Safe Handling of Plastics in a Museum Environment

Abstract

Research on the theory and mechanics of plastics degradation and conservation has made steady progress over the years, yet regarding the safe handling of plastics, current knowledge and practices are long overdue for an update. The purpose of this paper is to translate the science of plastics degradation into practical guidelines for the safe handling and conservation of plastics in a museum environment. The safety practices outlined here are based on an analysis of naturally aged plastics in museum collections, and are relevant to the specific problems faced by conservators, curators, and museum specialists who must handle and evaluate many types of plastic materials.

Background

Just as paintings, paper, glass, ceramic, and metal are collected for their historical and cultural significance, plastics, too, are collected as tangible evidence of the most widely used modern material of the 20th and 21st centuries. Plastics have an important place in the life of a museum, not only as objects of art and culture, but also in building facilities, exhibitions, and installations, making their proper care and handling a vital element of museum life. In the world of plastics, the last several decades have seen rapid growth in new methods of application, new technologies, and new composite materials. And as the earliest products of plastics technology have aged, the responsibility for conserving them has fallen to museum specialists, who have become repositories of the information and skills necessary to preserve many types of plastic products for future generations.

Many notable figures have contributed to advancements in plastics research and conservation. Scientists and conservators such as Mary Baker (Baker 1992), Sharon Blank (Blank 1990), Julia Fenn (Fenn 1995), David Grattan (Grattan 1993), Brenda Keneghan (Keneghan 1996, 2005), Thea B. van Oosten (van Oosten 1999), Anita Quye (Quye 1999), Yvonne Shashoua (Shashoua 2008), Scott Williams (Williams 2002), and Colin Williamson (Quye 1999), to name a few, have pioneered the field of plastics conservation.

Moreover, conservators at institutions such as the Museum of Modern Art, the Tate Modern, the Netherlands Institute of Cultural Heritage, the Getty Conservation Institute, and the Victorian and Albert Museum have consistently shared their new findings and techniques with others in the field. In 1996, in recognition of the need for new developments in the field of plastics conservation, the International Council of Museums established a working group called "Modern Materials and Contemporary Art" to address the urgent concerns of managing plastic materials in a museum environment.

Plastics Conservation

Following on the work of these pioneering figures and institutions, Mary Coughlin, Objects Conservator at the Smithsonian Institution (SI), initiated a program in 2006 to investigate the condition of the plastics collection at the National Museum of American History (NMAH). As part of this effort, Jia-sun Tsang of the SI's Museum Conservation Institute has surveyed hundreds of plastic artifacts at the NMAH, ranging from a cellulose nitrate vanity set from 1875 to polycarbonate safety glass made in 1971. Tsang has worked to identify the chemicals used to manufacture these modern materials and to assess their impact on both modern culture and their immediate environment. Working in collaboration with NMAH curators Ann Seeger and Eric Jentsch, Coughlin and Tsang made discoveries (Coughlin 2006; Tsang 2008) about the plastics in their collection that went far beyond the objects' cultural and aesthetic value. Significantly, they concluded that plastic is not the everlasting material it was originally considered to be.

Risks or Plastics Degradation

Plastics old and new have begun to show disturbing signs of instability. Plastics behave and degrade differently from more traditional materials. Because they are organic, they are subject to degradation by light, heat, moisture, and pollutants. They have a relatively long induction period during which the material is stable, followed by an accelerating degradation that is rapid and irreversible. The leaching, migration and evaporation, and degradation of plasticizers that result from plastic degradation are of special concern. In medical terms, plasticizers such as phthalate esters and bisphenol-A (BPA) are endocrine disruptors, and most regulatory bodies classify them as priority pollutants. The offgassing of volatile organic compounds (VOCs), which are major indoor air contaminants, can create a serious environmental hazard.

To a museum conservator, the degradation of plastics poses risks not only to the integrity of the objects themselves, but also to those involved in handling and exhibiting them. These risks are often downplayed by manufacturers seeking to promote the widespread use of plastics, and data from the scientific community and regulatory agencies is often controversial, conflicting, and inconclusive. It is difficult for museum specialists to sift through rapidly emerging scientific data and to separate solid information from myth and alarmism.

The most reliable studies, however, clearly show that plasticizers such as BPA, found in common objects like food containers, toys, medical devices, cell phones, and compact discs, can leach from plastics and have negative health effects. One recent federal study estimated that BPA is present in the urine of 93% of the population in the United States. It is uncertain whether the changes seen in animal studies are applicable to humans, but John R. Butcher, associate director of the National Toxicology Program, stated in 2008 that "we have concluded that the possibility that BPA may affect human development cannot be dismissed" (Layton 2008).

In a retrospective human biomonitoring study (Wittassek 2007), a group of German researchers reported finding metabolites of all known phthalates in over 98% of urine samples studied, indicating a ubiquitous exposure to phthalates among the German population throughout the last 20 years. Recent media attention on the widespread use and effects of phthalates has raised public interest and stirred intense

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debate in the arenas of medicine, industry, and government. Given the abundance of new and old plastics currently displayed and archived in museums, it is critical that conservators translate this emerging, interdisciplinary information on plastics degradation to the museum environment in order to grapple with the health and environmental concerns raised. Conservators are in a unique position to inform their colleagues of these concerns and to share valuable information with the community at large.

Plastics in Museum Collections: Challenges and Risks

Since modern plastics are the product of two centuries of innovation and development, it would be absurd to assume that any museum's artistic and cultural collections were devoid of plastics. Indeed, plastic can be found in textiles and costumes, furniture, industrial machinery, books and papers, sound recordings, and as single or composite entities. However, many museums are victims of "plastics denial syndrome," a term coined by Keneghan, "where those in charge will swear blindly that there are no plastic objects in their collection and are absolutely astonished when a hidden câche is uncovered" (Keneghan 1996). Although Keneghan reported (Keneghan 2005) that this syndrome has been eradicated at the Victoria and Albert Museum, it can still be found in many large and small historical and cultural museums in the United States.

A further challenge facing conservators and conservation scientists in dealing with plastics conservation is a lack of information. Since no two plastics were made the same way, with the same formulation, under the same manufacturing conditions, it is reasonable to expect that plastics vary widely in their response to heat, light, moisture, and solvents. Without proper information regarding the chemical components of various plastic objects, it is difficult to pin down the exact cause of degradation, separate harmful from safe plastics, and devise a suitable conservation plan. Thus, in order to properly and systematically identify existing and potential problems, a survey of plastics collections must include a chemical analysis of individual pieces.

The principle of caution that guides a good conservator should also inform an approach to plastics conservation. Whether or not the exact mechanisms of risk can be assessed for each individual object, handlers should observe standard guidelines to ensure their health and safety. Even in the generally safe and stable environment of a museum, plastic objects pose risks to the environment and the people who handle them. Plastics are relatively durable and degrade rather slowly. However, it is impossible to know whether plastic objects, prior to their accession to a museum's collection, were exposed to elevated temperatures, high humidity, or mechanical stress, all of which could initiate material degradation and the release of chemical pollutants. A loss of power in a museum facility, resulting in elevated temperature and humidity, could also initiate degradation. For this reason, it is important to document the condition of plastics, making no assumptions about the degree of degradation without thorough examination, and to thoroughly monitor working environments and record the way in which plastics are handled.

As new findings on plastics become available, new risks and concerns will undoubtedly emerge. For now, the major risks of plastics degradation and resultant chemical pollution are migration and evaporation of plasticizers and offgassing. These were the most prevalent issues in the survey of collections at the NMAH reported here.

Degradation of Plasticizers

Leaching, and migration and evaporation of plasticizers lead to the deterioration of plastics and shortening of a plastic object's usable lifetime. Leaching refers to the extraction of a substance from a solid via contact with a liquid medium. Since most of the plastics in museum collections do not come in contact with liquid, leaching is not a significant problem for conservators and will not be discussed in this paper. Migration refers to any method by which a component leaves a material as a gas, liquid, or solid. Plasticizers can evaporate to the environment as a gas and deposit as a liquid or solid onto the surface of the plastic. The migration and evaporation of plasticizers is a major cause of plastics degradation in a museum environment.

Plasticizers are low molecular-weight resins or liquids that form secondary (noncovalent) bonds to polymer chains, spreading the polymer apart. Plasticizers are added to reduce a plastic's tensile strength, hardness, density, melt viscosity, glass transition temperature, and electrostatic chargeability, while increasing its flexibility, elongation at break, toughness, and dielectric constant. Plasticizers, most commonly phthalates, make the hard, brittle plastic in polyvinyl chloride (PVC) pipe malleable and flexible enough to be made into Barbie dolls. Some PVC can consist of as much as 30% to 50% phthalates. "These liquid plasticizers, which have relatively high boiling points, may form sticky films at the surface of the plastics prior to evaporation. The sticky surfaces trap dust, which can harbor moisture and other pollutants resulting in further chemical degradation" (Shashoua 2008). During the NMAH survey of degraded plastics, it was noted that when these liquid plasticizers migrated to the surface of the plastics, they retained their high boiling point. The resultant sticky film is a "magnet" for dirt (Fig. 1).

Fig. 1 Dust-covered Bakelite helmet. Migrated plasticizers on the surface form a sticky film that traps dust.

Conservators and museum staff must be aware that when they wipe the dirty film from a plastic object, they are most likely wiping off, and thereby being exposed to, plasticizers such as phthalates. Observing proper health and safety precautions, even during the simple task of dusting plastic objects, must therefore include properly disposing of dust cloths and wipes, perhaps in the recycled waste bin.

Phthalate Plasticizers: Risks of Exposure

Developed in the 1920s, phthalates are widely used industrial additives that have been produced in large quantities since the 1950s, around the same time PVC was introduced. Phthalates can be found in plastic objects such as toys, textiles, tools, vinyl recordings, and everyday products from adhesives, cosmetics, and inks to food packaging and building materials such as paints and flooring.

Because phthalate plasticizers are not covalently bound to plastics, they can leach, migrate, or evaporate into the environment and, as a result, have become ubiquitous contaminants. Exposure may be through ingestion, inhalation, or dermal exposure and may begin in utero and continue throughout an individual's lifetime. Studies suggest that exposure to phthalates increases the risk of birth defects and hormonal alteration in baby boys, as well as reproductive problems and hormonal changes in adult men. Though phthalates are considered hazardous waste and are regulated as air and water pollutants, they are unregulated in food, cosmetics, and consumer and medical products. Exposure to infant care products such as lotion, powder, and shampoo has been associated with increased urinary concentration of monoethyl phthalate, monomethyl phthalate, and monoisobutyl phthalate (Sathyanarayana 2008).

Studies of workers in the building industry have shown that eye irritation, sore throat, and other nonspecific symptoms were often linked to volatile organic compounds (VOCs) such as phthalates. High concentrations (980-3000 mg/kg) of diethyl hexyl phthalate (DEHP), an endocrine-disrupting chemical, have been detected in dust samples taken from building sites (Hutter 2006). Plasticizers may be responsible for up to 50% of VOC emissions from flooring (excluding the adhesive). A 2008 publication (Hwang 2008) reported workers' exposure to indoor dust that contained high levels of DEHP.

The World Health Organization's International Agency for Research on Cancer has identified phthalates used in PVC as a carcinogen. The European Union has banned the use of DEHP, the most widely used plasticizer in children's toys. Scientists fear that even minimal levels of this chemical may reduce immunity, alter behavior in adults, and cause cancer. Responding to growing consumer anxiety, California lawmakers have enacted statewide restrictions on some widely used plasticizers in children's toys. Starting in January 2009, the use of some phthalates became restricted in California. Following California's lead, the U.S. Congress has banned the use of six phthalates in the manufacture of toys, effective beginning in 2009.

The migration of plasticizers such as phthalates to the surface of a plastic object poses a health risk for museum conservators. It is clear that phthalates can separate from aging plastics and contaminate both those who handle them and the museum environment. In a study of the mechanism of degradation of plasticized PVC under artificial aging conditions, Ito and Nagai (Ito 2007) reported that the concentration of plasticizers varied through each phase of the aging process. They observed the surface and a cross section of PVC during weathering conditions and found a stepwise outflow of inorganic components and plasticizer, presumably a main mechanism of plastic degradation. Phthalates can be found not only in PVC, but in many early plastics such cellulose acetate and cellulose nitrate. Because phthalates create surface residues on a wide variety of plastic objects, it is crucial that museum conservators monitor the handling of plastics and take proper precautions.

Case Studies of Phthalate Degradation

The survey of plastic objects at the NMAH included a man's loafer (Fig. 2), listed in the catalog as the first vinyl shoe

Fig. 2 Vinyl shoe from the Medicine and Science Division, NMAH. Migrated plasticizers form a sticky deposit on poorly ventilated areas of the shoe, such as the sole.

made in the U.S. It has been in the collection since 1981, and the manufacturer's name, International Vulcanizing Corporation, is visible on the sole. When it was routinely surveyed in 2007, the top of the shoe was found to be covered with sticky droplets, most likely the result of migration of plasticizers to the surface of the shoe. The follow-up survey in 2008 noted that since the object had been moved to a

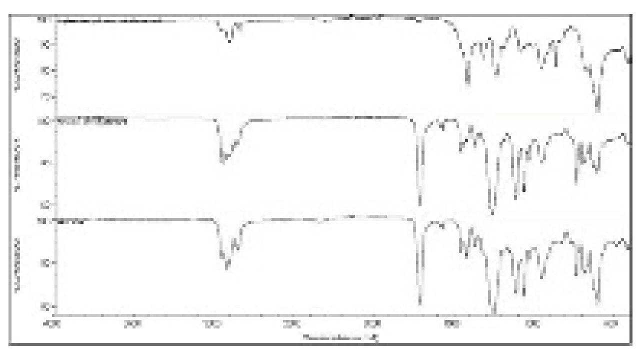

Fig. 3 FTIR-ATR spectrometry of unplasticized PVS standard (top), plasticized PVS standard (center), and a sample from the vinyl shoe.

well-ventilated location, the droplets had disappeared from the top of the shoe but were still abundant on the sole, which was not exposed to increased ventilation. A small sample of the vinyl shoe was taken for Fourier Transform Infrared-Attenuated Total Reflectance (FTIR-ATR) analysis (Fig. 3) and comparison with unplasticized and plasticized PVC. The material in the vinyl shoe matched the plasticized PVC standard. This information was added to the data file, along with a recommendation to store the shoe in a less ventilated environment.

The NMAH survey also uncovered a two-part buckle (Fig. 4), listed in the catalog as made of black plastic, with an

Fig. 4 Two-part buckle made of cellulose nitrate. Plasticizers have migrated to the surface and formed white deposits. Medicine and Science Division.

etched design picturing a rickshaw with a driver and passenger. Both circular pieces have six holes near the rim for sewing onto a garment. One piece has a metal hook and the other has a metal eye. On visual inspection, museum personnel were unable to determine whether the plastic material was cellulose acetate, cellulose nitrate, Bakelite, shellac composite, or polystyrene. Disfiguring stains were identified as some kind of adhesive. However, FTIR-ATR

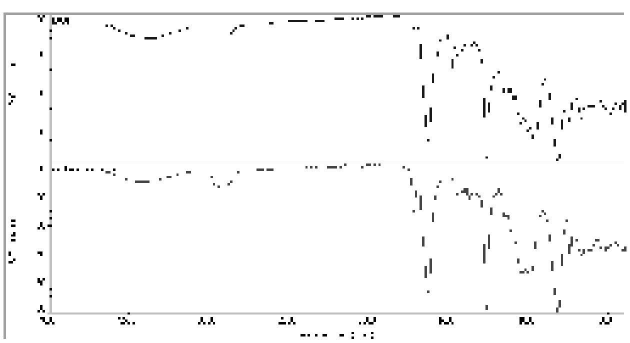

Fig. 5 FTIR-ATR spectrometry of cellulose nitrate buckle described in Fig. 4 (top) and cellulose nitrate standard (bottom).

analysis identified the plastic as cellulose nitrate (Fig. 5) and the stains were found to be solid deposits of plasticizers that had migrated to the surface.

Offgassing

Another feature of plastics degradation is offgassing, or the volatile emission of chemicals from a solid material. Building industry investigations have found that a large proportion of indoor VOCs comes from building materials such as plastics, paints, and adhesives. In a museum environment, offgassing of plastics comes from three sources. The first source is vapor released from newly manufactured plastics, such as those found in new flooring material, new installations, and newly produced artwork. New plastics release soluble oligomers present as unbound additives, including plasticizers or organic modifiers. These unbound volatile chemicals escape into the air, where some eventually disappear and others linger for some time. This type of offgassing is associated with what it was often described as “new car smell” or “new shower curtain smell.” When warmed to 50-60º C, plastics give off odors ranging from the sweet, fruity smell of acrylic to an odor similar to the preserving fluid urea-formaldehyde (Shashoua 2008, 119). These odors are evident at room temperature; at high temperatures and in poorly ventilated areas, these odors can be noxious.

The VOCs given off by newly manufactured plastics come from a wide array of materials, many of which have been shown to be toxic or carcinogenic. For example, sources of offgassing in a new car may include acetonitrile, decanol, formaldehyde, naphthalene, and carbon disulfide used in foams, adhesives, and fabrics. The two most toxic chemicals in most new vehicles are polybrominated diphenyl ethers, used as fire retardant, and plasticizers including phthalates (Chien, 2007). Even new flooring may be a source of numerous VOCs. Analysis of a PVC floor sample using solid-phase microextraction sampling techniques with GC-MS analysis identified acetic acid, styrene, alpha-pinene, benzaldehyde, n-decane, 2-theyl-1-hexanol, in addition to phthalates (Nuicolle 2008).

Another source of offgassing in museums is degraded plastics. As plastics degrade, they can emit acids, plasticizers, and solvents in the form of alcohols, ketones, and aldehydes. Plastics are made from fossil fuels, and as they age the large molecules of polymers break down into smaller molecules that react with moisture to produce acids and alcohols.

Additives and plasticizers can also be released as vapor, especially at high temperatures or high humidity. This type of offgassing is primarily a result of chemical degradation through oxidation and hydrolysis, and can be initiated by ultraviolet radiation and light, heat, oxygen, and moisture. As many as 92 VOCs are associated with the thermal degradation of acrylonitrile butadiene styrene (Shapi 1991), while 190 volatile compounds are emitted during the decomposition of polystyrene (Shapi 1990).

Additional VOCs from degraded plastics include nitrogenous organic gas from polyurethane, and hydrogen sulfide and sulfur-containing gas from rubber and vulcanite objects. Many other forms of chemical offgassing are described in the conservation literature.

A third type of offgassing encountered in museum collections is acid vapor specific to degraded semiplastics such as cellulose nitrate and cellulose acetate. The damage to objects caused by such acid vapors has been widely studied and reported. Less studied is the negative impact these acid vapors have on the safety and health of people who handle plastic objects in a museum environment.

Early plastics are more prone to degradation through release of acid vapors than anything else, but can still suffer the effects of migration and evaporation of plasticizers. Cellulose nitrate, a semisynthetic polymer, was discovered in 1845 in Germany and used commercially from the 1860s to the late 20th century. Deteriorating cellulose nitrate emits reactive nitrous oxide that can be converted to nitric acid, a strong oxidizing agent, by reacting with moisture, especially in high relative humidity.

This offgassing is flammable and toxic and can create dangerous fumes, fade dyes, corrode metals, and tarnish silver. These byproducts are harmful not only to the objects' environment, but also to the people involved in handling and transporting the objects.

Cellulose acetate, a plastic known for releasing vapors with a sour, vinegary odor, was developed in 1910 as a less toxic and less flammable alternative to cellulose nitrate. Also known as "safety" film, it was used in cartoon cels, medical devices, glasses frames, combs, and toothbrushes. However, 20 years after its development, handlers noticed that cellulose acetate emitted acetic acid and sulfuric acid when exposed to high temperature and high humidity. As it degraded, the plasticizers leaked, leading to hydrolysis and oxidation of the acid compound. The resulting effect was a sticky, acidic surface along with warping and breakage of the plastic object.

The negative effects of acid vapor release were evident in a routine collections survey at the NMAH. A single drawer (Fig. 6) contained a mixed assortment of metalware, handbags, glass, and plastic. Plastic objects in the center of the drawer had deteriorated and released an acid vapor. Over time, this slow offgassing resulted in corrosion of metal objects in the drawer, offering solid evidence that acid vapor released from plastic has a corrosive effect on other materials, and thus poses a risk to museum personnel.

Fig. 6 Acid vapors released from degraded plastic materials (center) have corroded a metal pan (photo center top) and a metal box (photo lower right) in the same drawer.

In the published literature, reports on the sensory indicators of plastics degradation have doubled in the last ten years. In addition to telltale odors and corrosion of nearby materials such as metal, textile, and paper, many visual signs indicate the degradation of plastics, such as blistering, blooming, breaking, brittleness, chalking, cracking, crazing, crumbling, dents, delamination, discoloring, fraying, pitting, scratching, staining, warping, weeping, and yellowing. (Quye 1999; Shashoua 2008).

Conservators should collect and regularly consult reliable data on the detection of plastics degradation and the environmental conditions that promote it. Such information is necessary in order to set institutional priorities regarding the preservation of collections, to protect collections from further damage, and to mitigate possible health risks to museum personnel.

Guidelines for the Safe Handling of Plastics in Museum Collections

Hand washing is the single most important way to prevent the spread of contaminants arising from plastics degradation. Yet despite the proven health benefits of hand washing, many people don't practice effective hygiene. Regular hand washing with simple soap and water has proven absolutely crucial in a conservation laboratory where conservators handle harsh chemicals and sensitive objects. Throughout the workday, conservators who handle plastics must ensure that they do not contaminate objects or surfaces through the spread of plasticizers. Hand washing should thus be regarded as a job requirement, not an option.

Proper Hand Washing Technique

Wet hands with warm running water and lather well with liquid soap or clean bar soap.

Rub hands together vigorously for at least 15 to 20 seconds.

Scrub all surfaces, including the backs of the hands, wrists, between the fingers and under the fingernails.

Rinse well.

Safe Handling of Plastics

Avoid direct contact with plastics. When handling plastics, always wear gloves that are impermeable to acid, dust, and plasticizers. Check chemical compatability guide for suitable gloves. (EZfacts, 2002)

Wear laboratory clothing when handling plastics.

Remove gloves and lab coats before leaving the workplace.

Wash laboratory clothing separately.

Use dedicated pens or markers when surveying or handling plastics.

Never smell or taste plastics; avoid wet chemistry tests involving heating and smelling, especially in poorly ventilated areas.

Wash hands and arms with soap and water after removing gloves and before leaving the work area.

Never eat, drink, chew gum or tobacco, smoke, or apply cosmetics in the work environment.

Remove gloves before touching phones, tools, doorknobs, etc.

Keep all work tables and benches clean and uncluttered.

Post a sign notifying others of possible hazards and list emergency contact numbers.

Safety in the Care of Plastics Collections

Isolate degraded plastics.

Use local exhaust ventilation to remove toxic fumes or dust at the source.

Ventilate the area with fresh air.

Train staff in proper handling of plastics collections.

Ensure that information on the chemical components of the plastics is available to curators, museum specialists, art handlers, and others involved with the plastics collections.

If degraded objects can be deaccessioned, contact your institution's environmental or safety officer for proper disposal techniques.

Keep the temperature at or below 20º C and relative humidity 30% to 50%, suitable conditions for most plastics.

Conclusion

Much has been written on the proper care of plastics in museum collections, with little focus on the health and safety of those who handle and care for plastic materials. This is unfortunate in light of increasing evidence, on a global scale, of the health and environmental risks posed by exposure to plastics. Further research and education are needed to develop safe handling practices and create safe environments for plastics collections.

In the meantime, conservators who handle plastics—especially degraded plastics—should work closely with their safety officers and building engineers to establish safety guidelines, and should develop habits of good personal hygiene as a precaution against potential contamination. The risks are too great to ignore.

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