Process and Chemical Reliability Requirements in Matching Reinforcement Materials with Solder Paste Flux Residue

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ABSTRACT

No-clean solder paste is generally preferred for the assembly of Mobile, Automotive and Consumer electronics. Increased reliability requirements for these electronics means manufacturers must use materials capable of withstanding in-use conditions and meeting these requirements. Handheld portable electronics are susceptible to being dropped and must be protected against the effects of mechanical shock. Automotive electronics require protection against vibrational and thermal effects that affect reliability. Underfill and Edgebond can be used to reduce the impact of mechanical and thermal stress on reliability. Traditionally, the focus of materials suppliers has been on reporting certain material properties of their Underfills and Edgebonds. Properties of these materials in a fully cured state, such as glass transition temperature (Tg), modulus of elasticity (E), coefficient of thermal expansion (CTE) and adhesion, are commonly reported and are used by customers to determine the suitability of a particular material for their assembly process based on reliability requirements. These material properties are very important to consider, but there are other factors that deserve our consideration as well. One such very important factor we cannot ignore, is the effect of interactions between Underfill and Edgebond materials and no-clean solder paste flux residue present on the assembly after reflow. How compatible the Underfill and Edgebond chemistries are with any flux residues present on the circuit board will ultimately determine how much of an effect these materials will have on the reliability of the final assembly.

This paper presents the methodology for evaluation of Underfills and Edgebond materials in combination with no-clean solder paste. Several crucial criteria were identified to determine compatibility of the materials: effect of solder paste flux residue on the curing of the Underfill and Edgebond materials, as well as adhesion of the materials not only on solder mask but also on surfaces covered by solder paste flux residue. The presence of Underfill and Edgebond materials in combination with flux residues increases the chemical complexity present on the board and the potential for electrochemical reliability issues. Surface Insulation Resistance (SIR) reliability of several combinations of Underfill and Edgebond with no-clean flux residues was measured assessed as per J-STD-004A (TM-650-2.6.3.3), J-STD-004B (TM-650-2.6.3.7) and ECM (TM-650-2.6.14.1).

The evaluation results showed that tested no-clean solder paste flux residue does not affect curing performance of tested Underfill and Edgebond materials. Some variation in materials adhesion strength was observed on different surfaces. For tested materials, no degradation in electrochemical reliability was observed for single materials versus combination of the materials (solder paste and Underfill and Edgebond). Recommendations for compatibility evaluation for solder pastes and Underfill and Edgebond materials were developed.

Key words: Underfill, Edgebond, Solder Paste, Reinforcement, No-Clean, Process, Chemical Reliability

INTRODUCTION

Underfill and Edgebond are engineered polymers used to reinforce assembled packages on printed circuit boards not robust enough to meet increasing thermal fatigue resistance and drop shock requirements. Handheld portable electronics are susceptible to being dropped and must be protected against the effects of mechanical shock. Automotive electronics require protection against vibrational and thermal effects that affect reliability. The glass transition temperature (Tg), Modulus, and CTE have long been the main material attributes considered in the selection process for such materials. Recently however, the impact of no-clean solder paste flux residues, which remain on the printed circuit board after the reflow process, on the performance of these materials, has come into focus.

A project was initiated to provide better understanding of the effect of this complexity on Surface Insulation Resistance (SIR) reliability of several combinations of Underfill and Edgebond with no-clean flux residues. SIR was measured as per J-STD-004A (TM-650-2.6.3.3), J-STD-004B (TM-650-2.6.3.7) and ECM (TM-650-2.6.14.1). Adhesion of the materials not only to solder mask but also to surfaces covered by solder paste flux residue were investigated. Differential Scanning Calorimeter (DSC) measurements were also conducted, to determine if the curing of the Underfill/Edgebond materials was affected by the presence of no-clean flux residue.

The results will be reviewed and discussed in detail in this article.

EXPERIMENTAL PROCEDURE

As a part of a larger project, compatibility of the Underfill and Edgebond material with three leading solder pastes were evaluated. DSC measurements were used to determine curing parameters and characteristics of the polymer materials alone, and in combination with solder pastes.

In the DSC study, Underfill and Edgebond materials were cured isothermally. A small amount of underfill material, 15ug, was heated from 40°C to 210°C with a heating rate of 10°C/min. For combination testing, 50µg of solder paste was reflowed in DSC from 40°C to 245°C at 10°C/min heating rate. After the solder paste cooled, 15 µg of underfill or Edgebond material was added to the Al pan with reflowed paste. The Underfill or Edgebond materials were then cured isothermally in the presence of reflowed solder paste flux residue, from 40°C to 210°C with a heating rate of 10°C/min.

Underfill and/or Edgebond materials are typically two-part pre-mixed and frozen epoxy systems which may contain inorganic filler particles to modify the physical properties of the material.[1] They are usually thermosetting, which means curing of the material is induced by heat. As heat is applied, the Underfill/Edgebond, which is a viscous liquid at room temperature, congeals into a rubbery gel as the curing reactions proceeds at higher temperatures. The Onset temperature in the DSC curve (Fig. 1) indicates the start of the reaction/cure. As curing advances, the rubbery gel transforms into a glassy solid at vitrification. The highest cure rate occurs at the Peak Temperature indicated on the DSC curve.

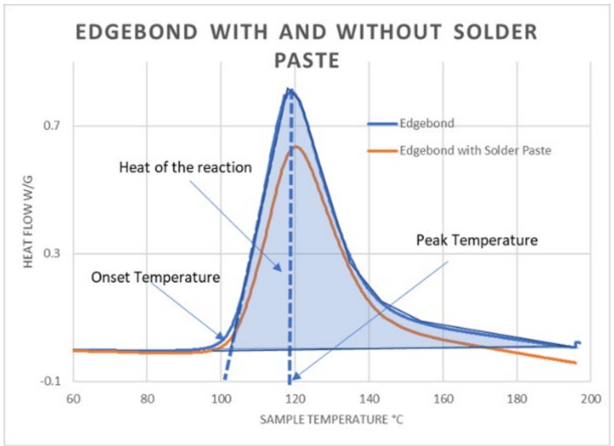


Figure 1. DSC Curve of the Edgebond with and without solder paste.

Another measure of the cure compatibility was adhesion of the Underfill or Edgebond on the various substrates and the flux residue. IPC - TM-650 2.4.42 Torsional Strength of Chip Adhesives was used to evaluate adhesion strength [2].

A very simple test vehicle was developed for evaluating adhesion strength (**Figure 2**). The board consists of three distinct sections: a bare copper section, a solder mask section, and an exposed laminate section. Solder paste was printed on mask and laminate, then reflowed. Solder paste coalesced into ball leaving flux residue for adhesion evaluation. This mimics the actual reflow process and potential solder paste residue left behind.

As per IPC - TM-650 2.4.42 method, small dots of adhesive were deposited in the three different sections of the test board and 1206 resistors placed onto the adhesive dots (**Figure 3**). The Underfill or Edgebond material was then cured as per manufacturer recommendation. Assemblies were staged for 24 hours prior to shear testing. The maximum shear force required to shear the 1206 resistors in the different sections of the board was measured and recorded

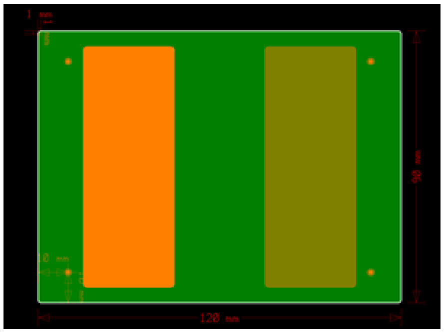
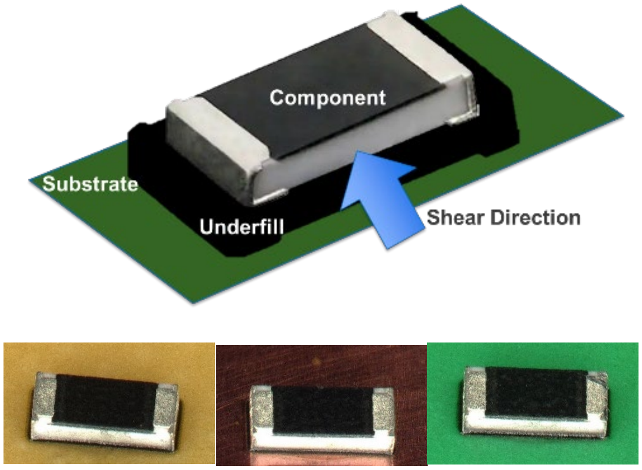


Figure 2. Board for adhesion test

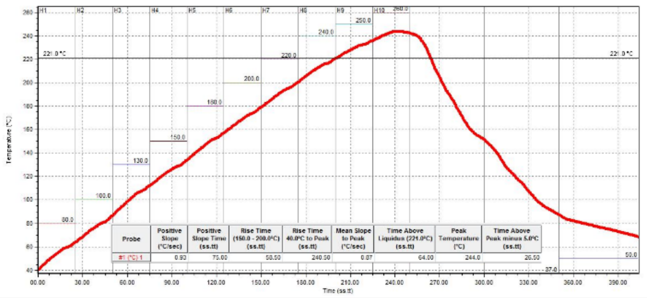


Laminate Bare Copper Solder mask.

Figure 3. Adhesion test sample assembly schematics and actual component placed on different substrates.

Very important requirements for any solder assembly are electrochemical reliability. Depending on the customer or application, requirements for the materials or combination of the materials were essential to be tested as per J-STD-004A (TM-650-2.6.3.3), J-STD-004B (TM-650-2.6.3.7) and IPC ECM (TM-650-2.6.14.1).

To evaluate the electrochemical compatibility of the polymer materials and solder paste flux residue, standard IPC SIR coupons were used. Solder paste was first printed on the comb patterns using a 6mil stencil and then the coupon was reflowed in air (profile is shown in **Figure 4).**



Probe	Positive Slope (°C/sec)	Positive Slope Time (ss.tt)	Rise Time (150.0 - 200.0°C) (ss.tt)	Rise Time 40.0°C to Peak (ss.tt)	Mean Slope to Peak (°C/sec)	Time Above Liquidus (221.0°C) (ss.tt)	Peak Temperature (°C)	Time Above Peak minus 5.0°C (ss.tt)
#1 (°C) 1	0.93	75.00	58.50	240.50	0.87	64.00	244.0	26.50

Figure 4. Reflow profile for SIR and ECM coupons

Underfill or Edgebond materials were then printed on top of the comb patterns with a 6 mil stencil allowing complete coverage of the combs (**Figure 5**). Coupons were cured in convection oven as per recommended procedure.

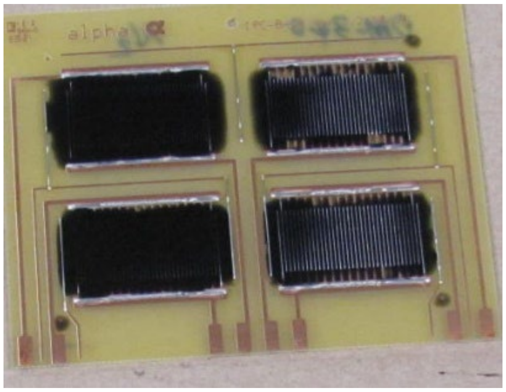


Figure 5. IPC B-24 coupon with solder paste and underfill material covering combs.

RESULTS AND DISCUSSION

1. DSC Results:

Multiple combination of Alpha and competitors Underfill and Edgebond materials were tested. The DSC curve shown in **Figure 6** for one of the Edgebond material along with three different solder pastes shows no shift in curing reaction start (onset temperature) or in peak temperature (temperature at which curing rate is highest). In all cases when Edgebond material was evaluated, no change in onset temperature or peak temperature were observed. **Table 1** shows example for two of the materials.

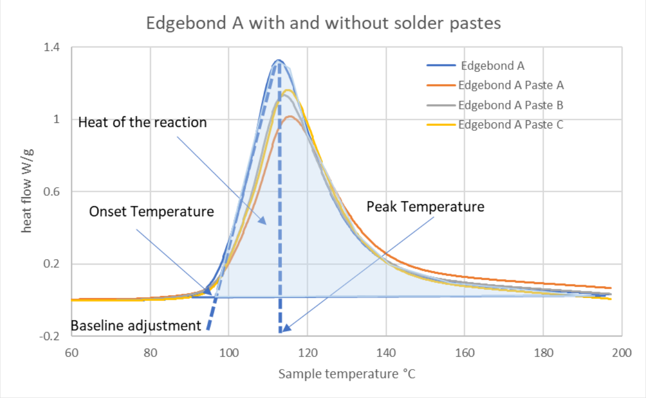


Figure 6. DSC curved for Edgebond material along and with three different solder pastes

Table 1. Onset and peak temperature for Edgebond materials with and without solder pastes.

	Onset T, C	Peak T, C
Edgebond A	96	113
Edgebond A + Paste A	96	115
Edgebond A + Paste B	96	114
Edgebond A + Paste C	96	115
Edgebond B	103	119
Edgebond B + Paste A	104	120
Edgebond B + Paste B	103	121
Edgebond B + Paste C	104	120

Somewhat different situation was observed with Underfill materials. In some cases, no interaction or change in DSC curves were observed between underfill material alone and with solder pastes. In some cases, however, onset temperature had a slight shift but always towards lower temperatures. This indicates that curing starts earlier. In the case of peak temperatures, sometimes there was no effect, but in some instances, there was a shift to slightly lower or slightly higher temperatures. This type of compatibility and underfill/flux residue interaction is very important to know and understand in order to recommend suitable processing and curing parameters for specific underfill/solder paste combinations. A shift of the onset and/or peak temperatures to higher temperatures when underfill and solder paste flux residue are tested in combination could have disastrous implications for ultimate board level reliability, in actual applications. The curing temperatures and times recommended by most material suppliers are based on DSC curves of the underfill or Edgebond material alone, not in combination with solder paste residue. If the suppliers curing recommendations are followed during the board assembly process but the underfill/flux residue interaction then results in a shift in the curing temperatures to higher temperatures, depending on how large the shift is, it could result in a situation where the underfill material is not being fully cured. To ensure the desired properties of the fully cured Underfill or Edgebond are achieved, resulting in the reinforcement required to meet reliability requirements, we need to be sure no-clean flux residues present on the board do not adversely affect the curing process of Underfills and Edgebond material.

Understanding how different build materials interact with each other and ultimately affect assembly level reliability is critical in selecting and recommending the appropriate solder paste and underfill materials.

Table 2. Onset and peak temperature for Underfill materials with and without solder pastes

	Onset T, C	Peak T, C
Underfill A	115	148
Underfill A + Paste A	111	144
Underfill A + Paste B	111	144
Underfill A + Paste C	112	144
Underfill B	151	161
Underfill B + Paste A	142	169
Underfill B + Paste B	148	167
Underfill B + Paste C	149	166
Underfill C	99	149
Underfill C + Paste A	79	155
Underfill C + Paste B	94	151
Underfill C + Paste C	96	150

2. Adhesion Test Results:

For each Edgebond and Underfill in this study, an adhesion map was created. Material was not only cured at one recommended time and temperature, but at longer and shorter times at specified temperature.

Figure 7 shows the adhesion map for one of the Edgebond materials. It shows the adhesion strength on laminate when material was cured at 150C for 5, 7 and 10 minutes. Because a known geometry was used (1206 component), it is easy to convert kg force measurements into MPa or psi if needed. **Table 3** shows shear force for Edgebond A cured at 130C for various periods of time.

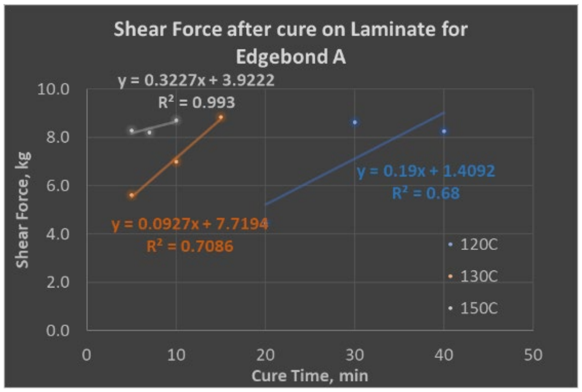


Figure 7. Adhesion map for Edgebond A

Table 3. Adhesion strength of Edgebond A cured at 130C for different times.

Cure temp.	Time, min	kg	MPa	psi
130C	5	5.6	11	1559
	10	7.0	13	1944
	15	8.8	17	2455

Various board designs are used for different size/pitch BGA packages. In some case the pad design on the circuit board will be solder mask defined and in other cases non-solder mask defined. It means that Underfill or Edgebond material should be able to adhere to laminate, solder mask, and exposed copper. In many instances, these surfaces would be covered to some degree by solder paste flux residue, and in the case of Underfills, it is critical that there is adequate adhesion to any flux residues present. **Figure 9** shows the adhesion of Edgebond on various substrates. This material adheres well on all the substrates. While Underfill C (**Figure 10**) adheres very well to FR4 but not as well to some of the specific flux residues. During selection of the underfill material, it is critical to know specific board design and solder paste chemistry.

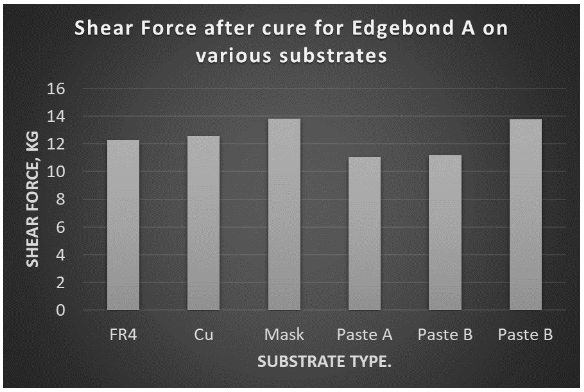


Figure 9. Adhesion strength for Edgebond A on various substrates

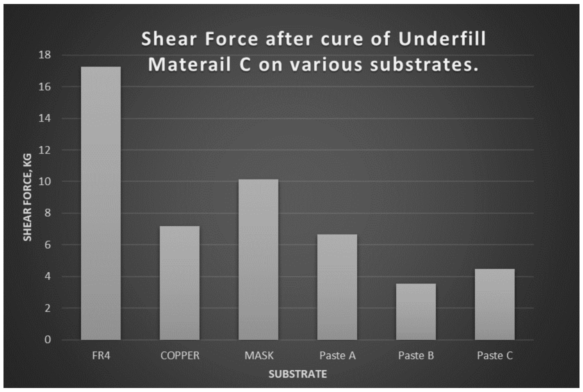


Figure 10. Adhesion strength for Underfill C on various substrates

Table 4: Results of the SIR testing of Underfill and Edgebonds by themselves and in combination with solder paste flux residue.

Edgebond /Underfill	Paste	IPC-004A	IPC-004B	ECM
Edgebond A	Paste A	Pass	Pass	Pass
	Paste B	**FAILED**	Pass	Pass
	Paste C	Pass	Pass	Pass
	na	Pass	Pass	Pass
Edgebond B	Paste A	Pass	Pass	Pass
	Paste B	Pass	Pass	Pass
	Paste C	Pass	Pass	Pass
	na	Pass	Pass	Pass
Underfill A	Paste A	Pass	Pass	Pass
	Paste B	**FAILED**	Pass	Pass
	na	Pass	Pass	Pass
Underfill B	Paste B	**FAILED**	Pass	Pass
	Paste C	**FAILED**	Pass	Pass
	na	Pass	Pass	Pass
Underfill C (competitor)	Paste A	**FAILED**		
	Paste B	**FAILED**		
	Paste C	**FAILED**		
	na	Pass		
Underfill D (competitor)	Paste A	**FAILED**		
	Paste B	**FAILED**		
	Paste C	Pass		
	na	Pass		

3. SIR Test Results

The effectiveness and reliability of underfill and Edgebond material in the presence of reflowed flux residue on a PWB will differ depending on the chemical nature of the residue and polymers used. Residual ionic residues in no-clean fluxes (from acid and base activators) generally have very low mobility in the solid resins contained in the flux, thus resulting in high insulation resistances. Surface insulation resistance (SIR) is usually somewhat less than bulk insulation resistance due to the incomplete encapsulation of the ionic species at or near the surface. These can be even further reduced by the presence of moisture and potential reaction between solder paste residue and polymer (underfill or Edgebond) materials. All SIR coupons were prepared either with soler paste only, with underfill/Edgebond only or in combination. It was observed that when material along or with solder paste were tested at IPC 004B condition (40ºC/90%RH) all materials and combinations did pass the test. When IPC-004A condition (85ºC/85%RH) was used, materials by itself did pass the test requirements, while some combinations with specific solder pastes did not meet requirements. Interestingly, during IPC ECM testing all samples met requirements. **Table 4** shows results for some of the tested materials.

IPC ECM testing is done at 65ºC/88%RH but test duration is 500 hours while all IPC SIR 004A and 004B test were only 168 hours. It could be assumed that the higher test temperature (85ºC) is a critical factor in moisture ingress and softening of the polymer material. Note that all the pastes tested in this study pass all mentioned tests by itself but in some cases failed with underfill materials.

Figure 11 shows the variation in surface insulation resistance of the Edgebond along and with two different solder pastes. It could be observed that SIR values vary depending on the solder paste used. It is important to understand compatibility of the Underfill and Edgebond with solder paste for long term electrochemical reliability.

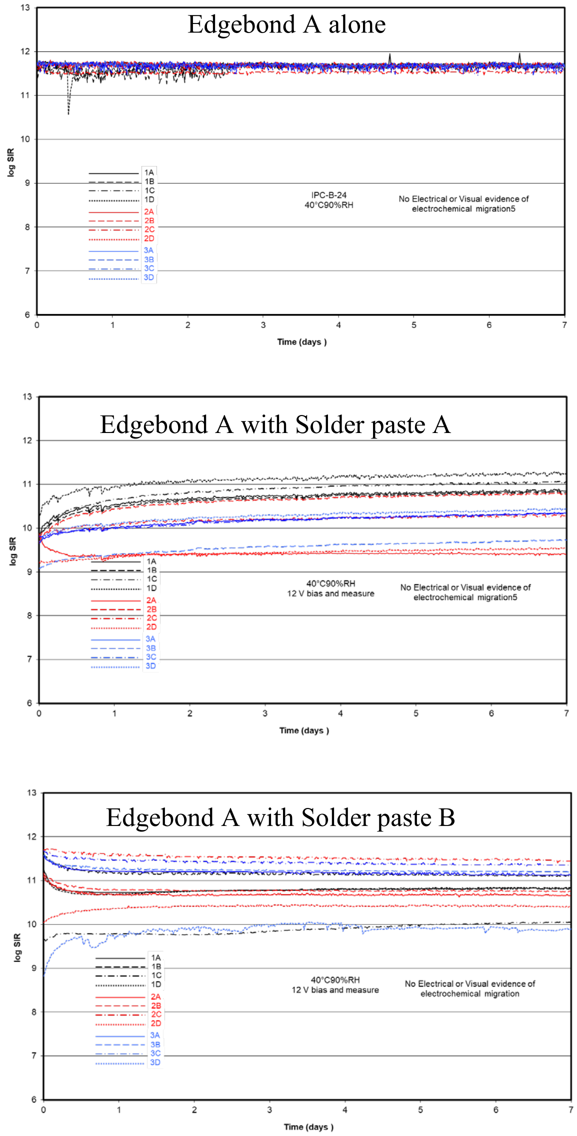


Figure 11. SIR curved showing variation in surface insulation resistance of the Edgebond along and with two different solder pastes

SUMMARY and CONCLUSION.

Compatibility of the Edgebond and Underfill materials with no-clean solder paste residue is a critical attribute of the combination in order to achieve essential mechanical and electrochemical reliability. There are several ongoing studies to develop better understanding and comprehensive selection guide for reinforcement material for specific board design and chosen solder paste.

FUTURE WORKS

Thermal Cycling (TC) and Drop Shock test are still ongoing. Final data expected to be available for analysis and presentation end-2022.

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REFERENCES

[1] IPC J-STD-030A, Feb 2014
[2] IPC-TM-650 2.4.42