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TECHNICAL NOTE

The Formation of Microenvironments in Polyester Enclosures

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Inert polyester sheets, such as Melinex and Mylar, are widely used in conservation to create envelope-like enclosures for storing and protecting flat objects (paper, parchment, papyrus, etc.). These materials are known to be chemically stable and present no direct risks to the enclosed items; however, as the films have a low permeability, such enclosures may lead to the creation of internal microenvironments. This will both limit the response to external changes and potentially trap any internally generated volatiles with the object. The likelihood of different forms of enclosures doing so is investigated in this paper. The resulting data will help to inform decisions about choices of construction of enclosures for particular objects, environments and purposes.

Keywords: Paper Conservation; Melinex; Paper Deterioration; Environmental Response; Microenvironments

Introduction

Inert polyester films, such as DuPont Melinex and Mylar, are widely used in the field of conservation for housing, storage and display solutions. In addition to their lack of chemical reactivity, they have many other desirable properties: they are transparent, with a high optical clarity, allowing objects to be readily observed; they are available in a variety of thicknesses and sizes; they can readily be cut, shaped and joined, enabling enclosures to be easily tailored to the requirements of specific items; and they are inexpensive and readily available. As a result, these films are often used to create enclosures and envelopes for fragile, damaged or fragmentary materials, and the facility with which this can be done means that this kind of solution can be carried out on a relatively high throughput basis.

It is known that the film material itself is non-reactive (Pretzel 2003; Thickett and Lee 2004), meeting the Library of Congress specification for polyester film (Library of Congress 2009), and so does not present a direct danger to objects stored in such enclosures. However, the stored objects are often in a deteriorated condition and may give off potentially damaging gases as they degrade; if the emitted volatiles remain trapped in close proximity to the stored item, this increases the likelihood that not only the stored item itself, but also any neighbouring items, will further deteriorate at a greater rate. Similarly, the rate at which the internal space in such enclosures will respond to changes in the external environment is also of importance. Therefore the aim of the work presented here has been to study the behaviours of such enclosures and to assess the potential for damaging microenvironments to be created within them.

This study has primarily concentrated on the polyester materials and methods employed at the British Library (BL) to create envelope-like enclosures for flat objects (paper, parchment, papyrus, etc.).

Six types of enclosures have been commonly employed at the Library. All consist of two sheets of Melinex, but vary in their methods of construction (**Figure 1**):

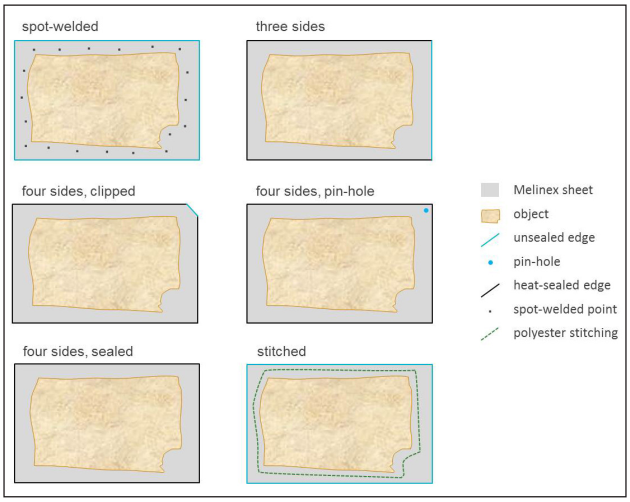

Figure 1: Construction of different forms of Melinex enclosures employed at the British Library.

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- spot-welded around the perimeter of the object using an ultrasonic spot-welder
- heat sealed on three sides
- heat sealed on four sides, with a corner snipped off for air exchange
- heat sealed on four sides, with a pin-hole for air exchange
- heat sealed on four sides
- sewn with polyester thread.

The method of sewing with polyester thread is no longer employed at the BL, but was included in the study as it was commonly used in the past, and numerous examples of it can still be found in the collection. These different methods each have their own advantages and uses: spot-welded and sewn enclosures can closely conform to the shape of the object, and they provide good support, especially for irregularly shaped items; enclosures sealed on three sides allow good access to the object, without requiring the enclosure itself to be dismantled; those sealed on four sides give the most protection and minimise any inadvertent contact with the object.

Microenvironments in such enclosures occur when the internal conditions (temperature, humidity, presence of reagents, etc.) differ from those of the external environment. This can arise in two principal ways: when changes in the external environment are not mimicked by corresponding changes in the internal space, or the rate of change is markedly different; or when an element within the enclosure drives changes in the internal environment which do not equilibrate with the external space. Both of these phenomena were investigated, the first by placing an environmental logger in the enclosures and changing the external conditions, and the second by enclosing a sample of acidic paper with an acid indicator strip and monitoring the colour change.

It should be noted that the creation of microenvironments is not necessarily problematic – for example, if certain objects are not well suited to the general conditions of a storage or display area, creating a more compatible local environment for them will be beneficial (Garside and Hanson 2011), and it may also serve to protect items from fluctuations in the wider environment.

Methods

Response to a Changing External Environment

The environmental response was measured using Maxim Integrated Products SL54TH iButton temperature/humidity loggers (17.5 mm diameter, 6 mm depth); these were set to record one data point per minute. These loggers were placed in holes which had been drilled in 80 × 150 mm sections of 5 mm Perspex and which were then sealed in Melinex enclosures using the six methods noted in the Introduction: heat sealing on three or four sides (the latter with three different provisions for air exchange), ultrasonic spot-welding, or sewing with polyester thread. (The Perspex was employed to minimise the free space in the enclosures, thereby more closely mimicking the situation encountered when flat paper or parchment objects are enclosed.) A similar logger without an enclosure was used as a control.

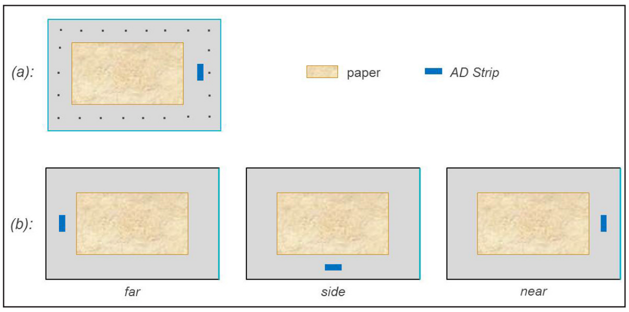

Figure 2: Placement of A-D Strips.

These enclosures were allowed to equilibrate at 50 per cent relative humidity (RH) before being placed in a chamber which was maintained at approximately 80 per cent RH using an appropriate saturated salt solution. They were left for several days, after which they were removed and the data were downloaded from the loggers.

Response to Internally Generated Volatiles

Melinex enclosures were created using the aforementioned six methods, with each containing a section of 40-year-old low-grade wood pulp paper (7 × 10 cm, pH ≈ 3) and an Image Permanence Institute A-D Strip (an indicator impregnated paper strip which undergoes a colour change from blue to yellow on exposure to volatile acids; although originally developed specifically to monitor acetic acid, these strips also respond to other volatile acidic species). Some of the enclosures were effectively symmetric regarding air exchange (spot-welded, fully sealed on four sides, sewn), whereas the remaining types of enclosures (sealed on three sides, sealed on four sides with clipped corner, sealed on four sides with pin-hole) potentially favour air exchange towards one side with respect to the enclosed item; for the former construction methods, a single A-D Strip was employed (**Figure 2a**), and for the latter, three different set-ups were employed, with the A-D Strips placed in different positions around the acidic paper (**Figure 2b**). Finally, a further enclosure, containing only an A-D Strip, was created as a control. All the enclosures were then left for 77 days, with L*a*b* colour space measurements recorded regularly using a Konica Minolta CM-2600d spectrophotometer (in each case, the average of five replicate measurements was used).

Results and Discussion

Response to a Changing External Environment

The internal RH values of the enclosures are presented in **Figure 3**. It can be seen that the responses for the enclosures which are spot-welded, sealed on three sides or sewn are very similar and lag slightly behind the control but are more rapid than for enclosures sealed on four sides. For these latter samples, the enclosure with the clipped corner exhibits the fastest rate of response, followed by the enclosure with the pin-hole. The internal humidity of the fully sealed sample does change slightly, and this is likely

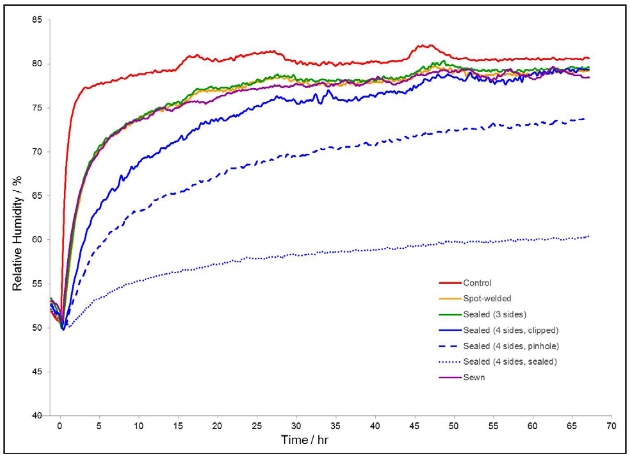

Figure 3: Internal RH values of different enclosures after exposure to elevated external RH.

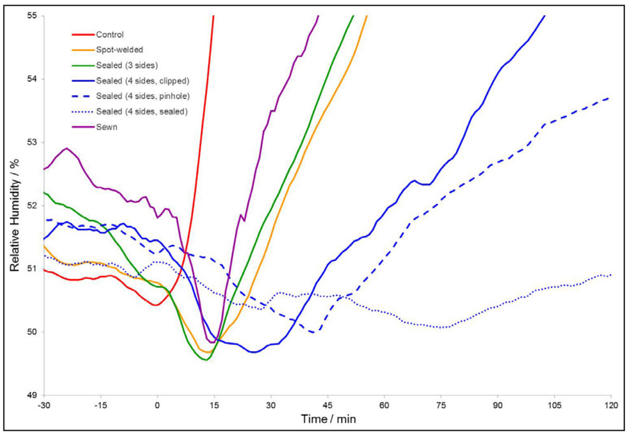

Figure 4: Initial response of RH changes.

	Approx. delay/min
Control	0
Spot-welded	15
Sealed (3 sides)	15
Sealed (4 sides, clipped)	30
Sealed (4 sides, pin-hole)	40
Sealed (4 sides, sealed)	75
Sewn	15

Table 1: Initial delay of the humidity response of Melinex enclosures.

to be due to the limited, but non-negligible, permeability of Melinex to water vapour; there may also be microscopic discontinuities in the seal, allowing some air exchange to occur, albeit slowly.

If the initial response is considered (**Figure 4**), it can be seen that the time taken for the internal environment to start to change with reference to the control varies significantly; this is summarised in **Table 1**. Although the precise responses are likely to change depending on the dimensions of the enclosure, its contents and the local environment, the pattern of these trends is expected to remain similar.

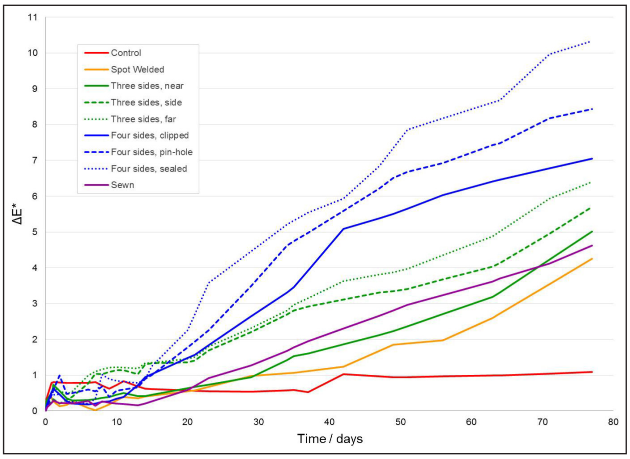

Figure 5: Measured ΔE^* values for A-D Strips in different enclosures.

Response to Internally Generated Volatiles

The colour change of the A-D Strips with respect to the values measured at the start of the experiment ($t = 0$) was calculated as a ΔE^* value:

$$\Delta E_t^* = \sqrt{(L_t^* - L_0^*)^2 + (a_t^* - a_0^*)^2 + (b_t^* - b_0^*)^2}$$

Where: ΔE_t^* = Colour change at time t.
L_t^*, a_t^*, b_t^* = L^*, a^*, b^* values at time t.
L_0^*, a_0^*, b_0^* = L^*, a^*, b^* initial values (i.e., at $t = 0$).

These were plotted against time for each of the samples (**Figure 5**). It was observed that for the enclosures sealed on four sides with either a clipped corner or a pin-hole, the results were much the same regardless of the position of the A-D Strip (**Figure 2**), so only one of the sets of data is shown for each of these; however, for the enclosure sealed on three sides, there were significant differences depending on the position of the A-D Strip, so all three sets of data are presented.

From this it can be seen that volatile acids accumulate most rapidly in the enclosures sealed on four sides; of the three samples prepared in this manner, this process occurs most rapidly in the fully sealed enclosure, followed by the one with the pinprick and then the one with the clipped corner. The heterogeneous behaviour of the enclosure sealed on three sides is also apparent from these data: volatile acids build up most readily in the areas further from the open edge, and in terms of initial behaviour these regions are similar to the enclosures sealed on four sides; however, as time progresses, the differences between the three sampling areas become less pronounced. In terms of overall behaviour, acids accumulate least rapidly in the enclosures that are either spot-welded or sewn.

Conclusion

The method of construction of these kinds of housings has a significant influence on their behaviour in terms of internal environments, and it is therefore important to bear these factors in mind when employing such enclosures to ensure that they are appropriate to both the external environment and the nature of the objects held within them. Objects which are prone to off-gassing may be better served by enclosures which ensure that the emitted volatiles are not trapped and do not thereby accelerate future damage. On the other hand, items which may experience environmental fluctuations in the local environment (for example during transport, where it is unlikely that museum-like conditions can be maintained) may benefit from more thoroughly sealed enclosures, which are shown to limit, lessen and delay the influence of such changes (**Table 1**).

It is not clear if the response of the A-D Strips, when used in this fashion and measured as a ΔE^* value, is linear or gives an accurate quantitative evaluation of the accumulation of volatile acids in the enclosures. Additionally, aside from the construction of the enclosure, the build-up of these gases will depend on other factors such as the rate at which the enclosed object off-gases and its size relative to the enclosure itself. Nonetheless, the use of A-D Strips does enable a qualitative appraisal of the properties of the enclosures to be made, and therefore judgements can be made on the suitability of particular enclosures for certain objects, based on condition assessments, known material sensitivities, etc.

The results are perhaps not unexpected, but this kind of systematic assessment of established techniques provides information which can be used not only to inform decisions about treatment methods for objects, but also to help explain and justify them to other stakeholders.

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