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A preliminary investigation into using Tyvek® bags for short-term storage as a means of protecting herbaria from damage by insect pests such as *Stegobium paniceum*

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Abstract
A preliminary investigation into the properties of Tyvek® as a physical barrier against insect pests, especially for use with botanical specimens, was undertaken. The physical properties of Tyvek® were investigated using SEM to establish the structure and its suitability as a barrier against insect pests. Various designs of Tyvek® enclosures were produced using heat sealers and plastic sealing clips for standard-size herbarium sheets. The conclusion is that this may be an effective tool to support museum-wide IPM regulations and will be subject to further testing.

Introduction
The aim of this project is to investigate Tyvek® as an option for temporary storage of herbaria to protect them from attack by insect pests while in transit as part of a museum-wide Integrated Pest Management (IPM) strategy, or when taken out of normal storage for a period of time.

Herbaria
These were traditionally bound in book form (Fig. 1) but which are now more commonly stored in folders (Fig. 2). These folders are kept in either wooden or metal cabinets. A herbarium consists of a collection of dried and pressed leaves, flowers and fruit together with information on habit, morphology, anatomy, biochemistry, ecology and distribution of the specimen in question (Clark, 1988; Gunn, 1994). This information can be handwritten in ink or pencil, or are printed. The specimens are mounted on conservation grade 'rag' paper and nowadays with reversible polyvinyl acetate adhesive. Historically, wheat starch paste, animal glue (including fish glue) and methyl cellulose were used to attach specimens, and even being left loose within folders has been an option, leaving them vulnerable to insect attach which if left unchecked can be catastrophic. Together with the plants, the storage cabinets, paper and glues can all provide food and/or shelter for insect pests.


Fig. 1. Herbaria in good condition (Courtesy of The Natural History Museum)

The botanical collection at the NHM includes over five million specimens of myxomycetes, lichens, algae, bryophytes, pteridophytes and seed plants, of which 120,000 are type specimens. All the geographical regions are represented. Additionally, many of the collections are of historic importance, as for example those of Sloane, Hermann, Banks and Solander. In common with other herbaria the collection is actively used by researchers and visitors both to and from outside the Museum via loan agreements. For example, during 1991 and 1992 it was estimated that 14,000 specimens were sent out on loan (Huxley, 1994). The demand on the collection is, therefore, very high.


Fig. 2. Herbarium sheets stored in a folder

Insect pests of herbaria
Well documented examples of damage caused by insects on herbarium specimens exist; these include the biscuit/drug store beetle *Stegobium paniceum* (Fig. 3) and the cigarette/biscuit beetle *Lasioderma servicorna* (Bridson & Forman, 1998) which feed directly on the preserved plant material. They will eat all dried stored products, and even substances that to other insects are toxic – they have even been found feeding on strychnine (Hickin, 1985; Florian, 1997; Bridson & Forman, 1998), as well as papier maché,

Fig. 3. *Stegobium paniceum*: adult (a); larva (b).
Source: www.ento.csiro.au (a); whatcom.wsu.edu (b)

freeze-dried animal specimens and fungi. They have also been recorded feeding on chocolate and on the leather spines of books (Hickin, 1985; Pinniger, 2001). They can tunnel through hard materials, and when first hatched only measure 0.5 x 0.125 mm and so can easily penetrate packaged foods. The development time depends on their supply of food and temperature, e.g. with a good food source and at 30 °C they can develop within five weeks. At lower temperatures the life cycle can be anything from six months to one year (Pinniger, 2001). Large numbers can be supported by a relatively small food source. Hundreds of beetles were found in a museum store where they had been breeding in a few old loose grain mouse baits (Pinniger, 2001). When the adults emerge they make neat round exit holes (Fig.4) and live for six to eight weeks. The damage from larvae can be quite extensive and even total destruction of plant specimens (Figs. 5, 6, 7).

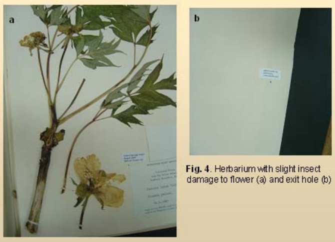

Fig. 4. Herbarium with slight insect damage to flower (a) and exit hole (b)

Fig. 5. Extensive insect damage to flower

Fig. 6. Verso of Fig. 5 showing extensive insect damage to paper support

Fig. 7. Complete destruction of plant specimen by an insect

Other insect pests of herbaria are those that feed on mould and detritus. In small numbers they can be a nuisance but large populations can cause serious damage. These include: spider beetles (e.g. golden spider beetle *Niptus hololeucus*), *Cartodere filum* (a small, slender beetle measuring 1.2–1.6 mm), silver fish (*Lepisma saccharina*), booklice (*Liposcelis* spp.), cockroaches, ants, carpet beetles and moths.

Pests are also resourceful in their ability to survive, e.g. *Tineola bisselliella* the webbing cloths moth has been recorded eating its way out of plastic bags in which bone specimens were stored (Kerr, 2005).

Control of insects and IPM

Historical control of insect infestations was largely based on chemical treatments such as methyl bromide or dichlorvos (marketed as Vapona), but most of these chemicals have now been withdrawn from use because of health and safety implications. Furthermore, the mounted herbarium sheets were historically treated with mercuric chloride, inorganic arsenic trioxide, barium fluorosilicate or organic pesticides including lindane, DDT and naphthalene. The residues of these are long lasting and extremely detrimental to health (Clark, 1988; Purewal, 2001). Freezing is now a preferred method, but other methods of insect pest control are being investigated (Åkerlund & Bergh, 2001; Warren, 2001; Conyers, 2001; Ackery *et al.,* 2005; Beiner & Ogilvie, 2006). These methods, however, are to treat infestations and as such do not give permanent protection, therefore good housekeeping practice is paramount, a point strongly emphasised by Child (1994), Blyth (2001) and Kinglsey & Pinniger, 2001).

To deal with issues of pest control a holistic approach known as Integrated Pest Management (IPM) are being introduced in many institutions. It involves institution-wide monitoring for pests, targeting treatment only where it is needed and modifying the environment to discourage pest attack (Pinniger, 2001).

Specifically, good housekeeping practices for keeping reinfestation to a minimum is essential as part of the IPM strategy. The NHM has implemented a system of identifying Risk Zones throughout the museum which incorporates IPM procedures such as trapping and regular monitoring.

Tyvek®

To help comply with IPM regulations, Tyvek® bags could prove to be a valuable contribution.

A search of the published literature showed that few studies had been done examining Tyvek® as a preventive conservation material. Only one independent study (Walker, 1986) was found that had looked in detail at the properties of Tyvek® as a storage material for artefacts. Generally, statements were made in the literature merely that Tyvek® had been used, but gave no further details. Additionally, research done by DuPont tends to published in its own journal (mainly in the US issue, which is not available in the UK), although some of it is also published on their Tyvek® website. It appears, therefore, that most of the information available on its effectiveness as a conservation material is anecdotal.

Tyvek® is the registered trade name for DuPont's spunbonded olefin, which is made from very fine, 0.5–10 µm high density polyethylene fibres (for comparison, human hair is *c.* 75 µm in cross-section). The fibres are spun, laid randomly and then bonded together by heat and pressure without using any adhesives or fillers (Anon., 1986; DuPont, 2002). The result is a bright white 'strong, lightweight, flexible, smooth, low-linting, opaque and resistant to water, chemicals, abrasion and aging' material that is also resistant to punctures and tearing, it is pH neutral (pH 7) and it is breathable (DuPont, 2002). Coloured varieties of Tyvek® are now also available, although white is preferred by conservators due to colour fastness concerns.

Three types of Tyvek® are available – types 10, 14 and 16. Type 10 is a smooth, stiff non-directional material resembling paper whereas types 14 and 16 are 'soft' and fabric-like. They are made in the same way but the finishing process determines whether it is the 'hard' type or the 'soft' type.

Tyvek® is widely used in medical sterile packaging because it is bacteria resistant, as a membrane and air filtration barrier in house building, for maps, charts and other printed material, wrapping materials and as envelopes. Its original use in conservation was for labelling archaeological objects from excavation sites (Winsor & Ball, n.d.) but has also been used for spine repair on books, as a book covering material, as dust sheets, as protective clothing and for labelling specimens. Tyvek® can be corona treated, which increases its ability to take ink (DuPont, 2002), have an anti-static treatment (potassium dibutylphosphate), but which is damaging to metals (Preserv'Art, 2005) or both surface treatments. If, however, the Tyvek® is to be used for sterile medical packaging, food or toys the surface is left untreated. Commercially, Tyvek® is recommended for: use in exhibitions; interleaving; envelopes, folders, portfolios; shipping cases; supports; packing; protection against dust and/or abrasion; documentation; and for storage.

DuPont considered that Tyvek® would not be a suitable material to use as a barrier against insects but acknowledged that they had not done any work in this area as it was not of immediate concern to them (pers. comm., 2006).

Methods

To assess whether there was a need for something like a Tyvek® bag to prevent insect attack of herbaria, a query was posted on a conservation website and informal discussions were had with a number of librarians and others interested in insect pest management (e.g. at the PRE-MAL Symposium, Stockholm, 2005).

Suppliers and the manufacturer were contacted in order to establish which Tyvek®-type was in use museum-wide.

Scanning electron microscope (SEM) images, using a variable pressure scanning electron microscope (Leo 1455VP) at the NHM, were taken at various magnifications (ranging from 80X to 500X) to identify the structure.

To create the bags a Crossweld® heat sealer (impulse sealer) 240 volt Mark 4 with a self-adhesive silicone coated barrier tape covering the jaws (Fig. 8) was used at various settings until a setting that was reliable and reproducible for heat sealing Tyvek® was found. This was also confirmed by SEM analysis. Once this was established, test bags were made large enough to hold standard herbarium sheets measuring 445 x 285 mm.

Fig. 8. Crossweld heat sealer (reproduced with permission from the Natural History Museum)

As the bags were made from one sheet of Tyvek® folded and heat sealed on two sides only, types of secure closure were sourced. Escal® strips currently used in the Palaeontology Department for anoxic environments and WeLoc® clips (marketed as Klippits™ for food bags), originally designed for use within hospitals to close bags of fluids were tested (Fig. 9).

Fig. 9. (a) Escal clip; (b) WeLoc clip

Samples of *Spirea* sp., *Mahonia* sp., sweet flowering cherry and flowering red current, which are attractive to insects, were obtained from a local garden centre[2]. These were prepared by placing them between blotting paper layered between newspaper and pressed under a heavy weight for three weeks to dry and then standard mounted. Once they were dried the plants were mounted by the Botany Department in the style used at the NHM. These are now waiting to be used in the insect trials as Phase 2 of the project.

Discussion

To comply with IPM regulations, it is generally agreed that a short-term barrier against insects for museum objects is required. For botanical collections this would include when herbaria are taken out of normal storage for study and left exposed in a working environment, or when being moved around the building to other departments where IPM regulations are less restrictive (e.g. when waiting to be photographed: A. Paul, pers. comm., 2005). Also herbaria are sent outside the Museum on loan, these may be through the standard postal system or couriered depending on the nature or condition of the herbarium in question. Some form of bagging system would also be useful for when new material arrives in the department which cannot be processed immediately with quarantine procedures (e.g. freezing).

It was established that three types of Tyvek® existed – types 10, 14 and 16. Type 10 is easy to identify as it is a stiff material that looks very much like paper and is marketed as such. Most people will be familiar with this type as it is used for the near indestructible white envelopes. Types 14 and 16, referred to as ‘soft’, are fabric-like, but from the literature it could not establish which type was used at the Museum. Neither Conservation by Design nor Conservation Resources Ltd, who both supply the material-like Tyvek®, were able to help me on this point. Eventually it was discovered that standard UK supplies were of type 14 with a weight of 43 gsm (1443R). A heavier weight (73 gsm) Tyvek® type 14 (1473R) also exists but this is not available in the UK.

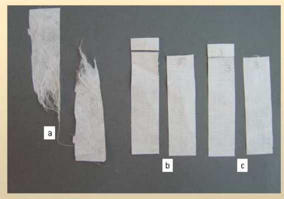

Fig. 10. Results of tensile tests on Tyvek® (a) not heat sealed, (b) with clear weld, and (c) with cloudy weld

The settings on the Crossweld® heat sealer that worked with consistent results were: weld 3 and 6 cool. However, on closer inspection it found that within the clear area of the sealed welds were small cloudy portions along its length. To see whether these cloudy areas affected the seal it was decided to do a tensile test (using Instron 4411). Although Tyvek® is not affected by such environmental conditions, the test was done at room temperature (23 ^{o}C) with an RH of 50%. Strips measuring 95 x 20 mm, 10 mm to weld were cut from the clear areas and from the cloudy areas. As a control, non-heat sealed Tyvek® was tested which stretched and distorted and then tore away producing ragged fibres (Fig. 10). It did not snap apart. Both the clear weld only strips and the strips with cloudy and clear welds easily tore, although the strips with only the clear areas snapped suddenly whereas the strips with the cloudy areas opened up along the edge of the weld and peeled away suggesting areas of weakness. To make them more secure it was decided that the Tyvek® bags would need to be double sealed. By double sealing it was hoped that the cloudy areas would be offset from each other thus reducing the areas of weakness.

On further investigation of DuPont’s literature it was found that the antistatic and the corona surface treatments can affect the uniformity of the heat seal. To overcome this it is suggested that a low density polyethylene coating is used with the Tyvek® when heat sealing it.

In the Palaeontology Department, Tyvek® cushions filled with Plastazote® ‘chips’ are used to protect delicate specimens when being examined. These are made using the Crossweld® heat sealer, but these seals do not have to be perfect as they are not being handled to any great extent and are only a temporary measure.

Further analysis by SEM taken at various magnifications confirmed the non-directional structure of the fibres that make up Tyvek® (Figs. 11 & 12). We intend to do further study to look at the 3-D structure to see how likely it is that a *Stegobium paniceum* larvae could push its way through the fibres, or for the

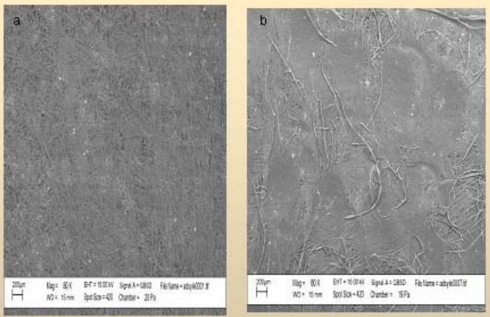

Fig. 11. SEMs of Tyvek type 10 (a) and type 14 (b) at 80X mag

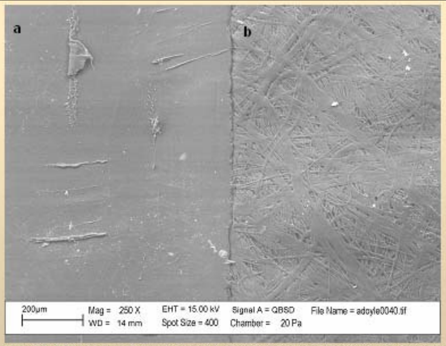

Fig. 12. SEM scans of Tyvek type 14 showing heat sealed weld (a) and original surface (b)

adults and larvae to chew their way through it. The medical packaging section of DuPont's website states that the pore size of Tyvek® is 0.5 µm and with the non-directional layering structure we believe these will make it difficult for the larvae to penetrate by pushing between the fibres but this has still to be confirmed by testing.

As the herbarium sheets measure 445 x 285 mm and the folders in which they are kept measure 450 x 305 mm it is advisable to have a further support inside the bag to make it more 'rigid'. This can be either of Plastazote® or archival board (with the corners rounded). These are best cut to dimensions slightly larger (i.e. 5 mm extra on each side) than the herbarium folder. To prevent the sheets from slipping inside the bag, corner strips can be added, which can be made from Tyvek® tape. Two styles of bags were made up from one length of Tyvek®: one sealed along the longest length and one sealed along the shortest length to fit the herbarium sheets or folders (Fig. 13). The bags of course can be made to any dimension required, limited only by the width of the heat sealer jaws.

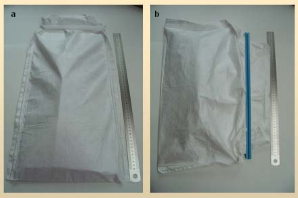

Fig. 13. Tyvek bags made up to size for herbarium sheets. WeLock clip used on short side (a) and Escal clip used on long side (b) of bags

The open end of the bag needed a secure closure mechanism and tests on various types were undertaken. Escal® strips, successfully used with Escal® barrier film, are advertised as hermetic seals for temporary use (website www.cwaller.de) and WeLoc® clips (marketed as Klippits), originally designed for hospital use for sealing fluid bags, are used for sealing food bags (www.weloc.co.uk). Both therefore provide a tight seal through which insects would not be able to penetrate (D. Pinniger, pers. comm., 2006; Figs. 9, 13). The Escal® strips measure 500 mm so will fit either style of bag (i.e. whether heat sealed along the long or the short edge) but it is difficult to use and appears to weaken with repeated use. (Also once it has been used to seal a thick layer it cannot then be safely used to seal a thin layer.) The WeLoc® clip 200 PA special measures 220 mm, it is easy to use and reliable on re-use, but it is heavy in comparison to the Escal® strip. Unfortunately, it is limited by its size and could only be used with herbarium bags that were open at the short edge. Experiments with hook and loop tape (e.g. Velcro®) showed that it was difficult to attach the strips and there will inevitably be an area at the heat sealed edges where it may not be fully covered with the tape, but this will need further testing.

Another consideration is the cost of producing these bags.

Together with the insect trails, Phase 2 is to undertake practical experiments to show the durability and effectiveness of these bags.

Conclusion

From this preliminary investigation it was established that Tyvek® type 14 (43 gsm) can be heat sealed and has the potential as a short-term protective barrier for herbaria. Further investigation also needs to be undertaken to find other suitable clips to seal the bags effectively. Everything is now in place for the insect and durability under handling trials to go ahead.

In summary, the advantages of Tyvek® as a preventive conservation material are that: it is readily available; the bags are easy to make; it can be heat sealed using the Crossweld®; and it has museum-wide application. The disadvantages are: the weld is uneven; the length of weld is limited by the size of the

Crossweld®; and limited by the size of effective clips.

These bags, therefore, have the potential to be re-used but they are intended for short-term storage only.

Endnotes

1. PRE-MAL (Pest Research and Education – Museums, Archives and Libraries). 'Strategies in the battle against pest insects in collections' Symposium held at the Swedish Natural History Museum, Stockholm, September 26, 2005.
2. Dutch Nursery, Brookmans Park, Hertfordshire.

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Websites

AATA http://aata.getty.edu
BCIN http://www.bcin.ca
Conservation on Line http://palimpsest.stanford.edu
Museums, Libraries and Archives http://www.mla.gov.uk

Appendix: Suppliers

Crossweld® heat sealer
Preservation Equipment Ltd
Vinces Road