A Method to Measure the Adhesive Strength of Glob Tops to Substrates

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P E Tomlins and J Nottay
Materials Centre
National Physical laboratory
Teddington, Middlesex
United Kingdom, TW11 OLW

SUMMARY

Good adhesion between glob top materials and their underlying components is critical for the functionality of the encapsulant to protect sensitive devices from exposure to hazardous environments. However there are no standard methods for measuring the degree of adhesion. In this report we describe a method whereby a pull stub is attached to the surface of a cured encapsulant using an appropriate adhesive. An increasingly large tensile force is then applied to the pull stub-adhesive-encapsulant-substrate assembly until failure occurs. The point at which the assembly breaks is usually at the interface between the encapsulant and the underlying substrate. The ultimate tensile force measured at this time can be used to rank different types of encapsulant or to investigate the effects of different finishes, substrates or environmental conditioning on adhesive strength.

ISSN 1361-4061

National Physical Laboratory
Queens Road, Teddington, Middlesex, TW11 0LW

Approved on behalf of the Managing Director, NPL
by Dr C Lea, Head, Materials Centre

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1 INTRODUCTION

Plastics used to encapsulate IC's and COB's (chip on board) are designed to protect the underlying components from exposure to harsh environmental conditions and from mechanical damage. Encapsulant materials can be classified into two types – 'glob tops' and 'dam and fill'. Glob top materials are relatively high viscosity formulations that are applied directly to the components and a limited area of the underlying circuit board. Dam and fill encapsulation is a similar process except that a high viscosity material is used to create a wall or dam around the component. This dam is then filled with a low viscosity polymeric solution.

The *initial strength* of the adhesive bond formed between the encapsulant and the substrate depends on the surface finish of the board, its surface chemistry and how clean it is. The *in-service* performance of the encapsulant mounted on the board depends on the similarity between the thermal expansion coefficients of the substrate and the encapsulant and the temperature range experienced by the assembly during thermal cycling. Where electronic circuitry is exposed to vibration the ability of the adhesive bond formed between the encapsulant and the substrate to resist fatigue is an important property. Understanding the behavior of an encapsulated component on a circuit board is further complicated due to the components geometry and differences between the properties of the component surface finish and that of the substrate. Other factors such as the thickness of the encapsulant and the presence of fillets around the base of components also contribute to the complexity of the system. Many of these issues can be avoided by using a 'simple' test board design that consists of encapsulated double comb patterns deposited on to a substrate. This test board can also be used to rank different encapsulants according to their moisture resistance as a function of temperature via surface insulation resistance measurements[1].

2 MEASURING THE ADHESIVE STRENGTH OF ENCAPSULANTS

Unfortunately non-destructive test methods such as surface insulation resistance or ultrasonics time-of-flight measurements are unable to reliably determine the adhesive strength of encapsulants. The destructive methods available usually measure the maximum shear or tensile force required to detach the encapsulant from an underlying substrate. Shear test methods are typically based on single lap joints or flexure tests and whilst these methods are suitable for relatively stiff materials such as FR-4, it is more difficult to generate data from stiffer substrates i.e. ceramic due to their brittleness. Single lap-joints are difficult to manufacture from flexible substrates unless they are attached to stiffer members which adds additional time and costs to preparing test specimens. Tests that rely on wedges being driven along the interface between the substrate and the encapsulant may also be used but they are difficult to perform due to the precision required in positioning and controlling the wedge. Measurements of the tensile force required to detach the encapsulants can be used for FR-4, flexible and ceramic substrates, although again there is an obvious requirement to attach the flexible substrate to a stiff support.

A pull stub has to be attached to the encapsulant prior to measuring the tensile force required to detach it from its underlying substrate. This can be achieved either by gluing the pull stub to the surface of a cured encapsulant or embedding it in the uncured encapsulant as it is being dispensed. The latter process is often seen as the preferred method but potential users should be aware of the additional stress concentrations and compressive forces that are found around the periphery of the pull stub as indicated in Figure 1. These are likely to cause the assembly to fail cohesively within the glob top itself.

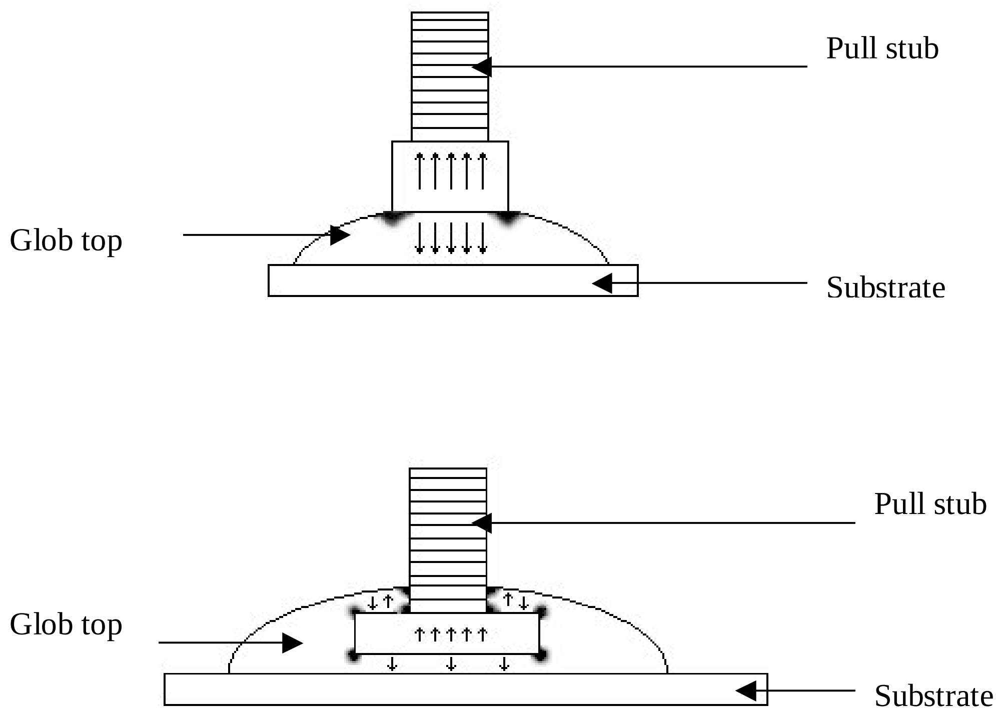


Figure 1: Attaching the pull stub directly to the surface of a cured encapsulant results in some stress concentration around its base (shaded area) and tensile forces within the encapsulant itself (as indicated by the arrows). More stress concentrations occur when the pull stub is embedded in to the encapsulant in addition to compressive stresses.

Attaching the pull stub directly to the surface of the cured encapsulant reduces the number of stress concentrations around the head of the pull stub providing that the adhesive fillets are removed. This results in a much simpler tensile stress field. This type of test is a method for measuring the pull off strength of coatings and adhesives and can be referred to as a butt tension test[2]. The tensile force required to detach the encapsulant from the substrate can be applied by a wide range of materials test equipment such as that supplied by Zwick[3], Instron[4] or Lloyd Instruments[5]. There are also specialist companies who have developed portable equipment for this particular test for the coatings industry such as Elcometer[6] and DFD[7].

2.1 BUTT TENSION TEST MEASUREMENTS

In the butt tension test a pull stub is attached to the encapsulant using a suitable adhesive, after curing the assembly is mounted into the test apparatus as shown schematically in Figure 2 for an Elcometer PATTI portable adhesion tester[6]. Compressed air is used to inflate the collar so that the pull stub and hence the encapsulant is subjected to a tensile force. The point at which the assembly fails is recorded as a burst pressure that can be converted into a tensile force by dividing it by the area of the pull stub. The burst pressure whilst a useful measure of adhesive strength does not contain any information relating to the time required for failure to occur, however this could be obtained by logging applied load as a function of time.

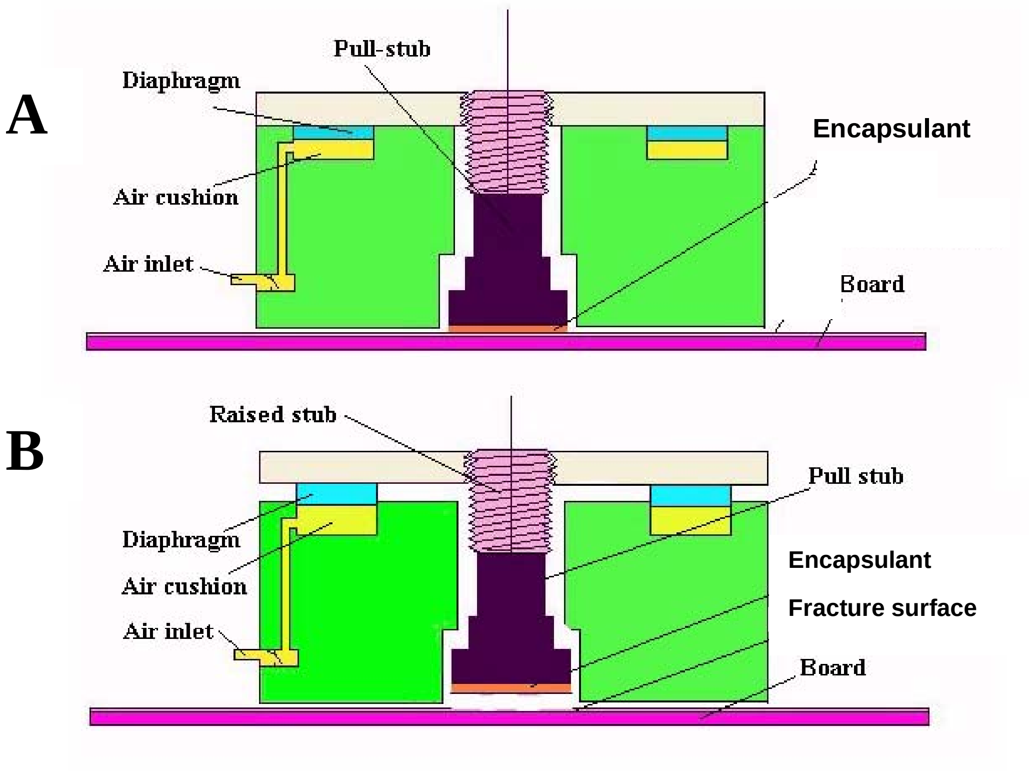


Figure 2: A schematic representation of the butt tension test, A) before and B) after detachment of the pull stub (and encapsulant) from the substrate.

2.2 BOARD DESIGNS AND MATERIALS

The board design shown in Figure 3 has been designed such that both measurements of the adhesion of glob tops to different substrates or substrate finishes and the surface insulation resistance performance can be assessed using the same test coupon. The board comprises of four double comb patterns i.e. two differently sized squares of length 25 mm and 13 mm respectively and two circles of diameter 7.2 mm. The guard rails shield the double comb patterns from noise. Each double comb pattern comprises of a 0.7mm pitch gold over nickel track (350 μm track and 350 μm spacing). (Note that alternative materials can be used for the track). This procedure is also independent of the pattern design shown in Figure 3, in principle any size or shape of double comb design can be substituted.

Prior to encapsulation the boards should be either processed as per production boards (if the objective of the test is to mimic in-service behaviour of the encapsulant) or cleaned if the purpose of the test is to compare a range of encapsulants. A recommended procedure for cleaning boards is to use an iso-propyl-alcohol (IPA)/water mixture (75:25) at 45°C. The cleaning time at this temperature is typically 10 minutes i.e. the time at which zero level ionic contamination is recorded by an ionograph.

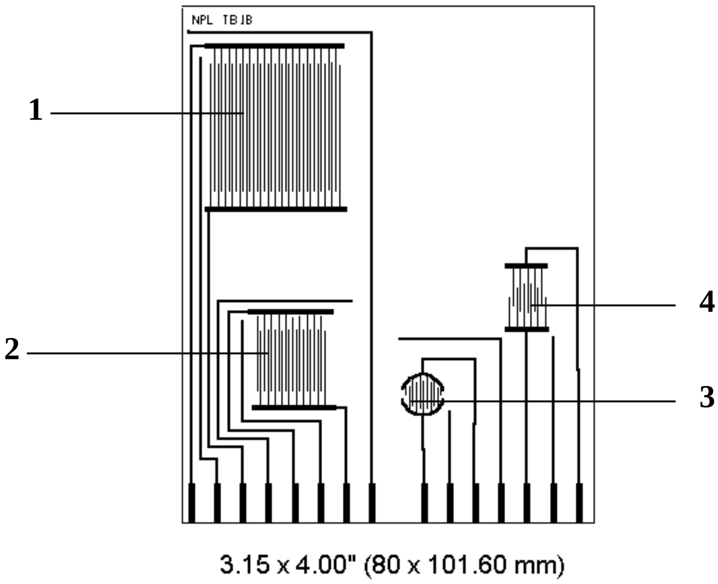


Figure 3: A test board comprising of four double comb SIR patterns labelled 1 to 4.

If there is a need to assess the adhesion of the encapsulant to the surface of a component, then an alternative board design may be used, as shown for example, in Figure 4. In this design dummy QFPs are mounted over double comb SIR patterns. The adhesion of the encapsulant to these assemblies can be measured using the butt tension test and information concerning moisture ingress can be obtained by SIR measurements.

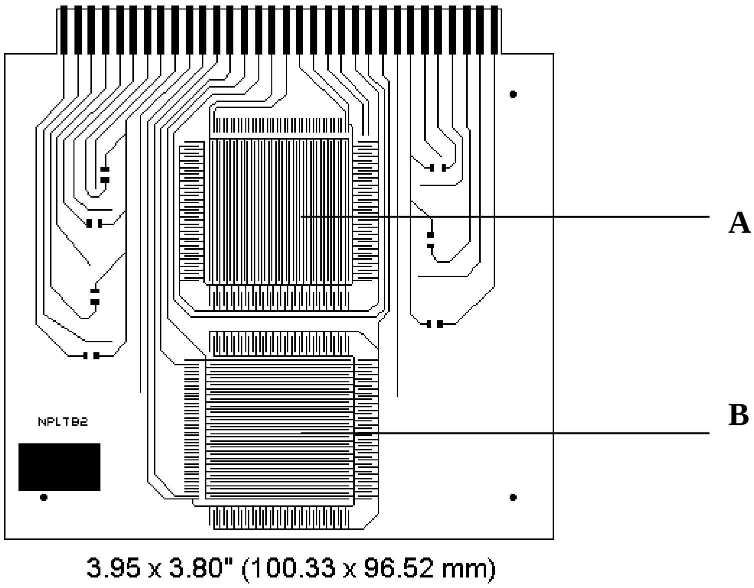


Figure 4: Two dummy QFPs mounted on double comb SIR patterns (A and B) can be used to assess encapsulant adhesion and to monitor moisture permeability during environmental conditioning.

2.3 DISPENSING AND CURE OF GLOB TOPS

An example of a glob top material being used to encapsulate double comb patterns deposited on to a resist coated ceramic board is shown in Figure 5. Single phase glob top materials are most reliably dispensed using single head dispensers that can be programmed to repeatedly dispense the same volume of material at a prescribed rate over defined regions of the test boards. Dam and fill glob tops generally require a two stage head for dispensing although it is possible to dispense the dams first followed by the fill material for small test runs. The different size and shapes of the double comb patterns will automatically produce variations in the depth of the encapsulant material on a single board. Significant differences in the dimensions of the cured glob tops will occur in comparisons of different manufacturers products. This variation can be attributed to differences in the surface tension of the encapsulant on different substrates and in the solid content of different formulations. The manufacturers recommendations should be followed for curing the encapsulant.

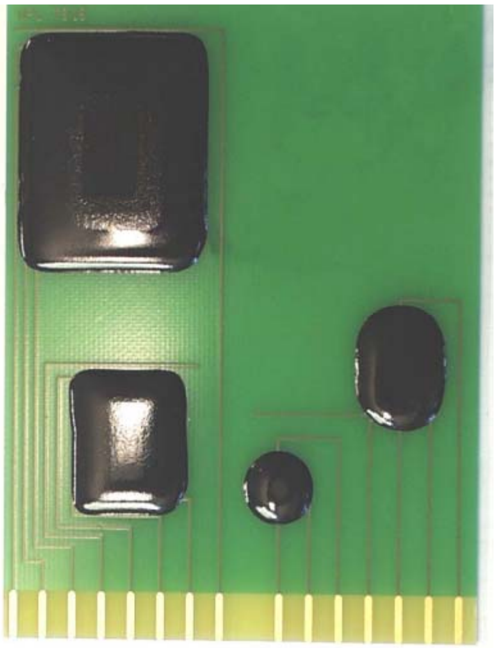


Figure 5: A typical encapsulant (polyurethane) dispensed on to a ceramic board covers not only the double comb areas but also regions of the board coated with solder resist.

Problems may be experienced in using some materials dispensed on to ceramic test boards. Some coatings are susceptible to delamination as the encapsulated boards are cooled down after curing at high temperature (150^{o}C). The large rectangular double comb pattern (Figure 5) is particularly susceptible to this problem that presumably reflects differences in the thermal expansion coefficient between certain encapsulants and the ceramic substrate.

2.4 ATTACHMENT OF PULL STUBS

The encapsulants should be cleaned using IPA and lightly abraded (400 grit) prior to bonding a pull stub to them. The surface of the pull stub should have a keyed surface to improve bond strength. The pull stub can be attached to acrylics and epoxies using widely available two-part epoxy adhesives. However these may be of lower strength than that required to detach encapsulants from their substrates. More specialised epoxy systems[7] such as Redux 312 are used as films that can be tailored to the dimensions of the pull stub before being cured at elevated temperatures. Regardless of the adhesive system used care should be taken to remove the fillet of adhesive that can form around the base of the pull stub during the bonding process as this can have a significant effect on the mechanical properties of the joints.

The pull stub should be positioned at 90^{o} to the encapsulant to ensure that a ‘pure’ tensile force is applied to the interface between it and the underlying substrate. This task is greatly simplified by using an alignment jig. The design of the jig should ensure that the pull stub can be accurately placed over the cured encapsulant and securely held as the adhesive between in it and the encapsulant is cured for different thicknesses of encapsulant. If a positioning jig is not used then the weight of the pull stub tends to compress the adhesive as it begins to cure forming a fillet. The pull stub also tends to lean during this time causing problems during testing.
An alternative approach to gluing the pull stub to the encapsulant is to immerse the pull stub into the encapsulant immediately after it has been dispensed but this induces additional significant stress concentrations around its periphery as previously described.

3 DATA ANALYSIS

3.1 VISUAL INSPECTION

The boards should be visually examined after both curing the encapsulant and after any environmental conditioning to look for signs of delamination or cracking. Any damage should be logged prior to attaching the pull stubs to the encapsulant.

3.2 INTERPRETATION OF TEST DATA

For simple comparisons of the adhesive strength of different encapsulants the maximum tensile force required to break the bond between them and their underlying substrates can be plotted as shown in Figure 6. In this figure the data are from different types of encapsulant, i.e. epoxies and a silicone supplied by different manufacturers. A previous investigation[8] has shown that the burst pressures (or maximum tensile forces) recorded from the differently sized double comb patterns of Figure 5 are, as expected, equivalent within experimental error. These data can therefore be averaged to give both a mean and an estimate of the standard deviation.

It has been reported elsewhere [9] that the tensile strength of silicone resins is less than that of epoxies or acrylics. This difference in behaviour has been attributed to the relative weakness of the silicone network.

3.3 INSPECTION OF FRACTURE SURFACES

Figure 7 shows the sites where the pull-stub – adhesive – encapsulant – substrate assembly can fail. In most instances failure of the assembly occur adhesively at the interface of the substrate and the encapsulant (C). Examples of some of the fracture surfaces are shown in Figure 8.

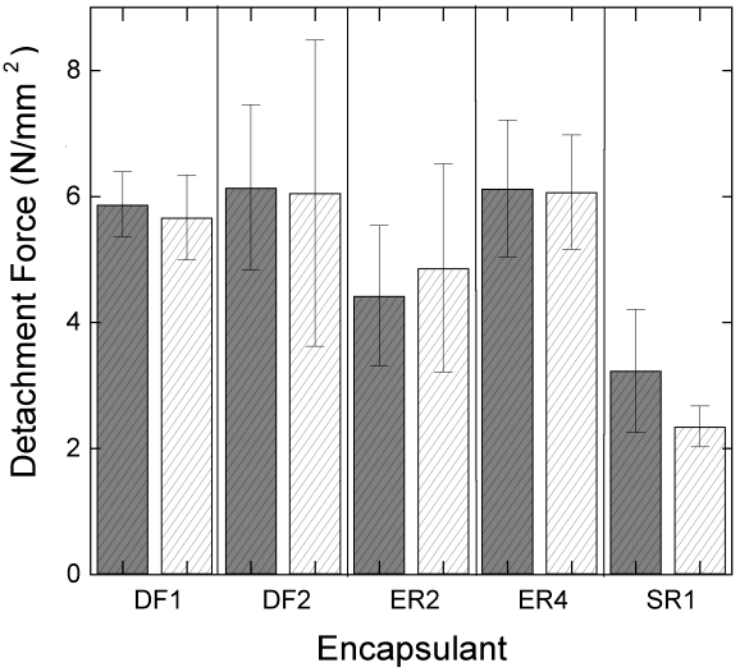


Figure 6: The adhesive strengths of different types of encapulants (epoxies: DF1, DF2, ER2 and ER4; silicone: SR1) attached to FR-4 can be easily compared in a simple histogram. These data suggest that exposure of the encapsulated board to 100 cycles over the temperature range of –40°C to 80°C has no influence on thermal strength (☐ = no thermal cycling, ■ = thermally cycled).

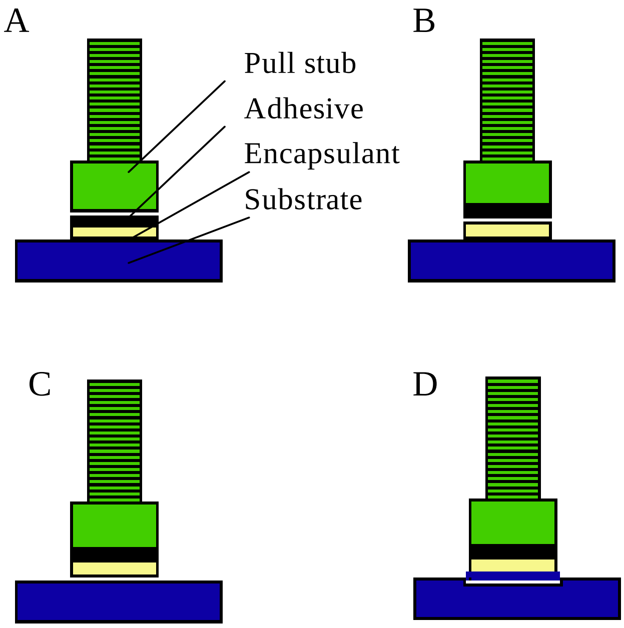
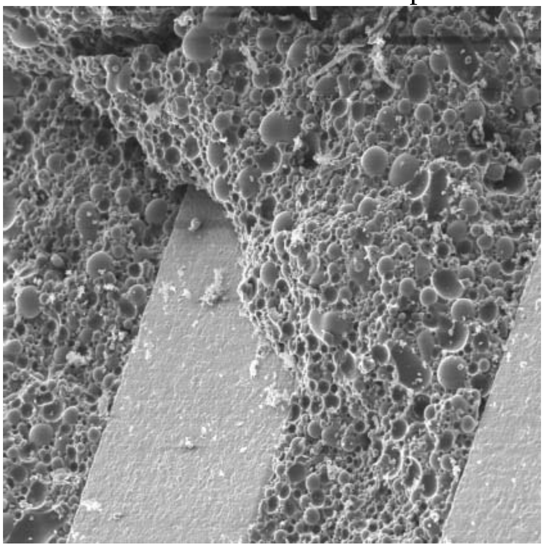


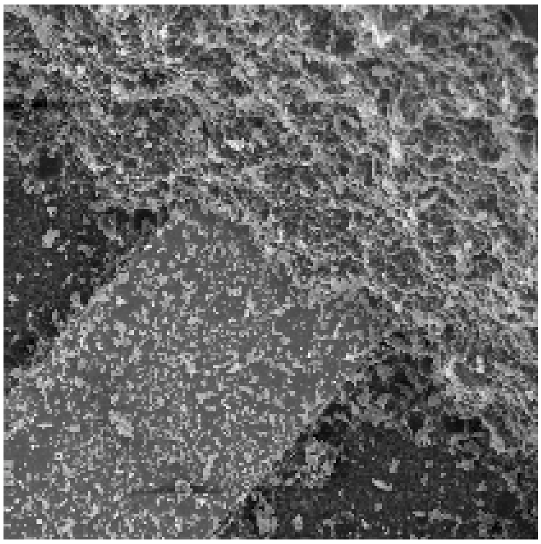
Figure 7: Failure of the encapsulant material can occur at:

- The interface between the pull stub and the adhesive system (A).
- The interface between the adhesive system and the encapsulant material (B).
- The interface between the encapsulant material and the substrate (C).
- Or within the substrate material (D).

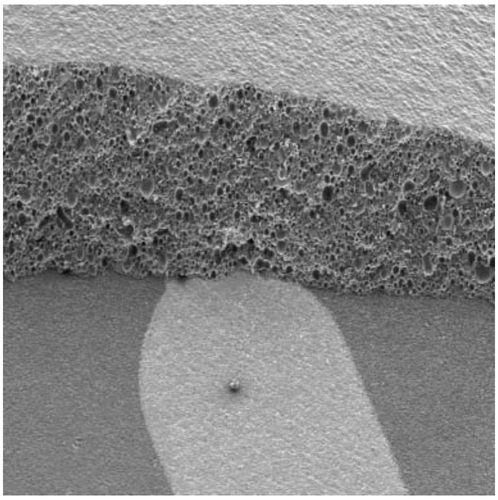
The fracture surfaces shown in Figure 8 identify the interface between the surface of the substrate and the bottom of the encapsulant as being the region where adhesive failure occurs (C in Figure 7). It is likely that failure occurs at this point, at least for FR-4, because of the presence of the double comb pattern that acts as a stress concentration. The encapsulated FR-4 fracture surfaces suggest that brittle failure has occurred with no signs of stress whitening, i.e. fibrillation of the polymer matrix. The ceramic substrate shows similar behaviour with even fewer remnants of the encapsulant remaining on it after failure.



Epoxy based encapsulant (dam and fill) on FR-4 (x55)



Epoxy based encapsulant on FR-4 (x150)



Epoxy based encapsulant on ceramic substrate (x80)

Figure 8: Typical fracture surfaces of encapsulated material deposited on to FR-4 and ceramic PCBs.

4 THERMAL CYCLING

In exposing encapsulated boards to a period of thermal cycling care should be taken to control the humidity of the conditioning chamber. In a recent study[8] it has been shown that thermal cycling has a negligible effect on the adhesion of encapsulants to, for example, FR-4 when care was taken to prevent condensation from occurring on the surface of the board during each successive cooling cycle. This can be achieved by bleeding dry nitrogen through the chamber throughout the test period.

5 ACKNOWLEDGEMENTS

The authors would particularly like to acknowledge Jamie Maughan and Bruce Seeton of Speedline for dispensing the encapsulant. H.K.Wentworth, Loctite and Emerson and Cuming for generously providing materials.

This work was funded by the United Kingdom Department of Trade and Industry as part of its programme of research on the Degradation of Materials in Aggressive Environments.

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