Adhesion of moulding compounds. Can material pre-selection increase the reliability of electronic components?

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Abstract

It is well known that high temperature storage can degrade moulding compounds for chip encapsulation to such an extent that the adhesion to surfaces like copper (lead-frames) or polyimide (chip coating) decreases drastically causing delamination. Also during normal operation of electronic components heat is generated locally (bond wire or chip surface) degrading the moulding compound and reducing the adhesion which in extreme cases can destroy the metallisation or bond wires.

1. Introduction

The adhesion between different materials on different interfaces is the base of high package reliability. The most important interfaces are moulding compound - chip surface and moulding compound – lead-frame. The properties of these interfaces are influenced by various materials and process parameters for chip surface and bond pad conditioning.

Standard tests as thermal cycling do not aim at quantifying adhesion, but predict in the case of adhesion loss, delamination.

An evaluation method based on a suitable test vehicle which enables the study of decoupled influence parameters for adhesion is missing. To characterise the adhesion of these interfaces a shear-test method of moulding compound buttons on different base materials can be used. The moulding compound buttons (for instance 2 mm x 2 mm) are applied on base material stripes with a dimension of 100 mm x 20 mm (e.g. on copper or silicon). The test setup and the typical test vehicles are shown in Figure 1.

2. Simulation and Experiments

First High Temperature Storage (HTS) experiments with temperatures up to 250 °C on copper stripes with moulding compound CEL showed a degradation of the moulding compound adhesion represented by a reduction of the maximum shear forces. Shear tests have been enabled to measure highly reproducible force – displacement curves which can be used to calibrate simulation models (Figure 2) using cohesive zone elements in order to describe the adhesion of the selected material combinations.

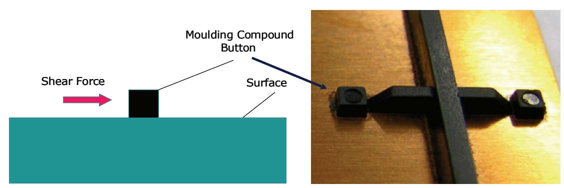

Figure 1: Experimental setup for enabling shear tests. The shear results are highly adhesion dependent.

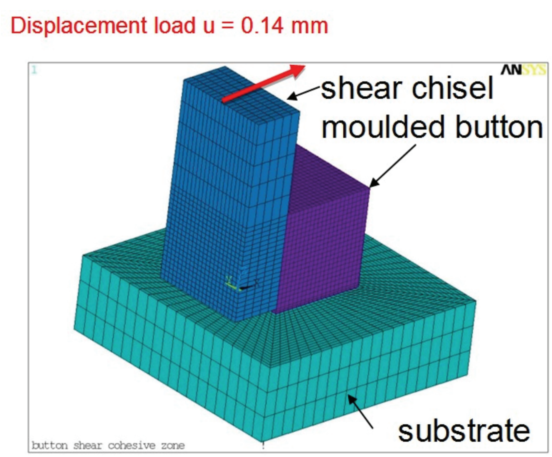

Figure 2: Simulation set-up of a shear test. The red arrow shows the shear direction.

In Figure 3 the complex stress distribution is shown for the principal stress S1. Delamination will occur when an interface crack will be initiated.

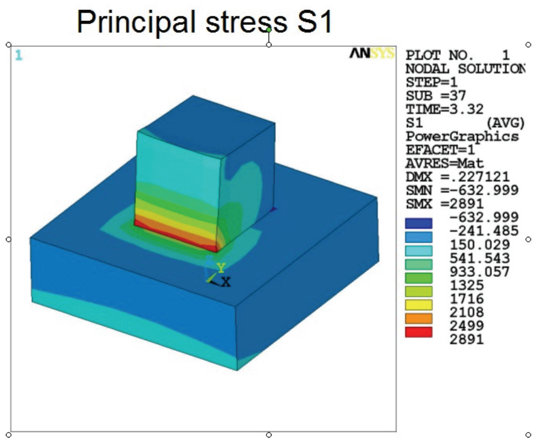

Figure 3: Principal stress S1.
Stress distribution applying a shear force.

The shear height dependency is given in Figure 4. The mode mixture (shear and pull) often makes it difficult to understand the dominant failure mode. Based on the simulation it was decided for all experiments to set the chisel 100µm beyond the substrate surface in order to address shear toughness.

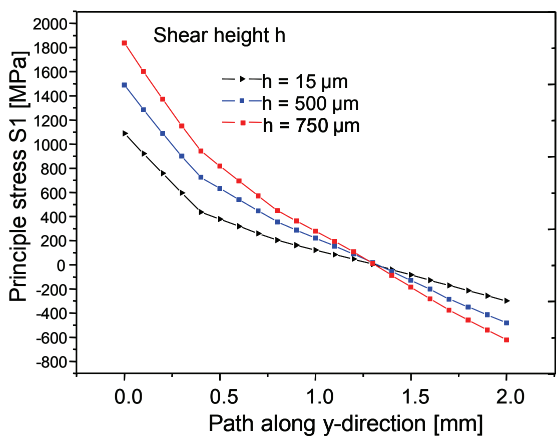

Figure 4: Shear height influence simulated.
At 0 position the stress is tensile (crack facilitating), at 2mm the stress is maximum and compressive

3. Results

Selection of material combinations performing simple shear tests offers a quick method to find the most promising combinations. Not all epoxy moulding compounds behave in the same way especially after ageing. It will be shown that even combinations with adhesion promoters sometimes do not improve the adhesion. A not negligible factor seems to be the wettability of the metal surface by the moulding compound.

In Figure 5 the decrease of adhesion is shown for the CEL moulding compound. Performing HTS tests at 250°C a complete loss of adhesion is expected after 250h.

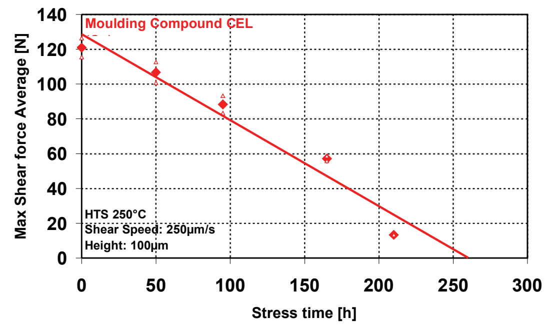

Figure 5: Ageing at 250°C (HTS).
A CEL moulding compound button shows a reduction of adhesion after high temperature storage at 250°C. After 250h a complete loss of adhesion is expected.

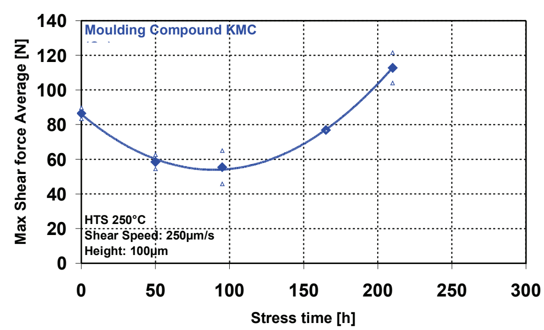

Figure 6: Adhesion of KMC moulding compound.
A KMC moulding compound button shows a different behaviour. After decreasing shear values up to 100h of temperature storage at 250°C the next 100 h a recovering with increasing shear values is observed.

The KMC moulding compound shows a different behaviour. After decreasing shear values up to 100h of temperature storage at 250°C the next 100 h a recovering with increasing shear values is observed (Figure 6). Degradation of adhesion after different stress tests (high temperature storage HTS, thermal shock TS, autoclave AC) has been studied. Moisture has been the major factor for delamination. In Figure 7 samples have been prepared for different moulding compounds (A..F) and different substrates Cu, Cu with adhesion promoter and Ni. Before the shear test, all the samples were conditioned in an autoclave (121°C, 2 bar 100%rH) for 24h. The expectations that samples with low moisture up-take and adhesion promoter should perform best can not be confirmed. Ni shows the weakest adhesion with all investigated moulding compounds (25 cN – 43 cN). For each test 8 samples have been sheared. Looking at moulding compound C all 3 investigated surfaces are shown. Ni is the worst (30 cN), Cu with adhesion promoter has 70cN but pure copper is unexpected the best with 113cN. Moulding compound B shows a better performance on copper (102 cN) but copper with adhesion promoter has only 30 cN. Sample A performs as expected , Cu has 59 cN and Cu with adhesion promoter has 73 cN.

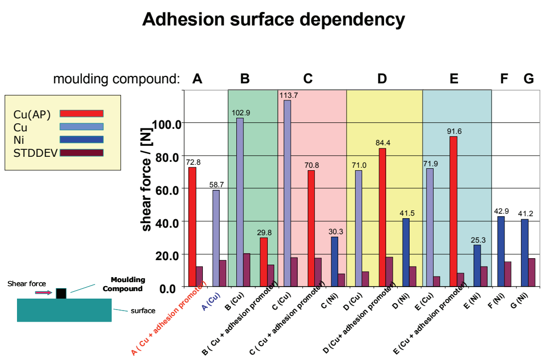

Figure 7: Material combinations.
Substrate variation Cu, Cu with adhesion promoter and Ni. Moulding compound are A..G. Pre-stress was autoclave AC (121 °C, 2 bar, 100 %rH) for 24h.

Up to now highly accelerated stress tests have been performed to show degradation within an acceptable time frame. Nevertheless, we have to show that reducing the HTS temperature from 250°C to 175°C the degradation of moulding compounds exhibit the same failure image even if we have to wait longer. In Figure 8 a fluorescence image of a cross section of a moulded plate is presented. It is assumed that oxygen is diffusing from outside into the moulding compound changing the emission of light. The front propagates quickly and in Figure 9 the first 24 h can be fitted with a Fick's diffusion law. Continuing the ageing at 175°C a second front is growing but much slower. Here it is called reaction zone and can be fitted using a linear function in the same Fick's plot.

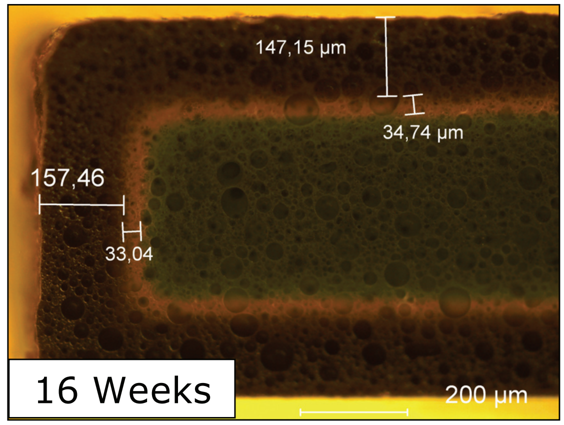

Figure 8: Fluorescence image after HTS at 175°C.
The cross section of CEL moulding compound plate shows 3 different coloured areas.

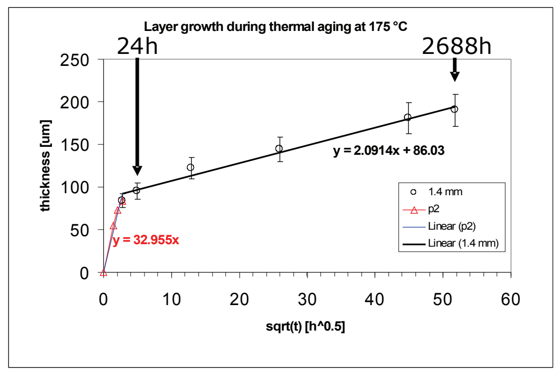

Figure 9: Growth of oxidation and reaction area.
HTS 175°C up to 16 weeks (2688h).

Looking at the moulded buttons cross sections were performed after ageing at 250°C. No oxidation zone is found, but a reaction zone is well visible. The propagation follows a Fick's law shown in Figure 10.

In order to prove the influence of oxygen, same samples were aged at 250°C in a vacuum oven. A cross section, Figure 11, is shown after 50h of ageing at 250°C. No track of any front is visible. The moulding compound looks the same as the not aged one. Up to now it is not understood that doing HTS tests in vacuum adhesion of copper and moulding compound completely disappears and the moulding button just fall off.

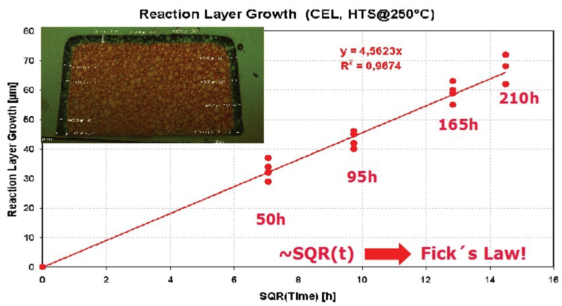

Figure 10: Growth of Reaction layer versus time. At 250°C the reaction front follows a Fick's law.

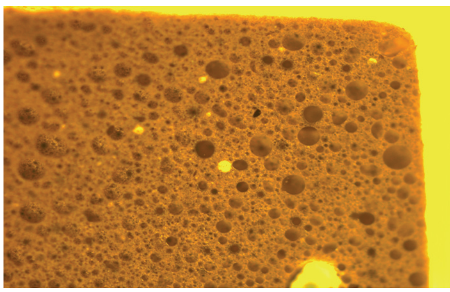

Figure 11: Fluorescence image after 50h of 250°C. In vacuum no degradation (oxidation) is detectable.

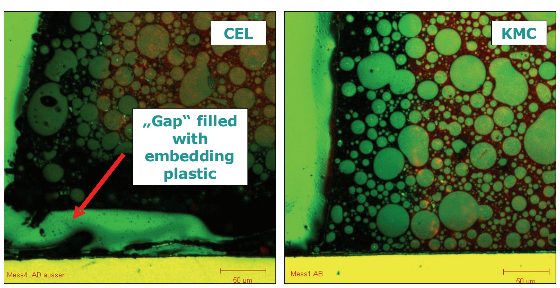

Figure 12: Comparison of moulding compound. Fluorescence image after 210h at 250°C. CEL has built a gap (propagated crack) to the Cu lead-frame. KMC apart from that the oxidation has moved along the lead-frame interface no crack is visible.

This is different to high temperature storage in air. CEL has built a gap (propagated crack) to the Cu lead-frame. For KMC the oxidation has moved along the lead-frame interface but no crack is visible (Figure 12).

Considering the fact that adhesion should be as high as possible at 0h and showing little degradation under thermal stress, delamination as shown in Figure 13 for a P-DSO 36 heat slug package can possibly be avoided.

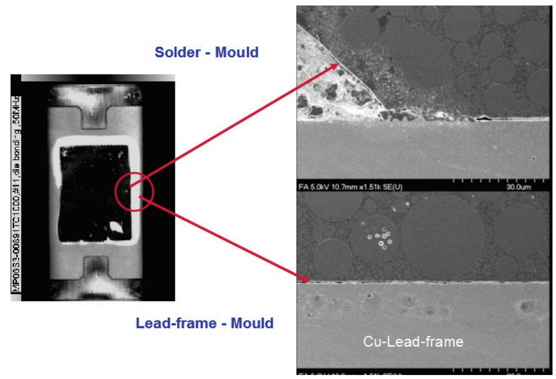

Figure 13: Delamination of moulding compound (acoustic microscopy).
A P-DSO 36 heat slug package shows delamination after 200 cycles (-55°C – 150°C) thermal shocks at the lead-frame and at the die attach solder

The objective to avoid delamination of moulding compounds (Figure 13) can be met by selecting the best combination of moulding compound and lead-frames considering the highest adhesion. Measurements based on button shear tests facilitates the decision if adhesion promoters are necessary and if they improve the adhesion. Simulation must be enabled such that a prediction of lifetime will be possible based on the known adhesion. A approach using cohesive zone elements looks very promising.

4. Conclusions

Understanding the adhesion of moulding compounds will allow developers to select material combinations such that delamination will not be a dominant failure under use conditions. Understanding the degradation of adhesion will allow more precise lifetime estimations. Green moulding compounds offer the possibility to support temperatures of 200°C and beyond for some hours. In the future it will be possible to make ageing of moulding compounds observable. Spectroscopic results (infra red IR and fluorescence) also in combination, can easily be used to predict the health status of the moulding compound. So delamination and a reduction of lifetime can be avoided.