Evaluating Reliability Enhancement of Polymer Reinforcement and Solder Alloy Combined Material Sets on Board Level Assemblies

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ABSTRACT

The utilization of larger Ball Grid Arrays (BGAs), ceramic packages, or Wafer-Level Chip Scale Packages (WLCSP) to increase device functionality requires enhanced reliability in harsh operating environments such as automotive printed circuit board assembly (PCBA). The process of selecting and evaluating polymer reinforcement materials such as underfills and edgebonds has become more demanding and challenging in recent years due to advanced device processing requirements. This complexity arises from a combination of factors including tightening product design requirements, the introduction of novel package materials and technologies, and the adoption of new, innovative semiconductor package designs to meet these processing demands. Each advancement in package technology requires a re-evaluation of the reinforcement material selection process. In order to meet the stringent reliability specifications for thermomechanical, vibration, and drop shock performance of advanced devices, the use of high reliability solders and polymer reinforcement materials such as Edgebond and underfill are becoming more common.

Two primary strategies for reinforcement are: the use of capillary underfill to completely fill any gaps or areas under the device or employing no-flow reinforcement (Edgebond) material to secure only the edges of the device. The choice between these strategies must account for application reliability requirements, device construction, and process throughput.

This paper presents a comprehensive study focusing on new high-performance underfills and Edgebond materials aimed at improving the reliability of various commonly adopted BGAs. The evaluation encompasses observations from various BGAs that exhibit different warpage signatures, pitch and sizes to assess their thermomechanical performance post-reinforcement with either Edgebond or underfill materials. Additionally, drop shock testing is conducted on the assemblies in their as assembled conditions and subsequently after reinforcement with underfill and Edgebond materials.

The findings of this study will shed light on the efficacy of different reinforcement strategies in enhancing the reliability of BGAs under diverse environmental stresses. By providing insights into the performance of new high-performance materials, this research aims to contribute to the advancement of robust electronic packaging solutions, vital for applications demanding high reliability in harsh conditions.

Key words: BLR (Board level Reliability), Reinforcement, Underfill and Edgebond, BGA, Drop Shock, Thermocycling.

INTRODUCTION

Reliability is defined as: "...the probability that an item operating under stated conditions will survive for a stated period of time" [1]. The design for reliability of electronic systems and assemblies need to cover all aspects ranging from electrochemical reliability to the solder joint mechanical and thermomechanical reliability. Any improvements should be oriented towards overall system reliability improvements and not just focusing on one specific aspect. Advanced packages with higher IO counts, multiple dies, and various die-to-body ratios typically have higher or variable stresses. Advanced electronic packages, which often feature higher input/output (IO) counts, multiple dies, and varied die-to-body ratios, are subjected to increased or variable stresses. These complexities necessitate effective solutions to mitigate stress on fragile packages. Polymer reinforcement, typically an epoxy-based adhesive, serves as a crucial method to enhance the reliability of these assemblies by filling gaps between ball grid arrays (BGAs) or wrapping around packages to strengthen the packaging system.

Polymer reinforcement is a great way to improve mechanical strength but also could influence electrochemical reliability and selection of the reinforcement material is critical to improve thermomechanical reliability [2]. There are very clear and well-established protocols for solder paste processing for electrochemical reliability assessment but there is no industry standard or recommendation to evaluate combined material sets with polymer reinforcement materials. Previously reported data [3] shows a new and innovative method was developed for integrated solution sample preparation materials interaction and correlation of test methodology and field performance. During Surface Insulation Resistance (SIR) testing at elevated temperatures and humidity, moisture can penetrate through semipermeable polymer materials. Various factors, including the formulation of the reinforcement material, cure parameters, compatibility with flux residue, residual amines in epoxy, and unreacted bonds, can influence SIR performance and potentially lead to failures. Despite these challenges, there are solder paste and polymer reinforcement materials which meet industry standards for electrochemical reliability using advanced test methodology.

There is significant industry evidence available showing mechanical improvement when reinforcement materials are used [4]. Understanding of Underfill and Edgebond behavior, properties and composition, its influence onto the reliability improvement of advanced packages and system is critical to meet reliability specification. Reliability requirements are continually evolving and becoming more sophisticated at using accelerated failure methods to predict product lifespan. End users in markets such as automotive advanced safety, powertrain, defense, and aerospace applications demand enhanced product assurance in challenging working environments and expanding lifespan requirements of the finished device.

RESULTS AND DISCUSSION

The objective of this study was to evaluate and assess compatibility of leading solder paste with various reinforcement materials such as underfills (UF) and Edgebonds (EB) which are commonly used to improve Board Level Reliability (BLR).

Mechanical Reliability: Vibrational Study.

The second most common cause of failure in electronics is Vibrations. There are different types of vibration: (1) Sinusoidal - electronics mounted on a motor that operates at a constant speed., (2) Drop/impact - cell phone falling on a floor and (3) Random vibrations - electronics mounted on a car or airplane. Multiple industry accepted standards are used to evaluate assembly or system performance and influence of vibration on reliability: MIL-STD-810G (Method 513). MIL-STD-202 (Methods 201-204), ETS 300 019-2-0, For electronic components JESD22-B103B and for Automotive Electronics ISO 16750-3.

Developed test vehicle (**Figure 1**) was thin 4.7" square boards with 1oz copper traces. All copper pads were solder mask defined (SMD). Using SMD pads allows us to accelerate failure while retaining solder-joint scale geometry. Previous study [5] details test vehicle development, component selection and vibrational test specifics. Most vibration testing are done on an electrodynamic shaker, but for this experiment, a repetitive shock (RS) chamber was used. The amplitude of vibration was controlled but no specific frequency profile could be achieved. The mechanical properties of lead-free solder are highly strain-rate dependent and different stress transport mechanisms dominate at low and high strain rates, shifting the solder failure mode from ductile to brittle. RS chambers induce a wide range of frequencies, which translates to a wide range of strain rates. Two different amplitude modes were used in this study (a) scaling amplitude and (b) constant amplitude. Vibrational profiles have 5 min vibration and 2 min pause (for measurements). Scaling profile has increase from 20Grms till 60Grms with 10Grms increase interval and Constant amplitude profile have 50Grms amplitude with the same 5 min vibration and 2 min pause for measurements. **Figure 2** shows vibrational test results for SAC305 solder alloy with two different vibrational amplitudes.

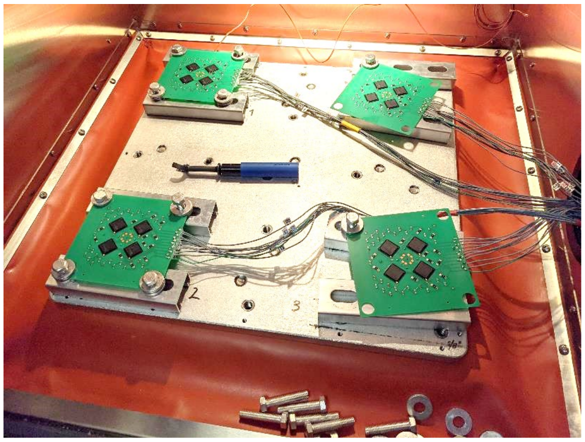
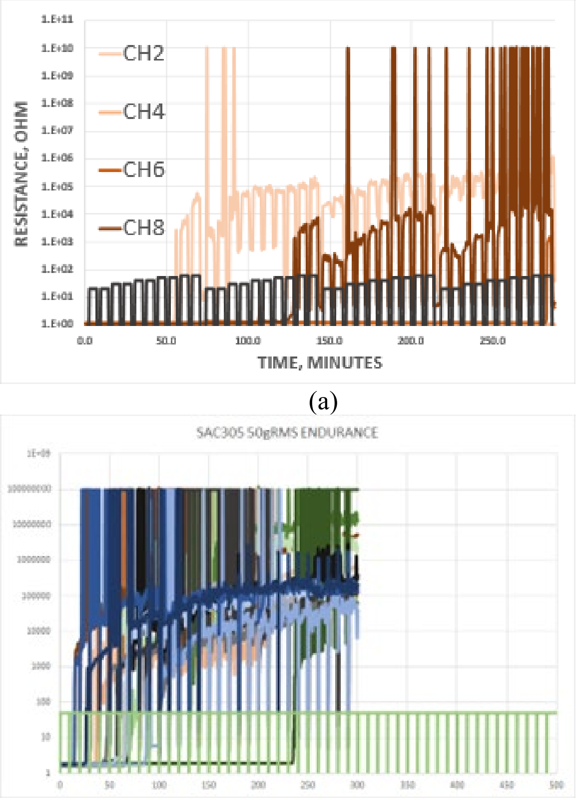


Figure 1: Boards appearance and position in the chamber.



(a)

b)

Figure 2: Amplitude ((a) scaling amplitude and (b) constant amplitude) and Resistance charts for SAC305 alloy only.

Reinforce material reduces stress applied onto solder joints and prolongs effective life of the devices.

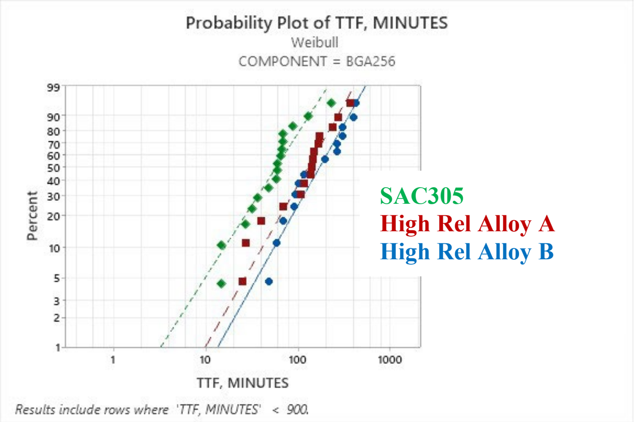
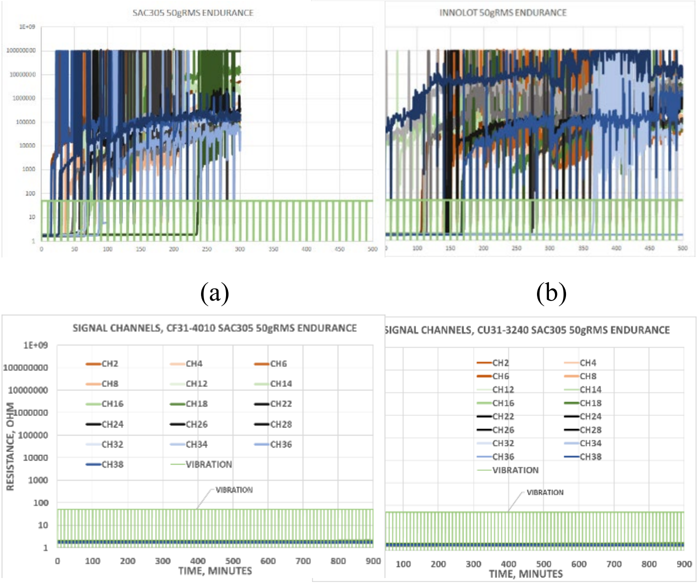


Figure 3: Weibull plots for three different alloys showing differences in reliability depending on alloy composition.



(a) (b)

(c) (d)

Figure 4: Resistance measurements for (a) SAC305 and (b) Innolot alloys without any reinforcement and (c) SAC305 assembly with Edgebond and (d) SAC305 assembly with Underfill.

Mechanical Reliability: Drop Shock Study

The drop shock testing was conducted based on JESD22-B111 standard recommendations: table height and striking surface were adjusted to obtain a half-sine shock pulse with 1500 G and 0.5 msec peak. Failure criteria: is defined as 1V lesser than the initial applied voltage (5 V) for the time duration of 0.5 msec for consecutive 4 drops. Test was terminated after more than 10,000 drops, in case of any survival components. The cumulative failures of the test were analyzed using the Weibull plots, in which the characteristic life corresponds to 63.2% of the cumulative failures. Board (**Figure 5**) and test conditions are shown in **Table 1**.

Table 1: Drop Shock test conditions.

Boards Details	Test Conditions
THK= 0.1mm	Shock 1500
Dimensions 132x77 mm	Pulse duration: 0.5msec ½ sine wave
Component: BGA84	Drop Height: 23-26 cm
Component location: 1,5,11 &15	Event detection: 0.5msec.

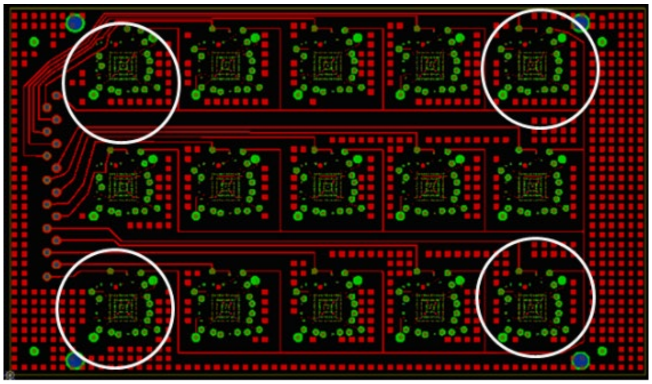
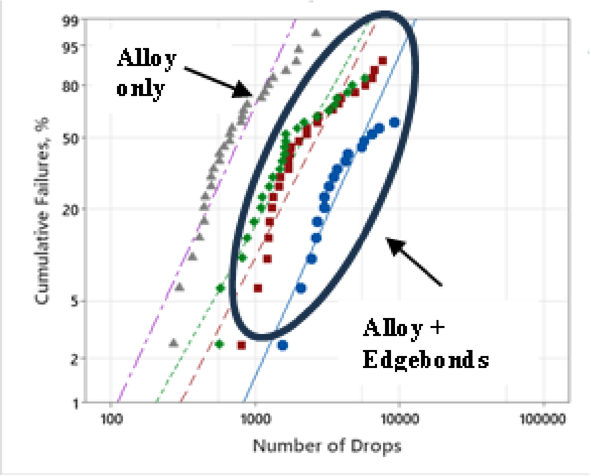
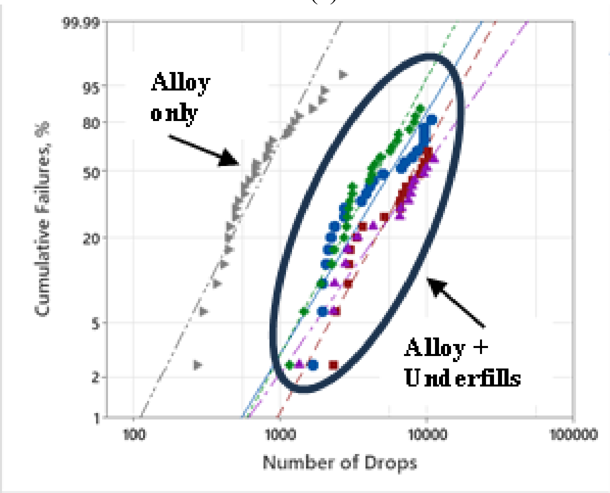


Figure 5.: Drop Shock test board and component locations.

CBGA84 was assembled with SAC305 alloy and some of the assemblies were reinforced with either Edgebond or Underfill. The drop shock test results obtained in this study and cumulative drop failures were plotted in Weibull plots. **Figure 6** shows Weibel plot for (a) SAC305 alloy by itself and with several different Edgebond materials reinforcement and (b) SAC305 alloy along and reinforced with various Underfill materials.



(a)



(b)

Figure 6: Weibull plots for (a) Edgebond and (b) Underfill reinforced assemblies,

Depending on Edgebond material mechanical properties and adhesion to the device, impact onto the reliability might be different but improvement in the characteristic life is evident. Any Edgebond materials used in this study significantly improved longevity of the system.

Four different Underfill materials were used to evaluate drop shock performance of the reinforced assembly. All those Underfills had very different Tg (glass transition temperature), CTE and Modulus, but during mechanical testing at room temperature all those materials significantly improved reliability of assemblies. In some cases, it was 10 times better characteristic life that without reinforcement.

Thermomechanical Reliability: Thermocycling Study

Test vehicle was designed to have integral copper 'loading' representative of production PCBs and component types. Copper OSP was used as a surface finish. Thickness of the PCB was 1.6mm (+/-10% tolerance). Board was designed to have 6 layers, 4 inner layers to be copper with square pattern or cross hatch to give approximately 60% copper/40% space (to approximate functional ground planes). 1 Oz copper was used in the inner layers. High Tg laminate material was used to avoid any decomposition, warpage or degradation at higher test temperatures. Assembled boards with and without reinforcement were subjected to thermocycling at -40ºC to +125ºC with 20 min dwell time. Slower transition rate was chosen because it offers the toughest challenge i.e., allows longer time for plastic deformation to occur in the solder joint. Resistance values of the I/O connections of the assemblies were monitored in-situ. Increase in resistance was indicative of solder joints failure/cracking. All assemblies were tested for up to 4000 cycles. Increase in resistance by 20% in five consecutive measurements was a failure.

Two components (details are in **Table 2**) were selected for evaluation because they had very distinct component size to die ratio. BGA228 had large die shadowing some of the IOs and BGA360 had much smaller die withing component body and not overshadowing any of the IOs (**Figure 7**). As a result of component design and materials used to fabricate, warp signature was very different.

Table 2: Thermocycling Components.

Available Components	Body size	BGA pitch	ball diameter
BGA228	12x12mm	0.5mm	0.30
BGA360	10x10mm	0.4mm	0.25

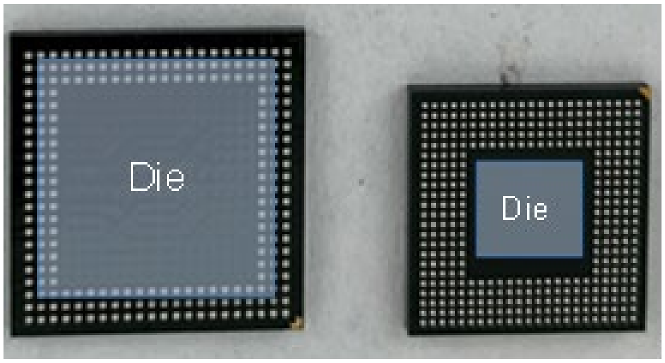
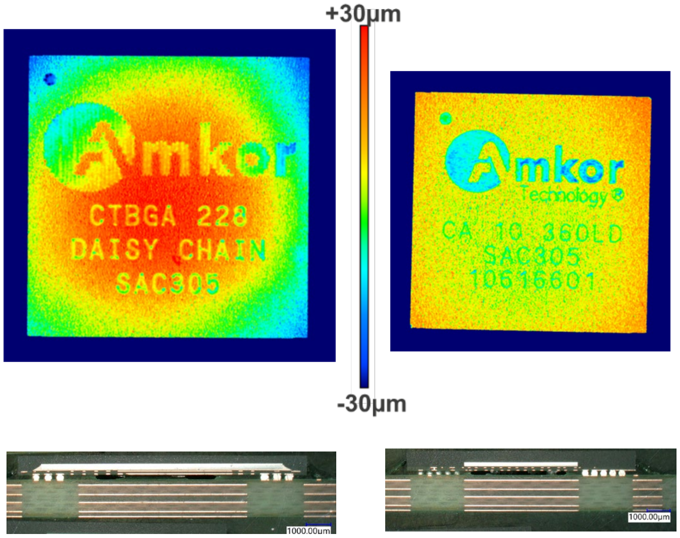


Figure 7: Image of the board and components (showing component design).

Cross section and height maps of BGA228 and BGA360 in **Figure 8**. The height /warpage is shown at +125ºC and it is clear that there is much more warpage especially at the corners of BGA228.higher stresses are applied on outer row of IOs.



(a) (b)

Figure 8: Height map at +125ºC and cross section of (a) BGA228 and (b) BGA360.

Reinforcement materials were carefully selected to avoid any generation and introduction of additional stress onto the system. Underfill and Edgebond were applied and cured at recommended conditions. Quality and uniformity of the reinforcement materials was evaluated visually and using SCAM and cross sections. Desired fillet height was from 50% or up to 100% of the substrate height. **Figure 9** shows schematics how reinforcement material was assessed and **Figure 10** shows appropriate fillet width, and it is at about 90% of component height.

The cumulative failures of in-situ thermal cycling test are plotted in Weibull curves, in which the data is censored at 4000 cycles. For better visualization, the in-situ failures are plotted into three Weibull curves (**Figure 11** and **Figure 12**). As the thermal cycling test was interrupted at 4000 cycles, not all the BGA228 reinforced with Underfill material failed while the ones without reinforcement or with Edgebond did fail. For BGA360 no significant difference in performance between Underfilled and Edgebonded assemblies were observed while assembly without reinforcement show much shorter characteristic life.

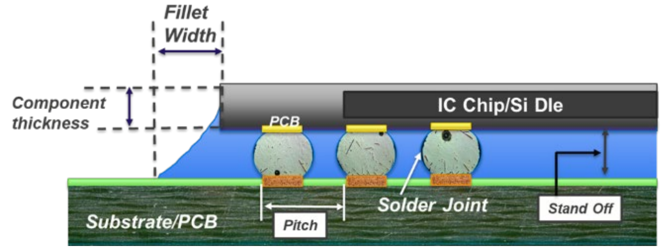


Figure 9. Schematics of underfill assessment.

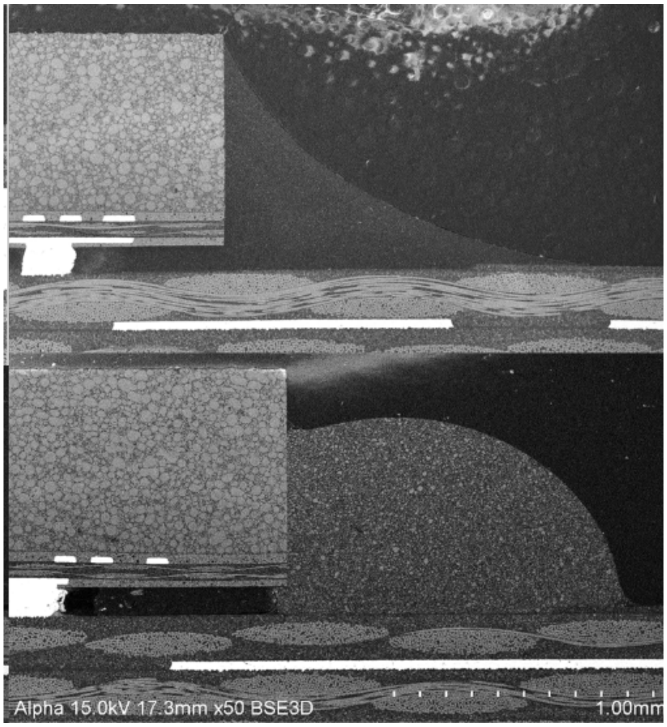


Figure 10: Images of the cross sectioned assemblies with Underfill and Edgebond assemblies.

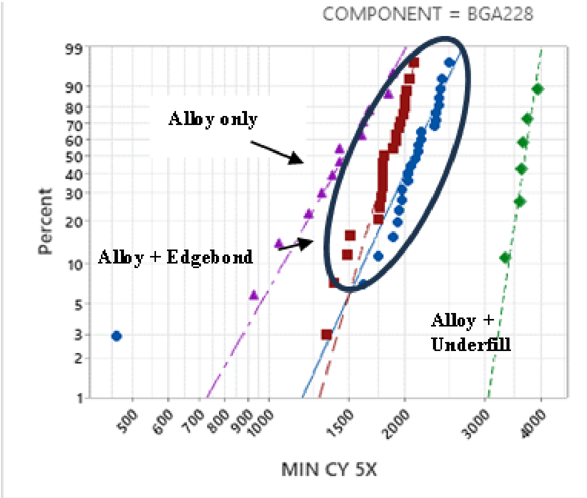


Figure 11: Weibull plot for BGA228 thermo cycled at -40ºC/+125ºC for 4000 cycles.

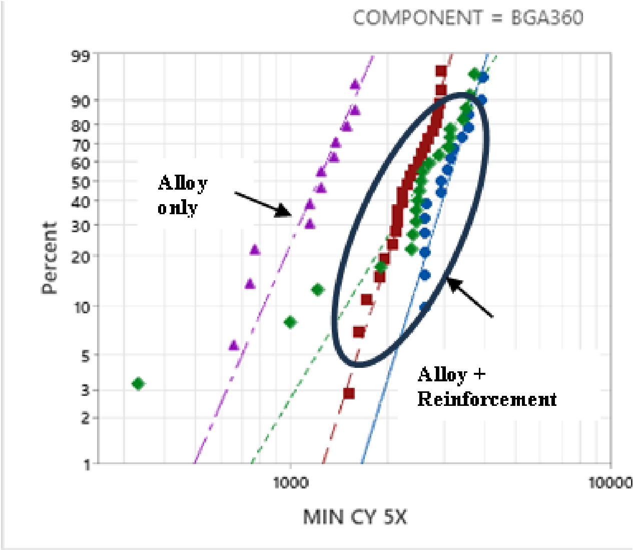


Figure 12: Weibull plot for BGA360 thermo cycled at -40ºC/+125ºC for 4000 cycles.

The thermal cycling characteristic life of SAC305 without reinforcement as expected. is much lower compared to the assemblies which were reinforced. Use of Edgebond and Underfill reinforcement on the solder joints shows an outstanding improvement in thermal cycling performance.

Failure analysis of the thermal cycled assemblies showed significant damage of the solder joints especially at the corners**. Figure 13** shows X-Ray images of the BGA228 after 4000 cycles without reinforcement (a) and with Underfill (b). The corner IOs without UF were deformed and completely crushed (**Figure 14**) while reinforced corner IOs are remain their shape. Comparing to BGA360 (**Figure 15**), this phenomenon was not observed, and this could be attributed to components construction and warpage shown in **Figure 8.**

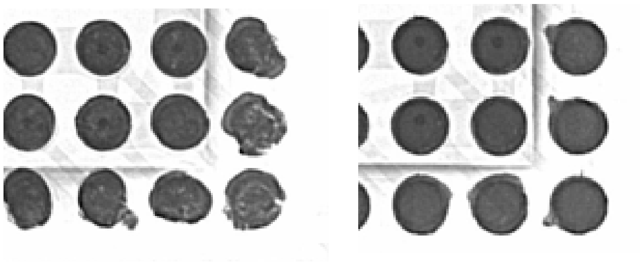

(a) (b)

Figure 13 X-Ray images of the BGA228 after 4000 cycles without reinforcement (a) and with Underfill (b).

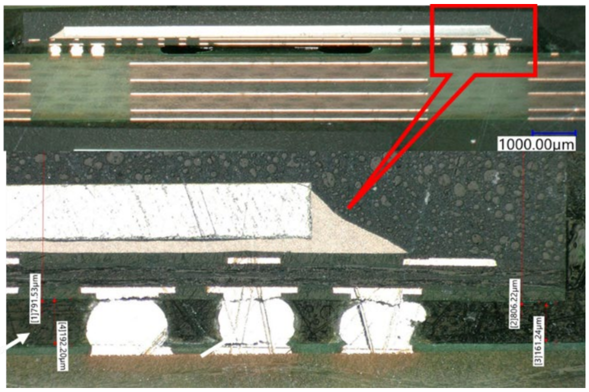


Figure 14 Optical images of the cross sectioned BGA228 without reinforcement showing ball deformation.

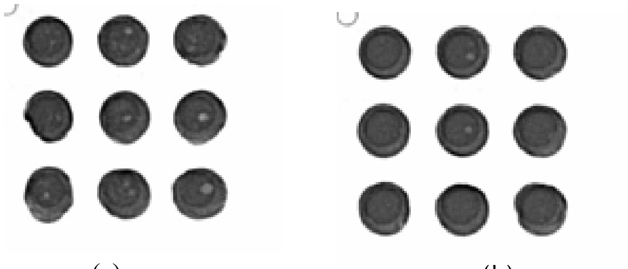

(a) (b)

Figure 15 X-Ray images of the BGA360 after 4000 cycles without reinforcement (a) and with Underfill (b).

Based on component design and warpage, Edgebond could be sufficient to achieve required reliability but in some instances, full Underfill is needed to meet requirements.

SUMMARY AND CONCLUSIONS.

All leading MacDermid Alpha Solder Paste materials and polymer reinforcement materials meet industry requirement regarding electrochemical reliability. In this study we evaluated reinforcement materials influence on mechanical and thermomechanical reliability. Increasing thermal mismatch (ceramic package, bare silicon, mold compound, etc), increasing component size (large BGA, large die, etc.), increasing stiffness of the board (number of layers) and decreasing standoff (small ball size, leadless package) result in increased stress level of the overall system. It becomes in some cases impossible to meet reliability criteria without reinforcing devices. Harsher environmental conditions, exposure to higher temperatures requires applying reinforcement materials with carefully selected mechanical properties suitable for application.

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