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Adhesives for Natural Science Specimens

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Introduction
Conservation is object centred; so all the approaches should start with the requirements of the object. When considering an adhesive treatment, ask whether it needs an adhesive treatment, or is that a cop-out in dealing with a more difficult underlying problem? What are the alternatives: are we proposing the right thing for the long term? There is a growing literature to aid the process of thought (Hornie, 1987).

Numerous, often undocumented, materials are added to specimens during a specimen's life which can be discovered e.g. a mount by a conservator or adventitiously e.g. oxygen from the atmosphere. All of these materials interact with the object, with each other and with the object. This complexity makes the process of planning important and to focus on long term effectiveness; but this is not a reason not to take any action to solve the real problem. Using an adhesive on an object is part of a long term process, from application through ageing to removal and any adhesives used on specimens need to be documented. Criteria have been proposed for choosing material added to an object.

There are three main components, the object, the added materials and their interaction. Reversibility is an important interaction and should be considered when planning. The reversibility can be classified in a number of ways.

- No known method of reversal, e.g. silane in stone.
- Return to a state approximating to original state, e.g. revarnishing painting.
- Return to a state that does not affect subsequent treatment, e.g. dismantling stuck pot.
- No evidence of initial treatment remains after reversal, e.g. no contamination or change.

What is an adhesive?
Liquid water is used as a (temporary) adhesive when transferring a piece of paper on a wet support fabric. But it does not last very long and it is not very strong; it is only temporary. English is poor at definitions and using them, so I have proposed a couple to help clarify;

- ***Adhesive***: a substance capable of joining materials by surface bonding (adhesion).

- ***Liquid adhesive***: a liquid which sets to a solid forming an adhesive bond.

A join between two components does not necessarily use an adhesive, even if you think you have added one. Joining can be achieved by mechanical interlocking, or by bonding (adhesion). Bonding requires wetting of adherend's surface by a liquid, setting of the liquid to form an adhesive which prevents movement at the joint, ability to adjust to stresses at bond interface.

Having made the bond, how does it fail? How would *you* want it to fail? Ideally, the adhesive should peel off the object, the adherend, leaving no trace behind, on demand. This is called adhesive failure and is what pressure sensitive tapes claim but never achieve. They leave a bit of the adhesive behind on the surface, because the adhesion is stronger than the adhesive, leading to cohesive failure of the adhesive. Worst of all is cohesive failure of the adherend, which breaks.

Liquid adhesives
All adhesives must be applied in liquid form in order to flow over the surface of the substrate. This creates severe restrictions on the composition and thence on the final adhesive composition and properties. A commonly used formulation in conservation (but rarely in industry now) is a polymer in solution. The polymer must first be dissolved in the solvent. The solution then flows over the adherend surfaces, then evaporates (in whole or part) to deposit a solid film of polymer which acts as the adhesive for the long term before being removed. Choosing the correct polymer to optimise each stage of this process has created many inappropriate solutions, which still remain on objects for conservators to reverse.

There are many different types and subtypes of polymer. Polymers can now be designed, and manufactured to suit the application. In choosing the adhesive components the complete life cycle of the process must be worked through.

The conversion from liquid adhesive to solid adhesive, setting, can result from a number of mechanisms:

- Cooling from a melt, e.g. paraffin wax.
- Cooling from a solution, e.g. gelling of a gelatine glue, with the subsequent evaporation of the solvent.
- Evaporation of a solvent, e.g. water from starch paste.
- Evaporation of a dispersant (usually water) from polymer dispersion, e.g. white PVAC wood adhesives.
- Chemical reactions between two or more components, e.g. polymerisation of cyanoacrylate monomers by initiation with water on a surface.
- Pressure sensitive adhesives are special liquids that are (or should be) designed to not flow away but remain as adhesives.

The setting process can be fast (seconds) or slow (weeks). It needs to be adjusted in the formulation to be suitable for the methods used to make the join. For instance, a very viscous liquid adhesive (e.g. epoxy) needs plenty of time to flow and wet the interstices of a surface, whereas a highly mobile cyanoacrylate needs much less.

Adhesives

There are many types of adhesives which can be classified in many ways, e.g. organic or inorganic, natural or synthetic, traditional or modern, well characterised or commercial secret, setting method, stability, mechanical properties. All choices are compromises, so both the benefits and disadvantages need to be explicitly considered in relation to the object. The normal starting point is the literature and customary practice in the field. However, each object needs to be considered individually. There is a tendency to keep reusing (inappropriate) materials without proper consideration for the application in hand.

All adhesives are mixtures of components, e.g. polymer and solvent and stabiliser. The composition must be tailored to the setting mechanism and the adherend, e.g. different epoxies for glass or leather, different glues for parts of a violin. Each component matters, to the adhesive and the object. The main component of an organic adhesive is the film forming polymer. In most commercial adhesives, many additives are included in a formulation to improve properties such as stability in storage, flow and wetting characteristics, and stability in ageing.

Polymers have two properties that set them apart from other commonly experienced materials; molecular weight and glass transition temperature. Polymers are made up of mixtures of large molecules. This is different from many other types of substances. The molecular weight, MW, of a polymer can be 100s to many millions, which affects the mechanical properties of the adhesive. The largeness of the molecules leads to strength, flexibility and viscosity in melt and solution. If the size of the molecules is increased, these properties are also increased. So when choosing, say, a poly(vinyl acetate) for an adhesive, there are many varieties available, from weak and low viscosity to strong and high viscosity, in solution or dispersion etc. One needs to be explicit about which material is chosen and why it was used – "PVAC" is an incomplete and inadequate description.

The high molecular weight of polymers leads to another property, the glass transition temperature, Tg. As one heats a polymer through this temperature (actually a range of temperatures), the polymer changes from a glassy rigid material to a plastic, mouldable, one. Further heating can lead to melting and flowing. Each polymer has its characteristic Tg. Some polymers are extremely flexible, such as silicone rubber, Tg= -125ºC. Some are rigid and glassy, such as poly(methyl methacrylate), Tg = 105ºC. The best adhesives have their Tg around the temperature of use, normally room temperature, which is why PVAC (Tg 17-26ºC) is frequently used.

Adhesives are chosen primarily because they do a physical task, holding components together. So their mechanical properties are important as is how the mechanical properties interact with those of the object.

When pulling a sample of polymer to destruction, the mechanical properties of stress (strength) and distortion (strain) can be measured (Figs 1 & 2). It is not usually possible to do the same test on objects to make sure that an appropriate adhesive is chosen. The aim is to ensure that any mechanical forces are dissipated in the adhesive and not concentrated in the object, leading to damage.

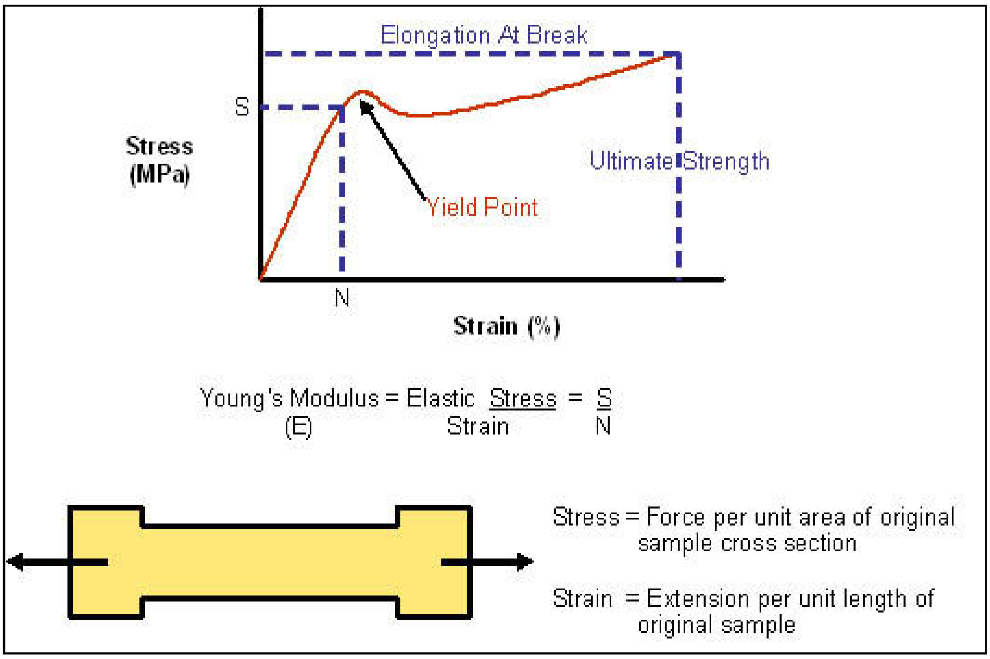

Fig 1. Measuring the mechanical (tensile) properties of a material.

Polymer	*E, Young's modulus MPa*	*Ultimate strength MPa*	*Ultimate extension %*	*Tg °C*
Silicone rubber	3	5	500	-125
PE (LDPE)	166	10	620	-20
PVAC	1200		15	17-25
PMMA	2600	65	4	105

Fig 2. The properties of typical polymers.

The next stage in an adhesive treatment's life cycle is ageing, when all the components and the object and the environment interact. The base polymer of the adhesive can deteriorate: cross-link, chain scission, yellow, shrink etc. The object can corrode, distort, give off degradation products etc. As a result, adhesion can be much weakened, without any outward signs, or be lost so the bond fails. Thus chemical and physical properties of properties of the adhesive change over time. Feller ((1978), proposed a classification of useful life, ranging from A1, >500 years, to T, <6 months. As it is impossible to remove all traces of an adhesive treatment, it is prudent to use treatments that have a useful life of at least 20 years, classification B. It should be noted that this "useful life" relates not to material but the total application. A join that may last many decades in a museum store, may fail in months if exposed outside.

Finally, the last stage in the cycle arrives, reversing the adhesive treatment. The removal process should be designed, and documented, as part of the original treatment. So the chemical effects of solvents and the potential of damaging swelling or mechanical scraping should be highlighted and minimised in the choice and application of the adhesive.

Conclusion

Many conservators spend inordinate time and effort reversing the damaging effects of previous treatments. Adding materials to an original object complicates its future use and conservation. This should be carried out only after eliminating the other possibilities and then optimising the technique chosen. This means understanding the physical and chemical properties of the object, the adhesive and their long term interactions.

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