A preliminary investigation into the influence of archaeological material on the yellowing of polyethylene storage bags

Karen M. Thompson[a] and Petronella Nel[b]

[a] Melbourne Data Analytics Platform, The University of Melbourne, Melbourne, Australia; [b] The Grimwade Centre for Cultural Materials Conservation, The University of Melbourne, Melbourne, Australia.

*Corresponding author: karenmthompson74@gmail.com; karen.thompson@unimelb.edu.au

A PRELIMINARY INVESTIGATION INTO THE INFLUENCE OF ARCHAEOLOGICAL MATERIAL ON THE YELLOWING OF POLYETHYLENE STORAGE BAGS

Concerns around the degradation of plastics have been part of conservation discourse for decades. The spotlight is usually on plastic art and objects, and conservation and display materials, however it could be argued that a significant volume of the plastics in museums is associated with storage bags. This study asked whether the condition of plastic storage bags might be influenced by what is stored inside them. If specific materials can be identified as more likely to affect plastic degradation, museums may have a lead-indicator for efficiently monitoring storage risks. This case study developed a methodology for applying multivariate analysis to collected data to answer this question. A subset of polyethylene self-seal bags used to pack archaeological material from the 'Casselden Place' assemblage at Museums Victoria was evaluated. Objective data was combined with subjective assessment of bag degradation features gathered during a collection survey and interrogated using multivariate statistical analysis. Results indicate (1) different levels of yellowing are associated with particular plastic bag stocks, and (2) ceramic, slate and tile finds are more likely to be contained within yellower bags than other materials. The research points to future enquiry and demonstrates this methodology shows promise for extension to other large cultural datasets.

Keywords: polyethylene, yellowing, storage, archaeological finds, preventive, data-intensive methodologies

INTRODUCTION

Museums and galleries are acutely aware of the unique risk plastics pose to their collections (for example, Williams 2002). In recent decades literature has concentrated on how plastic objects and works of art are impacted by environmental factors, how to store such pieces, and analysis of polymer-based display and conservation materials (for example, Grattan 1993, Williams 1997a, Williams 1997b).

Museums arguably hold a substantial volume of plastics in the form of plastic packing bags and boxes. Sealed plastic bags, containers and enclosures are extensively employed to protect the material inside by creating microclimates, preventing contamination, and guarding against environmental agents of deterioration (Bergmair et al. 2010). Except for investigations into self-sealing polyethylene and polypropylene containers by Larkin, Makridou & Comerford (1998) and Larkin, Blades & Makridou (2000), it is rare for attention to be given to plastics specifically used as storage, or how other materials affect plastic storage materials.

If a plastic storage enclosure degrades to the extent that it breaks open, the stored artefact is obviously at risk of damage and/or dissociation. Loss of labelling information, or the ungrouping of associated items from the one bag, severs critical contextual relationships and compromises research value. This is principally applicable to archaeology, soil samples, palaeontology, anthropology, and other sciences reliant on similar storage practices. Of these fields, archaeology is contributing a growing proportion of material to storerooms (Keene 2005, p. 35). Archaeological material is of more 'value' when it remains within the identification and storage regime determined at excavation and deposition as Keene (2002) points out: 'the connection of the object and context must be unimpeachable if these [archaeological] collections are to constitute reliable evidence' (Keene 2002, p. 17).

This research aimed to explore if the type of material stored influences plastic bag deterioration. A subset of the 'Casselden Place' archaeological assemblage, at Museums Victoria (MV), was the study sample for a novel methodology of applying multivariate statistical modelling to objective and subjective collection survey data. The intent was to provide insight into a real-world archaeological collection and contribute to guidelines for monitoring storage material with the broader purpose of protecting the integrity of the archaeological collections against dissociation and loss.

Alongside work such as that done by Duran et al (2017) and Tay (2020), this study aims to encourage and demonstrate the value of applying data-intensive analytic methods to the large datasets generated by cultural materials and conservation fields by collections and researchers. In showing that multivariate analysis to subjective data produces useful initial findings, it is hoped more researchers will explore this approach to uncover new knowledge.

BACKGROUND

Archaeological packing material

Guidelines for storage of archaeological materials from the following organisations were studied: Canadian Conservation Institute (Tétreault 2018), Heritage Victoria (2014 and 2004), National Museum of Ireland (2010), Museum of London (Grey 2006), National Park Service (2001), Society for Historical Archaeology (1993), Museums and Galleries Commission (1992), United States Federal Code 36 CFR Part 79 (1990), and United Kingdom Institute for Conservation (1983, in Sease 1984). Polyethylene (PE) is not only the preferred *plastic* but the preferred *material* for dry archaeological artefacts. Use of self-sealing PE artefact bags is so ubiquitous, archaeologists may have little reason to question their confidence in their durability.

Each type of archaeological material has a degradation path of its own, influenced by its archaeological context and post-excavation handling, particularly cleaning and storage. It is possible some materials build up degradation products while enclosed in bags that accelerate or otherwise interact with the degradation pathway of the bag.

Polyethylene

Polyethylene is a well understood hydrocarbon, and its deterioration mechanisms have been extensively described (for example, Gilbert 2017, Ronca 2017, Haider & van Oosten 2011, Horie 2010, Shashoua 2008, Peacock 2000, Kambe 1978, Schnabel & Kiwi 1978). The oxidation chain reaction can continue at room temperature and in the dark if the material was previously exposed to radiation, for instance a storage bag once exposed to ultra-violet radiation can continue to degrade even when well stored (Horie 2010, p. 40). Even heat applied during manufacture is sufficient to instigate degradation processes (Chew, Gan & Scott 1977, p. 361). Physical degradation is promoted by and in a cyclic relationship with chemical reactions, and Vink (1983) identified that polyethylene films oxidise more when exposed to mechanical stress (Vink 1983, in Haider & van Oosten 2011, p. 41). Observable degradation of particular relevance to PE film includes increased opacity, discolouration (commonly yellowing), increased brittleness and loss of flexibility, weakening and fragmentation.

In the late 1990s there was emerging concern about the long-term chemical stability of polyethylene (Larkin, Makridou & Comerford 1998). Larkin, Blades & Makridou (2000) recommend ‘self-sealing polyethylene and polypropylene containers should be stored for a time without their lids affixed (possibly for months) between purchase and utilisation’ (Larkin, Blades & Makridou 2000, p. 85) to off-gas, while Curran et al. (2017) detected ‘high levels’ of acids and aldehydes emitting ‘from a range of material samples composed of PE’ (Curran et al. 2017, p. 1609).

MATERIALS

Casselden Place assemblage

‘Casselden Place’ is part of the nineteenth-century urban ‘Commonwealth Block’ assemblage, excavated in Melbourne in 2002-03. Items were bagged in self-seal plastic bags with their Heritage Victoria site number, contextual information, and registration number hand-written on the bag, then placed in Corflute™ boxes or sealable tubs, according to material type and deposited with MV in 2005 (Hayes 2011, p. 55-56, Smith & Hayes 2010, p. 176).

During 2009-11, under the ARC-funded 'The Historical Archaeology of the Commonwealth Block 1850-1950' project, the collection was revisited, and the MV barcoded inventory control system was applied to all boxes and bags, and storage bags were replaced where the contents had torn the plastic (Hayes, pers. comm., 5 June 2018). Work commenced under the project continued sporadically until 2016 (ibid.).

The 'Casselden Place' assemblage (Figure 1**Error! Reference source not found.**) provided a large sample of bags with approximately 15 years of real time storage (collection survey undertaken in 2018). The timeframe for storage material purchases was constrained, the excavation period was limited with consistent artefact handling practices, and all bags experienced similar storage conditions.

PE storage bags

According to packaging industry literature, rectangular self-seal, or 'zip-lock', storage bags are composed of PE film to which is applied an internal seal strip on one side and the perpendicular sides are cut and sealed with localised heat. Often a stripe of colour is added above the seal to identify bags of different film thickness (Venus Packaging 2018).

METHODS

The research was approached in the following ordered steps: (1) sample selection; (2) collection survey; (3) data analysis.

Sample selection

Data was extracted from the MV collection management database (EMu), to gauge the size of the collection and determine the best sampling approach. Items on display were excluded from this work, and boxes stored in the freezer were excluded on grounds of minimising risk. This left 48674 storage bags in 892 storage boxes available. Boxes were chosen to ensure the study sample had a range of material type and random distribution across storage rows, bays, and shelf level.

Collection survey

The methodology developed specifically for this collection survey was grounded in previous extensive reading on the subject (for example, Keene 2002 and Taylor 2005). During the survey three boxes were collected from the storage unit at a time and moved on a trolley to the examination desk. Each box was opened in turn, with all bags removed at once (nitrile gloves were always worn and regularly changed), examined individually, data entered into a spreadsheet on a laptop, then replaced in the box. The work was undertaken in a dedicated space with no windows and consistent bench lighting.

To remove problems caused by multiple data collectors, such as inter-rater variability and reliability issues discussed by Taylor (2017) and Taylor and Stevenson (1999), all observations were made by one individual researcher. Protocols were formulated with the collection manager to handle situations such as finding one or multiple broken bags or breaking a bag during examination.

Of the available 892 boxes, 111 were selected for this case study, holding 3229 bags. Looking at the boxes by material type (Table 1), derived from the EMu database, highlights the dominance of ceramic and glass finds in this assemblage. The boxes were surveyed in groups by material type: all ceramic boxes first, then glass, wood, natural materials and seeds including fruit-stones, textile, tile and coal, brick, leather, metal.

Double- and triple-bagging was prevalent for leather and fabric finds (504 of the 3229 bags surveyed). Here, data was collected only for the external bag, as measuring the inside bag would have disturbed the stored material. These were ultimately removed from the analysis for reasons explained below.

Data collected

Data collected during the survey (Table 2) took the form of a large Microsoft® Excel® table, with one row per bag, and several fields collected for each bag. The dataset was designed specifically for this study hypothesis and included unique identifiers to enable MV to subsequently attach the information to their collection records.

The data fields can be grouped into five cohorts. The first was for survey administration, such as the date of data collection, box and bag numbers. The second cohort related to the box, including material type, count of bags in the box as listed in the MV collection database, and the actual count observed. An assessment of box condition was initially collected but was soon abandoned as all boxes appeared in similar condition, thus this field had little value for analysis. The third set of fields were objective observations about the storage bag, such as presence of text on the bag exterior (yes/no) and size of bag (in millimetres).

The fourth data cohort included subjective assessment of visible degradation characteristics. This subset was drawn from plastic deterioration categories in the work of Morgan (1993, p. 45-46), Morgan et al. (2008, p. 71), Coles (2008, p. 127), Shashoua (2008, pp. 271-274), and Nel & Bell (2018). Following consultation with the collection manager and experienced conservators, only a subset of the full list was deemed necessary for clear PE film (Table 3): yellowing, dent, dirt, stain, abrasion, tear, brittleness. During the initial stages it became clear that a useful assessment of brittleness was elusive, and this field was abandoned – a grade based on touch was harder to achieve than grades based on the presence of visual features.

Grades from 0 to 5 were assigned to each category for each bag: 0 indicating no degradation of that kind, 5 indicating significant degradation. For example, a grade of 1 for dent would have a small number (typically five or fewer) of deformations in the film; a grade of 4 would be given to a bag with a substantial proportion (typically over 75%) of the surface covered in dents. Figure 2 shows a comparison of yellowing of bags from the same storage box: the bag on the right was graded 3 and its yellowing is obvious when compared with the bag on the left graded 1. During the work it became necessary to introduce an intermediate level 0.5 for yellowing between 0 and 1.

In this preliminary study the grading assessment for each category was subjective, visual, and comparative (improvements for future research are suggested below), and as such all results must be considered tentative. Consistent lighting and a white A4-size handling board against which to gauge discolouration were used to aid reliability. Bags were reviewed a second time to re-measure bag size and re-assess yellowing. This second pass took less elapsed time than the first assessments, further reducing bias or evolution in the yellowing grade.

The fifth set of data fields were added as the survey got under way. This included identifying bags sufficiently yellowed that later instrumental analysis should prove informative.

Data analysis

The purpose of this analysis was to determine whether the observed level of degradation (the ‘response variable’) could be explained by any of the data fields (‘factors’). For this study the specific question was whether archaeological material, or bag stock, or other data field collected, was more likely to be associated with a yellowing bag. Yellowing was chosen as the sole degradation feature for this analysis because it is a well understood simple starting point for exploring the methodology. Further, during data collection it emerged as the most differential of the degradation characteristics, appearing across all material types. The others, such as dents and tears, were concentrated on materials with rougher physical morphology; and while physical damage interacts with chemical processes in PE degradation, often reinforcing each other, these were not explored in this study and are recommended for future research.

Often the first step in any statistical analysis is to examine averages, however complex interactions between factors can be hidden within such simple summaries. A particular kind of statistical analysis is required to tease out the independent influences from the combined data; multivariate analysis is ideal for this kind of work. Factors do not need to be numeric or even have a natural order, this model can use qualitative or descriptive factors, though it is best that the list of possible values for descriptions is constrained.

As already described, in this study yellowing was graded on a relative scale 0, 0.5, 1, 2, 3, 4, where each grade in the list is ‘yellower’ than the previous grade. While numbers have been used for each grade, it is not strictly *numeric*, i.e., a grade of 4 is not actually ‘twice the yellowing’ of grade 2. The yellowing grade is effectively descriptive with a natural order: these grades could in fact be replaced with letters, or words, and the model would work the same as long as the order was specified.

Due to the subjective nature of the collection of the yellowing grade, it was unwise to presume that it had any underlying statistical distribution. Employing many years of data modelling experience, and cross-checking with another experienced data modeller, an ordinal (*ordered*) multinomial logistic (*many categoric factors*) model was selected. This kind of model is appropriate for the kind of data collected in this study and returns results that are to be interpreted as ‘material A is more likely than material B to be associated with a yellower bag.’

Data from Microsoft® Excel® was imported into SAS® (Statistical Analysis System). It was then analysed using the generalised linear model (GLM) function with multinominal probability distribution (the response variable has more than two categoric values; see Johnston 1996) and cumulative logit link function (which describes how the response variable is related to the factors).

RESULTS

Collection survey

Material types

The type of material present in each individual bag was noted during the survey and used when referring to ‘material’ from this point. In a handful of cases this material type differed from that noted in the collection database. Ceramic and glass are prevalent, and there are reasonable numbers of bags with tile-slate and wood. Not all the 3229 bags surveyed were included in the statistical analysis. Bags were excluded if:

(1) Data was not collected due to material fragility preventing safe bag handling (e.g., all metal finds were excluded).

(2) Bags did not have exterior text and were therefore part of the rehabilitation project where old bags were replaced with new bags. This exclusion removed approximately 25% of bags surveyed.

(3) Bag size could not be determined due to content density.

(4) Double- or triple-bagging, where the external bag was not in contact with the archaeological material. Of these 504 bags, 313 were counted as part of exclusion (2), meaning this exclusion removed an additional 6%.

(5) More than one material type was in the bag.

After these exclusions 2064 bags remained (64% of the original 3229 bags surveyed; Table 4 summarises these by material type). The removal of multi-bagged samples mainly affected fabric and leather bags, leaving few in the analysis. Removing bags without exterior text reduced the number of seed and fruit-stone bags in the analysis.

It was observed that glass was commonly overpacked into boxes, putting bags at risk of perforation from sharp edges and material at risk of dissociation. The most degraded glass finds, with glass flakes present, were associated with bags showing less abrasion, suggesting friction between the bag and the glass led to sloughing glass surface off instead of the glass denting or abrading the bag.

Plastic bag seal-stripe features

Bag ‘stocks’ were characterised by top-stripe (TS) colour and bag dimensions to enable data grouping and analysis. Table 5 highlights that blue TS bags are most common in this sample (77%). Light-blue-TS bags were mostly used for glass and slate. Ceramic was almost entirely in blue-TS bags, but glass bags were more varied. Fabric finds were often in red-TS perforated bags. A few bags were created in custom-sizes by heat-sealing red-TS film. Only four bags in the entire sample had white writing panels.

Plastic bag sizes

Bag length and width were measured to the nearest 1 mm as a means of differentiating bag stocks. Figure 2 visualizes the sizes observed; with bag length on the horizontal x-axis, width on the vertical y-axis, the colour of the point represents the bag TS, and each point an individual bag size. There appears to be clustering around standard widths, with variable length. There is also an apparent separation of sizes for each TS, with the red clusters separate from the blue clusters.

Plastic bag condition

Prior to undertaking the multivariate statistical analysis, it is good practice to review the general shape of the data. Beginning with yellowing, Table 6 details how many bags were given each grade. For example, brick materials were assessed to be stored in: (1) fifteen bags with 0 yellowing, (2) sixteen bags graded 1, and (3) four bags graded 2. Treating these grades numerically, brick bags average yellowing grade is 0.7. Extending this across all degradation features assessed, Table 7 details average observations by material type. This simple one-way summary indicates that bags with ceramic materials were given the highest average yellowing grade within the whole study sample (0.8), with brick (0.7) and glass (0.6).

Looking at the same kind of summary by bag type (Table 8), the perforated bags exhibit lower yellowing grades compared to blue-TS bags. The light-blue-TS bags are remarkable for the near absence of yellowing.

It might be tempting to draw conclusions from these simple averages, such as (a) bags with ceramics are most yellow or (b) light-blue-TS and perforated bags barely yellow. However, such conclusions can be misleading, as averages are simplistic and hide the complexity of multiple interacting factors.

Whole box yellowing

It was observed that bags of similar size within some storage boxes exhibited uniform yellowing (Figure 4). It is hypothesised that bags in each of the storage boxes were processed concurrently and subject to some systematic influence, or perhaps the same bag stock was used for the box and some stocks are just ‘bad’ (e.g., anomalous impurities in a particular polymer batch). Further, it is known that some boxes have been subject to more handling than others – for example Hayes (2011) describes several theses examining ceramic finds – which perhaps increased airflow around the bags, added light exposure, and disturbed the micro-climates of the bags. This could not be investigated further in this work and remains a future line of enquiry.

Multivariate Analysis

Data setup: Bag size categories

To ensure the model could analyse the data, each descriptive factor needed to be compressed to a limited list of values, and so the wide variety of bag sizes needed to first be grouped into categories. Bags manually made from film were separated into their own group, as were all perforated bags. The ceramic and glass bags were separately analysed, and the categories combined. The average yellowing grade was also incorporated because the categories must be as homogenous as possible; grouping together significantly different bags hides potentially significant differences from the model. Finally, the count of bags of each size was important because each category needed to be sufficiently large for the model. The resulting 24 categories were delineated by bag width, and further split by length (Table 9). Note that during subsequent analysis some of these were further grouped together.

Some bag sizes were unique to some materials. For example, fabric appears mostly in bag sizes not observed for other material types. Such ‘exclusive groups’ can complicate interpretation of the statistical analysis.

Modelling results

Analysis found that yellowing was statistically related to the (1) bag TS, combined with (2) bag size group, as well as (3) the material contents.

All location factors – storage row, storage bay, storage level, packed top/bottom – also proved statistically significant initially. However, these models were poor fits, and it is possible that the location is behaving as a proxy for the individual boxes. This could not be understood in a meaningful way and exploring this aspect is deferred to future research.

These results do not technically suggest different materials or bag types *cause* yellowing. Instead, the modelling identifies a *statistically valid correlation* in the data. Results are phrased in terms of 'more likely' for this kind of model.

Material

Analysis identified some material types are more likely to be associated with yellower bags in the study sample, independent of which bag type they were stored in. In order, most to least likely: (1) ceramic and tile/slate, organic* and seed/stone* (*comment below), (2) glass, (3) brick, and (4) wood. The order here is different from the averages in Table 10, demonstrating the value of this analysis. There were not enough bags with the following materials for a statistically valid calculation to be made: building, charcoal, coal, fabric, graphite, leather, slag, stone.

* The model identified that organic finds (shell and natural materials), seeds and fruit-stones are as likely to be associated with yellowing bags as ceramic finds. However, given the smaller sample size for these material types compared to ceramic, glass, and tile/slate, this finding requires further study for confirmation.

Bag type

Analysis identified the bag type most likely to be associated with yellowing in the study sample were the large blue-TS bags centred on 30.3 cm wide x 40.3 cm long (group 18). Next were a grouping of small blue-TS bags centred on 7.5x11.0 (group 1), 7.6x11.4 (group 2) and 7.7x11.2 (group 3). Third most likely was the most populous in the sample: small bags centred on 7.7x11.5 (group 4), 7.7x11.7 (group 5), 7.7x11.8 (group 6), 7.7x14.8 (group 10) and 30.3x39.7 (group 17). By contrast, the light-blue-TS (group 11) bags are least likely to be associated with yellowing, followed by small red-TS bags centred on 7.7 cmx12.1 (group 8). **Error! Reference source not found.**The order derived from the statistical analysis is like that of the averages. Future research is needed to determine whether these associations are related to bag film thickness.

DISCUSSION

Working within the constraints of the data gathering process, multivariate statistical analysis is a promising methodology for uncovering new knowledge from large datasets. Analysis of data from this study sample identified that some material types (ceramic, tile/slate) are associated with more yellow bags, and that some bag stocks yellow differently.

For this archaeological assemblage, it is recommended the yellowest bags be monitored as indicators of the entire collection, particularly those in the ‘most yellow’ ceramic boxes. If it can be determined unequivocally that the light-blue-TS bags (7.7 cm x 14.8 cm) are original to the excavation, given their almost uniform lack of yellowing and lack of brittleness, it is recommended these be further examined.

This study points to a broader recommendation for collections of archaeological material held in PE bags. An initial visual assessment of a handful of storage boxes is achievable within limited resources and can identify which boxes and bags look the yellowest. These can then be regularly monitored as indicators of overall collection conditions.

This methodology commends itself to application to a larger collection, particularly one containing less fragile metal finds, and more organic materials such as seeds/fruit-stones, leather, and fabric. A collection with material stored in bags for longer period would also be interesting for examining a broader range of yellowing. The data collection protocol could also be expanded to evaluating internal bags where double- or triple-bagged.

This investigation is deemed ‘preliminary’ due to the subjective assessment of the assessment of bag condition, most importantly the grading of observed yellowing. It is recommended future research employ more objective methods – for example, colour spectroscopy via handheld spectrometer (not possible at the time of this investigation) for quantitative colour measurement.

Future investigations should explore brittleness as a key determining factor, as arguably this deterioration aspect is most likely to lead to film failure and dissociation. While yellowing may be associated with brittleness, they should be interrogated as separate aspects with potential interaction. Film thickness should also be investigated for the same reason, and because air exchange may impact degradation paths as well as visual assessment of yellowing.

An analysis of the black ink used to write the archaeological context on the bags should also be included in future research, as various inks may contain distinctive levels of solvents. If related archaeological excavation data could also be brought into the model (this could not be progressed in this study in the timeframe) more insights might be uncovered. For example, the soil conditions of individual contexts, or a particular cleaning method, could influence the degradation of material and/or bags.

This research also included non-invasive instrumental analysis of some of the PE bags surveyed. While the results were intriguing and point to future work, this aspect of the work has not been described here as it requires more space than available for adequate discussion. In summary: degradation species were more prevalent in the spectra for bags with a higher (subjective) yellowing grade, and subtle differences were observed between the bags holding ceramics versus glass finds. The small number of bags tested means these results are tentative, and the methodology needs extension to a larger sample size for results to be more conclusive.

CONCLUSION

This real-world archaeological survey confirmed different levels of yellowing of approximately fifteen-year-old PE self-seal storage bags. Statistical analysis of subjective condition data confirmed not all bags have yellowed in the same way, with some bag stocks more likely to be yellow than others regardless of their contents. Also, some archaeological materials – specifically ceramic and tile/slate – are more likely to be in yellower bags than other materials. This preliminary investigation provides pointers to future interrogation and hopefully encourages researchers to embrace data-intensive analyses of large datasets to discover new insights.

ACKNOWLEDGEMENTS

The authors would like to thank Museums Victoria for facilitating this research, particularly Alice Cannon. The authors also acknowledge the work of Museums Victoria’s Material Scientist Rosemary A Goodall. This research is supported by the Australian Government through the Australian Research Council’s Linkage Projects funding scheme (LP160100160). Thanks also to Dr Sarah Hayes, Senior Research Fellow, Deakin University, for data from The

Historical Archaeology of the Commonwealth Block 1850-1950 ARC Linkage project. And to Peter Grigaliunas, Director, Griga Actuarial Consulting, for statistical modelling advice.

AUTHOR BIOGRAPHIES

Karen M Thompson is a Research Data Specialist at the Melbourne Data Analytics Platform (MDAP) at the University of Melbourne. She has a BSc (1993) in Mathematics from the University of Queensland, is a Fellow of the Institute of Actuaries of Australia (2003), has a Bachelor of Fine Arts (2006) in Gold and Silversmithing from Royal Institute of Technology in Melbourne, and a MA in Cultural Materials Conservation (2018) from the University of Melbourne.

Dr Petronella Nel is a Senior Lecturer at the Grimwade Centre. She has a BSc Honours (1990) in Chemistry and a PhD in Chemistry (2000) and MA in Cultural Materials Conservation (2006), from the University of Melbourne. She is currently leading an ARC Linkage Project ‘A National Framework for managing malignant plastics in Museum Collections’ in partnership with Museum Victoria, Queensland Museum, Museum of Applied Arts and Sciences - Powerhouse Museum, South Australian Museum, Australian National Maritime Museum, Art Gallery of NSW, University of Sydney, University of Technology Sydney and Flinders University.

ORCHID

Karen M Thompson https://orcid.org/0000-0002-5498-0556

Petronella Nel http://orcid.org/0000-0002-8509-547X

REFERENCES

Bergmair, J, Krainz, M & Hemma, F 2010, ‘Packaging of museum objects: criteria and test methods for plastic film selection’, *E-Preservation Science*, vol. 7, pp. 102-107.

Chew, CH, Gan, LM & Scott, G 1977, ‘Mechanism of the photo-oxidation of polyethylene’, *European Polymer Journal*, vol. 13, no. 5, pp. 361-364.

Code of Federal Regulations (CFR) 1990, (36 CFR Part 79) *36 – Parks, Forests, and Public Property / Chapter I – National Park Service, Department of the Interior / Part 79 - Curation of Federally-Owned and Administered Archaeological Collections*, United States of America.

Coles, F 2008, ‘Challenge of materials? A new approach to collecting modern materials at the Science Museum, London’, in B Keneghan & L Egan (eds), *Plastics: Looking at the future and learning from the past, Papers from the conference held at the Victoria and Albert Museum, London, 23-25 May 2007*, Archetype, London, pp. 125-131.

Curran, K, Aslam, A, Ganiaris, H, Hodgkins, R, Moon, J, Moore, A & Ramsay, L 2017, ‘Volatile organic compound (VOC) emissions from plastic materials used for storing and displaying heritage objects’, in J Bridgland (ed.), *ICOM-CC 18th Triennial Conference Preprints, Copenhagen, 4-8 September 2017*, International Council of Museums, Paris, pp. 1602-1609.

Duran, C, Grau-Bove, J, Fearn, T & Strlič M, 2017, ‘Data mining in collections: From epidemiology to demography’, in Bridgland, J (ed), *ICOM-CC 18th Triennial Conference Preprints, Copenhagen, 4–8 September 2017*, International Council of Museums, Paris.

Gilbert, M 2017, ‘Chapter 5: Relation of Structure to Chemical Properties’, in M Gilbert (ed.), *Brydson’s Plastics Materials*, 8th edn, Butterworth-Heinemann Ltd, Oxford, pp. 75-102.

Grattan, DW (ed.) 1993, *Saving the Twentieth Century: The conservation of modern materials. Proceedings of a conference symposium: 15-20 September 1991*, Canadian Conservation Institute, Ottawa.

Grey, T 2006, *Archaeological finds procedures manual*, Museum of London Archaeological Services (MoLAS), London, accessed 6 April 2018, <https://idocslide.com/the-philosophy-of-money.html?utm_source=grey-t-2006-archaeological-finds-procedures-manualmolas>.

Haider, K & van Oosten, T 2011, ‘Lecture 005: Plastic bags – Research into polyethylene bags of the series ‘Bicycles’ by Andreas Slominski’, in T Bechthold (ed.), *Future talks 009: The conservation of modern materials in applied arts and design: Papers from the conference held at the Pinakothek der Moderne, Munich, 22-23 October 2009*, The International Design Museum, Munich, pp. 41-48.

Hayes, S 2011, ‘A historical archaeology of the Commonwealth Block 1850-1950: Artefact processing project report’, unpublished report, La Trobe University and Museum Victoria, Melbourne.

Hayes, S 2018, personal communication, email, May-June.

Heritage Victoria 2004, *Archaeological Artefacts Management Guidelines,* Version 2, Heritage Victoria, Melbourne.

Heritage Victoria 2014, *Guidelines for Investigating Historical Archaeological Artefacts and Sites,* Heritage Victoria, Department of Environment, Land, Water and Planning, Melbourne, accessed 3 April 2018, <https://www.heritage.vic.gov.au/__data/assets/pdf_file/0022/55336/Guidelines-for-Conducting-Historical-Archaeological-Surveys.pdf>.

Horie, CV 2010, *Materials for conservation: Organic consolidates, adhesives and coatings,* Routledge, New York.

Johnston, GO 1996, *SAS® Software to Fit the Generalized Linear Model,* accessed 15 February 2022, <https://support.sas.com/rnd/app/stat/papers/genmod.pdf>.

Kambe, H 1978, 'Chapter 8: The effects of degradation on mechanical properties of polymers', in HHG Jellinek (ed.), *Aspects of degradation and stabilization of polymers,* Elsevier, Amsterdam, pp. 392-430.

Keene, S 2002, *Managing conservation in museums,* 2nd edn, Butterworth-Heineman, Oxford.

Keene, S 2005, *Fragments of the world: Museum collections*, Elsevier Butterworth-Heinemann, Oxford.

Larkin, N, Blades, N & Makridou, E 2000, 'Investigation of volatile organic compounds associated with polyethylene and polypropylene containers used for conservation storage', *The Conservator,* vol. 24, no. 1, pp. 41-51.

Larkin, NR, Makridou, E & Comerford, G 1998, 'Plastic storage containers: A comparison', The Conservator, vol. 22, no. 1, pp. 81-87.

Lim, X 2018, 'The cultural treasures are made of plastic. Now they're falling apart.', *New York Times*, 28 August, accessed 29 August 2018, <https://www.nytimes.com/2018/08/28/science/plastics-preservation-getty.html>.

Morgan, J 1993, 'A joint project on the conversation of plastics by The Conservation Unit and the Plastics Historical Society', in DW Grattan (ed.), *Saving the Twentieth Century: The conservation of modern materials. Proceedings of a conference symposium: 15-20 September 1991*, Canadian Conservation Institute, Ottawa, pp. 43-50.

Morgan, L, Heuman, J, Pullen, D & Robson, S 2008, 'Exploring photogrammetry and laser scanning of plastic sculptures', in B Keneghan & L Egan (eds), *Plastics:*

Looking at the future and learning from the past, Papers from the conference held at the Victoria and Albert Museum, London, 23-25 May 2007, Archetype, London, pp. 70-77.

Museums & Galleries Commission (MGC) 1992, *Standards in the Museum Care of Archaeological Collections*, Museum & Galleries Commission, London, accessed 3 April 2018, <https://collectionstrust.org.uk/wp-content/uploads/2016/11/Standards-in-themuseum-care-of-archaeological-collections.pdf>.

National Museum of Ireland (NMI) 2010, *Advice notes for excavators*, National Museum of Ireland, Dublin, accessed 6 April 2018, <https://www.museum.ie/NationalMuseumIreland/media/Corporate-Information/Policies%20and%20Guidelines/Advice-Notesfor-Excavators-2010.pdf>.

National Park Service (NPS) 2001, 'Appendix I: Curatorial Care of Archeological Objects', in *NPS Museum Handbook*, National Park Service, Washington, accessed 3 April 2018, <https://www.nps.gov/museum/publications/MHI/AppendI.pdf.>.

Nel, P & Bell, J 2018, 'Polymuse: OHRM [online heritage resource manager] tutorial', video, accessed 27 June 2018, <https://vimeo.com/ 267183719>.

Peacock, AJ 2000, *Handbook of polyethylene: Structures, properties, and applications*, Marcel Dekker, New York.

Ronca, S 2017, 'Chapter 10: Polyethylene', in M Gilbert (ed.), *Brydson's Plastics Materials*, 8th edn, Butterworth-Heinemann Ltd, Oxford, pp. 247-278.

Schnabel, W & Kiwi, J 1978, 'Chapter 5: Photodegradation', in HHG Jellinek (ed.), *Aspects of degradation and stabilization of polymers*, Elsevier, Amsterdam, pp. 195-246.

Shashoua, Y 2008, *Conservation of Plastics: Materials science, degradation and preservation*, Butterworth-Heinemann, Oxford.

Smith, C & Hayes, S 2010, 'Managing the Commonwealth Block archaeological assemblage: An Australian case study', *Collections: A Journal for Museum and Archives Professionals*, vol. 6, no. 1, pp. 171-188.

Society for Historical Archaeology (SHA) 1993, 'The Society for Historical Archaeology Standards and Guidelines for the Curation of Archaeological

Collections', *Society for Historical Archaeology*, accessed 9 May 2018, <https://sha.org/resources/curationstandards-guidelines/>.

Tay, D 2020, 'Expanding the Singaporean discourse: Exploring artist materials from the 1950s to 1970s', *AICCM Bulletin*, vol. 41, no. 2, pp. 106-117.

Taylor, J 2005, 'An integrated approach to risk assessments and condition surveys', *Journal of the American Institute for Conservation*, vol. 44, no. 2, pp. 127-141.

Taylor, J 2017, 'Improving Reliability in Collection Condition Surveys by Utilizing Training and Decision Guides', *Journal of the American Institute for Conservation*, vol. 56, no. 2, pp. 126-141.

Taylor, J & Stevenson, S 1999, 'Investigation Subjectivity within Collection Condition Surveys', *Museum Management and Curatorship*, vol. 18, no. 1, pp. 9-42.

Tétreault, J 2018, *Products used in preventive conservation – Technical bulletin 32,* Canadian Conservation Institute (CCI), accessed 11 May 2018, <https://www.canada.ca/en/conservation-institute/services/conservation-preservation-publications/technicalbulletins/products-used-preventive-conservation.html>.

Venus Packaging 2018, *Plastic Bags*, accessed 27 July 2018, <https://venuspack.com.au/product-category/poly-bags-netting/plastic-bags/>.

Williams, RS 1997a, *CCI Notes 15/1: Care of Objects Made from Rubber and Plastic*, Canadian Conservation Institute, Ottawa.

Williams, RS 1997b, *CCI Notes 15/3: Display and Storage of Museum Objects Containing Cellulose Nitrate*, Canadian Conservation Institute, Ottawa.

Williams, RS 2002, *Care of plastics: malignant plastics*, accessed 15 February 2022, < https://cool.culturalheritage.org/waac/wn/wn24/wn24-1/wn24-102.html>.

Table 1. Summary of boxes and bags in collection survey, based on MV database

Material (majority in box)	**# Boxes in Assemblage**	**# Boxes surveyed in this study**	**Total # Bags in surveyed boxes**
Ceramic	211	24	1043
Glass	464	33	964
Wood	9	7	247
Natural / Seed	5	5	253
Fabric / Natural	11	8	150
Tile / Coal	15	9	262
Brick	15	8	43
Leather	43	15	255
Metal	72	2	12
Mixed	22	-	-
Other	25	-	-
Total	**892**	**111**	**3229**

Table 2: Data collected during collection

Data Cohort	Source / Type of Table input	Data Field	Possible values / Notes
Survey control	Manually typed as each box was surveyed	Box ID number	
		Bag ID number	**Data table: 1 row per bag**
		Date of observation	
Storage Box	MV collection data, checked during survey	Bag count (expected)	count of bags in box
		Storage – row	09 - 14
		Storage – bay	1, 2, 3
		Storage – level	A - I
		Storage – top / bottom	boxes are in two layers on a shelf
		Storage – col. from wall	1 - 12
		Box Type	Corflute / Blueboard / Tub
		Contents (material)	Ceramic, Glass, Wood, etc
	observed, added during survey	Bag count (actual)	(to compare to expected)
		Box condition	*abandoned during survey*
Packing Bag – objective data	observed, added during survey	Text markings	if text was written on bag: Y / -
		Bag size (mm)	measured twice
		Bag type	Eg. red, blue, pale-blue, perforated
		Item count	count of fragments in bag
		Contents Material	confirmation of material type
		Double- or triple-bag	Y / - ; if Y then count
Packing Bag – subjective data	visually observed, added during survey	Content condition	
		Sharps	if materials were sharp: Y / -
		Yellowing	graded twice; subjective judgement
		Deformation – dent	during the survey it became evident these visible degradation features were due to the morphology of the material
		Deposit – dirt	
		Deposit – stain	
		Other – abrasion	
		Other – tear	
		Touch - Brittle	*difficult to assess in a meaningful way*
Additional information	visually observed, added during Survey	New bag?	Y / - ; subjective, based on feel, clarity of film, absence of writing on bag, absence of visible degradation
		FTIR-ATR candidate?	Y / -

Table 3: Plastic deterioration terms

Action	Term	Sub-term : used in data table	Reason / Note
Not used in this study	Biological	Insect; mould	no evidence
	Colour change	darkening; fading	not relevant for transparent film
	Deformation	shrinkage; warping	difficult to discern
		fold	folds in the bags appear due to handling by archaeological staff, not a defect
	Deposit	bloom; droplet; dust; sweating	no evidence
	Other	blister; break; chip; crack; crazing; loss; peeling	no evidence
		change in gloss	difficult to discern with contents
		loss transparency	difficult to discern with contents
		scratch	difficult to discern with contents
	Touch/Feel	crumbly; greasy; hardening; sticky	no evidence
Used in this study	all given relative grading: 0, 1, 2, 3, 4, 5		
	Colour change	yellowing	0.5 describes noticeable change
	Deformation	dent	mostly caused by contents
	Deposit	dirt	mostly caused by contents
		stain	mostly caused by contents
	Other	abrasion	mostly caused by contents
		tear	mostly caused by contents
	Touch	brittle	not easy to discern

Table 4: Bags included in statistical analysis

FOR STATISTICAL ANALYSIS									For clarity	
Material (observed)	**# Bags**	EXCL 1 Too fragile	EXCL 2 No text	EXCL 3 No size	EXCL 4 double-bagged	EXCL 5 w- other materials	**# Bags For Analysis**		Double bagged Total	Other Materials Total
Brick	46	3	7	.	.	1	**35**		0	1
Building	8	.	.	.	.	.	**8**		0	0
Ceramic	1043	.	157	8	1	58	**819**		1	68
Charcoal	11	.	3	.	.	.	**8**		1	0
Coal	45	1	2	.	.	.	**42**		0	0
Fabric	142	9	52	4	63	13	**1**		118	22
Glass	925	14	69	7	1	32	**802**		5	38
Glass+Cork	24	1	14	.	3	.	**6**		6	0
Graphite	11	.	.	.	.	.	**11**		0	0
Leather	271	8	144	4	110	2	**3**		256	2
Organic*	44	1	10	6	5	2	**20**		16	4
Seed/Stone	205	.	165	1	4	1	**34**		80	2
Slag	12	.	.	.	.	.	**12**		0	0
Stone	11	.	2	.	.	.	**9**		0	0
Tile-Slate	163	2	15	1	.	.	**145**		0	0
Wood	246	1	128	7	4	1	**105**		14	2
z_Other	21	.	15	1	.	1	**4**		6	1
#N/A	1	.	1	.	.	.	0		1	0
TOTAL	**3229**	40	784	39	191	111	**2064**		504	140
		mutually exclusive			Not already counted 1-3	Not already counted 1-4			Out of 3229 bags – some of these bags are already counted in EXCL1,2,3,4	
*Organic: grouping of ‘natural’, ‘shell’, ‘organic’										

Table 5: Bag types per material group, where column heading is the top-stripe (TS) and notable features about the bag type (if required)

Material	**Blue**	**Blue / perf ***	**Blue / manual #**	**Light-Blue**	**Clear**	**Red**	**Red / perf ***	**Red / manual #**	**Red / White panel**
Ceramic	814				1	4			
Brick	33			2					
Fabric							1		
Glass	700			83	1	17	1		
Organic	2	1				1	9	3	4
Coal	31	1		10					
Tile-Slate	103	0		41		1			
Seed-Stone	3	14					17		
Leather		0					1	2	
Wood	5	24	18			1	54	3	
Other	34	5	0	13	0	0	6	0	0
Total	**1725**	**45**	**18**	**149**	**2**	**24**	**89**	**8**	**4**
%	82%	2%	1%	7%	-	1%	4%	-	-

*Perforated: the bag has been punctured (at manufacture) with many holes, to allow for air exchange
#Manual: bag specifically made for object by archaeologists, out of film, using heat sealer for edges

Table 6: Yellowing by material type, ordered by average

Material Type	Yellow = 0	Yellow = 0.5	Yellow = 1	Yellow = 2	Yellow = 3	Yellow = 4	Average Yellowing	Bag Count
Ceramic	150	209	342	108	9	1	0.8	819
Brick	15		16	4			0.7	35
Glass	318	185	210	66	27	2	0.6	808
Coal	15	14	9	4			0.6	42
Organic	6	12	1		1		0.5	20
Tile-Slate	68	35	32	9		1	0.5	145
Seed/Stone	12	17	4	1			0.4	34
Wood	63	31	9	2			0.3	105
ALL	**665**	**521**	**639**	**197**	**38**	**4**	**0.7**	**2064**

Table 7: Average condition observations, by material type.

Material	**Average grading**						
	Yellowing	**Dent**	**Dirt**	**Stain**	**Abrasion**	**Tear**	**# Bags**
Brick	0.7	3.4	2.1	1.0	3.8	0.1	35
Building	1.0	2.5	1.6	1.5	2.9	0.0	8
Ceramic	0.8	1.1	0.2	0.0	2.1	0.0	819
Charcoal	1.0	0.6	0.3	0.4	1.9	0.0	8
Coal	0.6	1.9	0.8	0.3	2.2	0.0	42
Fabric	1.0	0.0	0.0	0.0	0.0	0.0	1
Glass	0.6	2.0	0.2	0.1	2.5	0.1	802
Glass w cork	0.7	2.3	1.8	0.3	3.7	0.0	6
Graphite	0.3	0.5	0.0	0.1	1.5	0.0	11
Leather	0.3	0.0	0.7	0.0	0.7	0.0	3
Organic	0.5	0.5	1.1	0.6	2.0	0.0	20
Seed / Stone	0.4	0.6	1.4	1.0	2.8	0.0	34
Slag	0.2	3.2	1.8	0.3	2.9	0.0	12
Stone	0.8	1.3	0.4	0.1	2.2	0.0	9
Tile – Slate	0.5	1.8	0.5	0.6	2.4	0.1	145
Wood	0.3	0.8	0.9	0.5	1.6	0.0	105
Other	0.9	0.8	0.5	0.5	1.5	0.0	4
Total	**0.7**	**1.5**	**0.3**	**0.2**	**2.3**	**0.0**	**2064**

Table 8: Yellowing by bag type

Bag Type (TS/ perf.)	**Yellow = 0**	**Yellow = 0.5**	**Yellow = 1**	**Yellow = 2**	**Yellow = 3**	**Yellow = 4**	**Average Yellow**	**Bag Count**
Blue	420	455	620	190	36	4	0.8	1725
Blue / Perforated*	16	18	9	2			0.5	45
Blue / Manual#	10	7	1				0.3	18
Light Blue	147		1	1			0.0	149
Red	17	4	1	1	1		0.3	24
Red / Perforated*	50	31	7	1			0.3	89
*Perforated: the bag has been punctured (at manufacture) with many holes, to allow for air exchange #Manual: bag specifically made for object by archaeologists, out of film, using heat sealer for edges								

Table 9: Bag size categories by (selected) material

Centred on (width-length)	**Category Name**	**Ceramic**	**Glass**	**Fabric**	**Leather**	**Wood**	**Seed / Stone**
6.3 x 10.5	Group 24	2				4	8
6.3 x 11.0	Group 23				1	11	
7.5 x 11.0	Group 01	52				1	
7.6 x 11.4	Group 03	118	39			4	
7.7 x 11.2	Group 02	58	42				
7.7 x 11.5	Group 04	156	123		1	8	10
7.7 x 11.7	Group 05	49	11		2	3	2
7.7 x 11.8	Group 06	69	92	1	6	2	4
7.7 x 12.0	Group 07	109	14				1
7.7 x 12.1	Group 08	71	19				1
7.7 x 12.2	Group 09	10	1			1	
7.7 x 14.8	Group 11	1	110		8	6	3
10.0 x 20.0	Group 12	1	1		2	15	3
10.1 x 11.5	Group 10		32				
10.1 x 17.5	Group 22			12	8	5	2
various x 22.2	Group 20			19	2	2	
15.2 x 24.7	Group 12	43	157		5	6	
15.2 x 25.0	Group 13	40	74			2	4
15.2 x 25.4	Group 15	16	14			4	
15.3 x 25.0	Group 14	52	39		5	5	
20.2 x 27.4	Group 19			22	4	5	1
22.7 x 32.5	Group 16	30	50	3	4	3	
30.3 x 39.7	Group 17	1	12				
30.3 x 40.3	Group 18		4	13	1		

Table 10: Comparison: “how likely is the material to be associated with yellow bags”; (A) simple averages versus (B) results from the statistical analysis

(A) Simple average of yellowing grades							
Order	1	2	3	4	5	6	7
Material	Ceramic	Brick	Glass	Organic	Tile / Slate	Seed / Stone	Wood
Average Yellow	0.85	0.69	0.65	0.50	0.49	0.43	0.27
Notes	most yellow	similiar		very similar		-	least yellow

(B) Multivariate statistical analysis (modelling) : likelihood of material being associated with yellowing							
Order	1				2	3	4
Material	Ceramic	Tile / Slate	Organic	Seed / Stone	Glass	Brick	Wood
Notes	most likely yellow in both analyses	(a)	(b)		simple averages were similar, and position in order is similar in statistical analysis		least likely yellow in both analysis

(a) Quite different results from each analysis. The simple average is lowered by some Tile-Slate being packed in Light Blue TS bag which had very little yellowing. The statistical analysis splits the bag and material impacts out on their own.

(b) The model could not differentiate Organic from Ceramic with respect to association with yellowing. That means, for now, it seems that Organic / Seed / Stone are thought to be as likely as Ceramic and Tile / Slate to be in yellow bags. The lower rank in the simple average analysis is likely due to much of this material being in perforated bags, and the influence of those bags was separated out in the statistical analysis.

Figure 1. Storage of Casselden assemblage, Museums Victoria.

Figure 2. Example of a low-yellow bag (left) and high-yellow bag (right); both with ceramic finds.

Figure 3. Bag sizes. Overall (excluding heat-sealed). All top-stripe colours, with and without text

Figure 4. Example of whole box yellowing