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WIPING AWAY THE DIRT – A SAFE OPTION FOR PLASTICS?

Keywords: POPART, plastic, polymethylmethacrylate, polyvinyl chloride, cellulose acetate, high impact polystyrene, high density polyethylene, mechanical cleaning

ABSTRACT

Modern and contemporary collections are characterized by the diversity of materials present. Although plastics were once thought to be an indestructible product of the 20th century, museum professionals are now challenged by their conservation. One pressing challenge is cleaning plastics' vulnerable surfaces. This article presents the results of extensive research into the risks associated with cleaning flexible and rigid plastics. Mechanical cleaning tools were evaluated for their potential to damage plastic surfaces. Examination of PMMA, PVC, HDPE, HIPS, CA and EPS before and after cleaning using optical and microscopic techniques, changes in surface energy and gloss, suggested that the ten least damaging mechanical cleaning materials for all plastics were cotton bud, cotton cloth, microfiber cloth, spectacle cloth, leather chamois, sable hair brush, feather duster, synthetic feather duster, yellow Akapad sponge and canned air.

RÉSUMÉ

Les collections d'art moderne et contemporain sont caractérisées par la diversité des matériaux en présence. Si les plastiques étaient autrefois considérés comme un produit indestructible du xx^e^ siècle, les professionnels des musées sont aujourd'hui confrontés à leur conservation. Un des problèmes majeurs est le nettoyage des surfaces vulnérables des plastiques. Cet article présente les résultats de recherches approfondies sur les risques associés au nettoyage des plastiques flexibles et rigides. Des outils de nettoyage mécaniques ont été évalués afin de déterminer s'ils pourraient endommager les surfaces en plastique. L'examen de PMAM, PCV, PEHD, PSHI, AC et PSE avant et après nettoyage à l'aide de techniques optiques et

INTRODUCTION

Surveys of the condition of plastics conducted in museums conclude that 75 percent of collections require cleaning (Shashoua and Ward 1995). Oily fingerprints, carbonaceous dirt and crystalline degradation products on museum objects or artworks compromise their significances, chemical stabilities and other values. Despite the high demand, few conservation cleaning treatments for plastics have been established because of the fear of damaging them mechanically or chemically. In theory, thermoplastics, particularly polyethylene and plasticized polyvinylchloride, risk abrasion from contact with brushes, cloths and sponges. Solvents and detergents are known to extract additives from and migrate into flexible plastics and can induce environmental stress cracking in rigid plastics including polystyrene and polymethylmethacrylate.

As part of the EU 7th Framework Programme project POPART (Preservation of Plastic ARTefacts in museums), an exhaustive evaluation of mechanical, aqueous and non-aqueous cleaning techniques for their effectiveness at removing soil and effect on stability of plastics started in 2009 and will conclude with the publication of guidelines for cleaning in 2012.

Of the various techniques used to clean plastics, mechanical cleaning in the absence of aqueous cleaning agents or solvents is generally considered that offering the lowest risk of inducing permanent damage and therefore was the starting point. This paper discusses the evaluation of mechanical cleaning model samples of polymethylmethacrylate (PMMA), plasticized polyvinylchloride (PVC), high density polyethylene (HDPE), high impact polystyrene both cast and extruded (HIPS and EPS respectively) and cellulose acetate (CA). These plastics were selected for investigation because although they are well represented in museum collections and often require cleaning, cleaning procedures for them are lacking.

EXPERIMENTAL

Model plastics

Initial mechanical cleaning trials were conducted on new, colourless and transparent or pearlescent model plastics to investigate whether cleaning materials in the absence of aqueous or solvent-based cleaning agents damaged substrates. Uncoloured PMMA, PVC, HDPE, HIPS, EPS and CA were

microscopiques, ainsi que les variations de la tension superficielle et de la brillance ont montré que les dix matériaux les moins nocifs pour le nettoyage mécanique de tous les plastiques sont le coton-tige, le chiffon en coton, le chiffon en microfibres, le chiffon à lunettes, la peau de chamois, la brosse en poil de martre, le plumeau, le plumeau synthétique, l'éponge Akapad jaune et le pulvérisateur d'air.

RESUMEN

Las colecciones modernas y contemporáneas se caracterizan por la diversidad de los materiales presentes. Aunque en su día se creyó que el plástico era un producto indestructible del siglo XX, lo profesionales de los museos se enfrentan hoy al reto de su conservación. Uno de los problemas más urgentes es la limpieza de las superficies vulnerables del plástico. Este artículo presenta los resultados de una extensa investigación sobre los riesgos asociados con la limpieza de plásticos flexibles y rígidos. Se evaluaron las herramientas de limpieza mecánica en función de su potencial para dañar las superficies plásticas. Los análisis con técnicas ópticas y microscópicas de PMMA, PVC, HDPE, HIPS, CA y EPS antes y después de la limpieza, así como los cambios en la energía y el brillo de la superficie, sugirieron que los diez materiales menos perjudiciales para la limpieza mecánica de todo tipo de plásticos eran los hisopos de algodón, el paño de algodón, el paño de microfibra, los paños para limpieza de lentes, las gamuzas de piel, los cepillos de pelo de marta, los plumeros, los plumeros sintéticos, la esponja amarilla Akapad y el aire comprimido.

Figure 1
A selection of the tested cleaning materials

selected to exclude the influence of fillers and pigments on cleaning. All plastics were supplied in a thickness of 0.2 cm except for PVC (0.03 cm) and CA (0.04 cm). Plastics were supplied with protective films on both sides, with the exceptions of HDPE, PVC, EPS and CA and cut to the required size. Protective film was removed immediately prior to cleaning. Only ten cleaning materials were tested on CA, as this material was added to the project later than the others. The ten cleaning materials tested on CA were those which had caused least damage to the other five plastics.

Cleaning materials and techniques

Published literature and informal enquiries about industrial and conservation cleaning were used to select approximately 40 cleaning materials. Twenty-two complied with health and safety requirements, were available in all nine POPART partner countries and were investigated. They comprised cotton bud, cotton cloth, microfiber cloth, spectacle cloth, paper tissue, paper cloth, lens paper, leather and synthetic chamois, goat and sable hair brushes, nylon toothbrush, white and yellow Akapad sponges (formerly known as Wishab), natural latex and synthetic rubber make-up sponges, polyurethane ester cleaning sponge (Scotch-Brite) and melamine formaldehyde resin sponge (Duzzit), natural and synthetic feather dusters, canned and compressed air (Figure 1 and Table 1).

From literature and discussion with experienced conservators, it was clear that mechanical action was applied either in linear or circular directions and therefore both were investigated, though for CA only linear rubs were applied. An attempt was made to quantify the force applied when cleaning by applying materials to a sample placed on a top pan balance and recording the weight applied. Weights varied from 10 g for brushes and dusters to 40 g for cloths and sponges with an error of ±10 g. Because the measurements were unstable and because the actual area of the cleaning material in contact with the surface should be included in any calculations of force, quantification was abandoned.

Samples were cut to size (4.5 cm × 13 cm). Cleaning was conducted on the same side of each model plastic, since initial testing had revealed minor differences in gloss and contact angle between the two sides. Two areas measuring 3 cm × 4 cm were marked in the centre of each plastic to avoid unevenness or stress at the cut edges. Five linear rubs were applied to the upper areas with each cleaning material and five circular rubs were applied to the lower areas. Dust was present at surfaces immediately after cleaning either due to static electricity or plasticizer at surfaces. To minimize contamination, samples were placed in a covered box immediately after cleaning.

In addition to the 22 cleaning materials, cleaning with dry-ice was also tested. Dry-ice is solid carbon dioxide at -79°C. Carbon dioxide in snow form was applied to model plastics with a spray pistol attached to a compressor. The advantage of cleaning with dry-ice is that it sublimes immediately on making contact with warmer surfaces. This means that surfaces never become moist unlike with water or solvents. Cleaning was carried out by an employee from the company LTL Dry Ice APS and 'rubs' were only applied in one direction. Dry-ice cleaning was not conducted on CA.

Table 1
Model plastics and cleaning products evaluated

Plastics				
Plastic type	**Product name**	**Description**	**Material**	**Supplier**
PMMA	Plexiglas®XT 0A000	Transparent and colourless sheet	Polymethylmethacrylate	Rias A/S, www.rias.dk
PVC	Transparent oilcloth	Transparent and colourless film	Polyvinyl chloride	Jysk A/S, www.jysk.as
CA	Clarifoil®	Transparent and colourless film	Cellulose acetate	DAKA BV, www.daka-oss.com
HDPE	PE-HD 500	White sheet	High density polyethylene	Weber Métaux et Plastiques, www.weber-france.com
HIPS	Styrolux 80/20	Transparent and colourless sheet	High impact polystyrene	Bay Plastics Ltd., www.bayplastics.co.uk
EPS	Foam board	Transparent and colourless though it appears white and opaque	Polystyrene extruded	W Hobby Wholesale Ltd., www.hobby.uk.com

Cleaning materials				
Article name	**Product name**	**Description**	**Material**	**Supplier**
Cotton bud	Cotton Wool Hospital Quality code 5909	500g roll. Homemade cotton bud made on a china stick	Cellulose	Robinson Healthcare Ltd., www. robinsoncare.com
Cotton cloth	Dish towel	Woven cotton. Washed before used	Cotton	SuperBrugsen, www.superbrugsen.dk
Spectacle cloth	Spectacle cloth	Thin fibers and closed weaving	Polyester and polyamide	EverClean, www.brauner-as.dk
Microfiber cloth	Microfiber cloth	Thick fibers and open weaving	Polyester and polyamide	EverClean, www.brauner-as.dk
Paper tissue	Tork Premium Facial Tissue Extra Soft	Package with 100 sheets	Virgin fibres (cellulose)	SCA Hygiene Products A/S, www.tork.dk
Paper cloth	Tork Premium Multipurpose Cloth 510 Roll	Roll with 1000 sheets	Cellulose pulp, polypropylene and polyester fibres	SCA Hygiene Products A/S, www.tork.dk
Lens paper	Assistent Linsenpapier no. 1019	Package with 500 sheets	Cellulose	Assistent Glaswarenfabrik Karl Hecht GmbH & Co, www.hecht-assistent.com
Leather chamois	Leather chamois	Washed before use. Soft (fluffy) side was used for testing	Tanned lambskin	Stiwex/ DAY-system A/S, www.day-system.com
Synthetic leather chamois	Synthetic leather chamois	Synthetic chamois with small holes	Viscose and synthetic latex	Anton Walraf Söhne GmbH & Co, www.walraf.com
Goat hair brush	Japanese brush	Size 2 (width 50mm)	Goat hair	Deffner und Johann GmbH, www.deffner-johann.de
Sable hair brush	A&B brush no. 6074	Size 8	Sable hair	A & B pensler, www.bottzauw.dk
Tooth brush	Tooth brush	Soft hairs	Nylon hair	Unknown origin
Duzzit sponge	Duzzit sponge eraser	Package with four sponges in blue and white	Melamine formaldehyde resin	151 Products Ltd., www.151.co.uk
White Akapad sponge	Akapad white no. 4151 (Formerly known as Wishab)	Scouring pad with synthetic sponge. Recommended for paper	Styrene butadiene rubber	Akachemie Albert Kauderer GmbH, www.akachemie.de
Yellow Akapad sponge	Akapad hard no. 4121 (Formerly known as Wishab)	Scouring pad with synthetic sponge. Recommended for wall paintings.	Synthetic rubber	Akachemie Albert Kauderer GmbH, www.akachemie.de
Latex sponge	Make-up sponge	Bag with 20 sponges in white and skin colour	Latex	Netto Supermarket, www.netto.co.uk
Synthetic rubber sponge	Make-up sponge (synthetic)	Bag with 40 sponges in white and pink	Styrene butadiene rubber	M-cosmetics, www.matas.dk
Scotch-Brite sponge	Scotch-Brite® Non-Scratch Scrub Sponge no. 625	Scouring pad with soft sponge	Polyurethane ester	3M, www.3m.com
Feather duster	Feather duster	A single feather obtained	Ostrich feather	Handler textiler, www.handler-textiler.dk
Synthetic feather duster	Swiffer Duster Kit	Synthetic feather duster	Polyester and polypropylene microfibers	Swiffer®, www.swiffer.com
Canned air	Pressurised Air Duster	Can containing 400ml	Compressed air	Lyreco Danmark A/S, www.lyreco.dk
Compressed air	Compressed air	In-house compressed air. Technically cleaned for oil residues		
Dry-ice	Asco Carbon Dioxide	Temperature of solid CO_2: 79°C	Solid carbon dioxide	LTL Dry Ice APS, www.ltl-dryice.dk

EVALUATION OF CHANGES INDUCED BY MECHANICAL CLEANING

The techniques used to examine model plastics before and after mechanical cleaning were visual appearance, gloss, contact angle and percentage area scratched.

Visual appearance

Visual examination before and after cleaning was used to determine mainly whether the procedure had either introduced scratches or deposited residues. The cleaned area was compared with non-cleaned surfaces of the same plastic. Any changes visible to the naked eye were documented in an Excel database and colour coded to indicate the type of change.

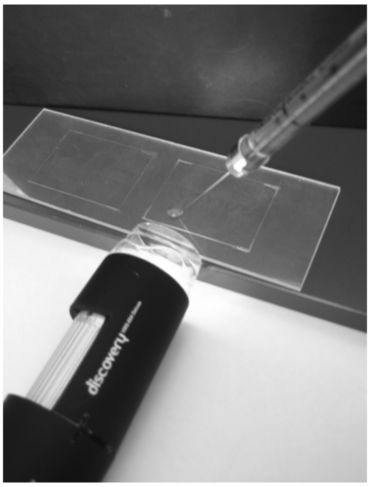

Figure 2
Setup for determining contact angle of distilled water on PMMA samples with a USB microscope

Contact angle

Changes in surface energies of model plastics induced by cleaning were likely to be caused by contamination from residues of cleaning agents or surface damage such as scratches. They were quantified using changes in contact angle formed between a droplet of distilled water on surfaces of model plastics (Figure 2). Water (20 µL) was applied by syringe and a simple, low-cost Veho VMS-004 Discovery Deluxe USB microscope, used at 400 times magnification was used to photograph the process. Contact angles were determined by analysing photographs with the Micro Capture software supplied with the USB microscope. To minimize the influence of static electricity developed during cleaning on the contact angle, particularly on HIPS and EPS, measurements were made 24 hours after cleaning. Contact angles were made in triplicate and the mean angle calculated.

Percentage area scratched

Photomicrographs were taken using a Carl Zeiss Jena NEOPHOTO 32 Large incident Camera Microscope in dark field. Magnification of the objective was × 3.2 and of the lens × 8. Photographs were taken with an InfinityX camera from Delta Pix and an area measuring 1280 pixel × 1024 pixel manipulated using DpxViewPro from Delta Pix.

Photomicrographs were examined for scratches, which were coloured falsely using imaging program Adobe Photoshop with a chosen line width of two units. Images were converted to black and white with Image-J free computer software (www.rsbweb.nih.gov/ij) and binary threshold used

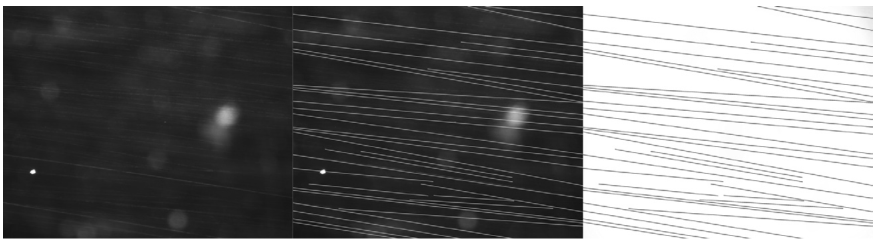

Figure 3
Photomicrograph (left) was falsely coloured using Abobe Photoshop (middle), converted to black and white using Image-J (right) and binary threshold used to calculate percentage area scratched

to calculate the percentage area scratched (Figure 3). The process was repeated in two areas and an average value calculated.

Gloss

Gloss is the ability of a surface to reflect specular light. Materials with smooth surfaces appear highly reflective (glossy), while very rough surfaces reflect no specular light and therefore appear matt.

Gloss of test substrates before and after cleaning was determined using a Minolta multi-gloss 268 reflectometer. The instrument was calibrated to 100 gloss units using the standard black glass tile supplied with the instrument. Calibration was repeated every ten minutes during measuring. It was possible to determine gloss at angles of illumination of 20°, 60° and 85°. It is recommended that poorly reflective surfaces are examined at 85°, semi-glossy surfaces should be examined at 60° and highly reflective surfaces at 20° (Minolta, 2009).

Because the test substrates were transparent and therefore likely to exhibit multiple reflections from internal surfaces, a grey, matt card was placed directly under them in an attempt to reduce extraneous reflections. The measuring area of the Minolta mini-gloss 268 was approximately 1.5 cm × 1.5 cm. For PMMA, PVC, HIPS and CA all gloss measurements on new test substrates were greater than 100 gloss units which can be attributed to the presence of multiple reflections in the bulk of the plastics. The grey matt card placed underneath the test substrates was replaced with both black and white cards in an attempt to reduce reflection from the lower surfaces. For the two opaque plastics, HDPE and EPS, all gloss measurements on new substrates were smaller than 100 gloss units. The standard deviation between measurements was calculated from the percentage gloss determined at 20 different positions on a new plastic films and sheets. For all plastics except PVC the error was found to be ±2 gloss units. After cleaning of each test area, three repeat measurements were made and the mean calculated. Only gloss measured at 60° were used in calculations because they showed lower variance than 20° and 85°.

RESULTS AND DISCUSSION

Visual appearance

In general, scratches were visible after mechanical cleaning of HIPS, HDPE and PMMA, but not of PVC, CA or EPS. Duzzit and Scotch Brite sponges left deep scratches on surfaces. Synthetic leather chamois, as well as all paper based products, such as the paper cloth, paper tissue and lens paper, left visible scratches on HDPE and HIPS.

Although no scratches were visible with the naked eye on model plastics after cleaning with cotton bud, spectacle and microfiber cloth, leather chamois, sable and goat hair brushes, natural latex make-up sponge, natural and synthetic feather dusters, all cleaning materials induced microscopic scratches on all plastics with the exception of canned and compressed air.

Residues were left by synthetic leather chamois, synthetic rubber sponge and both Akapad sponges on all plastics. Akapad sponges left crumbs at surfaces. They were removed as far as possible with canned air, thus avoiding making contact with surfaces with another cleaning material. Residues left by synthetic leather chamois and synthetic rubber sponge could not be removed with canned air.

None of the cleaning materials made visible scratches on PVC, but micro scratching was observed under the microscope at a magnification of x25. The scratches in PVC disappeared after approximately one month which may be attributed to migration of plasticizer to surfaces which filled them. Only ten cleaning materials were tested on CA, as this material was added to the project later than the others. None left visible signs. The fact that no scratches were visible on EPS was attributed to its uneven surface structure, which greatly influenced its appearance.

Dry-ice abraded all model plastics except for PMMA and PVC. Surfaces of HDPE and HIPS appeared to be sandblasted after cleaning and EPS was destroyed by it. Because damage to most plastics was severe after cleaning with dry-ice, samples were only examined visually.

Percentage change in contact angle

Visual examination suggested that some cleaning materials left residues at plastic surfaces. Compressed air, goat hair brush, latex sponge, synthetic leather chamois and white Akapad sponge caused large changes in contact angles, thus indicating the presence of residues (Ryan and Poduska 2008). Figure 4 shows results for HIPS, but reflects the general trend for all plastics. The percentage change in contact angle after cleaning with compressed air from a pressure hose shows that surfaces have been contaminated, most likely with compressor oil. This is interesting as the compressor is equipped with an oil filter, which means that the air was expected to be clean.

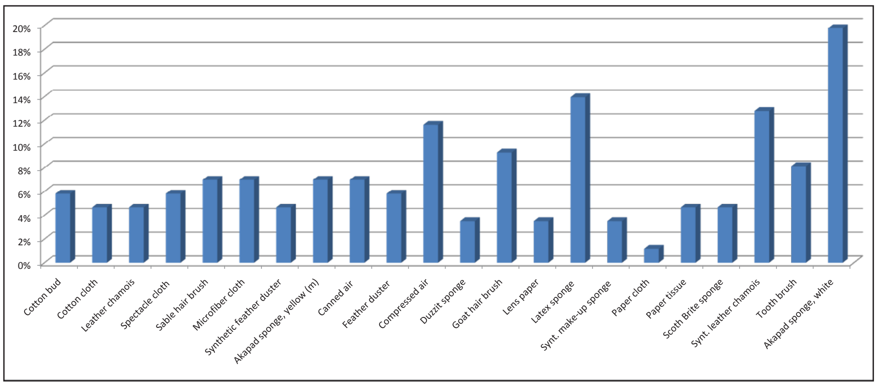

Figure 4
Percentage change in contact angle on HIPS after applying five linear rubs to surface

Percentage area scratched

Some plastics were more easily scratched than others. The most vulnerable plastics were HIPS and HDPE, followed by PVC, PMMA and CA. Scratches could not be measured on EPS due to its inhomogeneous surfaces. Two percent of the PMMA surface was covered by scratches compared to nine percent of the HIPS when both were cleaned using a cotton cloth. It should be noted that most of these scratches were invisible to the naked eye.

Figure 5 shows the percentage area scratched when cleaning HIPS. In general, sponges and paper based products caused more scratching of surfaces than other materials. Results from dry ice are not included in the graph.

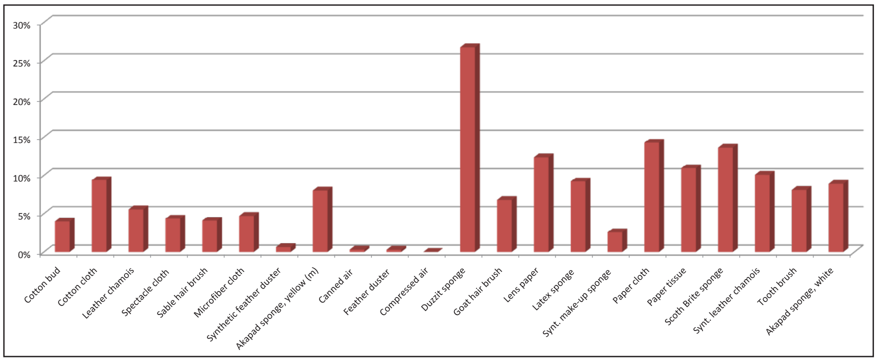

Figure 5
Percentage area scratched on HIPS after applying five linear rubs

Percentage change in gloss

Changes in gloss before and after cleaning were highest for EPS, HIPS and HDPE, though there was little variation between plastics. Reduction in gloss for HIPS and HDPE may be attributed to the many scratches induced by cleaning. The high percentage gloss change for EPS is related to the low gloss of the material itself. For fresh EPS the gloss at 60^{o} is only nine gloss units. This means that a change of just one single gloss unit results in a very high percentage gloss change.

The high flexibility of PVC made it difficult to measure gloss because small deformations caused by handling were reflected by the gloss measurements. Variation in gloss on new PVC were higher than on other plastics, indicating that gloss measurements were not the most reliable evaluation method for this material. Figure 6 shows the percentage change in gloss for HDPE, which reflects the general trend for all plastics. Duzzit sponge caused the highest percentage change in gloss while dusters, compressed air of both types induced some of the lowest.

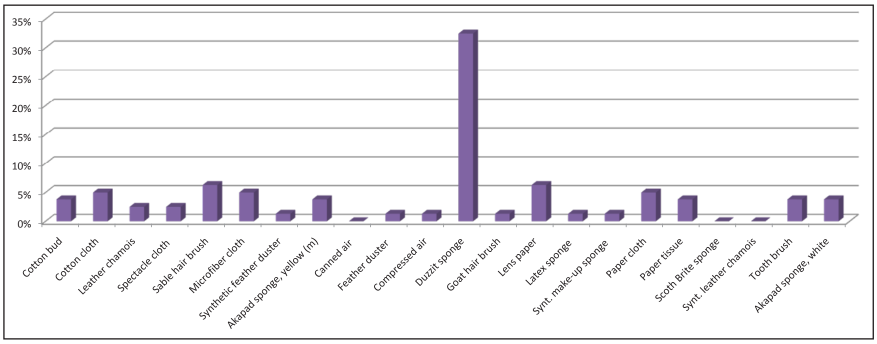

Figure 6
Percentage change in gloss on HDPE after applying five linear rubs to surface

VECTOR TO SUMMARIZE ALL MEASUREMENTS

The results from gloss measurements, contact angle and percentage of surface scratched were summarized using a vector based on the assumption that there was a relationship between them. The mechanical cleaning vector, M, was defined as:

$$M = \sqrt{(\%\ \textit{change in gloss})^2 + (\%\ \textit{change in contact angle})^2 + (\%\ \textit{area scratched})^2}$$

The higher the score, the more damaging the cleaning material. Figure 7 shows the mechanical cleaning vector for four of the plastics. The results of CA are excluded from this figure because only ten cleaning materials were tested on this material. Results of EPS are excluded because percentage area scratched was not measurable.

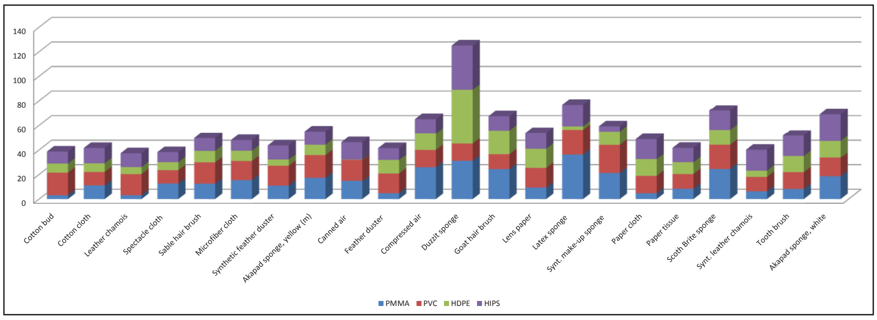

Figure 7
Addition of mechanical cleaning vectors for PMMA, PVC, HDPE and HIPS

Duzzit sponge was the most damaging material for all plastics. This finding fits well with visual examination because surfaces cleaned with Duzzit sponge were severely scratched. Almost all types of sponges, both synthetic and natural, had high mechanical cleaning vectors, some because of scratching and others because of deposited residues. Surprisingly, the goat hair brush caused more damage than the nylon tooth brush. Lens paper and paper cloth caused damage to plastic surfaces. Analysis of photomicrographs suggested that all paper based products, including paper tissue, had scratched a high percentage of the surface.

It should be noted that the results of the visual examination are not incorporated in the mechanical cleaning vector. Although the mechanical cleaning vector appeared low for synthetic leather chamois, visual examination and contact angle measurements had shown that the chamois left an unwanted residue on surfaces which could not be removed with canned air. On the other hand, the yellow Akapad sponge had a mechanical cleaning vector above average, but the visual examination showed good results as the crumbs left after cleaning could be removed by canned air. Photomicrographs revealed that the Akapad sponge left few scratches on surface.

CONCLUSION

Although mechanical cleaning has been generally perceived as the least damaging technique to remove soiling from plastics, experimental work suggests that the risks of introducing scratches or residues are measurable. It should be emphasized that this research has shown that *all* of the 22 selected cleaning materials scratched the plastic surfaces, but that some scratches were shallow and invisible to the naked eye. The interesting philosophical question one could ask is whether such damage matters. Repeatedly wiping away the dirt using dry mechanical cleaning is likely to cause visible scratches on plastic surfaces. Of the model plastics investigated, HIPS was the most vulnerable to scratching and PMMA the least.

The effect of linear cleaning motion was compared with circular motion. Although the results were almost identical for both techniques, it was concluded that linear rubs would actually remove dirt from surfaces, while circular rubs would merely redistribute it. Cleaning with dry-ice caused severe damage to HDPE, HIPS and EPS.

Evaluation of PMMA, PVC, HDPE, HIPS, CA and EPS, before and after cleaning, using optical and microscopic techniques, changes in surface energy and gloss, suggested that the ten least damaging mechanical cleaning materials for all plastics were cotton bud, cotton cloth, microfiber cloth, spectacle cloth, leather chamois, sable hair brush, natural and synthetic feather dusters, yellow Akapad sponge and canned air. These materials will be used to apply aqueous and solvent cleaning agents to model plastics in the next phase of the project.

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MATERIALS LIST

Veho VMS-004 USB microscope Deluxe model: www.veho-uk.com
Minolta Multi-Gloss 268 reflectometer: www.konicaminolta.com