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Sustaining the Unsustainable: Mitigation and Monitoring for Modern Materials

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Sustainability Committee Column

Recent practice of sustainable preservation has addressed energy savings through environmental control. Sustainability practices can also be applied to protecting and preserving the lifespan of collection items that are essentially unsustainable, such as plastic.

A basic understanding of the chemical and mechanical interactions of these man-made materials can allow conservators to create balance between sustainability and stewardship by using a multi-stage approach to managing risk and resources. For collecting institutions, economic models that also consider sustainable preservation mean that combining core values of "reuse, recycle, and reduce" with management solutions will naturally integrate sustainable objectives into day-to-day preservation practice and scientific research.

The degradation of plastic objects in cultural heritage collections presents many difficulties for taking a sustainable yet scientific approach because the materials themselves degrade in ways that are so specific to the material in question; reducing deterioration requires the amalgamation of knowledge and techniques that are less commonly applied to standard collections management procedures. Current plastics preservation research focuses on analysis and mechanisms of degradation, and scientific investigations have just begun to assess these risks in terms of sustainability.

Plastic objects can be difficult to preserve for a variety of reasons. Plasticizers leach, polymer chains break, colors change, and structures crystallize and break, often as a function of exposure to environmental conditions. It is hoped that this article will facilitate discussions about sustainability as one of the key considerations in the preservation of plastics and encourage this approach for museum collections as a whole.

Monitoring for Degradation

Beyond the environmental factors that affect collections en masse, conservators and collections managers often invest in various kinds of monitoring to document the condition of specific objects. For plastic objects, they often institute regular maintenance and assessment practices that include the most current understanding of plastics degradation. This requires staying current with relevant published literature to understand the myriad ways plastics may deteriorate and making changes to storage and exhibition strategies, as appropriate.

VISUAL

Many symptoms of plastic degradation are fairly obvious during an examination, survey, or assessment. Embrittlement, weakness, cracks, crazing, crumbling, weeping, and discoloration are usually visible to the naked eye. Other evidence of deterioration like off-gassing may be subtler, although sometimes these compounds can be detected by smell. Storage materials used to house plastics may provide additional warnings: boxes, tissues, and other storage materials can be examined for signs of deterioration; disintegrating or discolored paper, tissue, and cardstock may become brittle in the presence of acids emitted by deteriorating poly(vinyl chloride), cellulose acetate, and cellulose nitrate. In addition, metal objects will corrode in the presence of some deteriorating plastics.

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Condition surveys can provide baseline data or a "snapshot" of condition at one point in time, and this data can then be used to effectively allocate resources going forwards. However, the induction period for many plastics may shift quickly and without much warning so that "regular condition surveys would [be needed to] provide sufficient data to map the rate of degradation time for a collection" (Shashoua 2008). Visual monitoring of changes in plastics collections is time-consuming because the evidence is often more complex than indicated by simple physical or color change. In order to make survey efforts economically sustainable, a balance must be found between staff resources, the number of objects to be monitored, and the kind of information collected.

National Postal Museum, Smithsonian Institution

In 2013, the National Postal Museum (Smithsonian Institution) in Washington, DC, opened the William H. Gross Stamp Gallery (http://postalmuseum.si.edu/StampGallery/salon.html), designed as an open-storage display area. The exhibit solutions used are designed to absorb off-gassed pollutants and allow for ongoing inspection of paper-based, polymer-based, and composite materials housed in and comprising the display. The NPM team has built in monitoring and assessment as part of the long-term maintenance of the objects on exhibit.

Visitors had long hoped to see more of the NPM's collection, and the space accommodates 393 pull-out frames that hold 786 graphic panels with more than 10,000 United States postage stamps, stampless covers (folded envelopes sent through the mail), documents, artwork, and envelopes used to deliver mail.

The NPM team decided on a passive display that relies on absorbent tissue and matboard to contain off-gassed byproducts. Stamps were encapsulated in polyester, often with a sheet of buffered tissue inserted behind each object as an additional absorbent. The polyester sleeves were only partially sealed to allow some air exchange. Graphic panels were printed on Peterboro archival matboard, and additional layers of this matboard were inserted in between the two-sided displays in order to absorb gases that may arise from deterioration. In addition, each case, holding a bank of twenty-five frames, was fitted with a wireless datalogger to allow remote monitoring of the microenvironment over time.

Every month a collections management team cleans the outside of the frames and inspects the displays for object slippage or other anomalies. When graphic panels are updated, the conservation and exhibit team test the pH of the matboard panels to determine how materials in the frame are aging.

CHEMICAL

Prior to significant physical change, plastics degradation can be observed by detecting specific chemicals or degradation markers that, when measured, indicate the extent of deterioration. Identification of a specific chemical marker for a specific plastic by-product requires a sophisticated knowledge of the plastic itself and how it degrades. For example, as cellulose acetate film degrades, it can emit acetic acid. Using tools like acid detection strips (A-D strips) in a closed space allows a conservator to get a sense of relative concentration of the degradation marker (acetic acid) by comparing it to a reference guide. These strips were developed in 1995 by the Image Permanence Institute (IPI) specifically for cellulose acetate but conservators have used them for other purposes, such as monitoring potential exhibit materials (Nicholson and O'Loughlin 1996), evaluating acetate adhesives used in enclosure construction (Brewer 2014), and evaluating potential infill materials for use with textiles (Kaldany et al. 1999).

A-D strips rely on color change when exposed to acetic acid fumes, and 2012 research by Smithsonian conservators Jia-Sun Tsang and Beth Richwine showed that their effective use is dependent upon how they are deployed. Their research also shed light on the poor efficiency of broad-spectrum non-specific absorbents such as activated carbon and zeolites, which require frequent replacement and extensive institutional resources.

Future research on the use of degradation markers should focus on the identification of significant chemical compounds and finding new, more efficient ways to track their emissions and any build-up in a variety of exhibition and storage environments.

ODDY TESTS

The Oddy Test, commonly used to select materials used in storage and display by monitoring corrosion and/or vapors generated from a sample of the test material, can be modified to monitor off-gassing of other materials including some plastics. For example, lead coupons are useful to detect acid vapor from cellulose nitrate and cellulose acetate, whereas copper coupons can be used to detect some leached plasticizers, such as some phthalates (Tsang et al. 2009). The best results are attained by placing the metal coupon in direct contact with the sample for more than four weeks of testing time, depending on the type of plastic and the amount of plasticizer.

A similar approach was reported by Prosek et al. (2013) on the use of metallic sensors to provide continuous real-time monitoring of indoor air corrositivity. The POPART project used the direct approach of "[a] reference plastic 'doll'- made from a variety of different plastics placed in different museums to monitor environmental impact on natural aging; it was found to be an effective tool for monitoring dose-response functions" (Madden and Learner 2014).

ANALYTICAL

The extent of plastic degradation can also be monitored with scientific instrumentation. Optical spectroscopy, particularly FTIR, Raman, and NIR, are often used to measure objects directly. Pyrolysis GC-MS can decipher the major and minor organic components of a plastic. GC-MS with solid phase micro extraction (SPME) is recommended for detecting VOCs. Mechanical properties of a plastic, such as the brittleness, can also be measured in various ways. For example, dynamic mechanical thermal analysis has been used to monitor "the mechanical properties of the plastic . . . in response to changes in relative humidity and temperature" (Getty Conservation Institute 2010).

While a variety of handheld analytical instruments have been found particularly effective for rapid, on-site surveys of collections, bench-top research-grade instruments are often needed for full characterization of a material, including the detection of additives. Sampling is often required for some types of analysis like chromatographic techniques, mass spectrometry, and thermal analysis. Instrumentation and the resources necessary to interpret the results may not be readily available, thus limiting the usefulness of this approach.

Beyond Monitoring: Mitigation

Establishment and maintenance of stable museum environments that favor plastic preservation is extremely important for plastic artifacts, but choices for creating these environments are often dependent upon the particular plastic and its component chemical make-up.

TEMPERATURE

Temperature influences the rate of many chemical reactions. This relationship is often described by the Arrhenius equation (k = Ae-Ea/(RT)), which says that chemical reactions occur more quickly as temperature increases, thus suggesting that lower ambient temperatures favor plastic longevity. For example, storage at subfreezing temperatures could extend the useful life of cellulose acetate photographic film "by a factor of one hundred even for film that has already started to degrade" (Bigourdan and Reilly 2000). However, a cold environment may not be a clear choice for an entire collection, such as when film is mixed with other media, like magnetic tape (which can be affected adversely by freezing temperatures). Maintaining stable cold environments through refrigeration also has financial and environmental implications.

HUMIDITY

Along with lower temperatures, reducing the amount of moisture in the air can slow deterioration, especially for those plastics that degrade by hydrolysis, but this is not always the case. A study by the IPI (Bigourdan and Reilly 2000) showed that lowering relative humidity (RH) from 50% to 20% can increase the stability of cellulose acetate film by a factor of three. Conversely, some hygroscopic plastics like casein formaldehyde will dry out if stored in a low humidity environment. Because they are plasticized by water vapor, they need a moisture content around 60% RH to stay supple (Pagliarino and Shashoua 1999). For plastics whose main degradation pathway is through other means, like polyethylene (which degrades primarily by oxidation), the effectiveness of humidity control will be limited (Shashoua 2014).

A thorough knowledge of various types of plastics and their associated vulnerabilities is necessary for choosing appropriate environmental parameters that maximize available resources. This makes for complicated choices and suggests that microclimates might be a useful solution for collections containing plastics of mixed polymers.

OXYGEN AND GASEOUS POLLUTANTS

The air around plastic artifacts often includes compounds that initiate or accelerate deterioration of certain plastics. For example, acids, ozone, and even oxygen can react with hydrolysable and oxidizable plastics, leading to damage. In addition, some plastics may become sticky as plasticizers migrate to the surface, causing airborne dust and other particulates to stick to their surface. Control of indoor and outdoor pollutants requires different strategies that can be implemented in tandem to ensure that plastics degradation is slowed and that off-gassing from plastic objects themselves does not harm other collection materials. This may include selecting a particular method of storage and the use of chemical absorbents.

STORAGE CONTAINERS

Appropriate choices for the storage envelope can protect vulnerable plastics and contain deteriorating ones. Collection storage decisions can be made for multiple or individual items, and choices depend upon the needs of the object as balanced by the resources available. For example, segregating deteriorating objects from the rest of the collection can be an inexpensive solution, or may strain resources if extra space is not readily available. Choosing between open and sealed storage requires knowing the plastic composition (and evaluating its degradation trajectory) as well as evaluating what can be sustained institutionally through staff time, purchase of equipment, and the costs associated with environmental control.

For example, some museums choose to store deteriorating, acid-emitting cellulose nitrate, cellulose acetate, and poly(vinyl chloride) objects in the open. It has been debated whether sealed enclosures negatively affect cellulose acetate film that has already started to degrade. There can, however, be concerns about vulnerable objects stored nearby and the health of staff and visitors; one study reported by the POPART research project showed that thirteen plastic samples emitted more than 200 different volatile organic compounds (POPART 2012a).

For some plastics, the potential for degradation products such as acids and leached plasticizers catalyzing further degradation "must be very carefully tested and monitored" (POPART 2012b). Additionally, if an object is sealed in an anoxic package, the storage mode limits use or requires additional materials and time to re-seal it after examination requests. Additionally, such storage containers may need replacement over time, as it is difficult to create a perfectly leak-free seal. A study of the British Museum's collections, for instance, "concluded that oxygen adsorbent sachets require replacement every five years because it is impossible to prevent the slow leakage of air even when bags are well sealed" (Shashoua 2014).

For pollutants generated indoors, one low-cost solution is to absorb deterioration off-gassing byproducts with absorbent materials. Research has been conducted in using low-cost storage materials to absorb or react with acidic gases that are formed as plastics age. Guttman and Jewett (1993) found that storage materials can significantly protect against atmospheric pollutants even at concentrations much higher than those likely to be encountered naturally, and Shashoua (2014) suggests that "[a]rchival cardboard boxes for storing cellulose acetate objects may be more effective for slowing degradation than are conservation adsorbents [although] further research on this subject is necessary."

SCAVENGERS

In addition to using acid-absorbing storage and exhibition materials, specific deleterious compounds can be scavenged from the microenvironment by adding absorbents. Several classes of scavengers are available to target specific categories of compounds, requiring the conservator or collection manager to have a significant understanding of plastics in the collection to be able to determine the appropriate scavenger materials. Research data on scavengers is mixed; they may absorb some off-gassed materials, yet they are difficult to target, and information on their exhaustion capacities is not clear.

Common scavengers include:

- Activated carbon (sold in powder, cloth, paper, or boards) removes a wide variety of pollutants and vapors, and works particularly well for polyvinyl chloride and cellulose nitrate objects.

- Silica gel can absorb some plastic degradation products.
- Zeolites (sold as beads, powder, or coated on paper) are sold in paper form and are recommended for inhibiting discoloration in polyvinyl chloride objects. However, zeolite use is discouraged for cellulose acetate because its plasticizers are leached into the sorbent, leading to dimensional change in the object itself.
- Oxygen scavengers, such as those sold under the brand name Ageless, are a special category in which finely powdered iron reacts with oxygen to form iron oxides and hydroxides.

Challenges using scavengers include:

- Their use requires the creation of sealed microclimates
- The materials must be replaced regularly because it is difficult to tell when they are exhausted (or at holding capacity)
- They can absorb a wide spectrum of pollutants, instead of just the one targeted
- Many scavengers cannot be reactivated and therefore create waste at the end of their use
- Some, like silica gel with a cobalt chloride indicator, have their own toxicity and should be handled with care and disposed of as hazardous waste. A methyl violet indicator is currently considered more environmentally sustainable (Hernandez 2013).

Hagley Museum & Library

The Hagley Museum's collection of 70,000 objects includes numerous plastics from the DuPont Company, ranging from the early experimental stages of plastics produced in the 1930s through samples of every synthetic material the company has produced since, and includes materials made by competing companies.

In the last decade, the museum conducted an extensive survey of their plastics and began to see signs of deterioration. The most problematic objects were made of cellulose nitrate; an estimated 10-15% of the items exhibited significant deterioration, including yellowing, embrittlement, and a crystalline appearance.

With only one objects conservator for the collection, the preservation strategy focuses on widely applicable preventive methods. The goal is to slow initial deterioration since it cannot be stopped once it begins. Plastics are kept in the dark, in cold storage at 45˚F, with a relative humidity of 45%. Many are wrapped in acid-free tissue and placed in acid-free boxes to minimize exposure to atmospheric oxygen and in deference to the fact that open storage is not always practical, given the museum's space constraints. To deal with off-gassing, a bag of zeolites is placed in each closed box.

Once a year, students and technicians come onsite to inspect the plastics; they replace the paper and zeolites bag in each box, as there is no indication whether these items have ceased to be effective. Two people work about two full months to complete the check and mitigation efforts.

Conclusion (Housekeeping and Human Costs)

In general, the economic and environmental costs to maintain collections with plastic objects are significant, and these realities may play a role in mitigation and monitoring decisions. While most institutions routinely monitor relative humidity, temperature, light, and pollutants, the ranges and changes may be different for plastics than for other materials. Inspecting plastic objects for signs of deterioration ideally needs to happen regularly, but this may not be feasible for many institutions. More significantly, monitoring for these items may include gathering other types of information such as identifying degradation markers, analyses of off-gassing byproducts, and careful consideration of damaged housing materials. Upgrading housings for plastic objects requires a different decision-making process than for other collection components and may also require significant staff time—and large supply budgets.

Conservator Fran Coles' experiences in surveying incoming plastic objects for an exhibit at the London Science Museum helped to hone concerns for specific plastics and their care. She determined that most plastics would be fairly stable and concentrated her efforts on the four most common unstable plastics: cellulose nitrate, cellulose acetate, plasticized polyvinyl chloride, and polyurethane foam. To assist staff in the identification of these particularly problematic plastics, she developed fact sheets that detailed signs of deterioration and other indicators like corrosion and odors. The fact sheets include factors to consider such as the fabrication date of the object, odors, and flexibility. She also developed scorecards that include conservation and care costs for these plastics over a ten-year period and held clinics for curators to discuss the human costs associated with acquiring and preserving plastic materials.

If a collecting institution houses large quantities of plastic objects, conservators and collections managers may need to prioritize their actions and parcel their time appropriately to make the workflow sustainable. Additionally "[s]ome plastics are more susceptible to specific agents so it is therefore beneficial [both economically and environmentally] to concentrate on controlling that specific agent for that specific plastic" (Williams 2002). To be most effective, a thorough knowledge of the plastics present in the collection, as well as the research relevant to each type, is required. Sustainability considerations can then play a role in determining the best choice among the options presented for each application. By working together, collections managers, curators, and conservators can continue to improve our ability to predict and respond to the challenges present in caring for plastic objects. In these ways, we can attempt to sustain otherwise unsustainable collections for as long as possible.

Preservation Self-Assessment Program (PSAP)

Professionals at the University of Illinois at Urbana-Champaign (U of I) developed the Preservation Self-Assessment Program (PSAP) (https://psap.library.illinois.edu/) to aid archives, library, and museum professionals who have limited preservation experience to identify and better understand their collections, with a focus on audiovisual materials on plastic substrates as well as photographic and image materials. Through grant support from the Institute for Museum and Library Services, staff developed PSAP as an open-source, online, free assessment tool.

The PSAP includes collection management software and an educational resource describing various film formats, deterioration, and storage. Users first enter information about institutional policies, environmental data, disaster response, and storage mechanisms and then input data about individual collection items. The software may be used to help collection managers identify the format and condition of plastic-based objects using an extensive format identification guide. The tool also describes typical deterioration characteristics, risk levels, sources for further reading, and recommendations for storage, exhibition, and environmental controls for specific types of audio-visual materials. The software allows collection managers to assign scores and rank preservation priorities for assessed materials.

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