Physics Fundamentals-Adhesion

The subject of adhesion combines many other themes. For example, surface tension and surface effects generally are important in adhesion, and adhesives need both to wet and flow in order to be effective. Further information in Effects at liquid surfaces.

Mechanisms of adhesion

The mechanism of why adhesives bond materials together is not fully understood. Whilst surfaces can exert strong attractive forces, these are negligible unless the 'adherends' (surfaces to be stuck together) are in extremely close contact (of the order of 0.5nm) over a large area. This is usually impossible because, on a microscopic scale, almost all surfaces are too rough.

Convincing arguments have been put forward for a number of theories as to how bond strength is created:

By the adhesive interlocking around irregularities on the surfaces to be joined ('Mechanical Theory')

By a force of attraction between the surface molecules of the adhesive and the adherends at their interfaces ('Adsorption Theory')

Electrons are transferred from one surface to the other to build up dissimilar charges, exerting a force of attraction ('Electrostatic Theory')

The long chain molecules of the adhesive diffuse into the adherend, building up strong intermolecular forces.

Whichever is true, and the actual mechanism may involve a combination of them all, the function of the adhesive is to fill surface irregularities and increase the area of contact between the adherends.

The bonding between the surfaces is then dependent on two properties of the adhesive material:

- adhesion – the bonding strength of the adhesive to the substrate surface
- cohesion – the strength of the bond between adhesive particles

The ability of the adhesive to wet the surface is important, so its surface free energy has to be chosen with care, particularly if the bond is to be made to a polymer surface. Capillary action is also important, as this will aid the penetration of adhesive into small surface features, such as cracks, playing an important part in promoting locking to the substrate.

Why bonds break down

A chain is only as strong as its weakest link and therefore adhesion and cohesion should be in balance for optimum performance. When a properly made metal joint is stressed to the point where it fails, the failure normally occurs within the adhesive layer itself. However, continuous stressing in the presence of moisture can move the place of failure from the bulk to the interface with the metal. By analysing the interface forces between an adhesive and a slightly oxidised metal surface, it has been shown that water is preferentially absorbed on the oxide surface and displaces the adhesive from it, and that stress accelerates the displacement.

For structural adhesives, work has concentrated on preventing this displacement by making use of 'coupling agents': one component reacts with the adhesive, and the other with the oxidised surface and with itself to build a thin, polymeric coating chemically attached to the metal. In general, much emphasis on surface preparation for adhesive bonding has been aimed at removing loose, unstable, hydrated oxide and replacing it by a thin stable one.

Under prolonged static loading an adhesive joint fails under a smaller load than is needed to break it in the beginning. An important design factor is the 'endurance limit' of the joint, the theoretical load which can be sustained indefinitely. It has been demonstrated that cyclical stressing below this limit does not weaken the joint, whereas joints subjected to higher stress levels gradually reduce in strength – although damage is not visible, a small number of joints will fail during test.

Surface preparation

As in the case of solder, wetting is important in adhesive joints. Much of the strength of the joint will depend on how well the adhesive flows into the microstructure of the contact surface to maximise the surface area of the contact (Figure 1).

Figure 1: Schematic cross-section of an adhesive joint between two different surface finishes

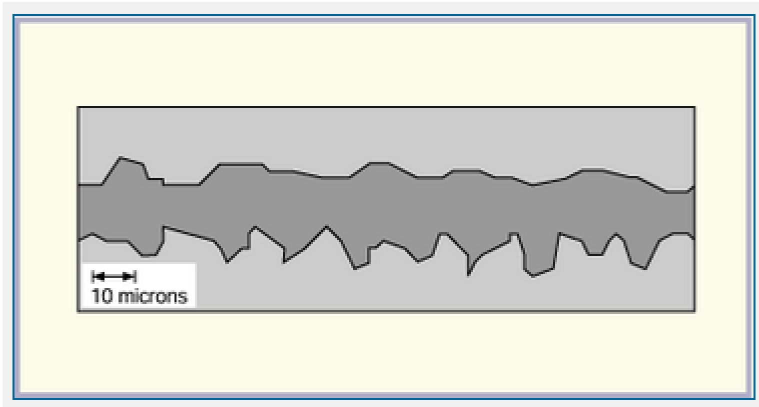
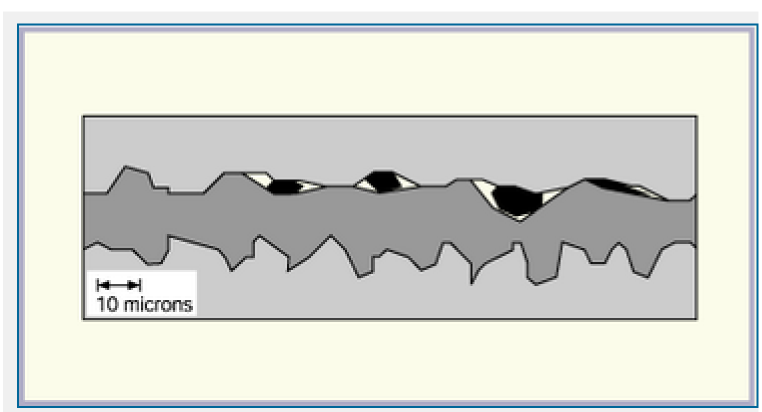


Figure 1: Schematic cross-section of an adhesive joint

However, adhesives with high surface energy (or ‘surface tension’) will not wet a surface of low energy such as polyethylene, polypropylene, and the fluorinated plastics. If an adhesive does not properly wet the surface, we must either look for an alternative adhesive or treat the surface to increase its surface energy.

Wetting also depends on the condition of the surface to be bonded. Any dirt or debris will reduce the strength of the joint by reducing the surface area of the adhesive bond (Figure 2). It is therefore very important that surfaces are kept extremely clean, and appropriate cleaning procedures, such as degreasing, scrubbing or priming, are important preconditions for optimum joint strength.

Figure 2: Schematic cross section of an adhesive joint between a clean and a dirty surface



On application, the adhesive must be sufficiently liquid to wet the surface, but most need to polymerise further in order to solidify. With adhesives, this process is generally referred to as ‘curing’.

Adhesion in practice

The printed circuit board itself totally depends on intimate adhesion between the resin, its reinforcement, and the foil of which the laminate is made. Where the laminate is drilled, and subsequently through-hole plated, then the adhesion to the plating is also important. It is the breakdown of adhesion in various ways which can cause some of the reliability issues we will be considering later in the module.

Also on the printed circuit board is solder mask and legend, both of which need to form good bonds to the laminate surface.

Adhesives are used within many components, for example to bond silicon die to the lead frame. At the same time, the adhesion between the encapsulant and the lead frame is an important factor in protecting the device against the ingress of moisture.

More obvious is the use of adhesives during the assembly process: devices intended for wave soldering are stuck to the board before immersion; heavy components may be supported with a local application of silicon adhesive; flipchips and µBGAs are underfilled.

And of course there are ways of bonding other than using adhesives. We have already become aware of soldering as a technique, but brazing and welding are joining techniques which are used for metal assemblies. For plastic components, solvent bonding and welding are both used. In almost every case, these ways of bonding require both surface activity of any infill materials and care in surface preparation. They also raise the issue of where the bond will break – in the bond line, or at either adherend, so the concepts of adhesion and cohesion still apply.

Finally, remember that what we think of as adhesives are just part of a much wider continuum of joining methods. In electronics manufacture, we need to use the most appropriate and cost-effective method for the application.

Author: Martin Tarr

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