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Identifying Efficient Methods for the Assessment of Materials Used in Object Storage and Display

A thesis submitted in partial satisfaction of the requirements for the degree

Master of Arts in

Conservation of Archaeological and Ethnographic Materials

by

Emily Kate Rezes

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ABSTRACT OF THE THESIS

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Professor Ellen J. Pearlstein, Chair

The selection of storage and display materials is a critical step in the successful preservation of material culture. While their purpose is to protect cultural materials from deterioration, they themselves can act as a source of pollutants and acidic vapors. To make the use of both archival and non-archival materials more reliable, conservators have developed standard methods of materials testing. The most ubiquitous of these assessments is the Oddy Test. However, its high cost and specialized equipment prohibit many smaller museums and archaeological projects from conducting the Oddy Test. Frustratingly, it is frequently such contexts in which untested, non-archival materials are used. Drawing on her experience and collaboration with the conservator and collections management staff at El Museo del Sitio de Pachacamac in Lima, Peru, the author proposes a potential solution to the challenges of materials testing. The Multi-Test is a two-step, multi-component assessment based in materials identification and acidic off-gas monitoring. This novel combination of assessments, as well as the standard Oddy Test, was conducted on a range of storage and exhibition materials collected in Lima. Comparison of the results of the two testing systems suggests that the Multi-Test may be an accurate and consistent method of materials testing.

The thesis of Emily Kate Rezes is approved.

Stella Nair

Glenn Wharton

Ellen J. Pearlstein, Committee Chair

University of California, Los Angeles

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1 Introduction

1.1 Materials Selection and Testing in Conservation

The selection of storage and display materials is a critical step in the successful preservation of material culture. These materials envelop or are in contact with artworks and artifacts for extended periods of time, and while their purpose is to protect cultural materials from deterioration, they themselves can act as a source of pollutants and acidic vapors. The processes by which storage and display materials can actively play a role in the deterioration of material culture has been well researched (Tetreault 2003; Hatchfield 2004; Grzywacz 2006; Schieweck and Salthammer 2009; Curran et al. 2017). One of the primary sources of pollutants in collections spaces are volatile organic compounds (VOCs) that are emitted from deteriorating plastics, foams, adhesives, wood, and numerous other composite or manufactured materials used in storage and display (Thickett and Lee 2004). These acidic gases induce corrosion in metal objects, as well as the oxidation and breakdown of organic materials (Schieweck and Salthammer 2009). To prevent these problems, archival products have been developed and tested to provide safe and effective housing solutions. However, these options are subject to variation between batches, processing defects, and unannounced changes in proprietary formulations. Most importantly, these materials are expensive and can be logistically challenging to locate when working outside of the United States, Canada, Europe, and the United Kingdom.

To make the use of both archival and non-archival materials safer and more reliable, conservators have developed standard methods of materials testing. The most ubiquitous of these assessments is the Oddy Test. Originally developed by Andrew Oddy at the British Museum in 1973, the Oddy test is an example of an accelerated corrosion test meant to identify materials that could emit VOCs (Oddy 1973). The test is based on accelerated aging, in which a sample material is subjected to elevated heat and humidity alongside a metal coupon in a sealed test chamber over a 28-day period. Silver, copper and lead coupons are each used, and the end of the test, the amount of corrosion observed on the coupons' surfaces determines whether a material is accepted for Permanent or Temporary use, or is Unacceptable for use with artworks. The test methodology has been refined many times since its inception. (Green and Thickett 1995; Korenberg et al. 2017). A survey of test practices completed in 1993 showed a wide range of methodologies being used across institutions, which resulted in inconsistent results. In an attempt to standardize practices, a follow-up comparison was completed in 1995 in which 10 institutions completed the test using the same set of procedures. In this early methodology, a single metal coupon is suspended in a degreased glass vial with 2 g of sample material and 0.5 ml of distilled water, sealed with a ground glass cap and heat shrink collar. (Green and Thickett 1995). When results were compared between institutions, variation was observed in both procedure and metal coupon interpretation, highlighting the impact of human error and resource variation in such a sensitive test.

Later improvements to the test included the 3-in-1 procedure in which a silver, copper and lead coupon are each included in the same test chamber (Bamberger, Howe, and Wheeler 1999; Thickett and Lee 2004). This assures that all three coupons are exposed to the same environment and reduces the amount of sampling and resources needed to complete the test. This methodology combined with the use of 2g of sample and 0.5 ml of water, constitute the most consistent thread between the current variations in test procedures. However, there is still significant variation in methodology between institutions, with the American Institute for Conservation (AIC) Wiki on Oddy Test Protocols listing 16 unique procedures ("Oddy Test Protocols" n.d.). Between these tests, the most significant variation comes from inconsistent preparation and interpretation of the metal coupons (Thickett 2016). Some work has been done to refine the process and set standards for coupon polishing (Korenberg et al. 2017) and to publish standard images of metal coupons from each of the three results categories (Buscarino 2018a, 2018b, 2018c). However, an effective solution might be the development of a test that does not include so much room for human error and procedural variation, in which the coupons are standard and purchased ready for use.

Another shortcoming of the Oddy Test is the application of results derived from metal corrosion to artworks and artifacts made of very different materials. There have been multiple attempts to address this concern. One method has been the introduction of cellulosic coupons meant to judge the effects of tested samples on organic materials (Breitung 2014; Strlič, Cigić, and Thickett 2010; Curran et al. 2014). Another method of expanding the applicability of results has been to identify the VOCs emitted by sampled materials. These techniques replace or supplement the metal coupons with absorbent media such as activated charcoal (Beiner et al. 2015) or cellulosic materials (Curran et al. 2017) and then analyze the captured VOCs with gas chromatography-mass spectrometry (GC-MS). The identified VOCs are then associated with deterioration in different media. The limitation to this technique is that it increases the cost, equipment requirements, and specialized skill needed for a test that is already expensive and resource prohibitive.

1.2 Challenges in Materials Testing and a Proposed Solution

In the summer of 2018, the author completed an internship at El Museo del Sitio de Pachacamac in Lima, Peru. This experience introduced several challenges that museums and archaeological excavations face in purchasing safe and effective storage and display materials. Museums and archaeological sites in Peru must overcome limited access to conservation materials manufactured abroad due to prohibitive costs, lengthy customs holding periods, and potentially damaging inspection practices (Adaniya 2018). For conservators working seasonally on archaeological sites in Peru, one solution is to bring supplies that were purchased before travelling. However, this practice is expensive, both when purchasing the materials and when having them shipped as oversized luggage. Supplies such as plastic boxes and large pieces of archival cardboard are also cumbersome and difficult to transport to remote sites.

Using locally available resources is a great solution. However, identifying safe materials that are unlikely to emit VOCs over their lifetime can be challenging, making materials testing essential for good conservation practice. Although the Oddy Test is the museum standard for this type of assessment, the cost and sourcing of the necessary equipment make the Oddy Test impossible to complete at many small museums and archaeological sites. As one example of the equipment pricing for the Oddy Test, the supplies used in this research are estimated at $385.00, without the purchase of the oven which can range in price from several hundred to thousands of dollars (**Appendix 1**). Although some of the supplies can be used again, others such as the metal coupons should not. In light of this, the goals of this research are to 1) identify locally available materials for use in conservation grade object housing at the Pachacamac Site Museum and 2) to identify and assess methods of materials testing that are accessible to museums and archaeological sites that do not have access to the equipment needed for the traditionally used Oddy test.

For materials assessment, the author proposes an alternative type of test that is customizable, uses simple equipment, and requires minimal preparation. The Multi-Test, as it is called throughout this paper, is a two-step process that relies on materials identification and acidic off-gas monitoring. The customizable aspect of the assessment is the implementation of appropriate materials identification tests depending on the type of storage and display materials being assessed. The identification tests used in this iteration of the Multi-Test were microscopy for fiber identification, the Beilistein test, and the combustion vapor pH test for the identification of plastics (Remillard 2007). In selecting the types of materials identification tests that would be most applicable for the Pachacamac Site Museum and archaeological excavations, consideration was given to the extensive chemical restrictions that cultural heritage institutions face in Peru. Restricted solvents and reagents include but are not limited to acetone, sulfuric acid, nitric acid, hydrochloric acid, calcium hydroxide, and potassium permanganate. (Sociedad National de Industrias and Oficina de las Naciones Unidas contra la Droga ye el Delito 2011; "Normas Legales" 2015). For this reason, of the identification tests used in this Multi-Test do not require the use of chemical reagents. An added benefit to the elimination of chemicals from the testing protocol is improved health and safety for those working small museum labs or temporary lab spaces set up for seasonal fieldwork.

Following identification, those materials that are recognized as unacceptable storage materials are eliminated. Others that are identified as potentially acceptable are then tested for acidic off-gassing using acid detector (A-D) strips developed by the Image Permanence institute. To address the cost concerns of the Oddy Test, the start-up equipment cost of the combustion vapor pH test, Beilstein test, and A-D strip test totaled approximately $123 (**Appendix 1**). To assess the consistency and accuracy of the Multi-Test, results were compared to those of the Oddy Test, completed on the same set of samples. The samples selection process and the methodologies employed for the individual assessments are discussed below.

2 Survey

A small survey was conducted in order to better understand the current acquisition, quality, assessment, and monitoring practices of storage and exhibition materials undertaken at archaeological sites and museums in Peru. The survey was sent to 15 cultural heritage professionals from the United States, Peru, and Britain. The goal in sending the survey to both Peruvian and foreign professionals working in Peru was to understand the practices and challenges of those whose work is based in permanent institutions in Peru as well as those who work seasonally in the country at archaeological sites.

2.1 Methodology

Google Forms was used to develop and distribute the survey. Two surveys were prepared, one in Spanish and one in English. Both options were sent to each recipient so that they could select which to complete. Survey questions were broken up into three sections: Materials Acquisition, Materials Assessment, and Materials Performance.

Materials Collection questions asked when and where different storage and display materials are purchased. Results on materials sourcing determined that samples for this research should be purchased from within Peru and assured that they were representative of the work being done in the field. This survey section also included questions about the availability of material manufacturing and composition information. The Materials Assessment section asked how respondents visually assessed or experimentally tested different materials before use. The test options presented in this section included the traditionally used Oddy Test as well microchemical tests and AD-Strips. There was also space for respondents to add any additional testing that they complete. Finally, the Materials Performance section asked if respondents had observed either or both the deterioration of their storage and display materials and condition issues in their collections that could be attributed to storage material deterioration. These questions helped determine the need for materials testing and identified which materials were causing the most concern.

2.2 Results

Of the 15 professionals who were sent the survey, seven responded. Respondents included archaeologists, anthropologists, and conservators from Peru, the United States, and Britain. Of the seven, three work at museums in Peru and have experience working on site and with archaeological materials in their museums. The remaining four respondents work seasonally in Peru for projects supported by museums and universities in the United States and Britain. Three of these are conservators and one is an archaeologist. Although the author recognizes that the sample size is very small, the respondents represent both Peruvian professionals that are based at their institutions all year and professionals who travel to Peru to work on seasonal projects. Importantly, many of the challenges and frustrations associated with completing materials assessments were shared amongst all respondents.

2.2.1 Materials Acquisition

Five out of seven respondents purchase their materials both before heading into the field and while working on site, reinforcing the need for materials testing methods that are conducive to the field environment. Six out of seven respondents shop for supplies at major hardware and grocery store chains, such as Maestro, Sodimac, and Metro. Four out of seven respondents source their materials from recognized vendors of archival materials, with only one of these four working full-time in Peru. Other sources of these supplies included small hardware and grocery stores, local markets, and art supply shops. When asked about the accessibility of manufacturing and composition information, only two of seven respondents said this information was available. When information is available, respondents said that it was limited to the types of plastic or plastic foam. Multi Top and Maestro were both noted as stores that make this information available. Six out of seven respondents were interested in having a reference list of safe materials that are used in storage and display materials.

2.2.2 Materials Assessment

When asked if they conduct a visual assessment or follow any guidelines when purchasing materials, five out of seven respondents said yes, and two said sometimes. The types of assessments included inspecting the color, odor, firmness, and feel of a material, and researching a material's composition and referencing standard lists of safe plastics, such as that provided by the National Parks Service. When asked whether they test purchased materials before use in storage and display, four of seven respondents said they do sometimes, while two of seven said they never do. The most common assessment was the pH test, with five out of seven respondents using it. Other assessments included microchemical tests, and the Beilstein test. One respondent noted using an UV exposure test that has yet to be explored further by the author but merits further research. No respondent uses the Oddy Test.

2.2.3 Materials Performance

All respondents said that the condition of their collections is at least sometimes monitored during storage and display. When asked if they had observed condition issues that could be attributed to storage or display materials, four out of six respondents said yes. Materials associated with condition issues included fabric, plastics, corrugated plastic, Tyvek, adhesives, and foam made of both polyethylene and unknown plastics. Other than artifact condition issues, respondents also noted the deterioration of plastic storage and display materials as being observed in their collections. Finally, respondents were asked to evaluate how important materials assessment is to collections safety on a scale of one to five, with five being most important and one being the least. Five out of seven respondents ranked the importance at five. These results reinforce the need for both a reliable list of safe materials as well as efficient, affordable, and accessible materials testing to help cultural heritage professionals avoid these problematic materials.

3 Sampling and Materials

Samples of storage and display materials were selected for testing based on three experimental goals. The first was to collect a variety of materials, including plastics, fabrics, adhesives, and foils that represent the range of supplies used in museum collection management and fieldwork. Having such a varied and representative sample set provided a more holistic comparison between the Multi-Test and the Oddy Test. The second goal was to collect only those materials that were locally available and accessible to the staff at El Museo del Sitio de Pachacamac, and in turn, to any conservator working in and around Lima. This second goal assured that even if the Multi-Test was found to be ineffective, the Oddy Test results would provide a useful list of locally sourced, safe materials that conservators and archaeologists could use for future storage and display solutions. Finally, the third goal was to inform best observational practices when selecting and purchasing materials for testing in Peru. This method was intended to mirror the types of visual and observational assessments mentioned by survey respondents.

To assure that the samples selected for testing were both properly sourced and representative of the range of materials useful to museum staff, the author collaborated with her internship supervisor, Angie Isa Adaniya, conservator at El Museo del Sitio de Pachacamac. At the museum, conservation and collections management staff have begun the process of creating microclimate housings for all of the climate-sensitive objects in their collections. As there is limited climate control and no building envelope in the collections storage space, this housing system allows each object to be stored in an environment best suited to the materials it is made from (Adaniya 2018). This developing protocol guided much of the materials selection process.

Many of the museum's storage boxes are made from corrugated plastic, analogous to Coroplast, and are pierced with an awl and sewn together. Layers of polyethylene foam are adhered together with hot melt adhesive to create cavity packaging, trays, and bumper supports for the objects. To control temperature and humidity levels, the boxes can be modified by adding layers of aluminum foil and polyethylene sheeting (Tétreault 2018; Grzywacz 2006). When supplemented with conditioned silica gel, this layered storage system has proven effective at maintaining relative humidity and temperature for extended periods of time. Ready-made plastic boxes with lids have also been used at the museum to create microclimate housing without needing to build up layers of materials. (Anderson and Harding 2015). Conditioned silica gel is also used in these ready-made boxes, and at times a bead of hot melt adhesive is applied along the inside of the lid, allowed cool, and then used as a gasket to further maintain the conditions inside the box. These ready-made materials were selected for testing, and where applicable, multiple examples of the same material were sampled from different brands.

Other commonly used materials, both at the museum and in the authors personal experience, were selected as well, including polytetrafluoroethylene (PTFE) tape, cotton muslin, two types of ribbon, paperboard, tulle, and Velcro. As Tyvek (olefin spun polyethylene fabric) is so widely used in conservation as a cover cloth, barrier layer, and to sew pillows, a readily accessible polyethylene/polypropylene fabric painter's suit was also selected to see if it could be used as an analogue.

To assure that the sample materials would be readily accessible to the museum in the future, they were selected from sources already in use by the museum staff. Larger, bulk purchases, such as corrugated plastic, polyethylene foam, and plastic baggies, are purchased by the museum directly from distributers. These bulk-purchased materials were sampled from the museum's supply. Smaller, individual items such as plastic boxes, plastic sheeting, hot melt adhesive, aluminum foil, and PTFE tape, are currently purchased by staff from local stores using a reimbursement system. The most consistently accessible and affordable sources of these smaller materials are big-name hardware and grocery stores including Sodimac, Promart, and Metro. The survey results discussed above show that these sources are commonly used at other projects and institutions, making the results garnered from these samples applicable to a broader audience of professionals. **Table 1** lists every sampled material, its associated sample number, source, and if available, manufacturer. **Appendix 2** lists every sample, the brand, and includes and image of the material and its packaging.

There was significant uncertainty about the composition and archival quality of many of the materials that were sampled. For the materials purchased from hardware and grocery stores, basic observational tools were used to select options that were more likely to be safe for use. For all materials, preference was given to options that were labeled with the material composition, such as the polyethylene sheeting and PTFE tape. For plastic containers, preference was given to those with an identifying symbol of a known safe plastic, such as high density polyethylene (HDPE), low density polyethylene

(LDPE), and polypropylene (PP) (Garside and Hanson 2011; Tétreault 2018). When no identification was provided, other positive characteristics were sought out, such as clear or translucent plastics with no yellowing and containers that did not have a strong smell when lifted off the store shelf. Food safe items such as aluminum foil and food storage containers were also preferentially selected. This methodology provided some confidence that the purchased materials would be safe for use. However, one challenge that was identified early on was the presence of misleading product names. Both of the sampled hot melt adhesives, one from the museum's supply and one from a hardware store, were labeled "Silicona". The term appeared to be a catchall for any hot melt adhesive, but the translucent yellow color and acidic smell of both adhesives suggested that they were made from an unstable acetate rather than silicon.

For those materials sampled from the museum's stores, there were no alternative options to select from. Testing of these samples was then focused on assessing the safety of the museum's supply. In all, it was determined early on that an efficient and accurate method of testing all of these materials would benefit the selection process and help further protect the museum's impressive archaeological collections.

Table 1: List of samples and completed assessments. An "x" marks that a test was completed on that sample.

Sample #	Material	Brand	Source	FTIR-ATR	Oddy Test	A-D strip	Combustion	Beilstein	Surface pH	Fiber ID
1	PTFE tape	Shurfix	Sodimac	x	x	x	x	x	x	
2	Aluminum foil	Triple B	Metro		x	x			x	
3	Aluminum foil	Krea	Metro		x	x			x	
4	Aluminum foil	U-Thil	Sodimac		x	x			x	
5	Silicona (Hot Glue)	Ove	Museum	x	x	x	x	x	x	
6	Silicona (Hot Glue)	Baras de Silicona, Top gan	Sodimac	x	x	x	x	x	x	
7	Polyethylene/Polypropylene	Steelpro Safety	Promart	x	x	x	x	x	x	x
8	Polyethylene foam		Museum	x	x	x	x	x	x	
9	Polyethylene foam		Museum	x	x	x	x	x	x	
10	Polyethylene foam		Museum	x	x	x	x	x	x	
11	White sulfite paper		Museum		x	x			x	
12	Yellowed sulfite paper		Museum		x	x			x	
13	White tissue paper		Museum		x	x			x	
14	Coroplast		Museum	Diff	x	x	x	x	x	
15	Polyethylene/Cotton sheet	House Solutions	Sodimac	x	x	x	x	x	x	x
16	Polyethylene sheeting		Sodimac	x	x	x	x	x	x	
17	Polyethylene bag	policlick	Museum	x	x	x	x	x	x	
18	Polyethylene bag	policlick	Museum	x	x	x	x	x	x	
19a	Polypropylene box	Duraplast	Sodimac	x	x	x	x	x	x	
19b	lid	Duraplast	Sodimac	x	x	x	x	x	x	
19c	handle	Duraplast	Sodimac	x		x	x	x	x	
20a	Polypropylene box	Rey plast	Sodimac	x	x	x	x	x	x	
20b	lid	Rey plast	Sodimac	x	x	x	x	x	x	
20c	handle	Rey plast	Sodimac	x		x	x	x	x	
21a	Polypropylne box	Wenco	Promart	x	x	x	x	x	x	
21b	lid	Wenco	Promart	x	x	x	x	x	x	
21c	handle	Wenco	Promart	x		x	x	x	x	
22	Ribbon, closed weave		Museum	x	x	x	x	x	x	x
23	Ribbon, open weave		Museum	Diff	x	x	x	x	x	x
24	Cotton muslin		Museum		x	x			x	x
25	Paper board, thinner		Museum			x			x	
26	Paper board, thicker		Museum		x	x			x	x
27	Velcro, toothed		Museum	Diff	x	x	x	x	x	x
28	Velcro, soft		Museum	Diff	x	x	x	x	x	x
29	Tule		Museum	Diff	x	x	x	x	x	x
	Resin Kit Plastic Standard	**Brand**	**Source**							
31	Polyvinylchloride		Resin Kit		x	x	x	x		
32	Cellulose acetate		Resin Kit		x	x	x	x		
33	HDPE		Resin Kit		x	x	x	x		
34	Polystyrene		Resin Kit		x	x	x	x		

4 Test Theory and Methodology

One goal in completing this thesis is to identify and assess methods of materials testing that are accessible to museums and archaeological sites that do not have the equipment needed for the traditionally used Oddy test. The inspiration behind the Multi Test is the idea that many of the accessible materials identification and off-gassing tests that are used to characterize materials found in artworks can and should be applied to the materials we use for display and storage (Coxon 1993). The two part system of materials identification followed by assessment of acidic off-gassing is designed to increase the efficiency of the testing system and to provide a more holistic characterization of the materials being tested. For example, the materials identification tests discussed below are quick, and the identification of an unacceptable material, such as cellulose acetate or polyvinyl chloride, can eliminate the need for the lengthier test for acidic off-gassing. In another case, the identification of an acceptable storage material, such as polyethylene, paired with a failed off-gassing test can provide valuable information about the possible presence of harmful plasticizers or additives in a manufacturer's products.

The materials identification tests used in the Multi-Test are: 1) The Beilstein Test for the Identification of Polyvinyl Chloride; 2) Combustion Vapor pH Test for the Identification of Plastics; 3) Combustion Residue Observation, an innovation added by the author; and 4) Fiber Identification. The identification test(s) performed on each object were chosen based on the type of material being assessed. To determine the accuracy of each test, Fourier Transform Infrared Reflectography was completed on each sample. To assess the reliability of each test, each material was sampled and tested three times. Each material was then tested for acidic off-gassing using AD strips from the Image Permanence Institute in one day, one week and 28 day intervals.

Due to the general acceptance of the Oddy test as the standard assessment for materials used in object storage, display, and travel, it was used in this thesis as the standard to which the results of the Multi-Test were compared. The field tests discussed below were completed on the appropriate samples and the results of each test were considered together to determine whether or not each sample material was considered to "Pass" or "Fail" the Multi-Test as a whole. The parameters by which individual materials were assessed in each component of the Multi-Test as well as the Oddy Test are discussed in the following sub-sections. The equipment required for each test is outlined in detail in **Appendix 1**.

4.1 Beilstein Test for the Identification of Polyvinyl Chloride (PVC)

Originally invented by F. Beilstein in 1872, the Beilstein test methodology used in this research was taken from Remillard's *Identification of Plastics and Elastomers: Miniaturized Tests* (Beilstein 1872; Remillard 2007). Of the 35 sample materials in this study, 26 are made of plastic and were tested along with four plastic standards from the *Resin Kit: The Complete Guide for Identifying and Testing Plastic Resins*. The Beilstein test is based in the formation of copper chlorides when a micro sample of organic material that contains chlorides is combusted while in contact with a clean copper wire (Odegaard, Carroll, and Zimmt 2000). A positive result indicated that the plastic was likely polyvinyl chloride (PVC). If a plastic was PVC, it was considered unacceptable for use in object display or storage, and failed this first round of the Multi-Test.

For the test, a thin copper wire was polished using sand paper and then degreased using ethanol and a Kimwipe. Holding the wire with a pair of metal tweezers, the end of the copper wire was heated to red hot in the flame of an alcohol lamp. The heated end was touched to the surface of the plastic being tested and then held in the blue part of the flame. A green flame indicated the presence of chlorides (**Figure 1**). The used end of the wire was trimmed off between samples. The test was also attempted with a simple lighter, which also proved effective.

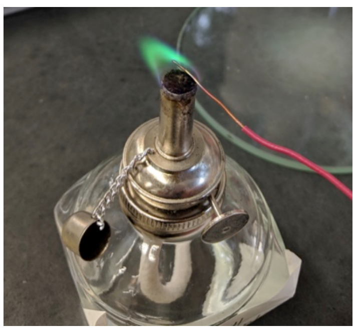


Figure 1: Image of positive Beilstein Test on a sample from the Resin Kit.

4.2 Combustion Vapor pH Test for the Identification of Plastics

The pH of the combustion vapor of each plastic material was recorded using the Pyrolysis Method pH test described in Remillard's *Identification of Plastics and Elastomers: Miniaturized Tests* (Remillard 2007). Remillard presents two sets of possible results for her test, one from Coxon with approximate pH ranges for each plastic and another from Braun with wider ranges of pH values that result from using litmus paper rather than pH strips that provide more specific pH readings (Braun 2013; Coxon 1993). The test completed in this thesis uses pH indicator strips and results are based on the plastic identifications provided by Coxon. In her work at the Royal Ontario Museum, Coxon discusses various methods and obstacles in the identification of plastics (Coxon

1993). In her tests, Coxon found consistency in the observed pH ranges of vapors released by different plastics upon combustion, providing a reliable method for plastic identification. **Table 2** provides the materials and the approximate pH ranges of their combustion vapors, as listed in the Coxon publication. These ranges were used to identify the plastic sample materials collected in Peru.

Table 2: pH Values of Vapors Released from Sheet Materials During Heating (Coxon 1993, pg. 403)

Material	**Approximate pH**
Polyvinyl Chloride (PVC)/ Polyvinylidene Chloride (PVDC)	0.0 to 0.5
Cellulose triacetate	2.5
Polyethylene/Polypropylene	3.0 to 4.0
Poly(ethylene terephthalate) (Mylar)	4.0
Polycarbonae	4.5 to 5.5
Polystyrene	5.5
Polyamide (nylon)	9.0 to 10.0

Of the materials listed in this table, plastics that were considered suitable for object storage and display include polyethylene, polypropylene, poly(ethylene terephthalate), polystyrene, and polycarbonate for long term use storage. PVC, PVDC, cellulose triacetate and polyamide were considered unsuitable for use (National Park Service 2004; Garside and Hanson 2011; Tétreault 2018).

Of the 35 sample materials, 26 are made of plastic and were identified using this test along with four known standards selected from the Resin Kit (*The Resin Kit: The Complete Guide for Identifying and Testing Plastic Resins.*, n.d.). A small sample was shaved or cut from each material using a scalpel. The scalpel blade was either replaced or wiped clean with ethanol and a Kimwipe before each sample was taken. Samples were dropped into the base of a new Fischerbrand 5 ¾" glass pipette. The capillary end of the pipette was sealed with small piece of Parafilm "M" laboratory film. Approximately 40 MColorpHast pH-indicator strips (pH 0-14) were cut lengthwise into thirds. For each test, a cut pH strip was wetted with deionized water (pH 5.5-6) and inserted into the open end of the pipette. The end of the pH strip was folded over the edge of the pipette and a larger piece of Parafilm was used to seal the sample and pH strip within the pipette.

The contained sample was then held horizontally over the flame of an alcohol lamp until the plastic material combusted and released vapors. An important methodological note provided by Coxon was also followed where the pH strip was held a sufficient distance from the sample and flame so as to keep vapors from the plastic strip carrier from skewing the results (Coxon 1993). Holding the pipette horizontal or with the capillary end slightly upwards allowed the heavy vapors to come in contact with the wetted pH strip. The pH strip was held in the pipette for 30 seconds to a minute until it stopped reacting with the vapors and the colors on the strip stabilized (**Figure 2**). The pH of the vapors was then recorded based on the comparison of the test strip to the color scale on the MColorpHast box. The test was repeated three times for each material. The test was also attempted with a simple lighter, which may be more accessible than an alcohol lamp. This method proved effective but was not used throughout testing.

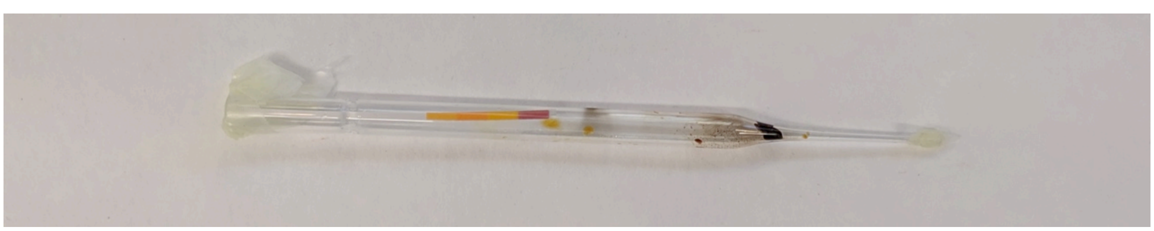


Figure 2: Image of completed combustion test showing a pH of approximately 3.

4.3 Combustion Residue Test

The Combustion Vapor pH Test revealed a variation in the residues that different plastics left behind after combustion. To better visualize these residues, samples were taken in the same way that they were for the Combustion Vapor pH Test. They were then placed on glass slides and held over the flame of an alcohol lamp until they began to bubble, release vapors and produce the residues seen when combusted in the glass pipettes. The residues were then imaged for comparison (**Figure 3**). The same visual comparison could be made using the residues in the glass pipettes, however the use of glass slides increased legibility for both analysis and documentation for this research.

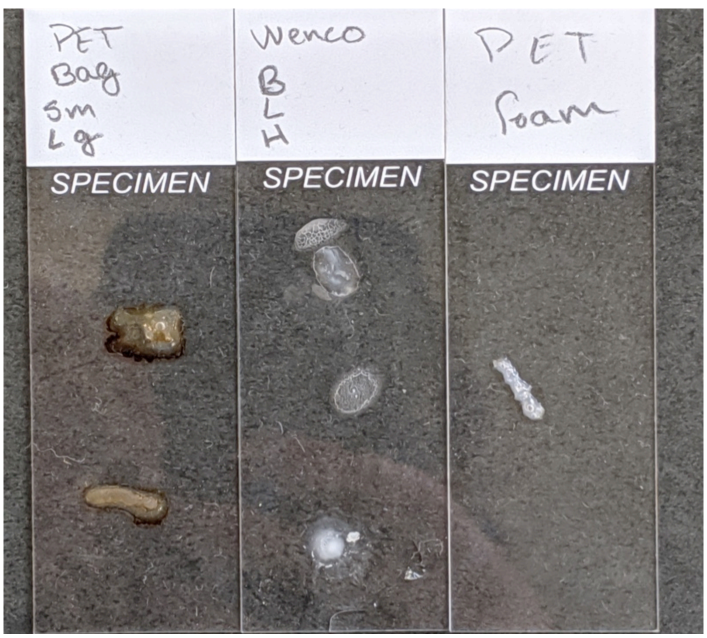


Figure 3: Left slide: samples 17 (top) and 18 (bottom); Middle slide: samples 21a (top), 21b (middle), and 21c (bottom); Right slide: sample 8. All were identified as polyethylene or polypropylene in the Combustion Vapor pH test.

4.4 Fiber Identification

Of the 35 sample materials, nine include synthetic or natural fibers. Fiber identification of longitudinal sections using an Olympus BH-2 transmitted light microscope was performed. Fiber samples were taken using tweezers and placed onto glass slides. The samples were spread out to reveal individual fibers, were covered with a glass slide and saturated with deionized water. The fibers were observed and imaged at 100 – 200x magnification under plane and cross-polarized light. Microscopy images were taken using a Nikon D90 DSLR camera.

4.5 Fourier Transform Infrared Reflectography (FTIR)

Analysis was done on all 35 sample materials and the four standard plastic samples from the Resin Kit using an Agilent Handheld FTIR G8181-64001 fitted with an attenuated total reflection (ATR) crystal. Absorptions were recorded from 4000-650 cm^{-1} with an 8 cm^{-1} resolution and readings were taken with 32 sample scans and processed through a triangular apodiztion. Data were processed in Agilent MicroLab software and the resulting absorption spectra were run through the Agilent Demo Handheld ATR Library. FTIR results were used to confirm the accuracy of the different identification tests discussed above.

4.6 A-D Strip Off-Gassing Tests (28 day, 7 day, 1 day)

A-D strips from the Image Permanence institute were used for the acidic off-gas monitoring portion of the Mulit-Test. The strips make use of the light and pH sensitive dye, bromcresol green. The dye indicates pH change between a pH of 3.8 (yellow color) and 5.4 (blue-green color) (Fischer and Reilly 1995). The strips were developed after research determined bromcresol green to be an accurate and efficient indicator of vinegar syndrome (acetic acid production and off-gassing) from cellulose acetate film. Soon after development, the strips were tested for use in screening conservation, storage, and exhibition materials (Nicholson and O'Loughlin 1996). In that study, it was determined that the strips could be used as a preliminary indicator of acidic off gassing. The authors also suggested that the strips could be used as a substitute for the Oddy test in situations where the resources for the Oddy test are not available, but that further comparison between the two tests was necessary. More recent research into the assessment of storage and display materials has considered the A-D strip test as a short-term indicator (Garside and Hanson 2011), while other work has focused on determining the strips' sensitivity to different acids (McCauley-Krish and Bigourdan 2018). In this thesis, there were two goals in testing the use of the A-D strips to assess storage and display materials: 1) determine how long it takes for the strips to indicate an unsafe amount of acidic off gassing, and 2) to compare the results of the A-D strip off gassing test with the Oddy test.

All 35 sample materials and the Resin Kit plastic samples were tested using this method. Four oz. glass jars with aluminum lids and polyethylene foam seals were washed using warm water with lab detergent, degreased using acetone and air dried. The foam seals were not degreased with acetone to avoid deterioration the plastic. Two-gram samples were taken from each material using a scalpel cleaned with ethanol. The samples were placed in the bottom of the jars. The A-D strips were cut in half to conserve resources. Half of an A-D strip was placed in each jar amongst the two grams of sample material (**Figure 4a**). The author recognizes that it would have been ideal to control the amount of contact each strip had with the sample materials, however some strips had no contact, partial contact, or were completely enveloped by the sample. The amount of contact depended mostly on the density of the sample and the space it occupied in the jar. The aluminum lids were tightly screwed onto the glass jars, and the jars were distributed between two closed cardboard boxes to prevent light exposure, which could interfere with the strips' performance (*User's Guide for A-D Strips: Film Base Deterioration Monitors* 2016). Two control jars were also prepared, one for each cardboard box, in order to monitor any off gassing from the jar itself, the cardboard box, as well as any unforeseen variables between the two boxes. The test was run three times for three different durations. The first test ran for 28 days to mirror the length of the Oddy test. The following two tests ran for one week and then one day to determine how quickly the strips indicate acidic off gassing. The same samples were used in each of the three runtimes, however jars and lids were cleaned and degreased between each round of testing, using the same cleaning methodology described above.

The final color of each A-D strip was imaged in comparison with a control strip as well as an unused strip. To make the imaging consistent using an accessible set-up, the strips were imaged using natural light and the camera on a Google Pixel 3, held over the samples using suction-cup phone mount supported by a vertical laptop screen. The strips were imaged immediately after the jars were opened to avoid interference from color shifting due to light or ambient air exposure (**Figure 4b, c**).

Materials were judged based on the level of color change observed in the A-D strips compared to the color shift of the control. No change or minimally perceptible change with the dominant color still being blue was given a Pass and the material was considered safe for use. A perceptible green shift in coloration was considered acceptable for Temporary Use. Finally, a bright green to yellow-green shift was Failed and the material was considered unacceptable for use. Early experiments with this test used the color scale printed on the pencil provided by the Image Permanence Institute with the AD Strips. However, it was difficult to compare results with the pencil as the saturation, gloss and hue of the 5 color grades on the pencil were all different from the AD strips.

Figure 4: Images of a) the prepared jars; b) the imaging set-up; c) example image

4.7 Oddy Test

The history and development of the Oddy Test is discussed above in the introduction. For this thesis, the “3 in 1 method” was used in which a polished copper, silver, and lead coupon is placed within a sealed test chamber along with the material being tested and a small amount of deionized water (Thickett and Lee 2004). Both no contact and partial contact test-chamber set-ups were used depending on the sample materials being assessed. Materials such as foam, fabric, Tyvek, and tissue were prepared with partial contact to all three metal coupons. This variation is meant to more accurately test materials that are intended to come into contact with objects (Muros, White, and

Gençay-üstün 2015). All other samples were prepared with no contact and were tested for off-gassing vapors only.

The Oddy Test was completed on all but 4 of the sample materials. Sample 25 was eliminated because there was not enough sample material available for testing. Samples 19c, 20c, and 21c were eliminated because there were not enough test supplies available for all samples and these three are the external handles of three different brands of plastic boxes, which would never interact with an artwork while the boxes are in use.

Test supplies and methodology were based on the Oddy Test protocols published by Ozge Ustun of the Autry Museum and Eric Breitung of the Metropolitan Museum of Art (MMA) on the Oddy Test Protocols Wiki ("Oddy Test Protocols" n.d.), as well as an earlier protocol published by the MMA (Bamberger, Howe, and Wheeler 1999). However, due to the number of tests that were required for this project and the considerable cost of ground glass weighing jars and KIMAX vials used by the Autry and the current MMA protocols respectively, an alternative was selected. The same 4 oz. glass jars and aluminum lids used in the A-D strip test described above were used here without their polyethylene foam seals. The glass jars, aluminum lids, 20mL glass beakers and 1.5ml capillary tubes were prepared by washing in lab grade glassware detergent and rinsing with deionized water. The jars and lids were then degreased with acetone on a Kimwipe and left to dry completely.

Copper, silver, and lead foils were cut into 1 cm by 2 cm coupons. The silver and copper coupons were soaked in acetone and lightly burnished with a glass bristle brush along the long axis. The coupons were then rinsed with acetone and then ethanol on a Kimwipe. The lead coupons were burnished only with a Kimwipe to prevent scratching or over polishing with a glass bristle brush. The coupons were rinsed with acetone and then ethanol on a Kimwipe.

A two-gram sample was removed from each material using a scalpel or scissors. The samples that were being tested only for off-gassing were cut, folded or crumpled into small enough pieces that they fit within the 20mL glass beakers. A copper, silver and lead coupon was folded in half and placed along the rim of the 20mL glass beaker with space between them and without contacting the sample (Figure 5).

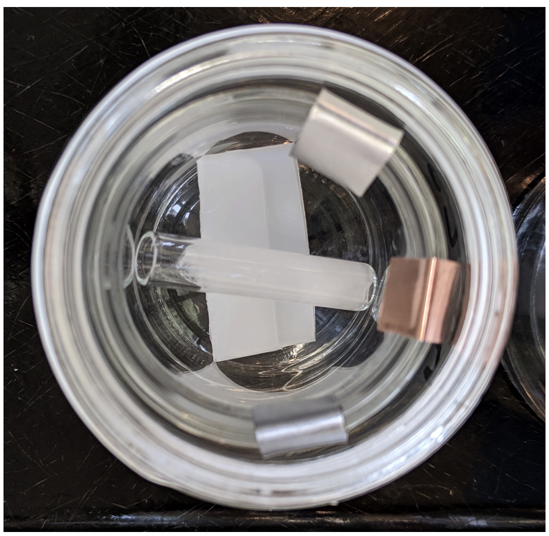


Figure 5: Prepared Oddy Test chamber for materials being tested for off gassing only.

Different arrangements were configured for the partial contact test chambers. For foam, slits were cut into the top surface and the coupons were inserted half way. For fabric and tissue, the samples were folded into a rectangle, and then 1/3 of the rectangle was folded up lengthwise, creating a channel with one wall twice as high as the other. The rectangle was then folded, and inserted into the test chamber where it was supported by the walls of the jar (Figure 6). The coupons were then inserted into the channel, separated from each other by folds in the sample material.

Figure 6: Oddy Test sample preparation method for materials being tested for partial contact with fabric and tissue. Image is of sample 24, cotton muslin.

One mL of deionized water was pipetted into the capillary tubes and small ball of cotton was inserted into the mouth of each tube to prevent spilling. The water, 20mL beakers, samples, and coupons were placed in the jars. The threads on the mouth of the glass jars were lined with Teflon tape and a generous amount of high vacuum silicone grease was applied on top of the tape. The aluminum lids were screwed tightly onto the jars. The test chambers were placed in a 60 degree Celsius oven for 28 days. The sealed chambers were weighed before and after accelerated ageing to monitor any water loss that might occur over the course of testing (Breitung 2019).

4.8 Surface pH Test

While avoiding materials that off-gas volatile organic compounds is a primary goal when selecting safe storage and display materials, surface pH can indicate unsafe, acidic materials that may not off-gas acidic vapors. These materials should also be avoided, particularly for storage and display solutions that involve direct contact with objects (Garside and Hanson 2011).

The surface pH was recorded from all 35 sample materials and 4 standard plastics from the Resin Kit: The Complete Guide for Identifying and Testing Plastic Resins. The surface of each tested material was wiped clean using ethanol and a Kimwipe. Each material was left to fully dry for 1-2 minutes before testing. A drop of deionized water was applied to the surface of the material using a glass dropper. pH readings were taken using a ϕ340 pH/Temp Meter by Beckman and the Thermo Scientific Orion 8135B Ross Flat Surface Probe. The probe was suspended in the water droplet without touching the surface of the sample until the pH reading stabilized. An analogous surface pH was planned, using the 40 MColorpHast pH-indicator strips (pH 0-14) which are more readily accessible in the field. However, as will be discussed in the results below, there was so little variation in pH between the samples, the pH strips would not have been sensitive enough register any difference.

5 Results

5.1 Beilstein Test

Of the 30 materials that were assessed using the Beilstein Test, only sample # 31, the polyvinyl chloride from the Resin Kit, gave a positive result for chlorides. Although it did not sort out any of the sampled storage and display materials, the results from the test show that it does provide accurate identification of chlorides when present in a plastic sample.

5.2 Combustion Vapor pH Test for Plastic Identification and FTIR

Each sample material was tested three times. The results from the three rounds showed consistency in the test's performance. Testing of the samples from the Resin Kit gave results that matched the listed identities of the plastics, showing a preliminary level of accuracy in the test (**Table 3**). Most of the storage materials passed this test, with polyethylene/polypropylene being the most common result at a pH between 3 and 4. Notable failures included the two hot melt adhesives that were identified as unknown acetates and the tulle fabric that was identified as nylon.

Table 3: Combustion Vapor pH test results showing all three pH readings, the material identification based on the Remillard publication, and whether or not the material passed the test, red indicating failure and green indicated a pass.

Sample #	Description	pH Test 1	pH Test 2	pH Test 3	Pass/ Fail	Material
1	PTFE tape	1	1	1		Unknown
2	Aluminum foil					
3	Aluminum foil					
4	Aluminum foil					
5	Silicona (Hot Glue)	1.5	2	1.5		Unknown, acetate
6	Silicona (Hot Glue)	2.5	2	2		Unknown acetate

7	PET/PPE sheeting	7	4	4		PET/PPE
8	Polyethylene foam	3	3	3		PET/PPE
9	Polyethylene foam	3	3	3		PET/PPE
10	Polyethylene foam	3.5	3	3		PET/PPE
11	White tissue paper					
12	Yellowed tissue paper					
13	White sulfite paper					
14	Coroplast	3	3.5	3		PET/PPE
15	Polyethylene/Cotton sheet	3	3	3		PET/PPE
16	Polyethylene sheeting	3	3	3		PET/PPE
17	Polyethylene bag	3.5	3.5	3.5		PET/PPE
18	Polyethylene bag	3	3	3		PET/PPE
19 a	Polypropylene box	3.5	3	3.5		PET/PPE
19 b	lid	3.5	3	3.5		PET/PPE
19 c	handle	3.5	3	3.5		PET/PPE
20 a	Polypropylene box	3.5	3	3		PET/PPE
20 b	lid	3	3	3.5		PET/PPE
20 c	handle	4	3	3		PET/PPE
21 a	Polypropylene box	3	3	3		PET/PPE
21 b	lid	3	3	3		PET/PPE
21 c	handle	3	3	3.5		PET/PPE
22	Ribbon, closed weave	2.5	3	2.5		PET/PPE/Unknown
23	Ribbon, open weave	10	10	10		Nylon
24	Cotton muslin					
25	Paper board, thinner					
26	Paper board, thicker					
28/29	Velcro, toothed	2.5	2	2.5		Cellulose acetate
30	Tule	9	9	9.5		Nylon
31	Resin Kit Polyvinylchloride	0.5	0	0		PVC/PVDC
32	Resin Kit Cellulose acetate	2	2.5	2		Cellulose acetate
33	Resin Kit HDPE	3	3	3		PET/PPE
34	Resin Kit Polystyrene	5.5	5	5.5		Polystyrene

All of the test results were consistent with those recorded with FTIR (**Table 4**). Sample 1, PTFE tape, was the most inconsistent between the two tests, as it was not successfully identified by the Combustion test. However, it being unidentifiable led to it failing the test, which was consistent with its final pass/fail FTIR result. Samples 5 and 6, the two hot melt adhesives, were also more accurately identified by FTIR than by the combustion vapor test. The combustion vapor test successfully identified them as acetates, but the table used to correlate pH values and plastic types is limited and both were identified as cellulose acetate within these parameters. FTIR gave a more specific identification of ethylene vinyl acetate copolymer. However, like the results for sample 1, the combustion vapor identification lead to a failing grade for these adhesives, which is consistent with the FTIR identification.

Importantly, more samples were successfully tested with the Combustion Vapor pH test than were tested with FTIR due to the size, flexibility/rigidity, surface texture, or structure of the samples. Smaller samples of any physical form or texture could be successfully tested with the Combustion test, whereas thin, small, highly textured, flexible or open structured materials were too difficult to test with the portable FTIR. A limitation to the Combustion pH Vapor test is that it only works on plastics. As a result, samples such as the cotton face of sample 15, the polyethylene/cotton sheeting, could only be characterized with FTIR.

Table 4: Comparison of FTIR and Combustion Vapor pH test results. Shows the FTIR result, the quality of the result, the Combustion Vapor pH test result, whether or not the material would pass or fail each test, red indicating a failure and green a pass. The final column shows the accuracy of the Combustion Vapor pH test, using its consistency with FTIR as the standard. Green indicates that the results are consistent and yellow indicates that the results were not the same but did not affect the final pass/fail determination for the material. Bright green indicates that the Combustion test achieved a result when FTIR did not.

Sample #	Material	Quality	FTIR Result	Pass/ Fail	Combustion Test Result	Pass/ Fail	Accur-acy
1	PTFE tape	0.92808	Polytetrafluoroet-hylene		Unknown		
2	Aluminum foil						
3	Aluminum foil						
4	Aluminum foil						

5	Silicona (Hot Glue)	0.87131	Ethylene_vinyl acetate copolymer		Cellulose acetate		
6	Silicona (Hot Glue)	0.78805	Ethylene_vinyl acetate copolymer		Cellulose acetate		
7	Polyethylene/ Polypropylene	0.80732	Polypropylene		PET/PPE		
8	Polyethylene foam	0.9327	Polyethylene		PET/PPE		
9	Polyethylene foam	0.97018	Polyethylene		PET/PPE		
10	Polyethylene foam	0.90376	Polyethylene		PET/PPE		
11	White tissue paper						
12	Yellowed tissue paper						
13	White sulfite paper						
14	Coroplast				PET/PPE		
15C	Polyethylene/Cotton sheet	0.98142	Cellulose Paper Filter				
15P	Polyethylene/Cotton sheet	0.91481	Polyethylene		PET/PPE		
16	Polyethylene sheeting	0.97729	Polyethylene		PET/PPE		
17	Polyethylene bag	0.9422	Polyethylene		PET/PPE		
18	Polyethylene bag	0.95939	Polyethylene		PET/PPE		
19a	Polypropylene box	0.87026	Polypropylene		PET/PPE		
19b	lid	0.9227	Polypropylene		PET/PPE		
19c	handle	0.9269	Polypropylene		PET/PPE		
20a	Polypropylene box	0.95075	Polypropylene		PET/PPE		
20b	lid				PET/PPE		
20c	handle				PET/PPE		
21a	Polypropylene box	0.9161	Polypropylene		PET/PPE		
21b	lid	0.92662	Polypropylene		PET/PPE		
21c	handle	0.9265	Polypropylene		PET/PPE		
22	Ribbon, closed weave	0.94499	Polyester Fiber		PET/PPE/Unknown		
23	Ribbon, open weave				Nylon		
24	Cotton muslin						
25	Paper board, thinner						
26	Paper board, thicker						

28/29	Velcro, toothed				Cellulose acetate		
30	Tule				Nylon		
31	Polyvinylchlorid e				PVC/PVDC		
32	Cellulose acetate				Cellulose acetate		
33	HDPE				PET/PPE		
34	Polystyrene				Polystyrene		

5.3 Combustion Residue Test and FTIR

Observing the plastic residue that remains after combustion may provide more information about the presence of potentially deleterious plasticizers such as phthalates (Saviello et al. 2016). Of the 21 plastic samples that were tested, 12 had a brown to black colored, burnt residue. The FTIR spectra from each of the 12 materials that produced a burnt residue had a notable variation from the standard FTIR spectrum for that plastic in the Agilent software (**Table 5**). This suggests that there is either some level of deterioration in the sampled material or the presence of an additive or plasticizer that is being identified by FTIR and influencing the combustion residue of the plastic sample. Most of the variation included peaks at around 1729 and 1654 cm−1 that suggests the presence of phthalates (Saviello et al. 2016). **Figure 7** presents an example of a plastic sample with spectral variation from its identified plastic, polyethylene, and a burnt combustion residue. **Figure 8** presents a case where there is no notable spectral difference between the sample and the identified plastic, and the sample material melts cleanly on the glass slide. All FTIR spectra can be found in **Appendix 3** and images of the each combustion residue can be found in **Appendix 4**.

As this was a novel test, there were no Pass/Fail qualifications prepared before testing or interpretation of the overall Multi-Test. However, this preliminary testing does suggest that the combustion residue of a plastic material does correlate with its overall performance in the Multi-Test. Each of the samples whose FTIR spectra show variation from the library standard, and produced a "burnt" combustion residue, were later graded for either Temporary Use or Failed the overall Multi-Test (**Table 11**, Section 6: Discussion). Further testing could be done in this area to see how accurately this method identifies the presence of additives or plasticizers, and see if this test can further characterize those plastics that pass the initial Combustion Vapor pH Test.

Table 5: shows the observed combustion residue characteristics of the melted plastic samples. Variation between the sample and standard FTIR spectra are recorded with Y=yes to variation and N=no variation. Under "Residue Appearance" B= burnt: appearance ranges from amber colored to brown/black and carbonized; C= clean: appears melted with no black carbonization

Sample No.	Description	Plastic ID	Variation in FTIR Spectra	Residue Appearance
7	Polyethylene/Poly-propylene sheet	Polypropylene	Y	B
8	Polyethylene foam	Polyethylene	Y	B
9	Polyethylene foam	Polyethylene	Y	B
10	Polyethylene foam	Polyethylene	Y	B
15	Polyethylene/Cotton sheet	Polyethylene	Y	B
16	Polyethylene sheeting	Polyethylene	Y	B
17	Polyethylene bag	Polyethylene	Y	B
18	Polyethylene bag	Polyethylene	Y	B
19 a	Polypropylene box	Polypropylene	N	C
19 b	lid	Polypropylene	N	C
19 c	handle	Polypropylene	N	C
20 a	Polypropylene box	Polypropylene	N	C
20 b	lid	Polypropylene	N	C
20 c	handle	Polypropylene	N	C
21 a	Polypropylene box	Polypropylene	N	C
21 b	lid	Polypropylene	N	C
21 c	handle	Polypropylene	N	C
22	Ribbon, closed weave	Polyester Fibers	Y	B
23	Ribbon, open weave	Nylon	Y	B

28/29	Velcro, toothed	Cellulose acetate	Y	B
30	Tule	Nylon	Y	B

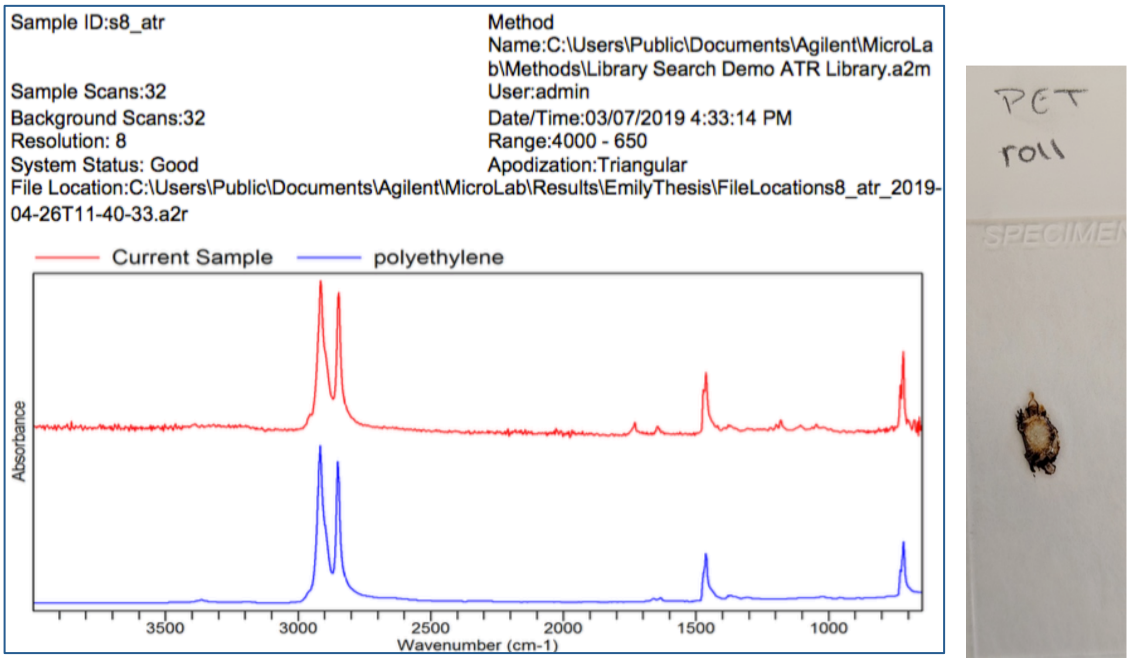


Figure 7: Left: FTIR spectrum of sample 8, identified as polyethylene, with extra peaks at around 1729 and 1654 cm−1 that could be a phthalate plasticizer, commonly used in PVC (Saviello et al. 2016). This sample had a “burnt” residue; Right: burnt appearance of the sample following heating.

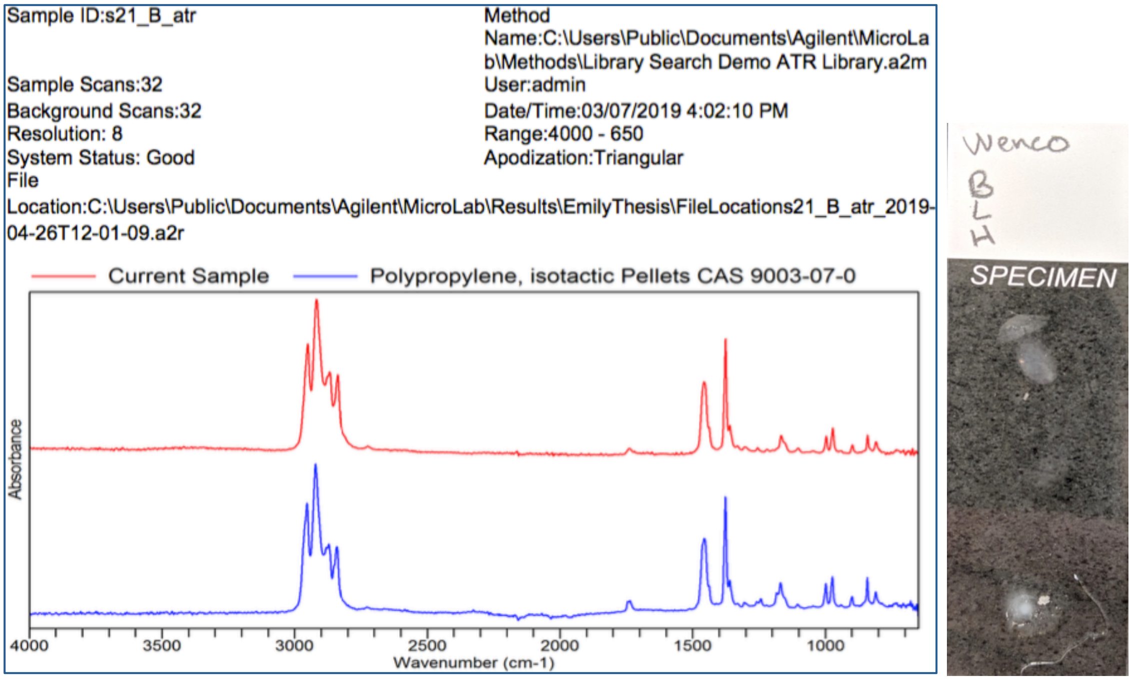


Figure 8: Left: FTIR spectrum of sample 21a, identified as polypropylene, with very minimal variation from the library spectrum. This sample had a "clean" residue; Right: clean melt appearance of the sample (top) following heating.

5.4 Fiber Identification

Fiber identification was successfully completed on three samples. The goal of fiber identification was to confirm the fibers used in the materials matched those advertised on the packaging. Sample #24, cotton muslin, and Sample #15, Polyethylene-Cotton sheeting, were both confirmed to contain cotton (**Figure 9**). Both of these materials were determined to be safe for use based on this identification. Sample #7, Steelpro polypropylene/polyethylene (Tyvek) suit, was difficult to identify. A standard PLM image from the McCrone Atlas of Microscopic Particles was compared to Sample #7. There were visible differences between the two materials, including fiber thickness and the inclusion of yellow, globular formations on some of the Steelpro fibers (**Figure 10**). Combustion Vapor pH testing and FTIR identified the Steelpro sample as polypropylene, while some of the opaque inclusions seen in Sample #7 could be a titanium delustrant, as can be seen in the McCrone example. This result highlighted the importance of having reference samples or images when completing this assessment.

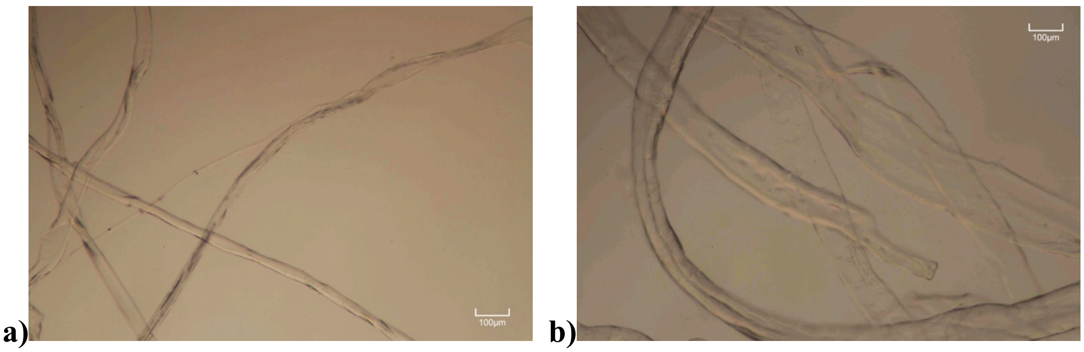


Figure 9: a) Sample # 24, cotton muslin, PPL at 20x magnification; b) Sample # 15, Polyethylene-Cotton sheeting, sample taken from cotton side, PPL at 20x magnification. Both samples show characteristic ribbon form of cotton fibers.

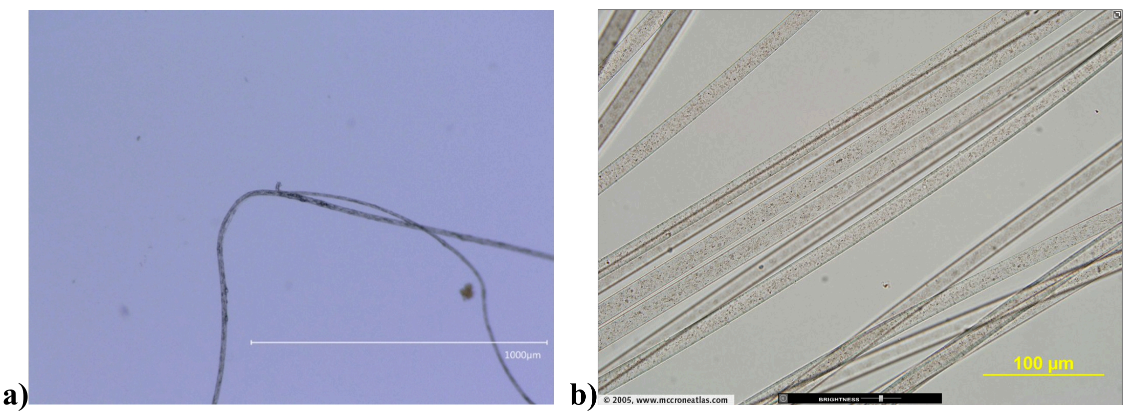


Figure 10: a) Sample # 7, Steelpro Tyvek suit, taken using a Keyence VHX 6000 digital microscope; b) PLM image of melt spun PET with a titanium delustrant from the McCrone Atlas of Microscopic Particles.

5.5 A-D Strip Off-Gassing Tests (28 day, 7 day, 1 day)

In interpreting the results from the A-D Strip Off-Gassing Tests, there were three aims: to compare the results observed in each of the one, seven, and 28 day long test times, to incorporate these results with those from the materials identification tests to complete the Multi-Test, and to compare the A-D Strip Test and Multi-Test results to those from the Oddy Test. The results from the different A-D Strip Off-Gassing Test runtimes is presented in **Table 7,** and the percentage of samples with Passing, Temporary Use, and Failing grades for each runtime is presented in **Table 8**. Images of each A-D strip are found in **Appendix 5.**

Table 7: A-D strip test results for the 28, 7, and 1-day runtimes. The results columns record the original results of Pass (green), Temporary Use (yellow), and Failure (red).

Sample #	Material	28 Day	7 Day	1 Day
1	PTFE tape	[yellow]	[green]	[green]
2	Aluminum foil	[green]	[green]	[green]
3	Aluminum foil	[green]	[green]	[green]
4	Aluminum foil	[green]	[green]	[green]
5	Silicona (Hot Glue)	[red]	[red]	[red]
6	Silicona (Hot Glue)	[red]	[red]	[red]
7	Polyethylene/Polypropylene	[yellow]	[green]	[yellow]
8	Polyethylene foam	[yellow]	[yellow]	[green]
9	Polyethylene foam	[green]	[yellow]	[yellow]
10	Polyethylene foam	[red]	[red]	[yellow]
11	White tissue paper	[green]	[green]	[green]
12	Yellowed tissue paper	[green]	[green]	[green]
13	White sulfite paper	[green]	[green]	[green]
14	Coroplast	[yellow]	[yellow]	[green]
15	Polyethylene/Cotton sheet	[yellow]	[yellow]	[green]
16	Polyethylene sheeting	[red]	[red]	[red]
17	Polyethylene bag	[yellow]	[yellow]	[green]
18	Polyethylene bag	[yellow]	[yellow]	[yellow]
19a	Polypropylene box	[yellow]	[green]	[green]
19b	lid	[green]	[green]	[green]
19c	handle	[green]	[green]	[green]
20a	Polypropylene box	[red]	[yellow]	[green]
20b	Polypropylene lid	[yellow]	[green]	[green]
20c	Polypropylene handle	[green]	[green]	[green]
21a	Polypropylene box	[green]	[green]	[green]
21b	Polypropylene lid	[yellow]	[green]	[green]
21c	Polypropylene handle	[yellow]	[green]	[green]

22	Ribbon, closed weave			
23	Ribbon, open weave			
24	Cotton muslin			
25	Paper board, thinner			
26	Paper board, thicker			
28/29	Velcro, toothed			
30	Tule			
31	Polyvinylchloride			
32	Cellulose acetate			
33	HDPE			
34	Polystyrene			
CON1	control 1			
CON2	control 2			

Table 8: Percentage of samples that were graded Pass, Temporary Use or Failure for the 1, 7, and 28 day tests. Fourth column, P&T, is the combined percentage of Pass and Temporary grades for each test, considering that the distinction between the two may be too subjective to be valid.

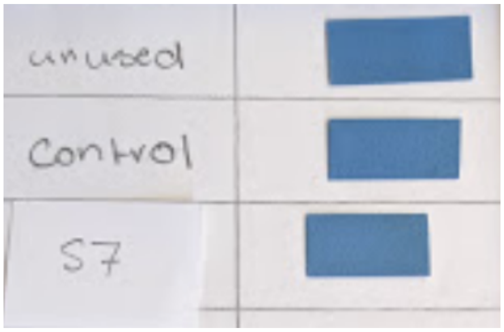
	P	**T**	**F**
1 day	63%	24%	13%
7 days	61%	21%	18%
28 days	45%	32%	24%

In the 28 day test, only 17 out of 38 (45%) of samples passed, with their A-D strips showing none to minimal color change. In the 7 day test, 23 samples (61%) passed and in the 1 day test, 24 samples (63%) passed. These results suggest that the test is at least somewhat dependent on the total runtime, with notably fewer materials passing after 28 days compared to seven or one days. The 28 day test also produced the highest variation in test results, with 45% Passing, 32% graded for Temporary Use, and 24% Failing, suggesting that with time the test has a greater sensitivity to different levels of off-gassing by each material. However, the one and seven day tests both successfully identified more than half of the samples that received a Failing grade in the 28 day test, suggesting that shorter runtimes can provide some warning against the most volatile materials. Previous research has supported the application of seven day runtimes due to observed rapid color change in the strips and a divergence from calibrated results in longer runtimes (Nicholson and O'Loughlin 1996; Hackney 2016). However, the possible negative impact of a longer runtime is still being researched, and the Image Permanence Institute states in its User's Guide that strips left in contact with the material being tested for several weeks still provide accurate results (*User's Guide for A-D Strips: Film Base Deterioration Monitors* 2016). Finally, the increased variation in the results provided by the 28 day test suggests that there could be some benefit to a longer runtime. For this reason, the results from 28 day test were incorporated into the overall results for the Multi-Test.

It was hypothesized that results would worsen with each progressively longer runtime, however this was not consistently observed. The most irregular change in results between the three runtimes was within the Temporary Use category (**Table 8**). There was a decrease in Temporary Use grades and a rise in Failed samples between the one and seven day tests, which could have been due to increased off gassing over the course of the longer runtime. However, as can be seen in **Table 7**, there are only two samples whose grades changed from Temporary Use to Failure between the one and seven day runtimes. On the other hand, there are five samples that were graded for Temporary Use in the one day test and then given a Pass in the seven day test. It is then most likely that much of the variation between the Pass and Temporary Use categories is due to inconsistent interpretation of the A-D strips.

One possible limitation to the interpretation of the A-D Strip Test results is the impact of relative humidity on the performance of the A-D Strips. Previous research has shown that between 60 and 90%, increasing RH induces a stronger colorimetric change, but that variation in RH below 60% did not significantly impact results. (Hackney 2016). Ambient RH conditions in the lab at the Getty Villa student labs do fluctuate, however, even in the wettest months between January and March, RH fluctuations trend below 60%. This suggests that variable and high humidity conditions over the three different runtimes did not play a primary role in the inconsistent interpretation of results. However, this is certainly something to consider when preparing the test for use in humid field conditions. To mitigate fluctuations in RH and T in a field setting, the test chambers should be stored in the most stable climate available such as an inner room of a field lab or even a living space. They should also be kept in a buffered container, such as nested cardboard boxes.

Another possible cause of inaccurate interpretation is the subjectivity of color change recognition. Lighting conditions and the unique perception of the individual interpreting the results are likely the primary sources of uncertainty in these tests. In particular, the difference between minimal color change (Pass) and notable color change, possibly with a green tint (Temporary Use) may have been too subjective to make a consistent distinction between results. **Figures 11 and 12** show two examples of inconsistent strip interpretation for two samples whose performances improved from Temporary Use to Pass with increasing runtimes. **Figure 11** shows the A-D strips from the one day and seven day runtimes for sample 7, and **Figure 12** shows the strips from the seven day and 28 day runtimes for sample 9. However, there is minimal to no color difference between the strips. This suggests that inconsistent interpretation led to inaccurate grading.

a) 

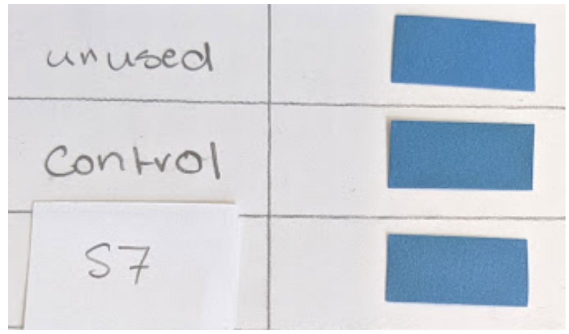
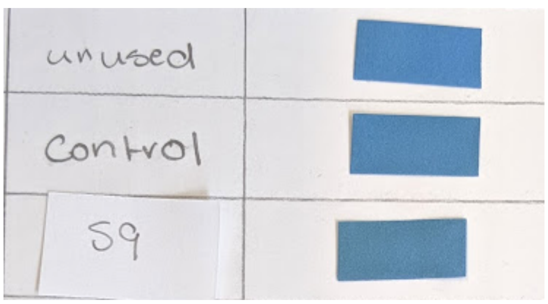
b) 

Figure 11: AD-Strip results for sample 7, polyethylene/polypropylene sheeting: a) 1 Day, Temporary Use; b) 7 Days, Pass. The strips are very similar in color and should have been graded the same.

a) 

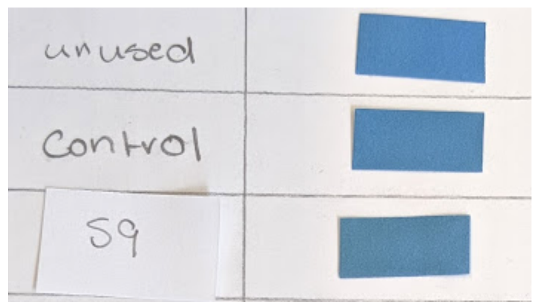
b) 

Figure 12: A-D Strip results for sample 9, polyethylene/polypropylene sheeting: a) 7 Day, Temporary Use; b) 28 Days, Pass. The strips are very similar in color and should have been graded the same.

The difficulty with interpretation also likely led to Control 2 being given a Temporary Use grade in the one and seven day runtimes. Comparing these strips was the first sign that the difference between Pass and Temporary Use could be difficult to determine. **Figure 13** shows both control strips in the seven day runtime. There is a perceptible color difference that could have been due to an improper seal on the jar for Control 2 or contamination within the jar or on the strip. However, the color difference is minor and both should have passed.

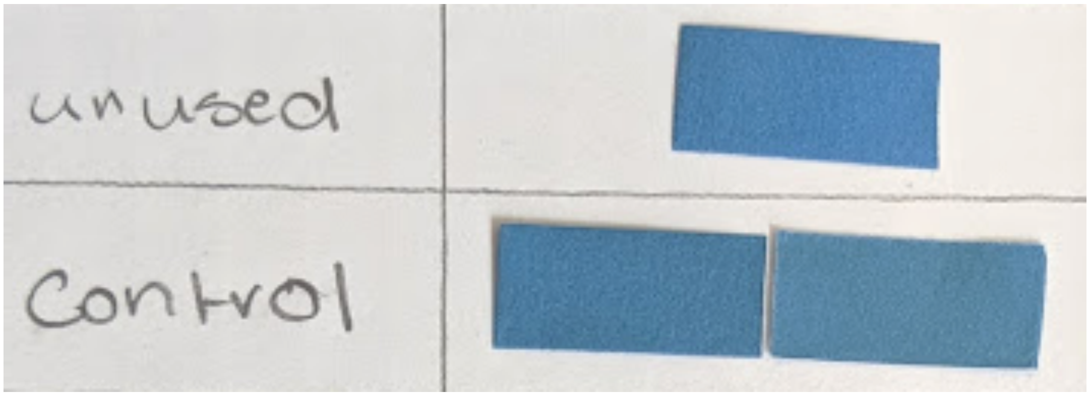
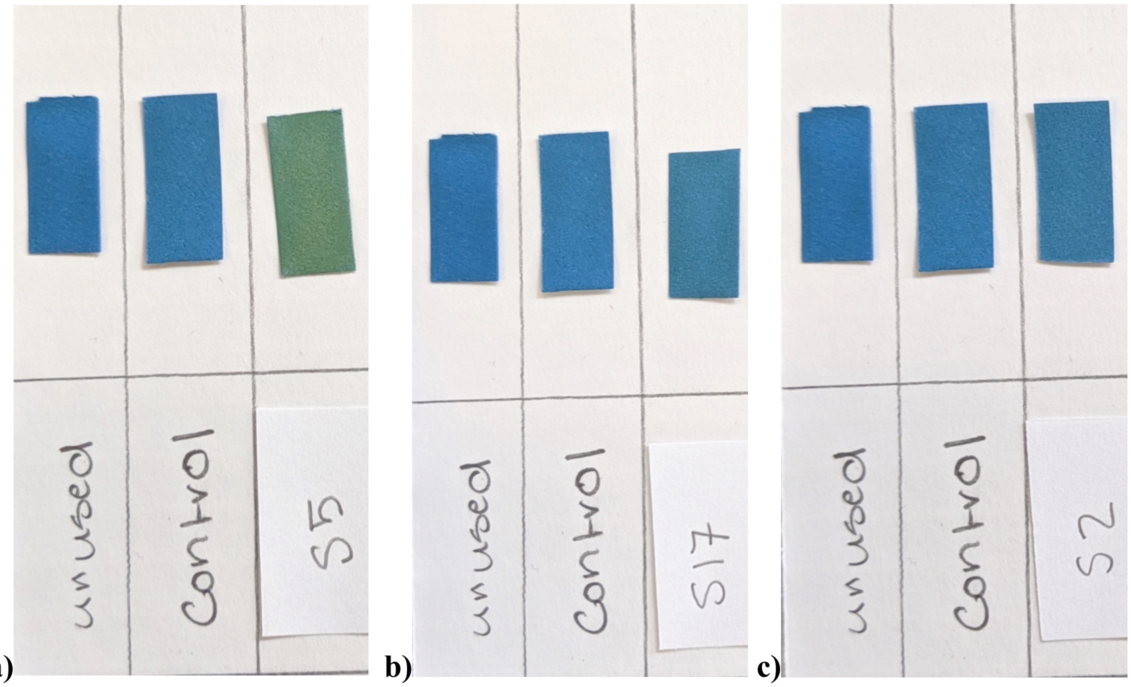


Figure 13: Control strips from the 7 day runtime, compared to an unused strip.

The bright green or yellow tinted A-D strips, marking a Failed sample, were readily distinguished from other results (**Figure 14**). Consistent interpretation was seen in all failed samples, as no sample was given a Pass or Temporary use grade if it failed a shorter runtime. As is provided in the MMA Oddy Test Protocol, ("Oddy Test Protocols" n.d.), reference images of Pass, Temporary Use, and Failing A-D Strips, including examples of variation within each category, would be helpful in making interpretation more consistent between tests and interpreters. Further research could be done into standardizing the interpretation process using a colorimeter, reflectance spectrophotometer, or Photoshop. However, these techniques require expensive equipment or standardized lighting conditions for imaging, both of which could be prohibitive in a field setting.



a) b) c)

Figure 14: a) Failing A-D strip from sample #5, hot melt adhesive; b) A-D strip from sample # 17, polyethylene bag, graded for Temporary Use, now passing; c) Passing A-D strip from sample # 2, aluminum foil. Results taken from the 28-Day test and imaged using overcast natural light and the camera of a Google Pixel 3.

5.7 Oddy Test

Interpretation of the Oddy Test results was done using the silver, copper and lead coupon libraries provided by the Metropolitan Museum of Art (MMA) in their Oddy Test Protocol on the AIC Wiki (Buscarino 2018b, 2018c, 2018a). Individual coupons were given a Pass, Temporary Use, or Fail grade based on the MMA protocol. The grade given each sample overall was based on the coupon in the test chamber with the lowest grade. Interpretation was completed the day that coupons were removed from the oven to ensure that the appearance of the coupons was representative of the environment within the test chambers and minimally influenced by the ambient lab environment. Images of each set of metal coupons were taken using a Keyence VHX 6000 digital microscope, which can be found in **Appendix 6**.

To judge the validity of the test protocol, a control was prepared with both the glass beaker and polyethylene medicine cup. The control received a Temporary Use rating while the medicine cup control Failed. Both of these results should raise suspicion about the validity of the test, however other results suggest that the controls could have been outliers or contaminated in some way. To judge the reliability of the test, three iterations of sample 20b were prepared, one of which (sample 20b/3) was prepared with the medicine cup. Sample 20b/3 received a Passing grade, suggesting that the medicine cup is not inherently problematic as test chamber furniture. The other two tests of sample 20b resulted in a Temporary Use rating. With only a slight variation between the three iterations of sample 20b, and all results being acceptable for at least Temporary Use, the various set-ups within the test chambers were considered to provide reliable results.

Seventeen out of 38 samples (45%), failed the Oddy Test. 18 samples (47%) passed for Temporary Use, while only three samples (8%) were given a Pass (**Table 9**). The three materials that passed were the Triple B aluminum foil (sample 2), the Duraplast polypropylene box (sample 19a), and 1 of the 3 triplicated tests of the lid to the Rey plast polypropylene box (sample 20b/3). Due to limited resources, samples 19c, 20c, 21c, and 25 were not tested. There was no observable pattern in the types of materials

In interpreting the results of the Oddy test, it became apparent that water retention was highly correlated with the grade given to each metal coupon. This correlation highlights the importance of weighing the test chambers before and after testing is completed to measure the amount of water retained during the test. **Table 9** notes the difference in weight of the test chambers before (BT) and after testing (AT).

Table 9: Oddy Test results for all tested samples. The results are grouped by Fail/Pass/Temporary Use ratings. The table also indicates the amount of weight loss observed in each camber at the end of the test, and whether each test chamber was set up for vapor or partial contact testing.

Sample #	Material	Vapor/ Contact	S Weight (g)	BT Weight (g)	AT Weight (g)	Weight Loss (g)	Pb	Cu	Ag	F/P/ T
24	Cotton muslin	C	2.01	147.95	147.97	-0.02				F
14	Coroplast	C	2.00	119.23	119.22	0.01				F
30	Tule	C	1.96	119.76	119.75	0.01				F
32	Cellulose acetate	V	1.99	122.01	122	0.01				F
5	Silicona (Hot Glue)	V	2.01	127.11	127.08	0.03				F
10	Polyethylene foam	C	1.94	119.09	119.06	0.03				F
Med. Cup.	Medicine Cup Control	V		119.31	119.28	0.03				F
3	Aluminum foil	V	1.94	152.36	152.32	0.04				F
9	Polyethylene foam	C	1.93	119.41	119.36	0.05				F
7	Polyethylene/Po lypropylene	C	2.01	120.22	120.16	0.06				F
16	Polyethylene sheeting	C	2.01	153.64	153.56	0.08				F
6	Silicona (Hot Glue)	V	2.05	129.65	129.42	0.23				F
33	HDPE	V	1.85	122.14	121.82	0.32				F
18	Polyethylene bag	C	2.01	155.09	154.76	0.33				F
34	Polystyrene	V	2.01	122.22	121.47	0.75				F
8	Polyethylene foam	C	1.92	119.15	118.29	0.86				F
31	Polyvinylchlori de	V	1.89	120.98	120.07	0.91				F
19a	Polyethylene box	V	1.97	128.53	127.65	0.88				P
20b/3	lid third	V	1.94	122.2	121.27	0.93				P
2	Aluminum foil	V	1.98	153.31	152.35	0.96				P
12	Yellowed tissue paper	C	1.99	119.94	119.86	0.08				T
22	Ribbon, closed weave	V	0.51	127.03	126.94	0.09				T
13	White sulfite paper	C	1.94	119.46	119.11	0.35				T
15	Polyethylene/C	C	1.99	119.36	118.96	0.4				T

	otton sheet									
20b/2	lid second	V	2.05	127.81	127.35	0.46				T
20a	Polyethylene box	V	1.94	132.76	132.26	0.5				T
19b	lid	V	1.98	128.29	127.69	0.6				T
23	Ribbon, open weave	V	0.50	128.13	127.46	0.67				T
20b	lid	V	1.91	128.92	128.18	0.74				T
21b	lid	V	1.95	129.47	128.65	0.82				T
21a	Polyethylene box	V	1.93	127.76	126.94	0.82				T
17	Polyethylene bag	C	1.99	153.32	152.47	0.85				T
28/29	Velcro, toothed	C	1.98	119.2	118.34	0.86				T
Contro l	Control	V		127.67	126.79	0.88				T
1	PTFE tape	V	2.00	126.45	125.55	0.9				T
4	Aluminum foil	V	1.97	157.16	156.19	0.97				T
11	White tissue paper	C	2.01	119.06	118.06	1				T
26	Paper board, thicker	V	2.01	128.56	127.52	1.04				T
25	Paper board, thinner									
19c	handle									
20c	handle									
21c	handle									

Those samples with a Fail grade lost an average of only 0.22g of water with more than half losing less than 0.1g. Those that were deemed acceptable for Temporary Use lost an average of 0.66g of water, and those that were given a Pass lost an average of 0.92g of water. This could suggest a universal flaw in the test protocol that led to water retention being the primary variable between samples. However, there was notable variation in how individual coupons reacted, suggesting different volatiles were influencing test results and not a common contaminant. Dialogue between the author and different institutions that regularly conduct the Oddy Test have revealed that with a perfect seal and 100% water retention, many materials perform worse than anticipated based off of their material composition or known archival quality (McInnis 2019; Breitung 2019). This observation deserves further investigation, beyond the scope of this thesis, questioning whether the Oddy Test accurately determines if a material is unsafe for use or only that a perfect seal was achieved in a test chamber.

5.8 Surface pH Test

All pH readings ranged between 7.13 and 7.84 (**Table 10**). Although there was some variation between samples within this tight range, it could not be clearly attributed to material type and was not directly correlated with the results of later off-gassing tests. This is likely due to the fact that most of the samples, being plastic or aluminum, are impermeable to water. The short amount of time that the water was in contact with the samples before testing also likely impacted results. Due to the tight range of pH results, and the 1 pH step resolution of the 0-14pH MColorpHast pH-indicator strips, there was no reason to continue on to the field test that uses these simple strips.

Table 10: Surface pH readings taken using the ϕ340 pH/Temp Meter by Beckman and the Thermo Scientific Orion 8135B Ross Flat Surface Probe.

Sample #	Description	Surface pH
1	PTFE tape	7.47
2	Aluminum foil	7.49
3	Aluminum foil	7.53
4	Aluminum foil	7.43
5	Silicona (Hot Glue)	7.31
6	Silicona (Hot Glue)	7.38
7	Polyethylene/Polypropylene	7.44
8	Polyethylene foam	7.46
9	Polyethylene foam	7.38
10	Polyethylene foam	7.45
11	White tissue paper	7.63

12	Yellowed tissue paper	7.44
13	White sulfite paper	7.61
14	Coroplast	7.47
15	Polyethylene/Cotton sheet	7.48(PET)/7.35(cotton)
16	Polyethylene sheeting	7.39
17	Polyethylene bag	7.61
18	Polyethylene bag	7.63
19 a	Polyethylene box	7.5
19 b	lid	7.49
19 c	handle	7.54
20 a	Polyethylene box	7.59
20 b	lid	7.56
20 c	handle	7.57
21 a	Polyethylene box	7.6
21 b	lid	7.56
21 c	handle	7.43
22	Ribbon, closed weave	7.13
23	Ribbon, open weave	7.23
24	Cotton muslin	7.21
25	Paper board, thinner	7.74
26	Paper board, thicker	7.77
28	Velcro, toothed	7.6
29	Velcro, soft	7.84
30	Tule	7.56
31	Resin Kit Polyvinylchloride	7.5
32	Resin Kit Cellulose acetate	7.52

6 Discussion

6.1 Multi-Test Results: Combining Materials Identification and the A-D Strip Test

The theory behind the Multi-Test is that the information provided through material identification and acidic off-gas monitoring is enough to determine if a material is safe to use in object storage and display. Before the results of the Multi-Test were compared with the standard Oddy Test, the results from each of the individual component tests were combined into a final Multi-Test grade for each sample material, presented in **Table 11**. The results for the Material ID were compiled from the Beilstein Test for PVC, the Combustion Vapor pH Test, and Fiber Identification.

The lowest score between the two steps of the Multi-Test determined the final test score. Of the 38 samples, 15 (39%) Passed the Multi-Test, while 12 samples (32%) were graded for Temporary Use, and 11 samples (29%) Failed. Importantly, six out of the 11 Failed samples (55%) were failed due to the result of only one of the two steps of the Multi-Test. Samples 1, 23 and 30 were failed due to their Material ID, while samples 10, 16 and 33 were failed due to their performance in the A-D Strip test. These results reinforce the importance of completing both types of assessment in order to identify those materials which are unfit for use with objects.

Table 11: Results of the Multi-Test presented along side the A-D Strip Off-Gassing and Material ID test results. Red= Fail; Yellow=Temporary; Use P=Pass, and a grey box means that a test for Material ID was not completed

Sample #	Material	Brand	Source	A-D Strip	Material ID	Multi-Test
1	PTFE tape	Shurfix	Sodimac			F
2	Aluminum foil	Triple B	Metro			P
3	Aluminum foil	Krea	Metro			P
4	Aluminum foil	U-Thil	Sodimac			P
5	Silicona (Hot Glue)	Ove	Museum			F
6	Silicona (Hot Glue)	Baras de Silicona	Sodimac			F
7	Polyethylene/ Polypropylene	Steelpro Safety	Promart			T
8	Polyethylene foam		Museum			T
9	Polyethylene foam		Museum			T
10	Polyethylene foam		Museum			F
11	White tissue paper		Museum			P
12	Yellowed tissue paper		Museum			P

13	White sulfite paper		Museum			P
14	Coroplast		Museum			T
15	Polyethylene/ Cotton sheet	House Solutions	Sodimac			T
16	Polyethylene sheeting		Sodimac			F
17	Polyethylene bag	policlick	Museum			T
18	Polyethylene bag	policlick	Museum			T
19a	Polypropylene box	Duraplast	Sodimac			T
19b	Polypropylene lid	Duraplast	Sodimac			P
19c	Polypropylene handle	Duraplast	Sodimac			P
20a	Polypropylene box	Rey plast	Sodimac			T
20b	Polypropylene lid	Rey plast	Sodimac			T
20c	Polypropylene handle	Rey plast	Sodimac			P
21a	Polypropylene box	Wenco	Promart			P
21b	Polypropylene lid	Wenco	Promart			T
21c	Polypropylene handle	Wenco	Promart			T
22	Ribbon, closed weave		Museum			P
23	Ribbon, open weave		Museum			F
24	Cotton muslin		Museum			P
25	Paper board, thinner		Museum			P
26	Paper board, thicker		Museum			P
28/29	Velcro, toothed		Museum			F
30	Tule		Museum			F
31	Polyvinylchloride		Resin Kit			F
32	Cellulose acetate		Resin Kit			F
33	HDPE		Resin Kit			F
34	Polystyrene		Resin Kit			P

6.2 Comparing the Oddy Test and Multi-Test Results

The results of the Multi-Test were then compared with the Oddy Test results (**Table 12**). The goal of this comparison is to see if the Multi-Test provides results that agree with or are more conservative than those of the Oddy Test. For each sample, the results from the Multi-Test were determined to be Acceptable, Unacceptable, or Cautionary based on their agreement with the Oddy Test results. Acceptable results were those where the Multi-Test gave the same or a worse grade to a sample as the Oddy Test. 19 out of 34 tests (56%) were deemed Acceptable. Unacceptable results were those where the Multi-Test gave a Passing or Temporary Use grade to a material that Failed the Oddy Test. Eight out of 34 tests (24%) were deemed Unacceptable. Importantly, only three of the eight Unacceptable tests were cases where a material Passed the Multi-Test but Failed the Oddy Test. Cautionary Multi-Test Results were those where a material was given a Passing grade in the Multi-Test but were graded for Temporary Use in the Oddy Test. These tests were distinguished from the Unacceptable Multi-Test assessments because both the Multi-Test and the Oddy test approve them for use for some length of time. Seven out of 34 tests (20%) gave Cautionary results.

Table 12: Presents the results of the Multi-Test and Oddy Test, organized by the agreement between the two tests. In both results columns Green=Pass, Yellow= Temporary Use, Red=Failure, and a grey box means that the test was not completed on that sample. In the Agreement column, A=Acceptable; U=Unacceptable; C=Cautionary.

Sample #	Material	Brand	Source	Multi-Test	Oddy Test	Agreement
1	PTFE tape	Shurfix	Sodimac			**A**
5	Silicona (Hot Glue)	Ove	Museum			**A**
6	Silicona (Hot Glue)	Baras de Silicona	Sodimac			**A**
10	Polyethylene foam		Museum			**A**
16	Polyethylene sheeting		Sodimac			**A**

23	Ribbon, open weave		Museum			**A**
28/29	Velcro, toothed		Museum			**A**
30	Tule		Museum			**A**
31	Polyvinylchloride		Resin Kit			**A**
32	Cellulose acetate		Resin Kit			**A**
33	HDPE		Resin Kit			**A**
2	Aluminum foil	Triple B	Metro			**A**
21a	Polypropylene box	Wenco	Promart			**A**
15	Polyethylene/ Cotton sheet	House Solutions	Sodimac			**A**
17	Polyethylene bag	policlick	Museum			**A**
19a	Polypropylene box	Duraplast	Sodimac			**A**
20a	Polypropylene box	Rey plast	Sodimac			**A**
20b	Polypropylene lid	Rey plast	Sodimac			**A**
21b	Polypropylene lid	Wenco	Promart			**A**
4	Aluminum foil	U-Thil	Sodimac			**C**
11	White tissue paper		Museum			**C**
12	Yellowed tissue paper		Museum			**C**
13	White sulfite paper		Museum			**C**
19b	Polypropylene lid	Duraplast	Sodimac			**C**
22	Ribbon, closed weave		Museum			**C**
26	Paper board, thicker		Museum			**C**
7	Polyethylene/ Polypropylene	Steelpro Safety	Promart			**U**
8	Polyethylene foam		Museum			**U**
9	Polyethylene foam		Museum			**U**
14	Coroplast		Museum			**U**
18	Polyethylene bag	policlick	Museum			**U**
3	Aluminum foil	Krea	Metro			**U**
24	Cotton muslin		Museum			**U**
34	Polystyrene		Resin Kit			**U**
19c	Polypropylene handle	Duraplast	Sodimac			
20c	Polypropylene handle	Rey plast	Sodimac			
25	Paper board, thinner		Museum			
21c	Polypropylene handle	Wenco	Promart			

Overall, it appears that the Multi-Test provides results that reliably mirror results provided by the Oddy Test, supporting the case that the combination of materials identification and acidic off-gas monitoring were able to accurately and consistently determine if the materials in this sample group were safe for object storage and display.

7 Conclusion

Due to its agreement with the Oddy test results, the Multi-Test has shown potential for alternative forms of materials assessment. The version of the Multi-Test presented here addressed several core issues with the Oddy Test. The A-D strips provided a standard coupon that are purchased ready to use, reducing the amount of human error in the preparation of the test. The materials required both for the A-D Strip Test and each of the materials identification tests are less expensive, more accessible, and less cumbersome than the equipment required for the Oddy Test. The Multi-Test also holds potential to be a significantly shorter assessment. The results of the seven day A-D strip test show that shorter runtimes still provide valuable information and are worth completing if a longer runtime isn't an option. Several, more recently recorded limitations of the Oddy Test were also highlighted and discussed. Perfect water retention in the test chamber may lead to inaccurate Failing grades, although more research is necessary to confirm this preliminary observation.

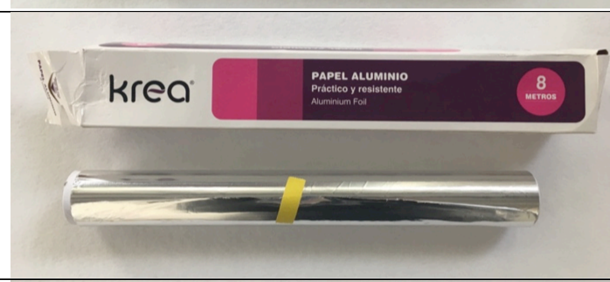
Future research avenues could focus on standardizing the interpretation of the A-D Strip Test as well as understanding the impact of temperature and humidity on test results. Future experiments could identify methods for reducing temperature and humidity extremes and fluctuations in the A-D strip test chambers. The results of the Combustion Residue Test were promising, and support continued research into how this simple technique could provide information about the presence of plasticizers or other additives. Finally, in a broader sense, this paper should encourage conservators working in smaller museums and on archaeological sites to do the best they can with the resources available to them. When determining if a potential storage or display material is safe for use, consider what needs to be known about the material in order to make that decision and find a way to determine that information. This method has the potential to provide a more holistic characterization of the materials being tested as well some form of materials assessment where there might have been none.

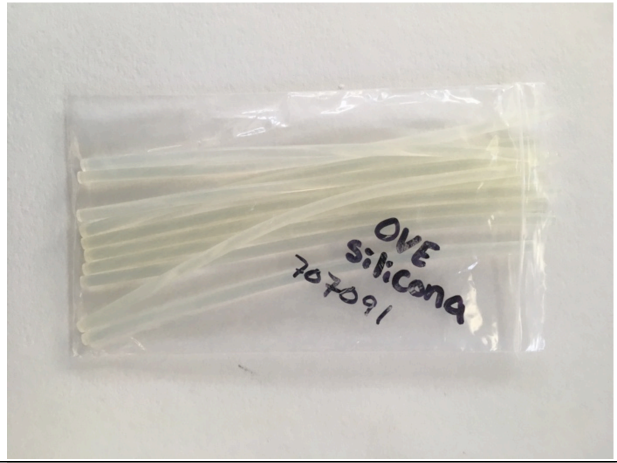
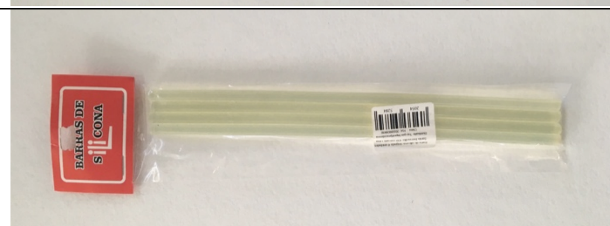
Appendix 1 – Testing Equipment

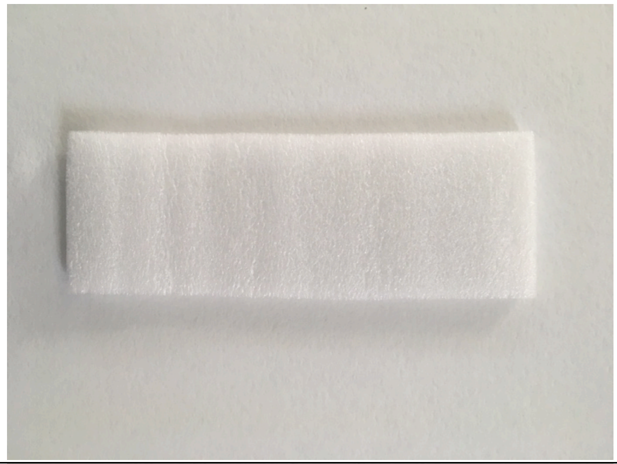
Test	Tool / Materials	Manufacturer	Possible Source	Cost
Surface pH Test				
	Kimwipe	Kimberly-Clark Professional, Mississauga, Ontario, Canada		
	ϕ340 pH/Temp Meter	Beckman Coulter, Inc. Fullerton, CA		
	Orion 8135B Ross Flat Surface Probe	Thermo Fisher Scientific, Waltham, MA		
	Deionized Water	Hach Company, Loveland, CO		
Combustion Vapor pH Test for the Identification of Plastics				\$19.59 – \$26.10
	5 ¾" Fisherbrand™ Dispo sable Borosilicate Glass Pasteur Pipets	Fisher Scientific, Hampton, NH	Fischer Scientific	\$0.15 ea. \$5.10 for 34 tests
	Parafilm "M" laboratory film	Bemis Company, Inc. Neenah, WI	Amazon	\$21.00
	Plastalina	Van Aken International, North Charleston, SC	Blick Art Materials	\$14.49
	Deionized / Distilled Water	Hach Company, Loveland, CO	Grocery store	Varies, low
	Alcohol Lamp or Lighter	N/A	Store or market	Varies, low
Combustion Residue Test				
	VWR mircro slides, superfrost white	VWR International, LLC, Radnor, PA		
	Alcohol Lamp or Lighter	N/A	Store or market	Varies, low
Beilstein Test				\$2.59
	Small gauge electrical copper wire	N/A	Sodimac	S/ 8.90, \$2.59 on 06/10/ 2020
A-D strip off-gassing test				\$94.20
	A-D Strips	Image Permanence Institute, Rochester Institute of Technology, Rochester, NY	Image Permanence Institute	\$60.00
	Glass jars with aluminium PE lined cap	SKS Science Products	SKS Science Products	\$0.95 ea. \$34.20 for 36
Fourier Transform Infrared Reflectography				
	Handheld FTIR G8181-64001	Agilent Technologies, Santa Clara, CA		
Oddy Test				\$385.24

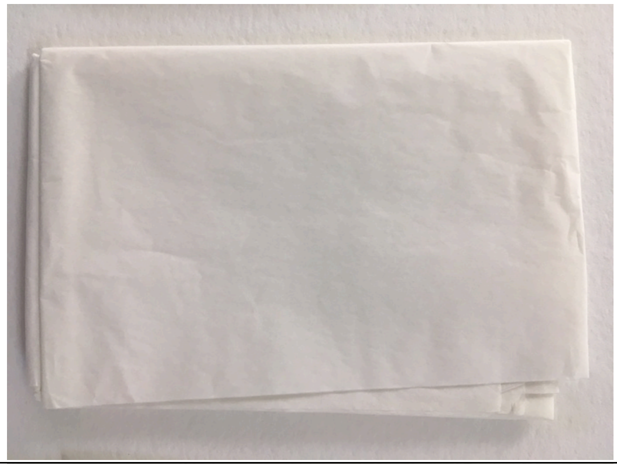
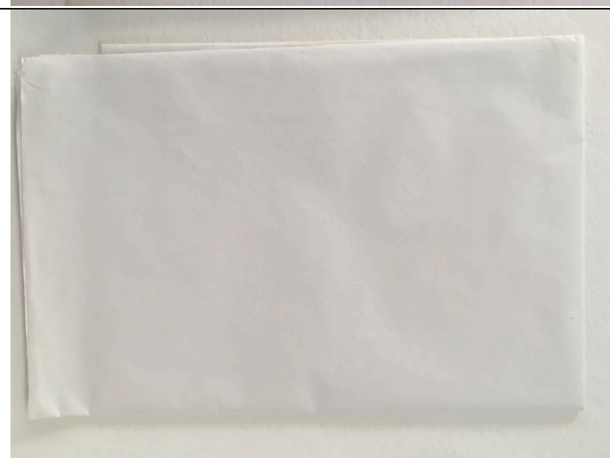
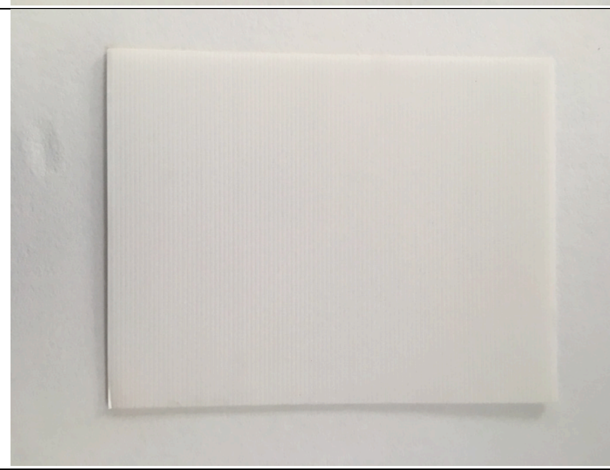
				(without oven)
	Oven		Thermo-Fisher Scientific	\$900.00 - \$3000.00
	Glass jars with aluminum PE lined cap	SKS Science Products	SKS Science Products	\$0.95 ea. \$34.20 for 36
	Electrolytic Copper Foil, 0.02"	EM Science, Gibbstown, NJ	Sigma Aldrich	\$60.00
	24ga Silver sheet, 0.5mm	Metalliferous, New York, NY	Metalliferous	\$73.46 for a 6x2" sheet
	Lead Foil, 0.5mm	GoodFellow Cambridge Limited, Huntingdon, England	GoodFellow	GBP 111.00, \$141.53 on 06/10/2020
	Glass Bristle brush	N/A	Metalliferous	\$12.75
	Kimwipe	Kimberly-Clark Professional, Mississauga, Ontario, Canada	Sigma Aldrich	\$25.40
	High vacuum silicone grease	Dow Corning Corporation, Midland, MI	Sigma Aldrich	\$37.90
Imaging				
	Nikon D90 DSLR camera	Nikon, Minato, Tokyo, Japan		
	Google Pixel 3	Google		
	Keyence VHX 6000 digital microscope	Keyence, Osaka, Japan		

Appendix 2 – Sample Materials

Sample #	Material	Brand	
1	PTFE tape	Shurfix	
2	Aluminum foil	Triple B	
3	Aluminum foil	Krea	
4	Aluminum foil	U-Thil	

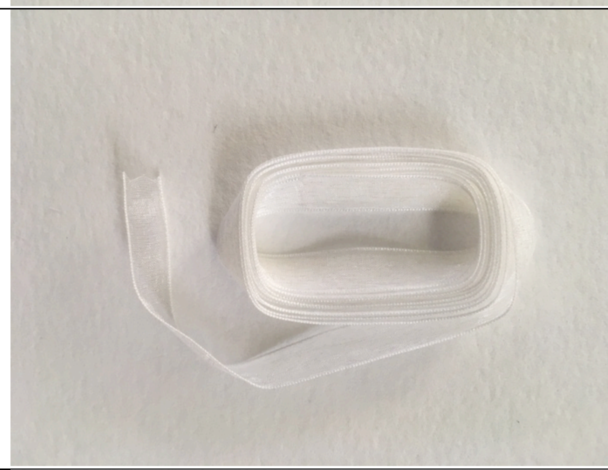
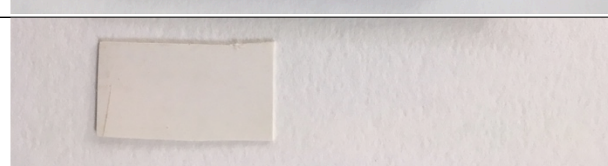
5	Silicona (Hot Glue)	Ove	
6	Silicona (Hot Glue)	Baras de Silicona, Top gan	
7	Polyethylene/ Polypropylene	Steelpro Safety	
8	Polyethylene foam		

9	Polyethylene foam		
10	Polyethylene foam		
11	White sulfite paper		

12	Yellowed sulfite paper		
13	White tissue paper		
14	Coroplast		

15	Polyethylene/ Cotton sheet	House Solutions	
16	Polyethylene sheeting		
17	Polyethylene bag	policlick	
18	Polyethylene bag	policlick	

19	Polyethylene box, lid, handle	Duraplast	
20	Polyethylene box, lid, handle	Rey plast	
21	Polyethylene box, lid, handle	Wenco	

22	Ribbon, closed weave		
23	Ribbon, open weave		
24	Cotton muslin		
25	Paper board, thinner		

26	Paper board, thicker		
28/39	Velcro		
30	Tule		

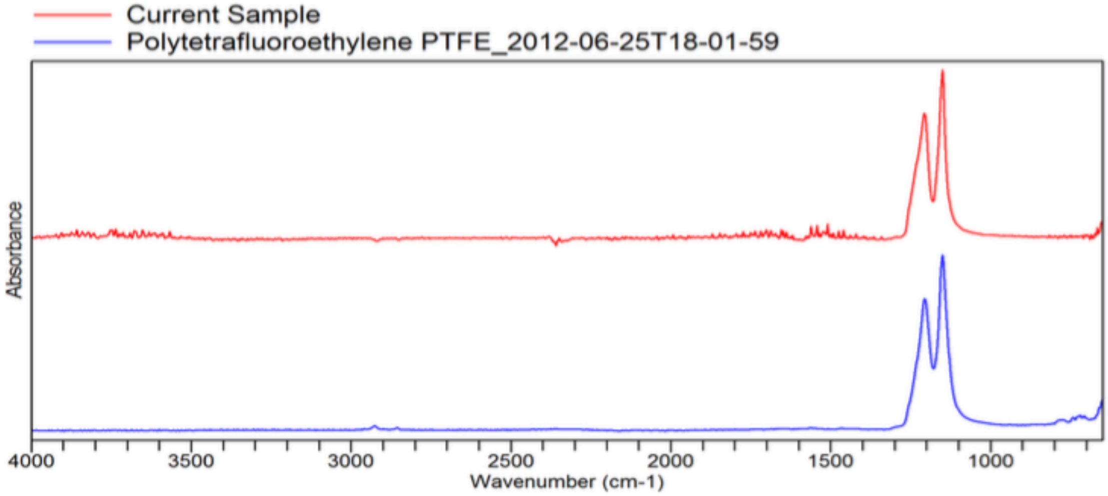
Appendix 3 – FTIR Spectra

Sample ID:s1_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 3:59:17 PM
Range:4000 - 650
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations1_atr_2019-04-26T11-38-12.a2r

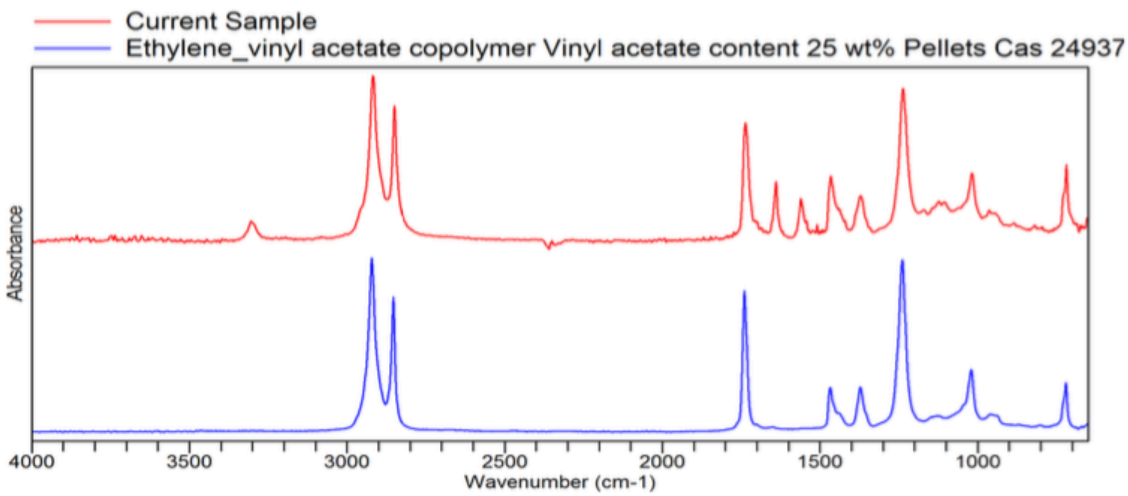


Sample ID:s5_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 3:54:44 PM
Range:4000 - 650
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations5_atr_2019-04-26T11-26-16.a2r

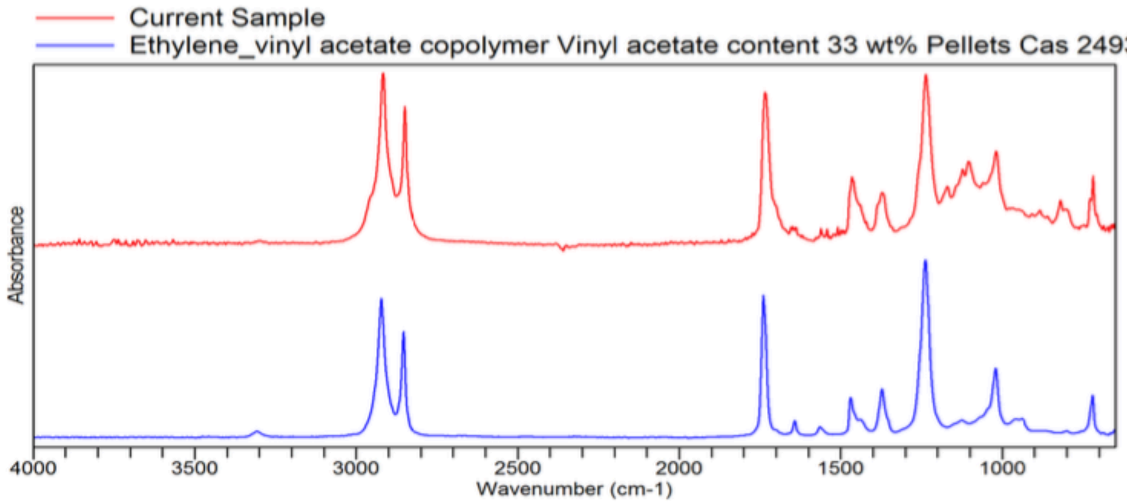


Sample ID:s6_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 3:55:42 PM
Range:4000 - 650
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations6_atr_2019-04-26T11-43-52.a2r

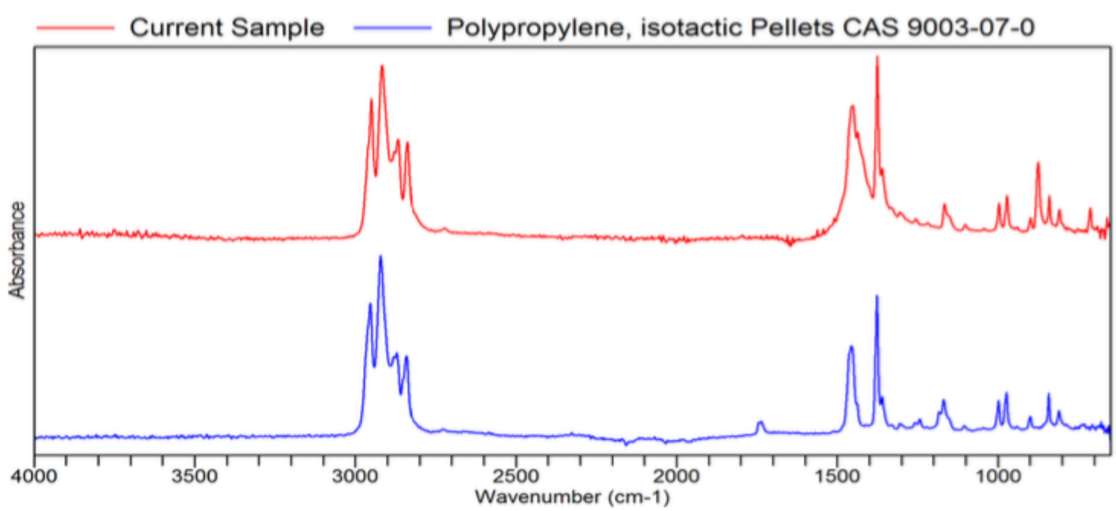


Sample ID:s7_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:21:19 PM
Range:4000 - 650
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations7_atr_2019-04-26T11-51-47.a2r

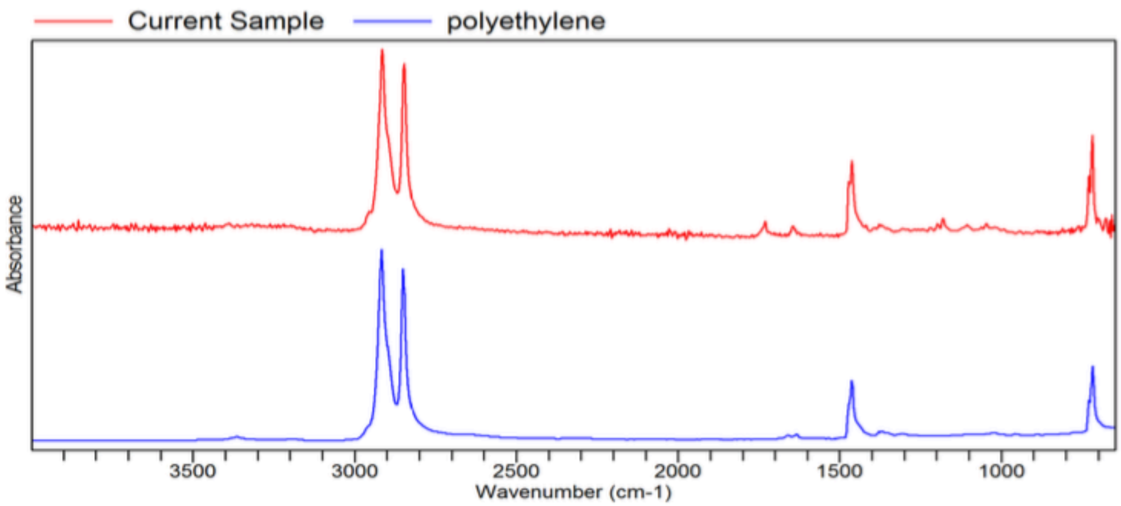


Sample ID:s8_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:33:14 PM
Range:4000 - 650
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations8_atr_2019-04-26T11-40-33.a2r

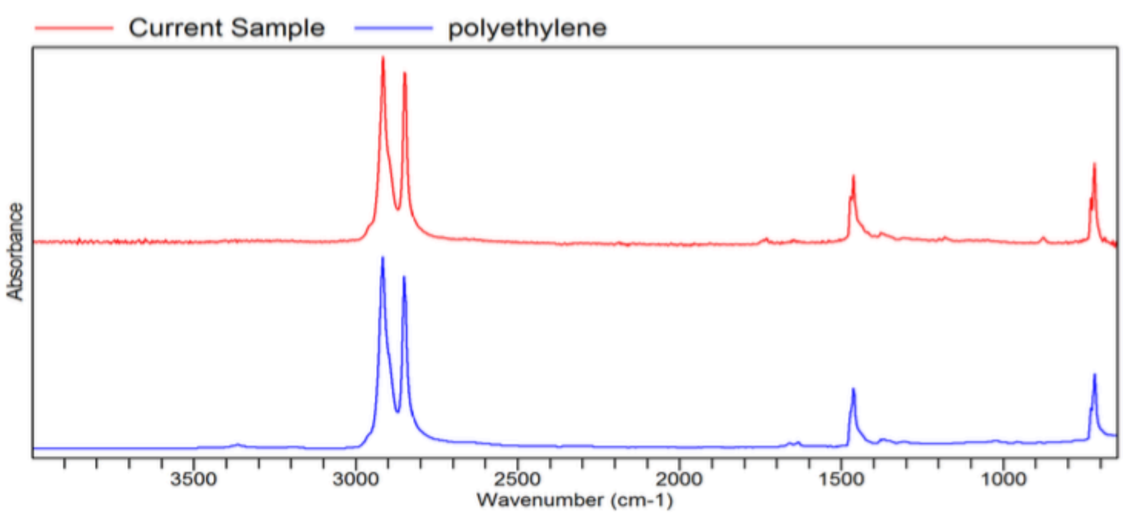


Sample ID:s9_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:31:36 PM
Range:4000 - 650
Apodization:Triangular

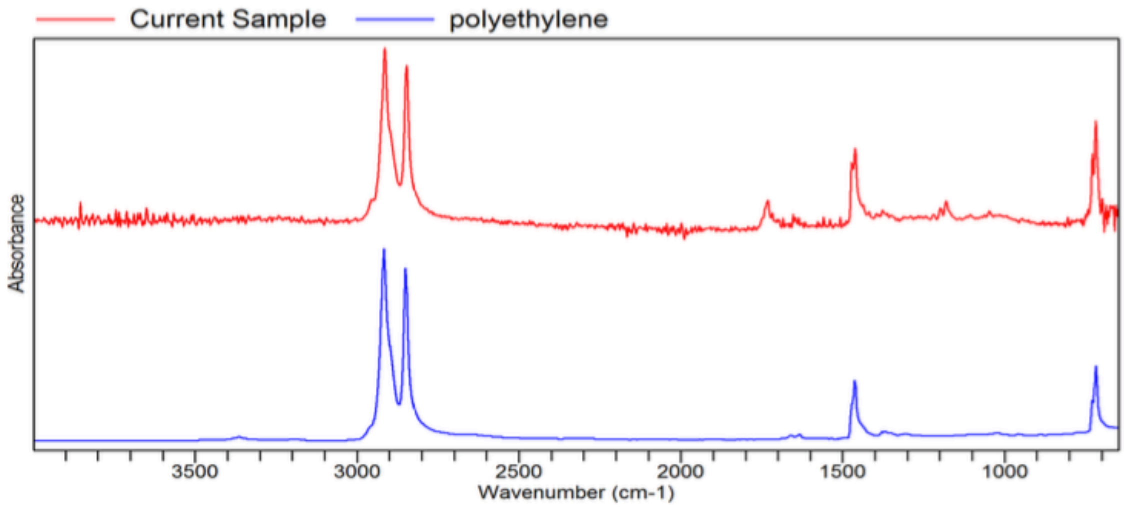
File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations9_atr_2019-04-26T11-46-28.a2r



Sample ID:s10_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good
File
Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations10_atr_2019-04-26T11-33-17.a2r

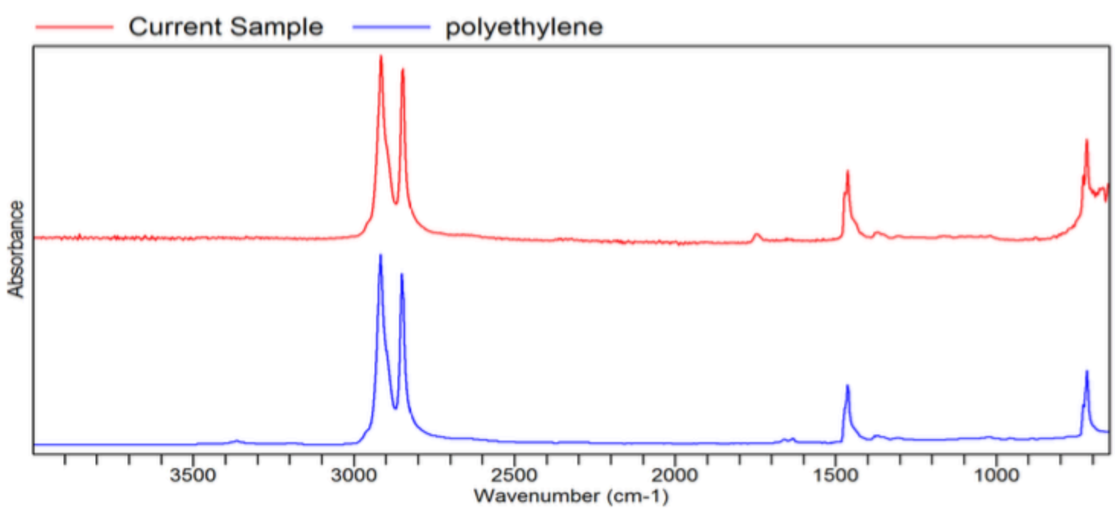
Method
Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:30:24 PM
Range:4000 - 650
Apodization:Triangular



Sample ID:s15_P_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good
File
Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations15_P_atr_2019-04-26T11-50-24.a2r

Method
Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:23:50 PM
Range:4000 - 650
Apodization:Triangular

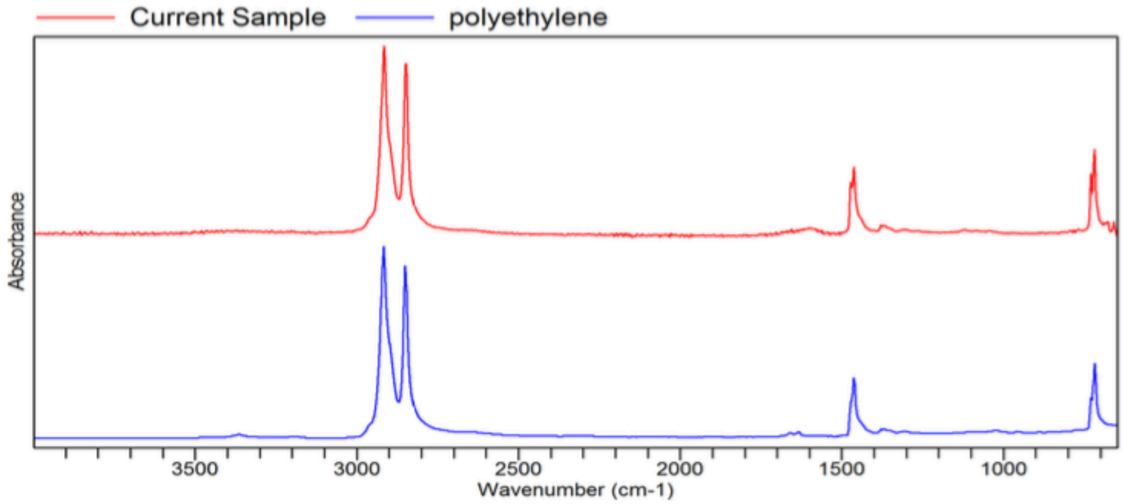


Sample ID:s16_atr

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m

Sample Scans:32
User:admin
Background Scans:32
Date/Time:03/07/2019 4:35:02 PM
Resolution: 8
Range:4000 - 650
System Status: Good
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations16_atr_2019-04-26T11-39-23.a2r

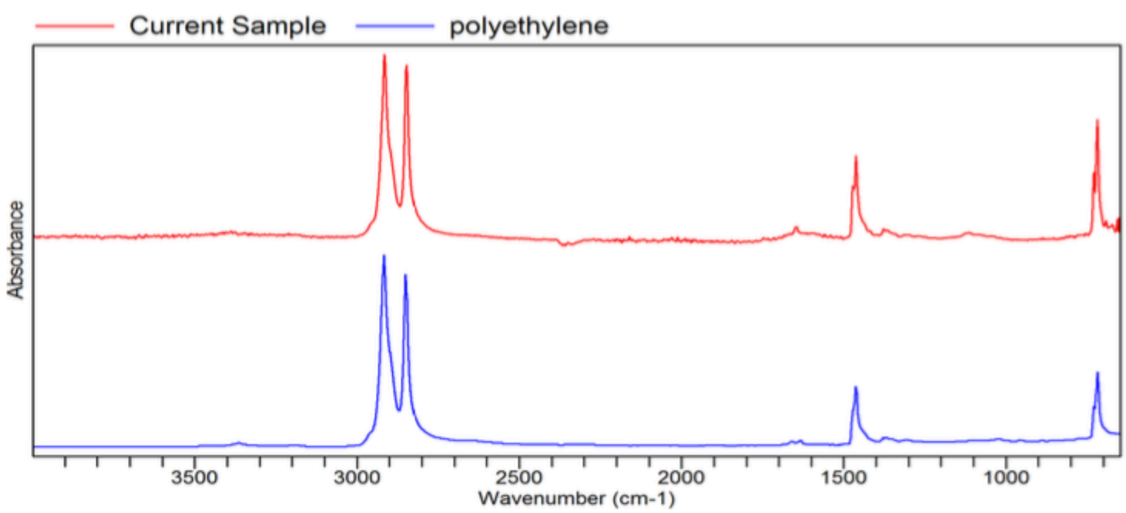


Sample ID:s17_atr

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m

Sample Scans:32
User:admin
Background Scans:32
Date/Time:03/07/2019 4:10:00 PM
Resolution: 8
Range:4000 - 650
System Status: Good
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations17_atr_2019-04-26T11-54-07.a2r



Sample ID:s18_atr

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m

Sample Scans:32

User:admin

Background Scans:32

Date/Time:03/07/2019 4:09:26 PM

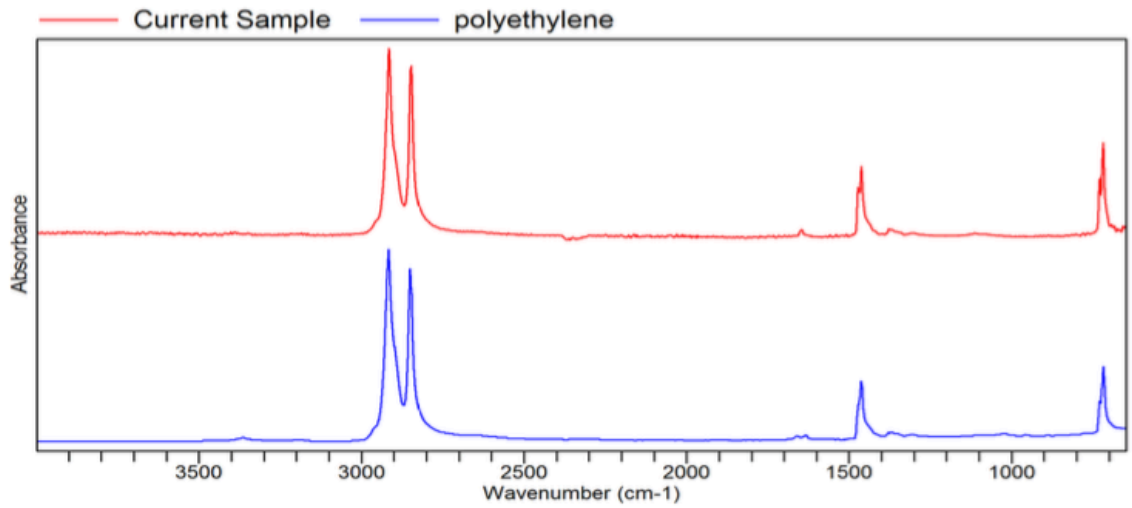
Resolution: 8

Range:4000 - 650

System Status: Good

Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations18_atr_2019-04-26T11-55-57.a2r



Sample ID:s19_B_atr

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m

Sample Scans:32

User:admin

Background Scans:32

Date/Time:03/07/2019 4:05:55 PM

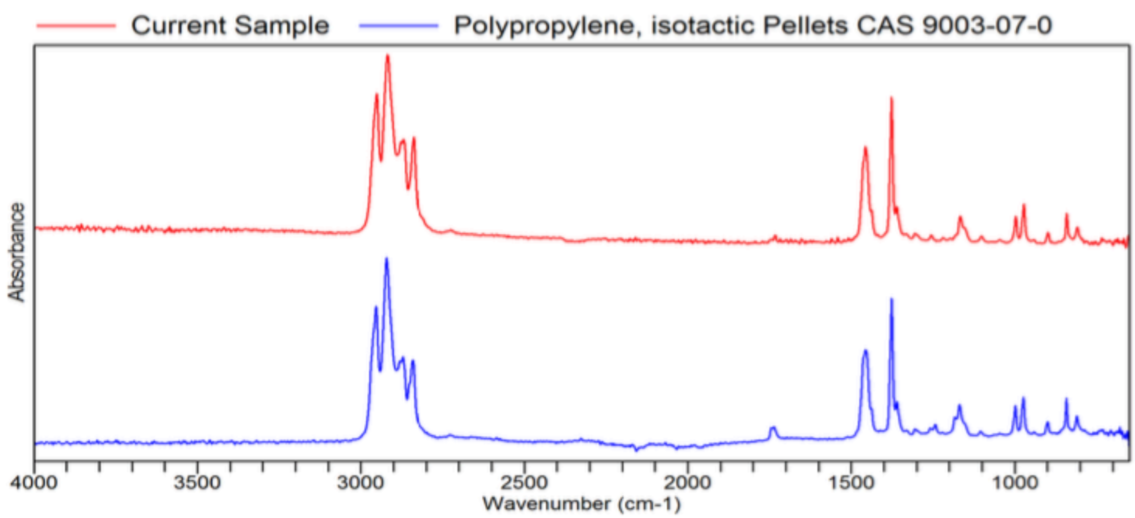
Resolution: 8

Range:4000 - 650

System Status: Good

Apodization:Triangular

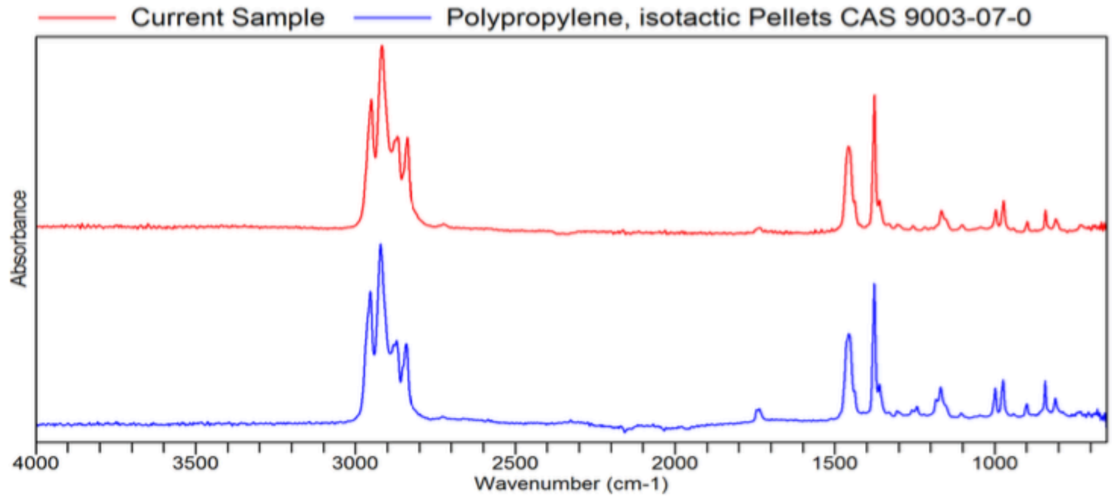
File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations19_B_atr_2019-04-26T11-59-14.a2r



Sample ID:s19_L_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good
File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations19_L_atr_2019-04-26T11-57-52.a2r

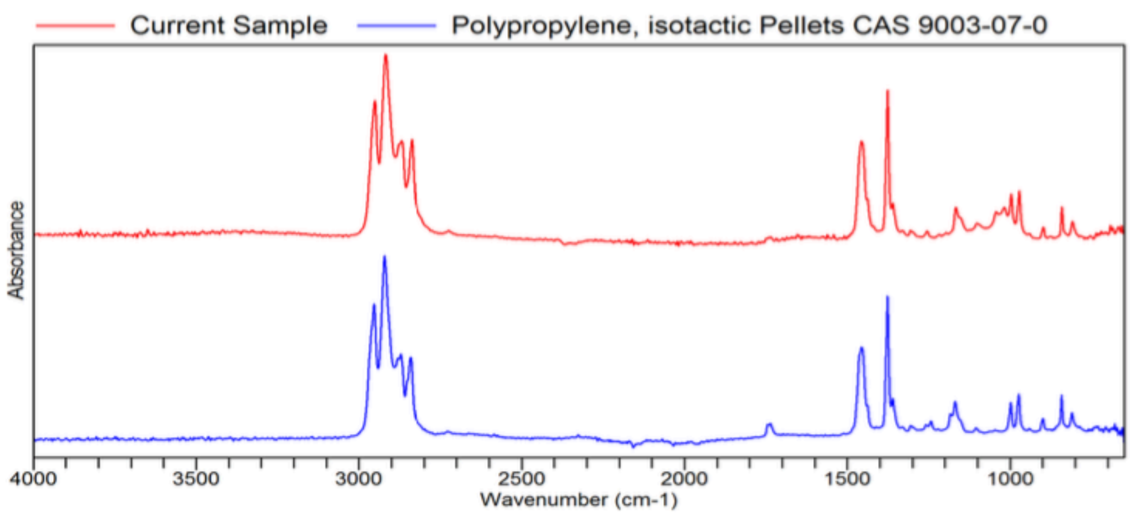
Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:07:17 PM
Range:4000 - 650
Apodization:Triangular



Sample ID:s19_H_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good
File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations19_H_atr_2019-04-26T11-57-03.a2r

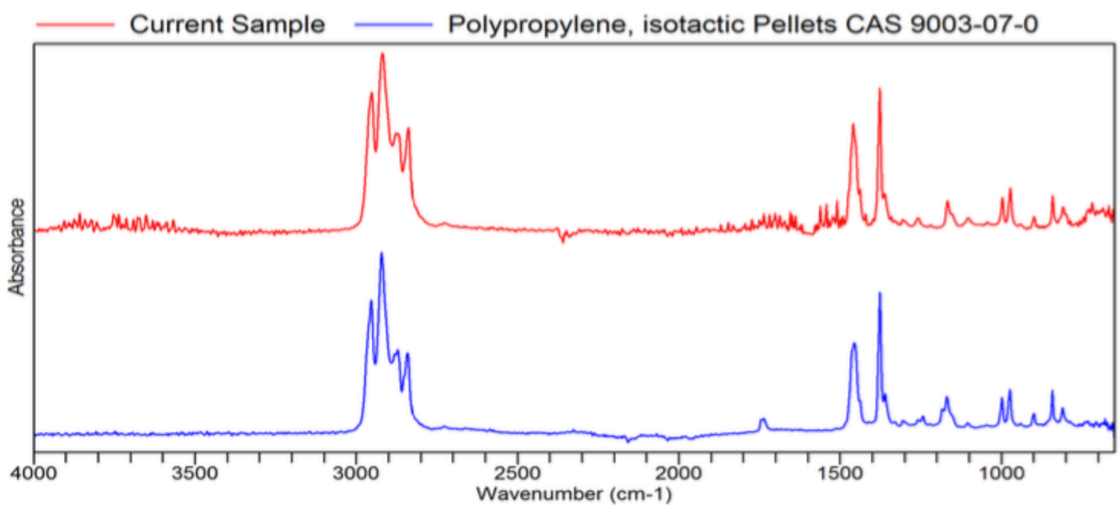
Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:07:49 PM
Range:4000 - 650
Apodization:Triangular



Sample ID:s20_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good
File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations20_atr_2019-04-26T12-00-13.a2r

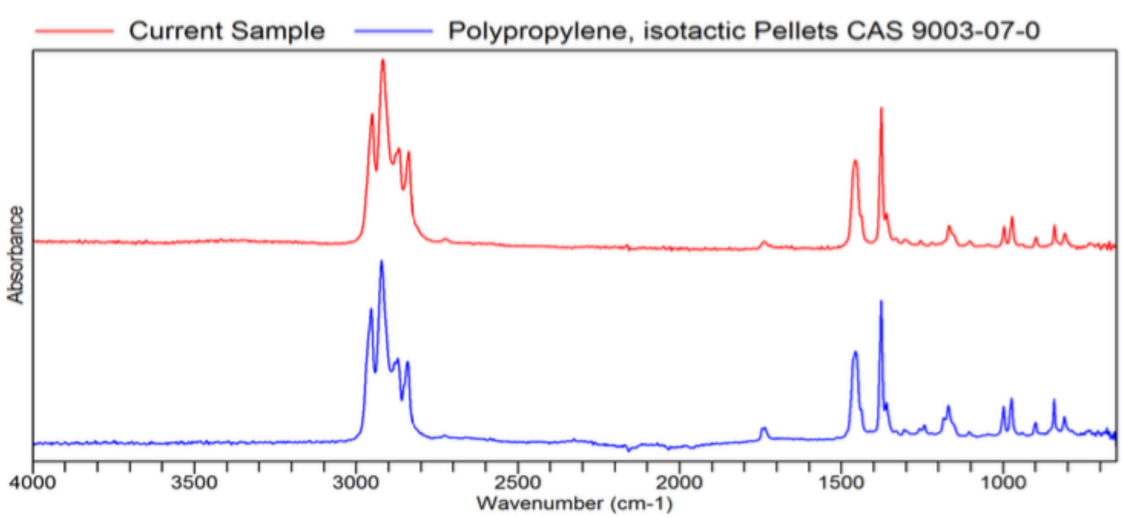
Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 3:56:40 PM
Range:4000 - 650
Apodization:Triangular



Sample ID:s21_B_atr

Sample Scans:32
Background Scans:32
Resolution: 8
System Status: Good
File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations21_B_atr_2019-04-26T12-01-09.a2r

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m
User:admin
Date/Time:03/07/2019 4:02:10 PM
Range:4000 - 650
Apodization:Triangular



Sample ID:s21_L_atr

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m

Sample Scans:32

User:admin

Background Scans:32

Date/Time:03/07/2019 4:01:32 PM

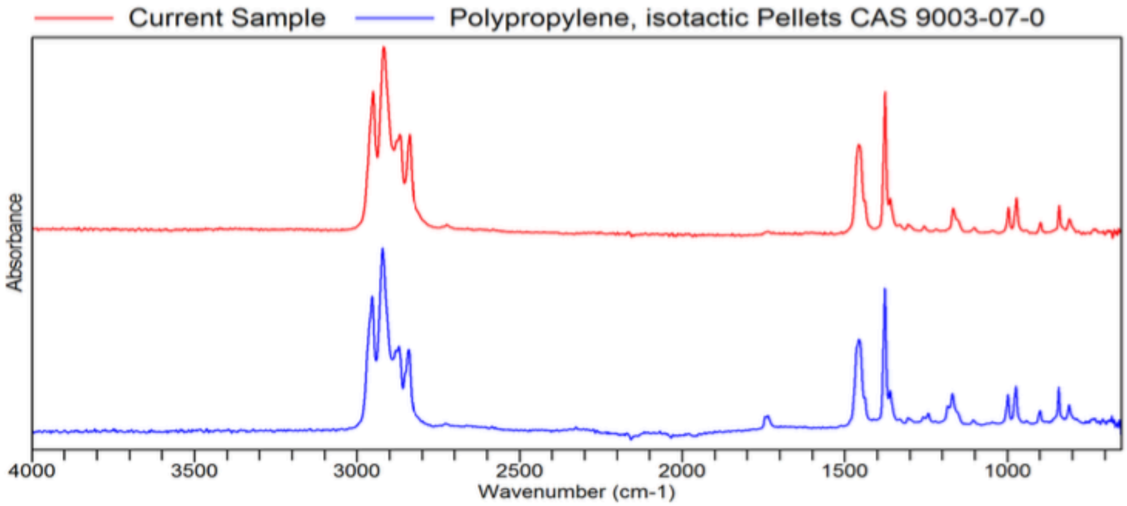
Resolution: 8

Range:4000 - 650

System Status: Good

Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations21_L_atr_2019-04-26T12-02-15.a2r



Sample ID:s21_H_atr

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m

Sample Scans:32

User:admin

Background Scans:32

Date/Time:03/07/2019 4:03:14 PM

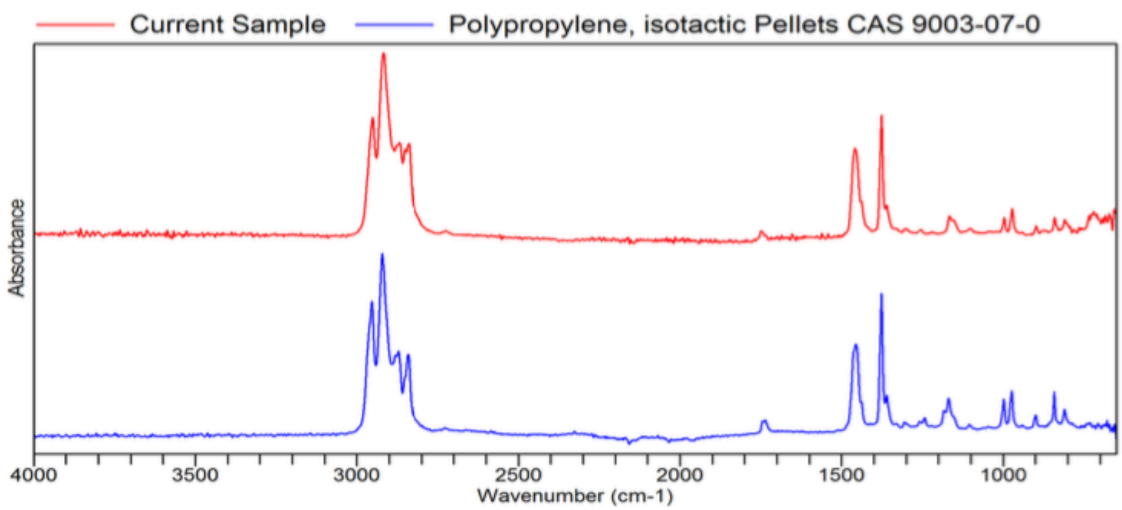
Resolution: 8

Range:4000 - 650

System Status: Good

Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations21_H_atr_2019-04-26T12-03-06.a2r



Sample ID:s23_atr

Method Name:C:\Users\Public\Documents\Agilent\MicroLab\Methods\Library Search Demo ATR Library.a2m

Sample Scans:32

User:admin

Background Scans:32

Date/Time:03/07/2019 4:10:51 PM

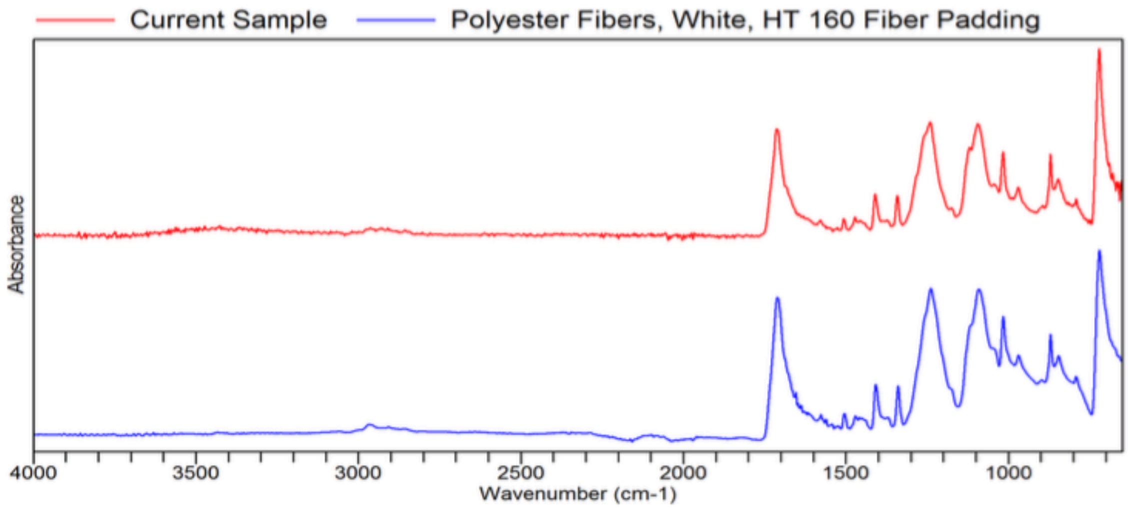
Resolution: 8

Range:4000 - 650

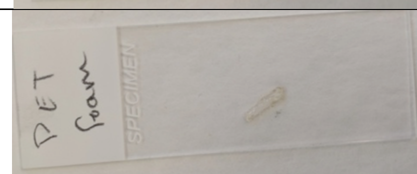
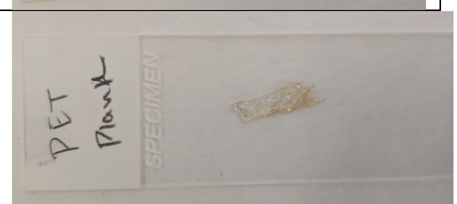
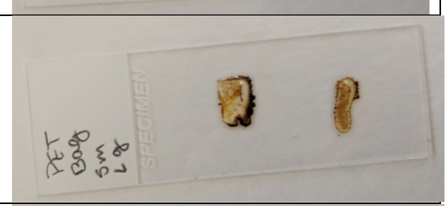
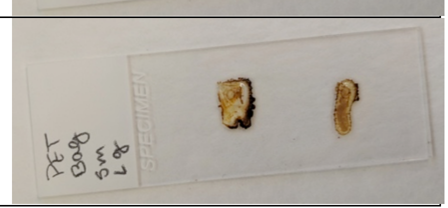
System Status: Good

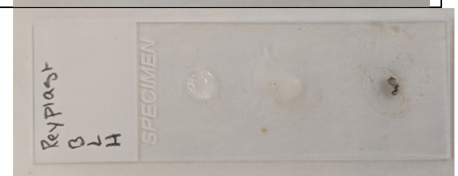
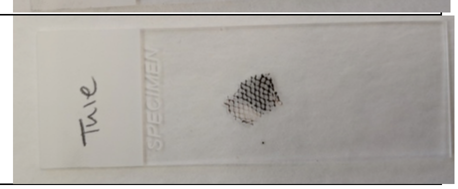
Apodization:Triangular

File Location:C:\Users\Public\Documents\Agilent\MicroLab\Results\EmilyThesis\FileLocations23_atr_2019-04-26T12-04-19.a2r



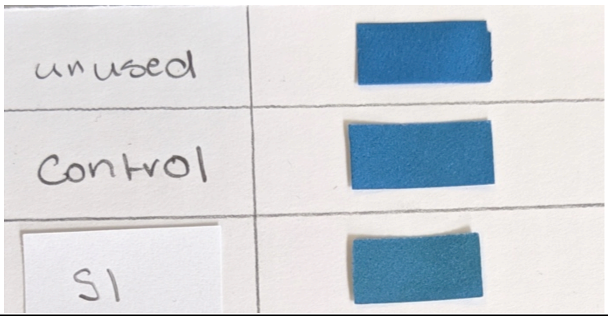
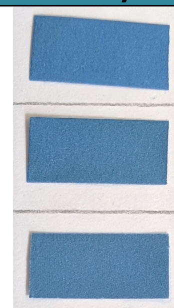
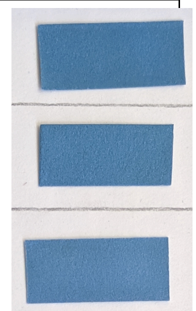
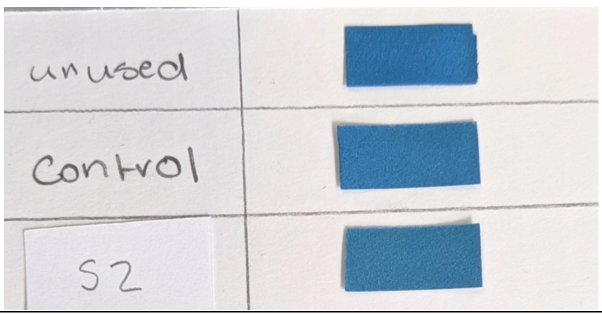
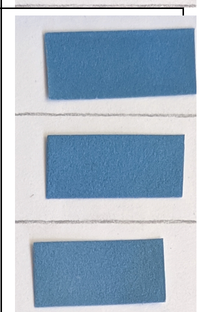
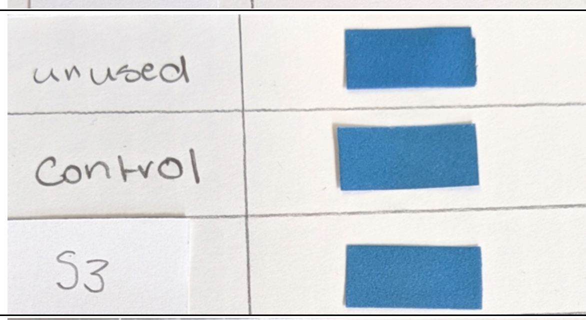
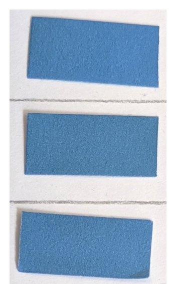
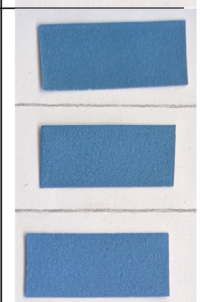
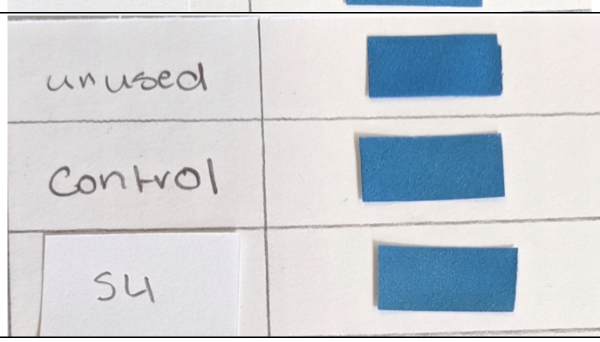
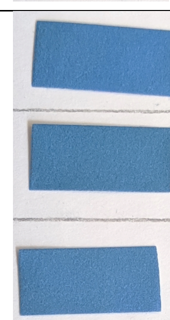
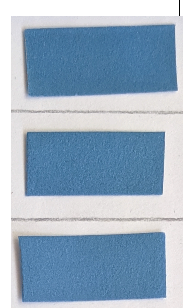
Appendix 4 – Combustion Residue Images

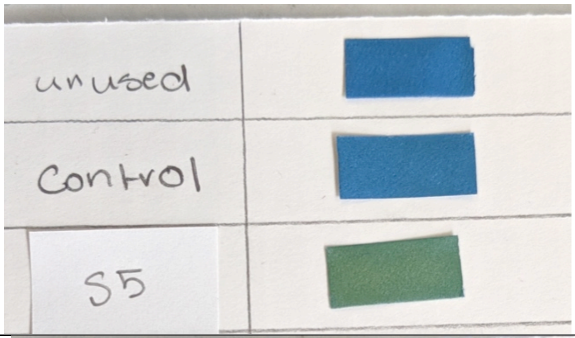
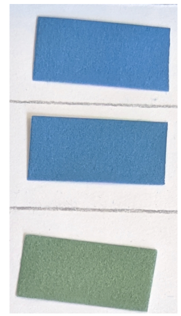
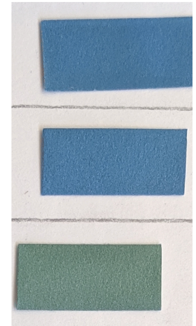
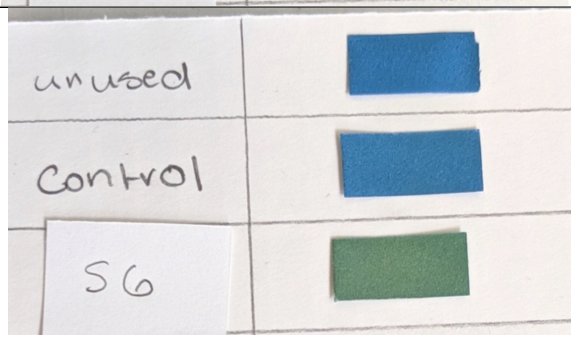
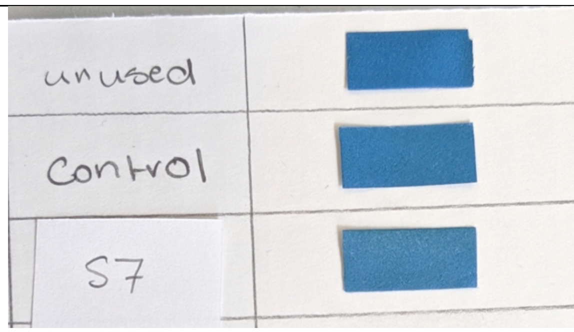
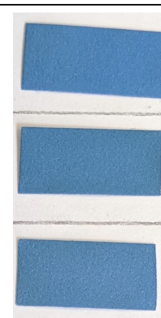
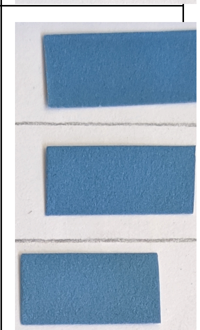
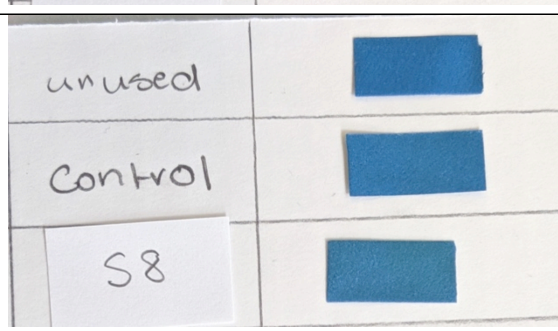
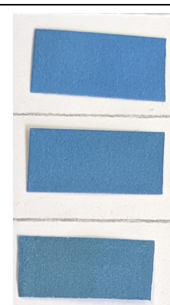
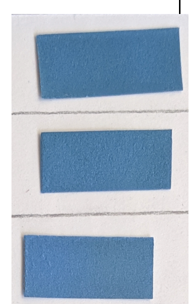
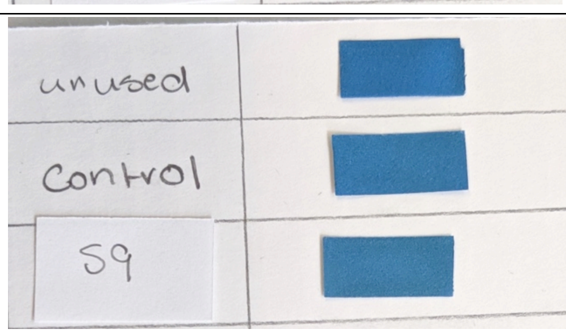
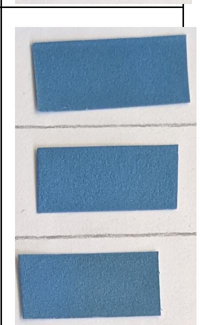
Sample No.	Description	Plastic ID	Variation in FTIR Spectra
7	Polyethylene/Poly-propylene sheet	Polypropylene	
8	Polyethylene foam	Polyethylene	
9	Polyethylene foam	Polyethylene	
10	Polyethylene foam	Polyethylene	
15	Polyethylene/Cotton sheet	Polyethylene	
16	Polyethylene sheeting	Polyethylene	
17	Small polyethylene bag (left)	Polyethylene	
18	Large polyethylene bag (right)	Polyethylene	

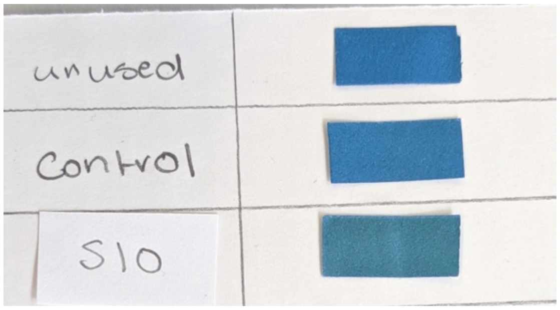
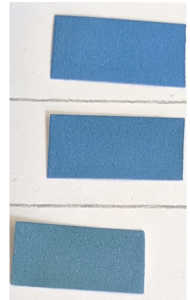
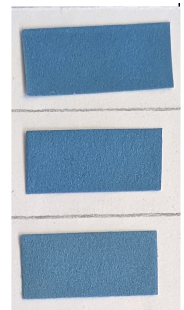
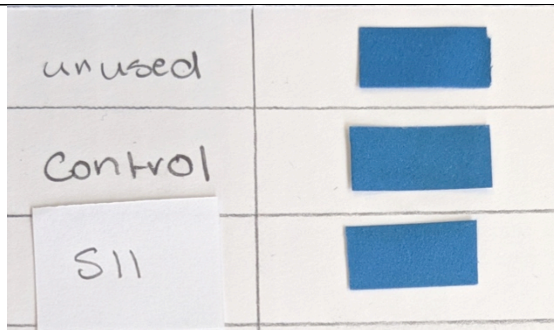
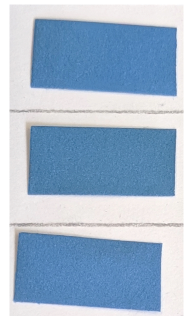
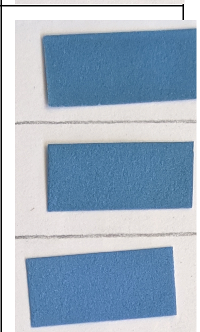
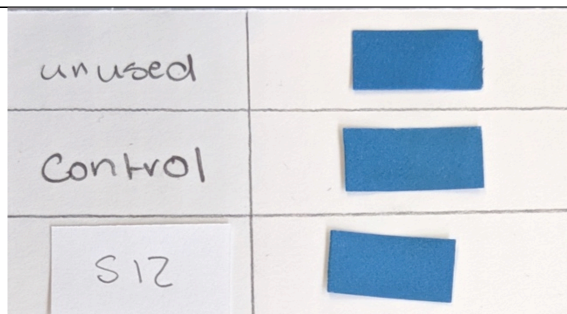
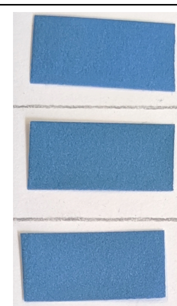
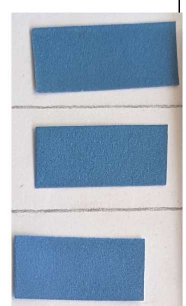
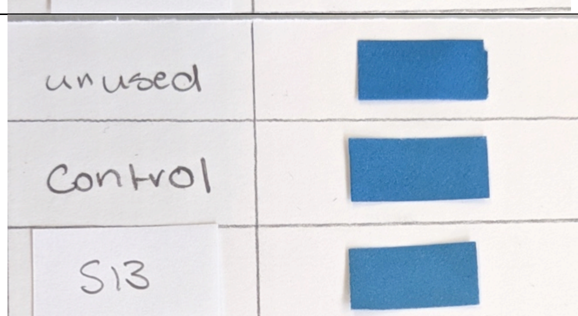
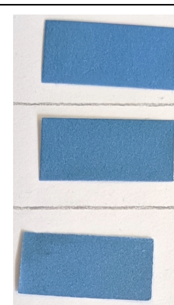
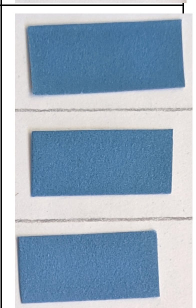
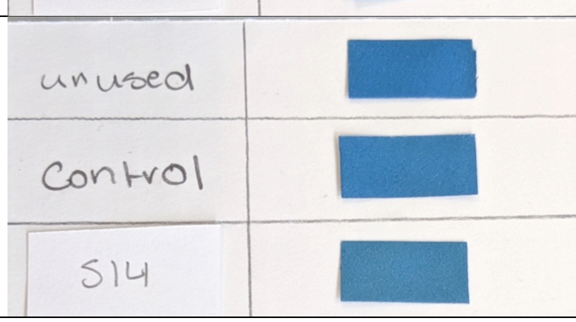
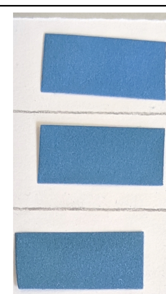
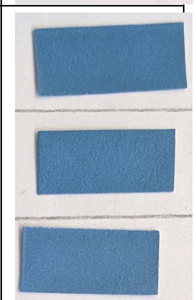
19 a, b, c	Plastic box, lid, handle – from left to right	Polypropylene	
20 a, b, c	Plastic box, lid, handle – from left to right	Polypropylene	
21 a, b, c	Plastic box, lid, handle – from left to right	Polypropylene	
22	Ribbon, closed weave (left)	Polyester Fibers	
23	Ribbon, open weave (right)	Nylon	
28/29	Velcro, toothed (28 left, 29 right)	Cellulose acetate	
30	Tule	Nylon	

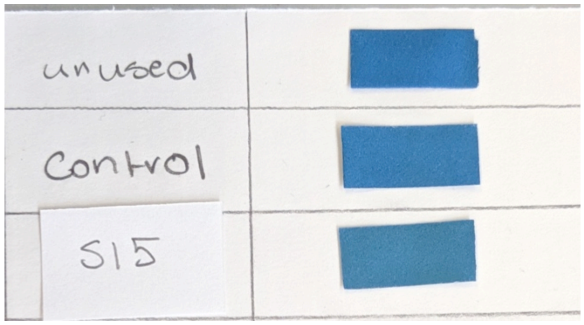
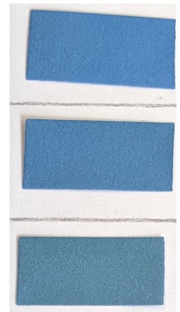
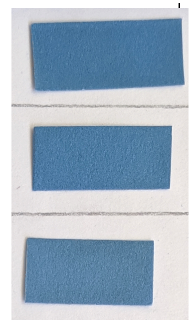
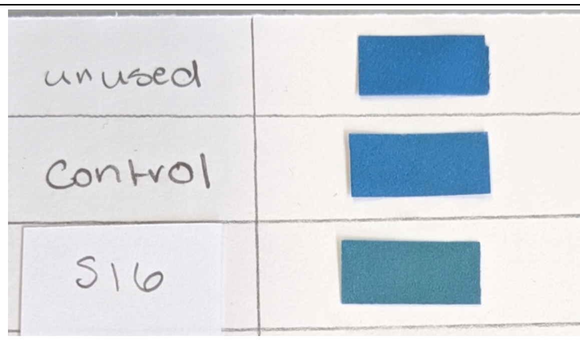
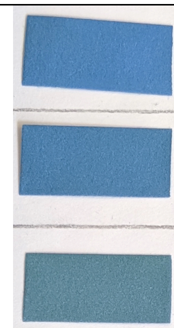
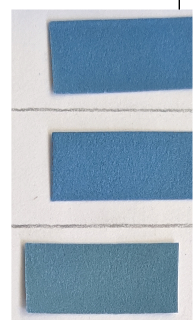
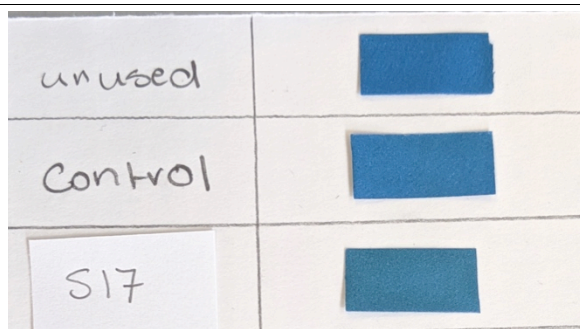
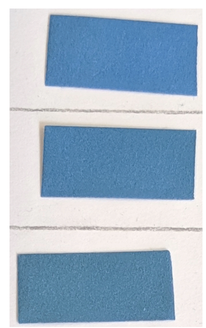
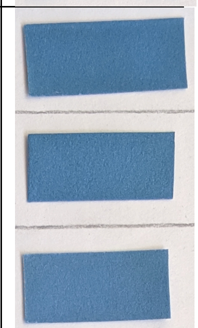
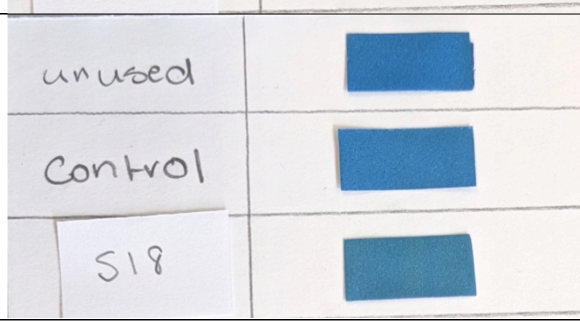
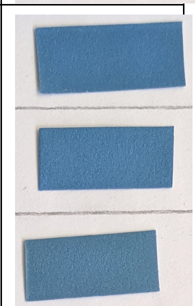
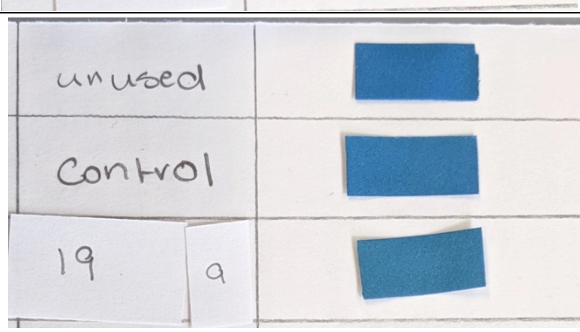
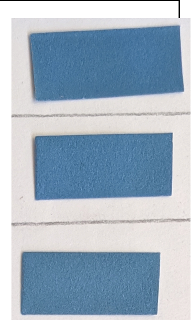
Appendix 5 – A-D Strip Test Results

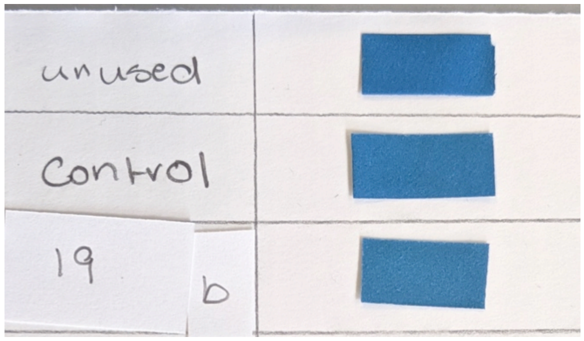
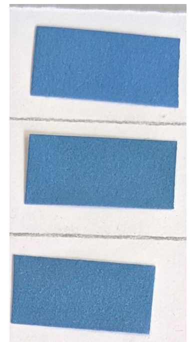
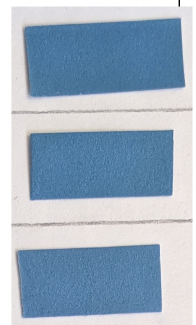
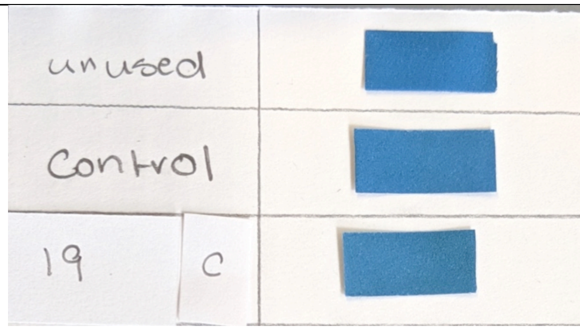
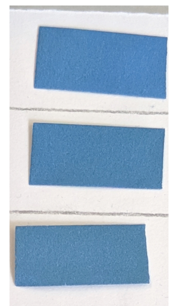
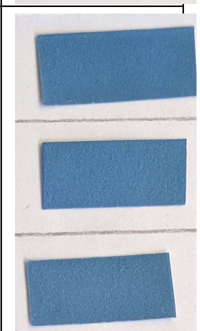
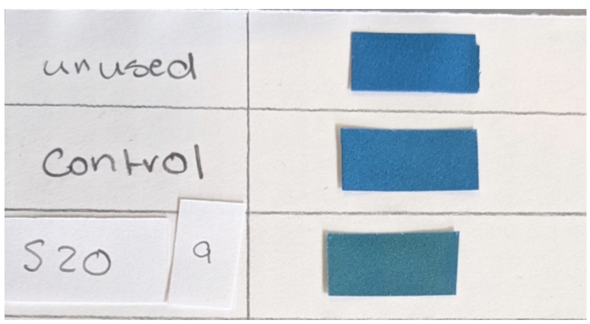
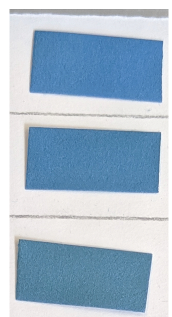
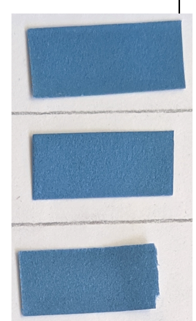
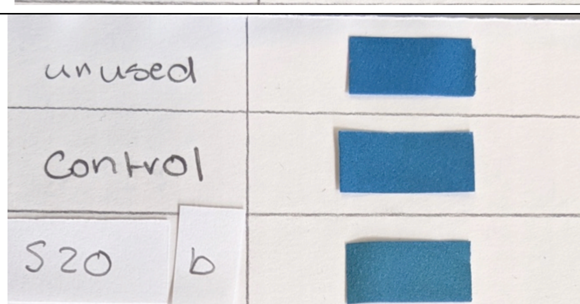
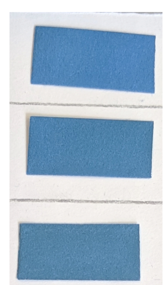
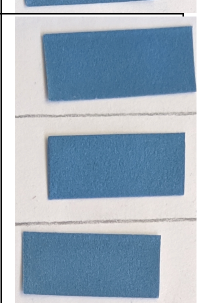
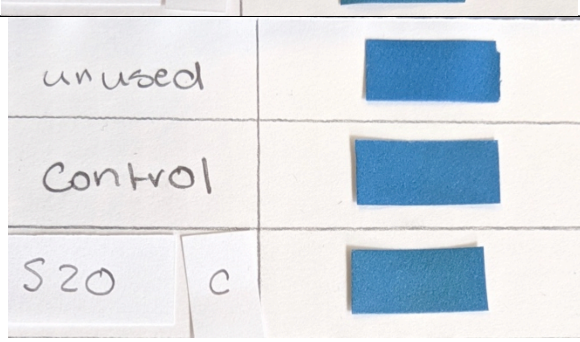
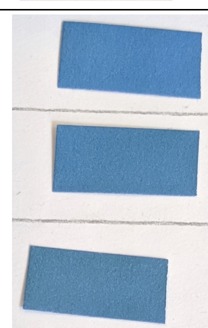
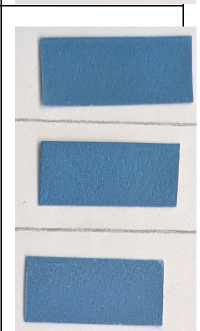
Note the sample number shift at sample #22. A change in sample organization after images were taken led to some numbers being changed. The accurate sample number for each set of A-D strips is listed in the leftmost column.

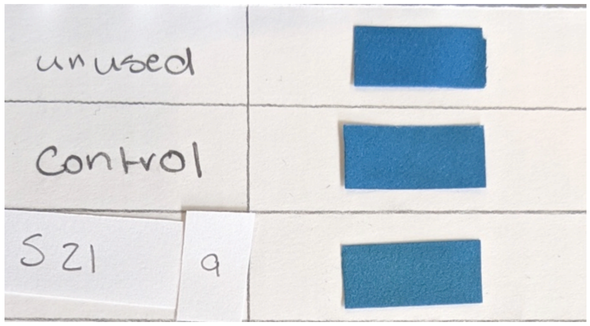
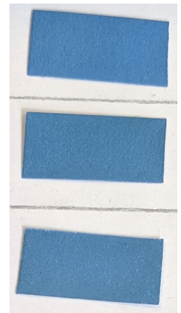
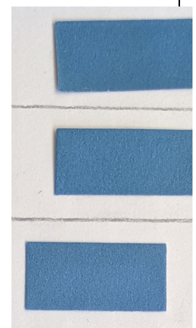
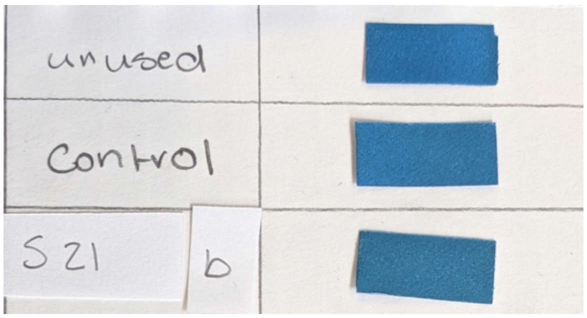
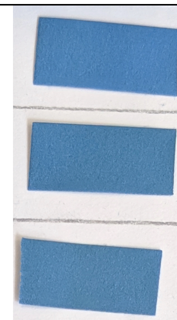
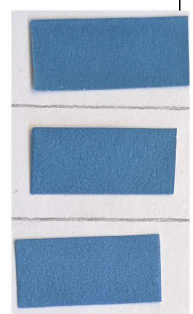
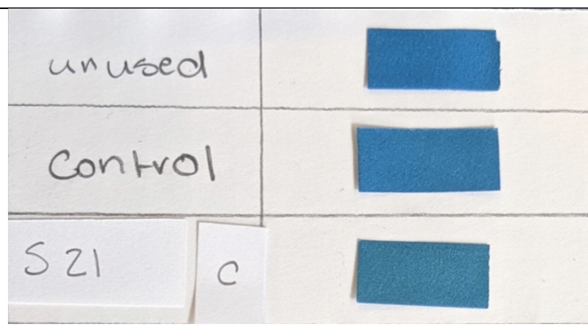
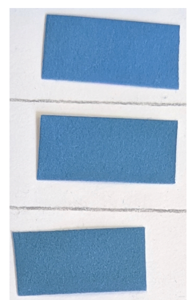
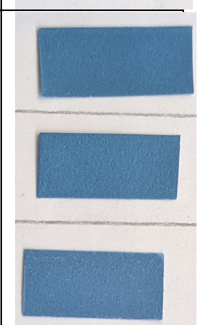
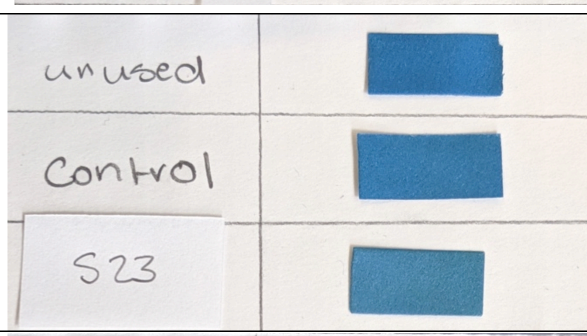
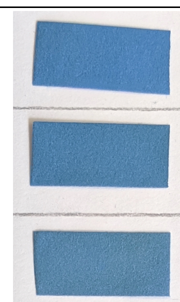
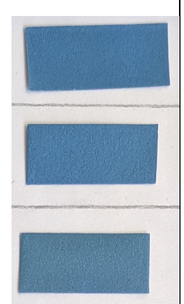
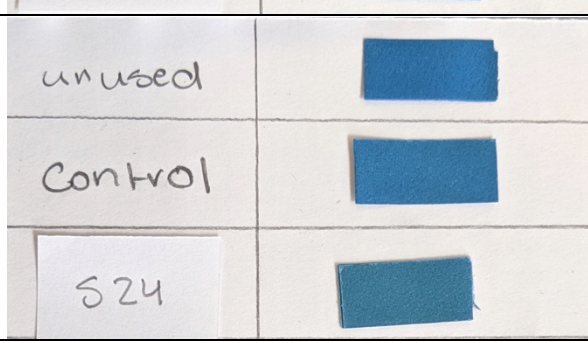
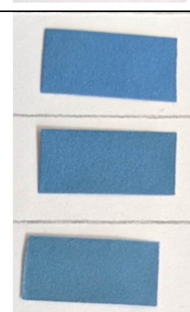
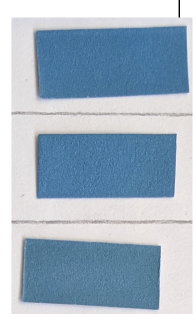
Sample	28 Days	7 Days	1 Day
1			
2			
3			
4			

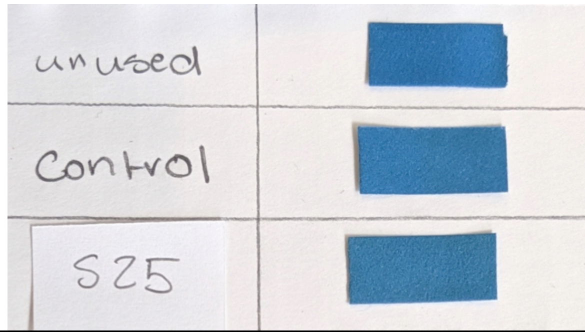
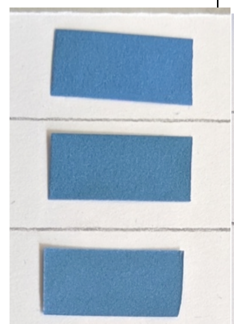
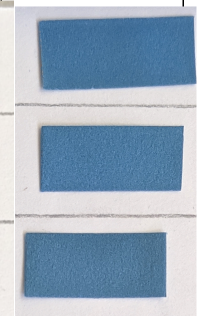
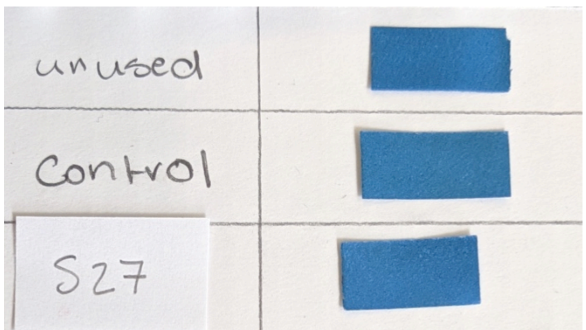
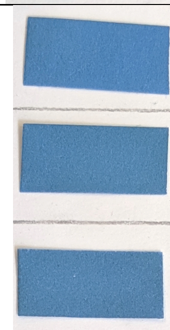
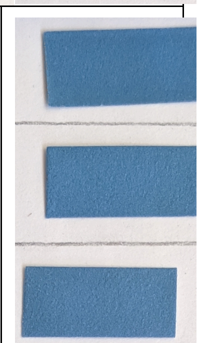
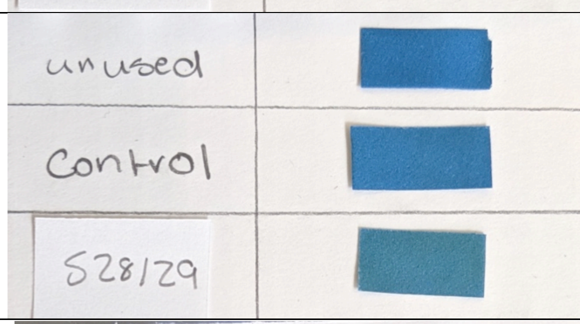
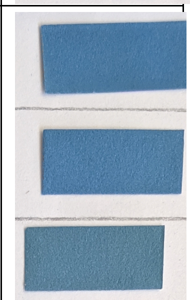
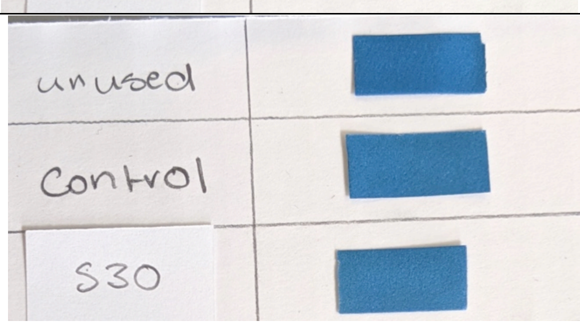
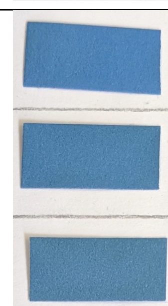
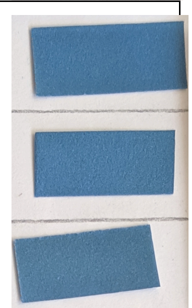
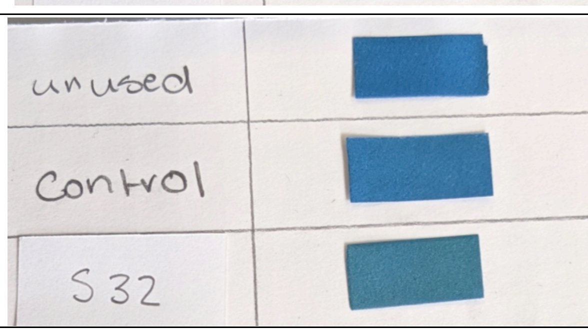
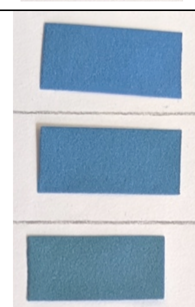
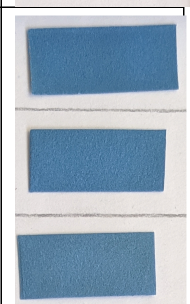
5	unused Control S5		
6	unused Control S6		
7	unused Control S7		
8	unused Control S8		
9	unused Control S9		

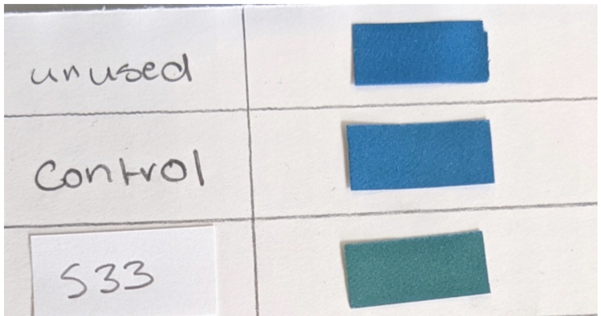
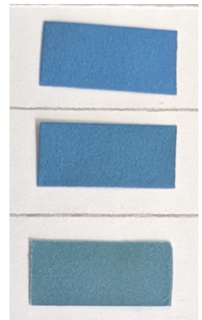
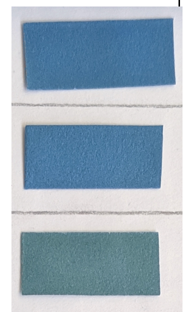
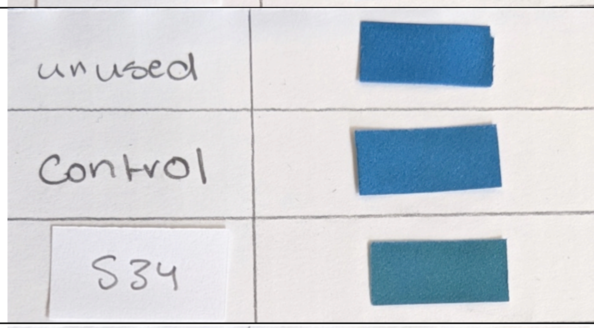
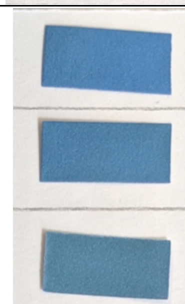
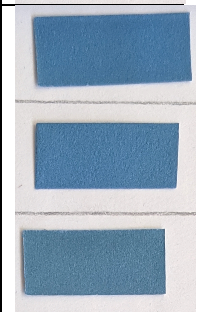
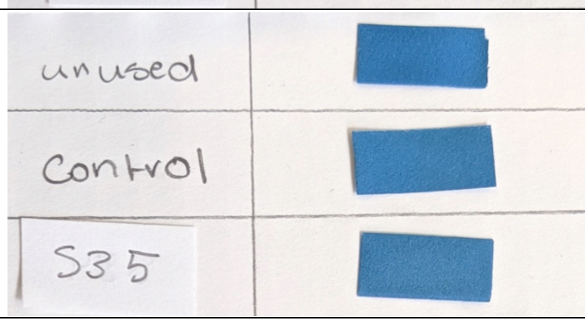
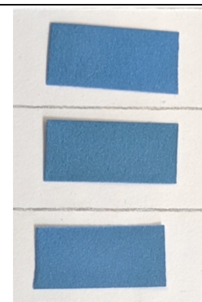
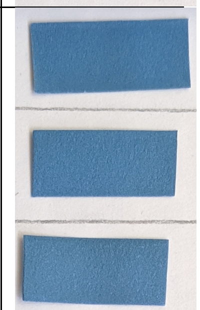
10	 unused Control S10		
11	 unused Control S11		
12	 unused Control S12		
13	 unused Control S13		
14	 unused Control S14		

15			
16			
17			
18			
19a			

19b			
19c			
20a			
20b			
20c			

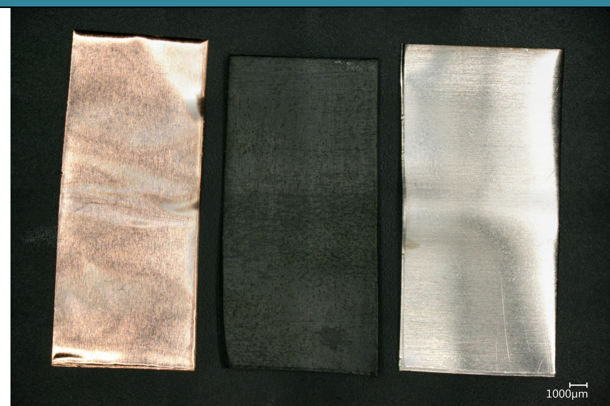
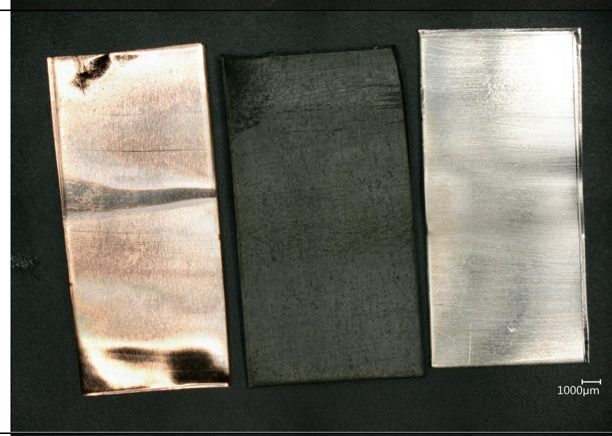
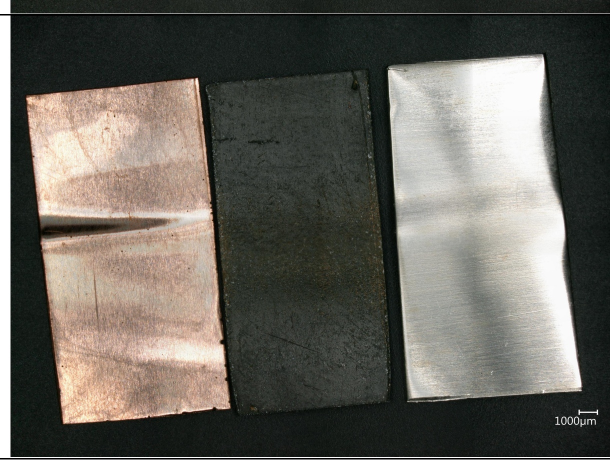
21a			
21b			
21c			
22			
23			

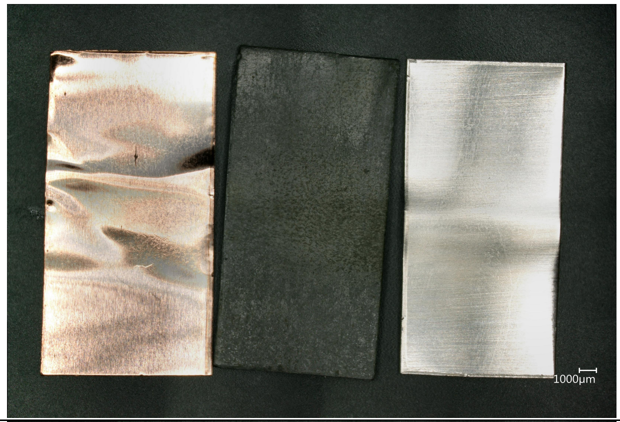
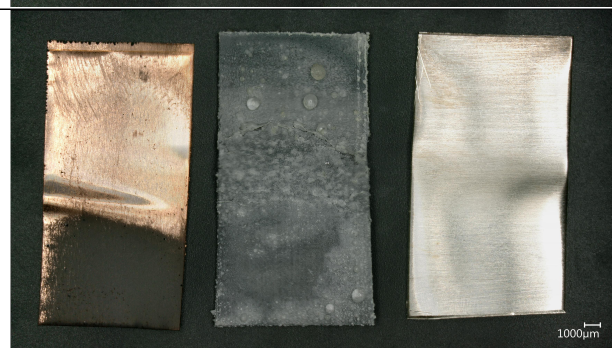
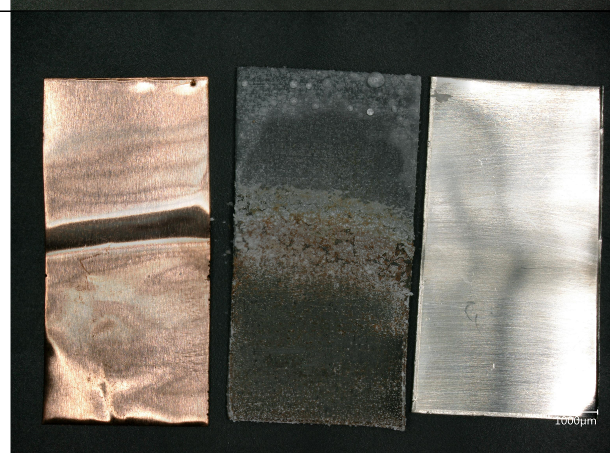
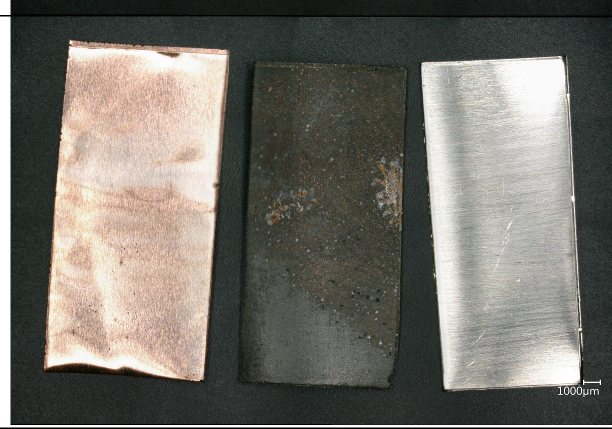
24			
26			
28/29			
30			
31			

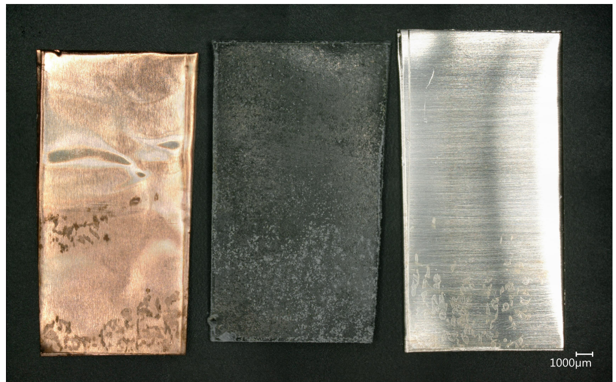
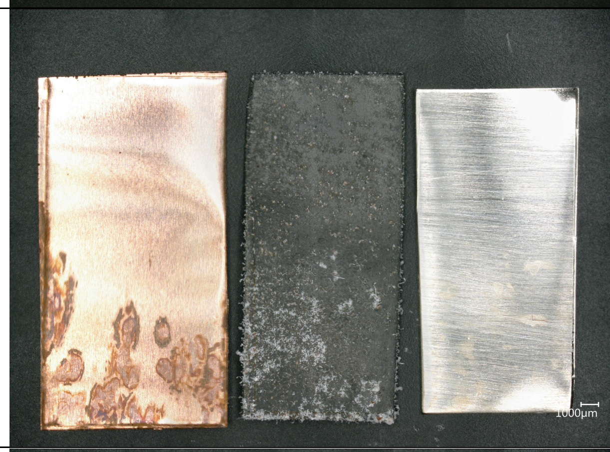
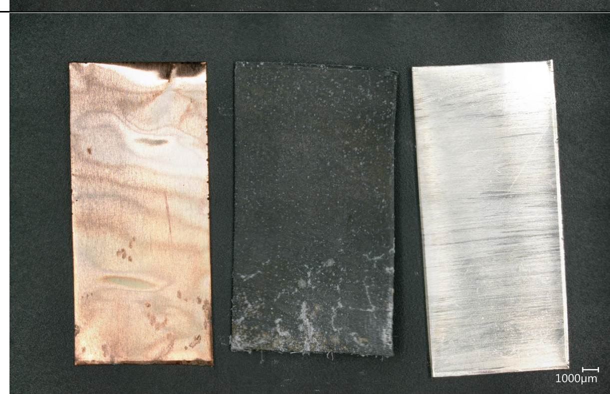
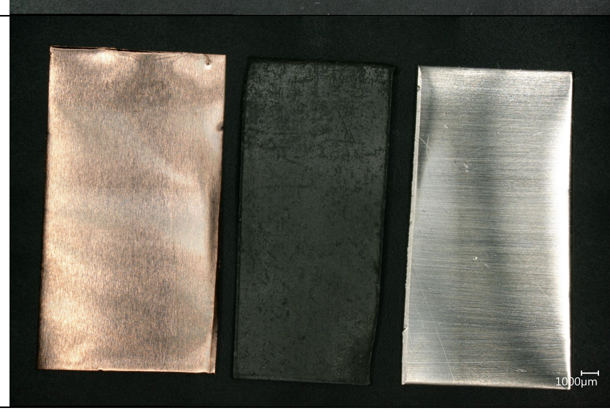
32	 unused Control S33		
33	 unused Control S34		
34	 unused Control S35		

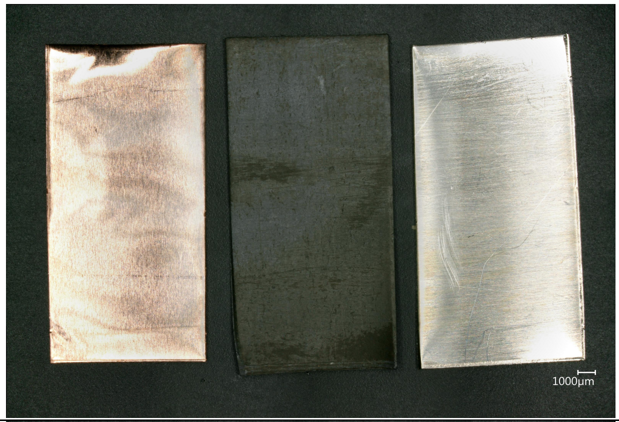
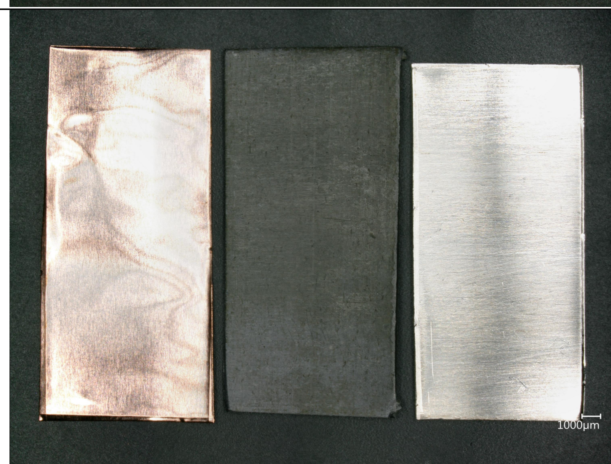
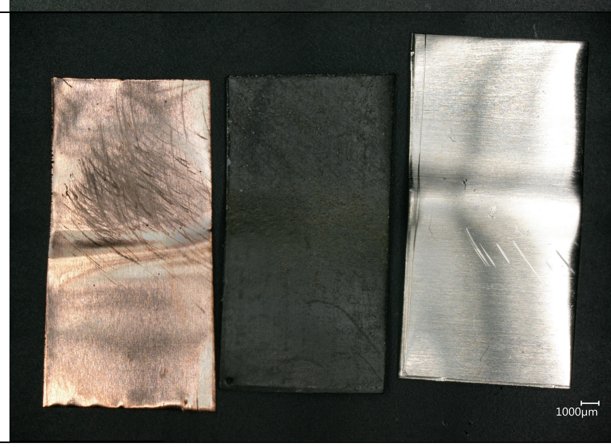
Appendix 6 – Oddy Test Coupons

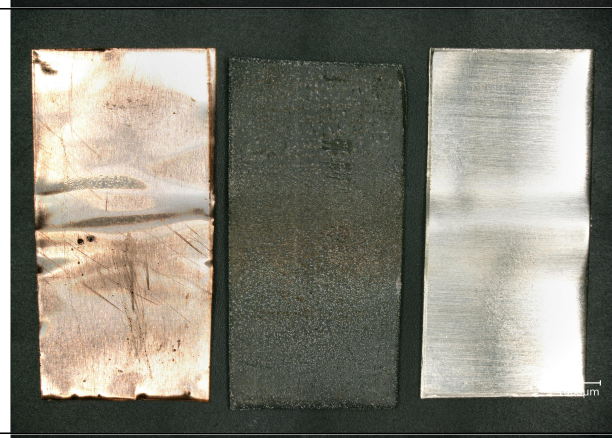
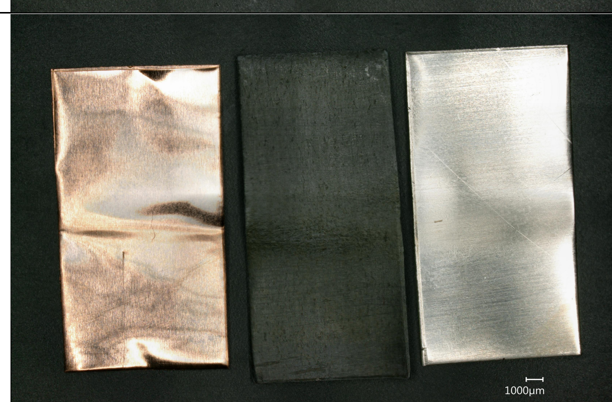
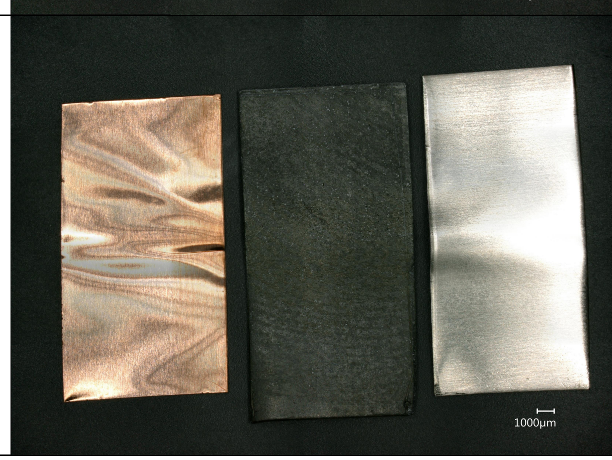
For those coupons that were tested in partial contact with the sample material, the area of the metal foil that was in contact with the sample is on the lower half of the coupon.

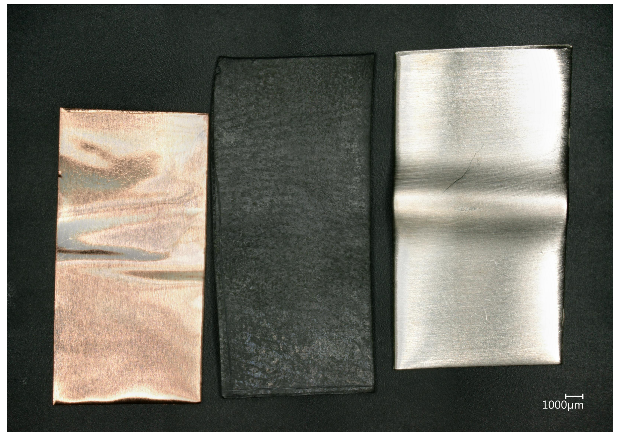
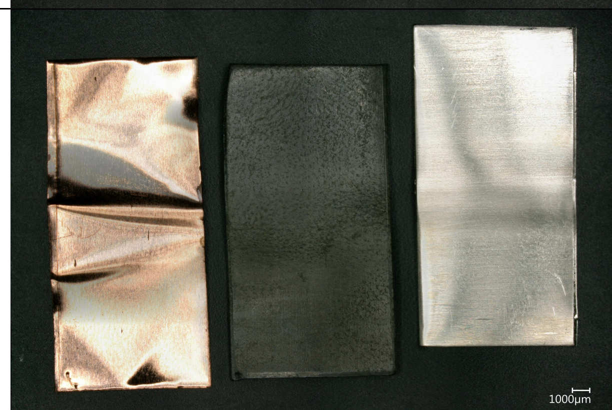
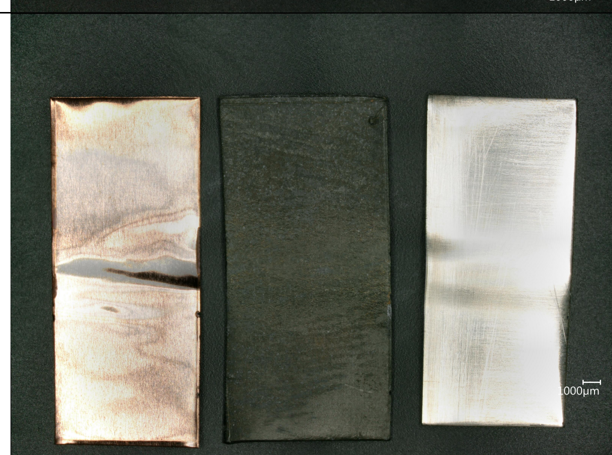
Sample #	Material	Vapor / Contact	
1	PTFE tape	Vapor	
2	Aluminum foil	Vapor	
3	Aluminum foil	Vapor	

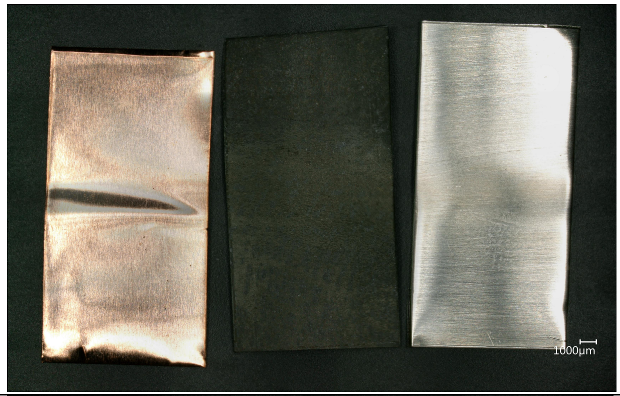
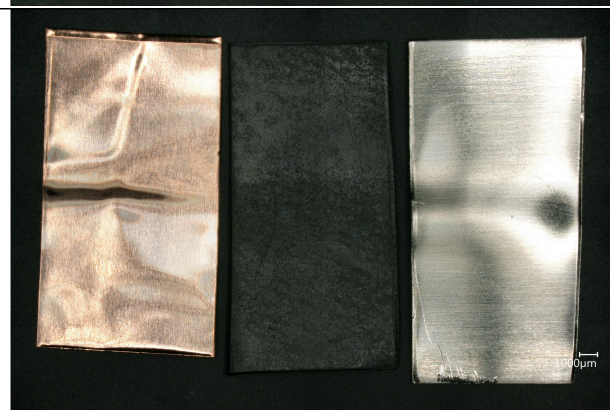
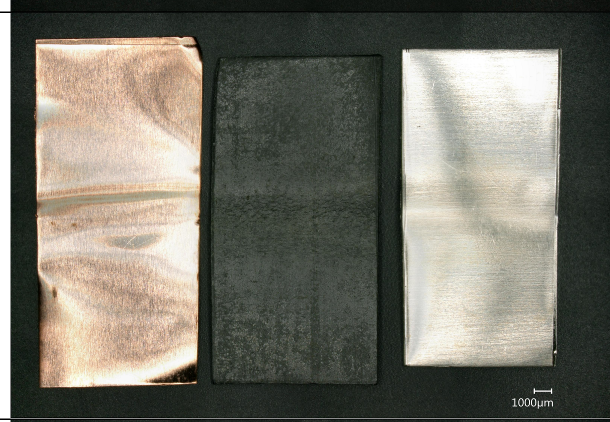
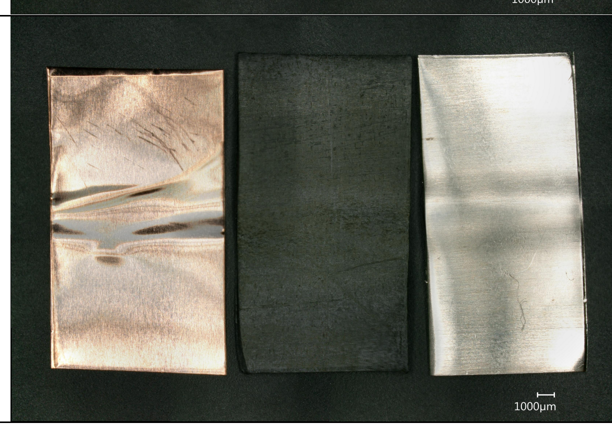
4	Aluminum foil	Vapor	
5	Silicona (Hot Glue)	Vapor	
6	Silicona (Hot Glue)	Vapor	
7	Polyethylene/ Polypropylene	Contact	

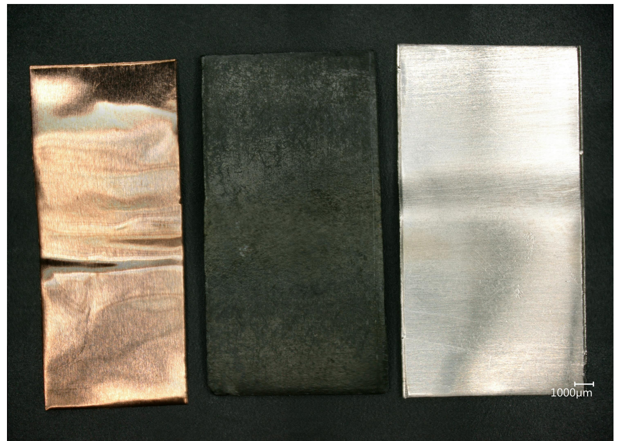
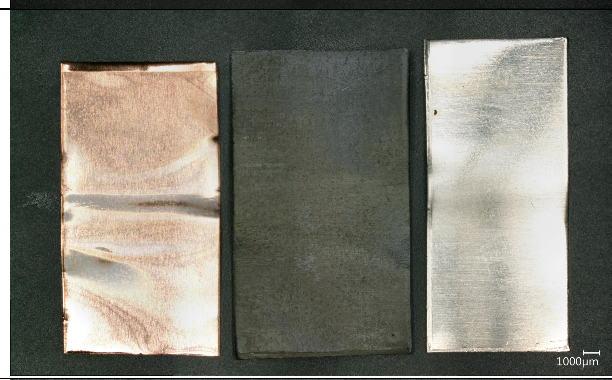
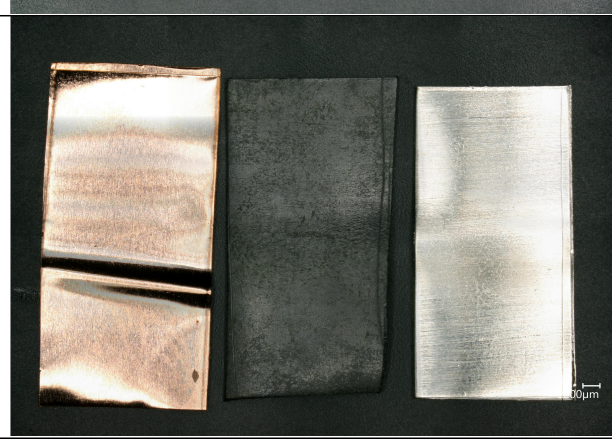
8	Polyethylene foam	Contact	
9	Polyethylene foam	Contact	
10	Polyethylene foam	Contact	
11	White sulfite paper	Contact	

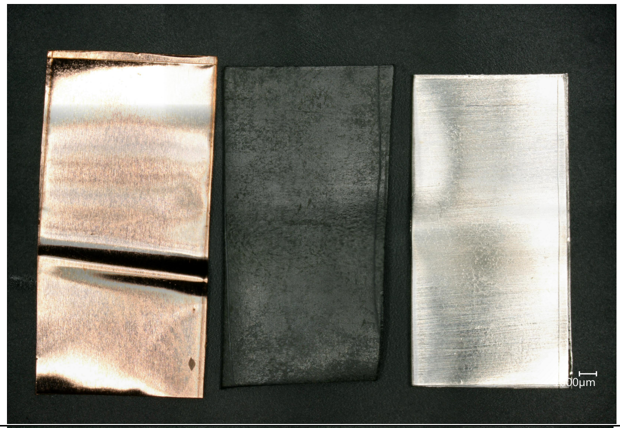
12	Yellowed sulfite paper	Contact	
13	White tissue paper	Contact	
14	Coroplast	Contact	

15	Polyethylene/ Cotton sheet	Contact	
16	Polyethylene sheeting	Contact	
17	Polyethylene bag	Contat	
18	Polyethylene bag	Contact	

19a	Polyethylene box, lid, handle	Vapor	
19b		Vapor	
20a	Polyethylene box, lid, handle	Vapor	
20b1		Vapor	

20b2		Vapor	
20b3		Vapor	
21a	Polyethylene box, lid, handle	Vapor	
21b		Vapor	

22	Ribbon, closed weave	Contact	
23	Ribbon, open weave	Contact	
24	Cotton muslin	Contact	
25	Paper board, thinner	Vapor	

26	Paper board, thicker	Vapor	
28/29	Velcro	Contact	
30	Tule	Contact	

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