPTn0w%2F0t8eryoUyt83%2Fw%3D%3D

VIII. Oddy Test Material Sample Preparation Guide

Material	Proposed Cutting Method
Board - composite (e.g. Corian, drywall)	Cut with universal blade band saw into 0.5" cubes. Use utility knife to produce smaller pieces to make 2.0g.
Board - natural (e.g. wood, cotton)	Cut with universal blade band saw into 0.5" cubes. Use utility knife to produce smaller pieces to make 2.0g.
Board - plastic/polymeric/synthetic	Cut with universal blade band saw into 0.5" cubes. Use utility knife to produce smaller pieces to make 2.0g.
Carpet - natural/non-synthetic fiber	Cut with scissors or utility knife into 1 x 1" squares. To reach 2.0 g, cut pieces that represent the sample's composition—example: the correct ratio of carpet material, blended fibers in carpet, and base of carpet.
Carpet - plastic/polymeric/synthetic fiber	Cut with clean scissors or utility knife into 1 x 1" squares. To reach 2.0 g, cut pieces that represent the sample's composition—example: the correct ratio of carpet material, blended fibers in carpet, and base of carpet.
Coating - floor (e.g. stain, anti-wear, anti-slip)	Follow manufacturer's instructions regarding dilution; if to be used dry, paint out on Mylar® and cure per manufacturer's guidelines; if to be used wet, use 0.5mL of liquid in lieu of water.
Coating - grease, oil, wax	Into a 5mL beaker, weigh 2.0 g of sample. Carefully place into the sample jar. Other borosilicate vessels that fit are acceptable as long as they are no more than 4cm tall.
Coating - paint & primer	Paint material onto a Mylar® sheet and spread to a thickness that reflects how it will be used in the museum. Cure the material according to manufacturer's instructions. After curing, cut the painted Mylar® into 1.5" wide strips and weigh to 2.0 g, taking the weight of the Mylar® into account by subtracting it from the total sample weight. Put a small piece of Mylar® at the bottom of the jar if there's concern about the material sticking to the glass. Roll the sample strips into a coil with the sample material facing inward, and place in the bottom of the jar.
Coating - protective (e.g. anti-UV, -abrasion, -tarnish)	Paint the material onto a Mylar® sheet and spread to a thickness that reflects how it will be used in the museum. Cure the material according to manufacturer's instructions. After curing, cut the painted Mylar® into 1.5" wide strips and weigh to 2.0 g, taking the weight of the Mylar® into account by

	subtracting it from the total sample weight. Put a small piece of Mylar® at the bottom of the jar if there's concern about the material sticking to the glass. Roll the sample strips into a coil with the sample material facing inward, and place in the bottom of the jar.
Fabric - batting & padding	Cut material with clean fabric scissors into 1 x 1" squares. To reach 2.0 g, cut small segments from a 1" square.
Fabric - book cloth	Cut material with clean fabric scissors into 1 x 1" squares. To reach 2.0 g, cut small segments from a 1" square.
Fabric - exhibition/woven	Cut material with fabric scissors into 1 x 1" squares. To reach 2.0 g, cut small segments from a 1" square.
Fiber or Thread	Cut the length of sample that weighs 2.0 g. Wind it loosely and neatly around two gloved fingers, remove, and place in the bottom of the sample jar.
Inorganic - (e.g. fillers, salts, rocks)	Keep the sample as is or prepare it as it would be used in the museum. For example, if you are testing salts, do not grind them further unless that's how they are used in the museum setting. Weight 2.0 g of sample.
Metal - mechanical fastener	Place whole fastener in jar.
Paper-based (e.g. folder, cardboard, sheet)	Cut material with clean scissors into 1 x 1" squares. To reach 2.0 g, cut pieces from a 1" square.
Paper-based, Filled (e.g. fillers such as silica gel, zeolites, alumina)	Cut material with clean scissors into 1 x 1" squares. To reach 2.0 g, cut pieces from a 1" square.
Paste - filler/binder mixture (e.g. plaster, acrylic spackle, non-paint)	Extrude onto a Mylar® sheet. Spread to a thickness that reflects how it will be used in the museum setting. Cure material per manufacturer's suggestion. After cured, peel the material from the Mylar® if possible and weigh to 2.0 g. If the material cannot be freed from the Mylar®, remove excess Mylar® and weigh the material to 2.00 g, taking the weight of the Mylar® into account by subtracting it from the total sample weight.
Polymer - adhesive - caulk or sealant	Extrude onto a Mylar® sheet. Spread a thickness that reflects how it will be used in the museum setting. Cure per manufacturer's instructions. After curing, peel the material from the Mylar® if possible and weigh to 2.0 g. If the material cannot be freed from the Mylar®, remove excess Mylar® and weigh the material to 2.0 g, taking the weight of the

	Mylar® into account by subtracting it from the total sample weight.
Polymer - adhesive - glues - liquid (e.g. acrylics, wood glues, starches)	Extrude adhesives onto Mylar® sheeting in a thickness that reflects the actual material application thickness. Cure per manufacturer's instructions. Cut the sample into 1 x 1" squares. Weigh the dried material on Mylar®, taking into account the weight of the Mylar® attached to the sample. To reach 2.0 g, cut pieces from a 1 x 1" square.
Polymer - adhesive - heat activated (e.g. hot melt, heat set)	Extrude 2" strips of melted material onto aluminum foil. Allow to cool. Peel from aluminum foil and weigh out 2.0 g of sample. If material does not remove from foil, repeat on Mylar® and account for the weight of the Mylar® in weighing the sample.
Polymer - adhesive - pressure-sensitive	Cut 2" lengths of tape, taping the adhesive sides, to the backed sides to form a small 2.0 g block of tape. Place the sample onto Mylar® to protect the jar from the adhesive
Polymer - adhesive tape - double sided	Fold the tape onto itself "accordion style" every 2" while removing the backing. Put 2.00 g sample on a piece of Mylar® to protect the jar from the adhesive, and carefully place in the bottom of the jar.
Polymer - adhesive tape - single sided	Cut 2" lengths of tape, taping the adhesive sides, to the backed sides to produce a small 2.0 g block of tape. Place the sample onto Mylar® to protect the jar from the adhesive
Polymer - block/bulk/pellet	If material comes in a block, cut into 0.5" cubes using a band-saw. If the material comes in small pellets that fit in the sample jar, use whole uncut pellets. To reach 2.0 g, shave material from one cube or pellet using a utility knife.
Polymer - foam - building insulation	For dense foam, cut with universal band saw into 0.5" cubes. To reach 2.0 g, remove material from one cube using a utility knife. For soft foams, cut material with clean scissors into a 1.5" wide strip that weighs 2.0 g. Compress the strip into a roll, and insert into the bottom of the jar. Make sure the foam does NOT touch the metal coupons when it expands.
Polymer - foam - non building insulation	For dense foam, cut with universal band saw into 0.5" cubes. To reach 2.0 g, shave any excess material on only one cube using a utility knife. For soft foams, cut material with scissors into a 1.5" wide strip that weighs 2.00 g. Compress

	the strip into a roll, and insert into the bottom of the jar. Make sure the foam does NOT touch the metal coupons when it expands.
Polymer - foam sealant	Cut material with clean scissors into a 1.5" wide strip that weighs 2.0 g. Compress the strip into a roll, and insert into the bottom of the jar. Make sure the foam does NOT touch the metal coupons when it expands.
Polymer - gasket	Cut material with clean scissors into 2" length strips.
Polymer - glove	Cut material with clean scissors into 1 x 1" squares. To reach 2.0 g, cut pieces from a 1" square.
Polymer - membrane (<1mm thick)	Cut material with clean scissors into 1 x 1" squares. To reach 2.0 g, cut pieces from a 1" square.
Polymer - sheet (>1mm thick)	Cut material with clean scissors into 1 x 1" squares. To reach 2.0 g, cut a minimal amount of strips from a 1" square.

IX. Oddy Test Form

METROPOLITAN MUSEUM OF ART - *ODDY MATERIALS TESTING*

Department of Scientific Research/ Sherman Fairchild Center for Objects Conservation

Oddy Test Number:

Date In:

Name:

Tester In:

Dept:

Date Out:

Phone:

Tester Out:

Email:

Exhibition/ Dept:

Class of Material (polymer, fabric, etc):

Type of Material (polyethylene, cotton, etc):

Known Components (type of polymer, wood, additives, etc.):

Manufacturer (Supplier if unknown):

Make & Model (e.g. UltraV, #505):

Specifications (dimensions, prod. processes, etc.):

Results Cu:

Weight in (g)A:

Results Ag:

Weight out (g)A:

Results Pb:

Weight in (g)B:

Designation:

Weight out (g)B:

Metal Purity:

MicroMesh grit:

Red Silicone O-ring used:

Amount of water used (ml):

Notes: