

## RELIABILITY ASSESSMENT OF REBALLED BGAs

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### ABSTRACT

The Printed Circuit Board (PCB) assembly domain has almost completed its transition to a lead-free environment. This shift has resulted in the obsolescence of tin-lead components. However, occasionally, on-going production or repair processes require SnPb components which are no longer available. Using a lead-free device in such cases could result in reliability concerns (due to the use of lead-free components on a SnPb PCB assembly). This issue is of particular concern with lead-free Ball Grid Array (BGA) devices due to the relatively high volume of lead-free alloy in the final solder joints. One possible solution is to manually attach lead-free components at a rework station. Due to the inherent manual nature of this process, it is time consuming and reproducibility is difficult to ensure. This process is typically prone to a relatively high defect rate. Therefore, a BGA rebalancing process was introduced as a fall back solution for a scenario in which lead-free components had to be populated on PCB assemblies that were initially manufactured through a SnPb process.

In this study, SAC305 solder bumps from lead-free components were replaced with SnPb solder bumps. A series of tests and inspections were carried out to evaluate the reliability of these rebalanced components. After the rebalancing operation, the solder bump sizes were measured and they exhibited 'good' dimensional consistency. Voiding, which has been reported as a concern in the case of rebalanced components, was assessed via X-ray inspection and was determined to be a non-issue. Ball shear testing, which was used as a solder joint-level mechanical test to evaluate the strength of the re-balanced solder joints, indicated adequate solder joint strength. Solder joint microstructure was studied via metallographic techniques. It was found that the thickness of the interfacial Intermetallic Compound (or IMC) was in the acceptable range. In addition, after assembly of the rebalanced BGA components, the packages were subjected to Environmental Stress Screening (ESS) tests, followed by in-circuit and functional tests. No failures were detected. It was therefore inferred that the re-balanced components exhibited adequate performance without any degradation and can serve as a solution for such a 'mixed' system.

Key words: Printed Circuit Board Assembly, BGA Components, Re-balling, Reliability, Mixed Alloy Assembly

### INTRODUCTION

Due to the restrictions imposed by regulations such as RoHS (Restriction of Hazardous Substances) and WEEE (Waste Electrical and Electronic Equipment), some hazardous materials are prohibited from being used in electronic products. Among the materials identified for elimination, lead is one of the key elements for electronics manufacturing and has made a dramatic impact on the manufacturing process [3]. Lead is mainly used in solder paste and components' solder joints, such as Ball Grid Array (BGA) components. For Surface Mount Technology (SMT) assembly, eutectic solder paste that consists of 63% Sn and 37% Pb was used and required to be converted to a lead-free version, which is typically composed of 96.5% Sn, 3.0% Ag, 0.5%Cu or 95.5% Sn 4.0% Ag, 0.5%Cu.

This mandated conversion to lead-free solders has led to the rapid replacement of SnPb-packages across the consumer electronics domain [4]. However, for high reliability electronics assembly, SnPb based manufacturing is still on-going. On one hand, the exemption of the European Union RoHS directive allows high reliability electronic equipment producers to comply with the directive while continuing to run current SnPb manufacturing processes until reliable lead-free processes are fully developed. On the other hand, there are still some uncertainties about the reliability of lead-free products for high reliability applications [7]. Reliability tests which have been traditionally used for SnPb assemblies may not provide a comprehensive picture vis-à-vis the reliability of lead-free assemblies, and long-term reliability is still a big concern. Consequently, some on-going production houses are continuing to run SnPb processes for high reliability applications.

From the component suppliers' perspective, in order to meet RoHS requirements and due to logistics and cost considerations, they are gradually reducing their tin-lead components in stock and some of them have stopped producing SnPb components and provide only RoHS lead-free compliant ones. When SnPb compatible components become unavailable, manufacturers have to use the lead-free version of the components within the SnPb assembly process. Lead-free components attached to a Printed Circuit Board (PCB) using tin-lead paste are known as 'backward compatible assemblies'. A significant number of industry studies have focused on developing this mixed assembly process. However,

implementation of a backward compatible process is challenging for many manufacturers.

Lead-free reflow soldering with Sn/Ag/Cu (SAC) alloys requires much higher reflow temperatures than SnPb soldering, because the melting point of the SAC alloy is about 217°C. Consequently, the peak temperature of the assembly may need to be around 240-245°C to ensure proper joint formation. However, SnPb eutectic solder liquefies at 183°C and therefore the maximum tolerance temperatures for some SnPb compatible components is only around 230-240°C. Therefore, in order to completely melt the joints of lead-free components with SnPb paste to achieve homogenous structure, elevated reflow temperatures or a longer soak time should be adopted. However, this strategy could result in damaging the Pb compatible components and PCBs. In addition, running a high temperature profile while using SnPb paste could cause other concerns such as voiding or bridging.

Along with the difficulty of directly assembling the lead-free components in the SnPb assembly system, the reliability of such mixed joints is also a concern. When SnPb and SAC are combined in a reflow process, a new alloy is created with a substantial amount of Sn, Ag, Cu and Pb. Further complicating the issues is the fact that the extent of alloying between SnPb and SAC is highly dependent upon reflow peak temperature and the Time Above Liquidus (TAL). Additionally, if the peak temperature is not high enough or the TAL is not long enough, solder joints may form two distinct microstructural regions, where one region is composed primarily of SnPb and the other region is primarily SAC. All these changes of the microstructure of the joints could have a dramatic impact on the robustness of the joint connection and make the reliability of such mixed alloy systems unpredictable.

Another option to assemble the lead-free components on to a PCB that contains a preponderance of SnPb devices is to manually attach the lead-free components at a rework station. The relatively higher temperatures can be carefully applied within a localized area on the PCB assembly while concurrently ensuring that a good solder joint was obtained. However, due to the inherent manual nature of this process, it is time consuming and reproducibility is difficult to ensure.

The third option is to perform BGA reballing, which especially takes on increased significance as Original Equipment Manufacturers (OEM) continue to populate PCBs with a large number of lead-free BGA components [5]. The reballing process consists of removing the lead-free solder balls from a BGA component and replacing them with new SnPb ones. Reballing BGA process mainly consists of the following five steps: (i) original solder ball removal; (ii) pad clean up, and removal of residual solder; (iii) solder paste/flux deposition; (iv) aligning the spheres to the pads; and (v) component reflow.

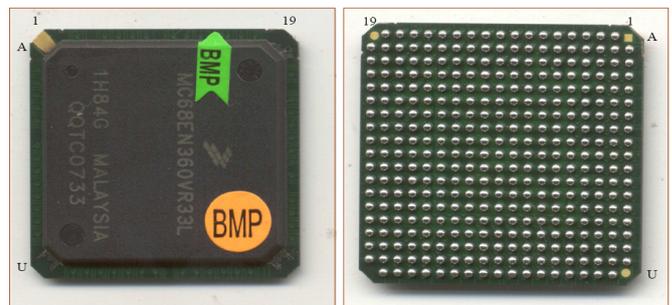
Every step of the BGA reballing sequence should be done under strict process control because of numerous and

potentially damaging (thermal or mechanical) issues involved. To the reballed BGA components, a careful inspection and evaluation must be carried out to decide whether there is any degradation of materials and if there are reliability issues.

The purpose of this study is to evaluate the reballed BGA components, which are being transitioned from a lead-free to a SnPb process, while concurrently determining whether component reballing can be a solution for such mixed assembly situations. In the present work, the original lead-free BGAs were reballed with SnPb spheres, and a comprehensive evaluation was performed to ensure the quality of the reballed BGA from both a mechanical robustness and a functionality point of view.

## EXPERIMENT

The component test vehicle used in this study is a 21×21mm 357 I/O BGA with 1.27 mm solder ball pitch, as shown in Figure 1. The original SAC 305 alloy solder balls were replaced with eutectic tin-lead balls.



**Figure 1** Reballed BGA Components

To evaluate the reliability of the BGA reballing process, two key areas were initially addressed. First, the reballed components could not exhibit degradation in strength when compared to those components that had not been reballed. The size of the attached spheres should be consistent, in order to preclude coplanarity concerns and to help achieve a low defect rate after assembly. Second, component integrity and functionality could not suffer due to the additional thermal cycles that the component goes through during the reballing process. It is very important to detect any degradation of the materials or damage.

In this study, a series of tests and inspections were carried out to evaluate the reliability of the reballed components. Visual inspections were performed to (i) detect damage and (ii) to assess and evaluate solder joint formation. A joint-level mechanical test and a cold ball shear test were conducted to evaluate the strength of reballed solder joints. Voiding and bridging issues were assessed via X-ray inspection. Solder joint microstructure was studied via metallographic techniques. In addition, reballed BGA components were populated and the packages were subjected to Environmental Stress Screening (ESS) tests followed by in-circuit and functional tests. The evaluation matrix is shown in Figure 2.

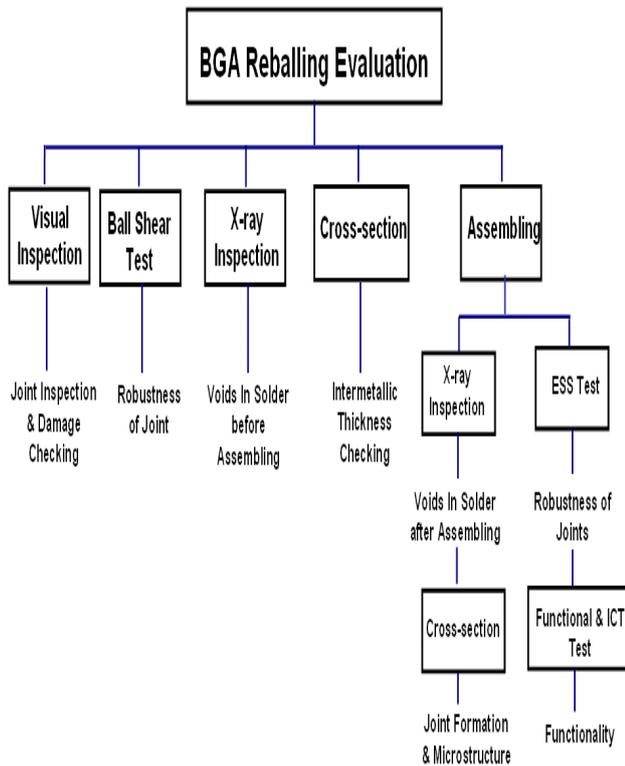


Figure 2 Reliability Evaluation

## EVALUATION AND ANALYSIS

### Visual Inspection

The multiple thermal cycles that the component goes through during the reballing process directly degrade or damage the components' materials. For ball removal and pad preparation, the pads and mask layer can be easily damaged if too much pressure or aggressive thermal profiles are used. Therefore, reballled BGA components should be inspected carefully prior to assembly. In this study, visual inspection was performed with a microscope to detect damage on the package and to evaluate solder joint formation. As seen in Figure 3, no damage was detected and all the joints were formed properly with good solder ball collapse.

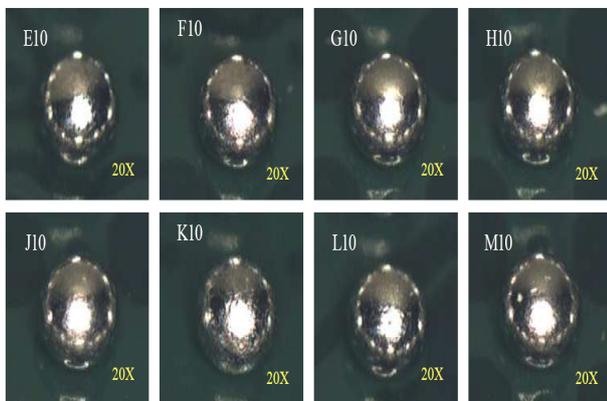


Figure 3 Visual Inspections on Solder Joints

### Ball Diameter and Height Measurement

For the size of the reballled spheres, two aspects should be focused on: (i) the diameter and height should be within the specified range according to IPC-7095B standards, and (ii) the consistency of the height and diameter. For a

reballled BGA, it is possible to get inconsistent ball sizes because the solder that was initially there was not completely removed prior to the attachment of new spheres. Inconsistent solder size can cause coplanarity issues or some other issues, such as bridging or insufficient solder after reflow. Solder volume and joint shapes can have an important impact on the mechanical and thermo-mechanical performance of the solder joint. Therefore, the dimensions of reballled BGAs should be checked to ensure that the solder joint size is consistent.

The components were cross-sectioned (Figure 4), and both ball diameter and height were measured. In order to evaluate the process capability of the reballing process, the  $C_{pk}$  values were used. A capable process would have  $C_{pk}$  values  $>1.33$ . For ball diameter,  $C_{pk}$  was calculated as 2.87 with the mean value as 28.47 mils as shown in Figure 5. For ball height,  $C_{pk}$  was 4.42 with the mean value of 24.12 mils (see Figure 6). Hence, the  $C_{pk}$  values indicate a high level of consistency with respect to both diameter and height.

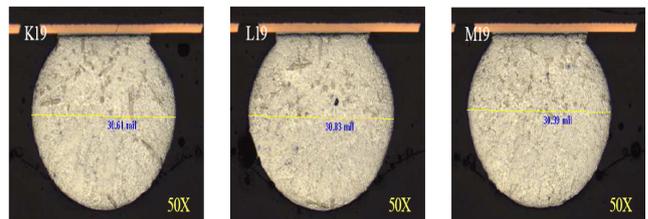


Figure 4 Cross-Section Images of Reballled Joints

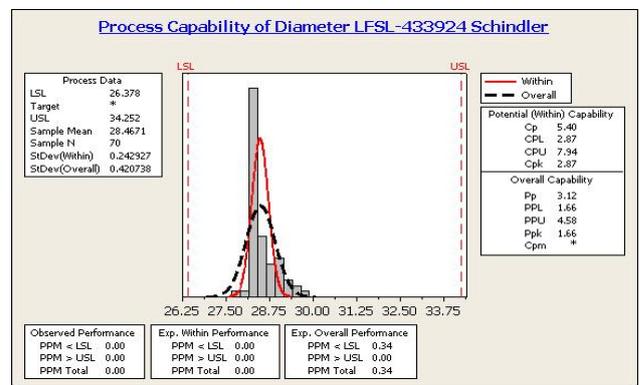


Figure 5 Process Capability of Ball Diameter

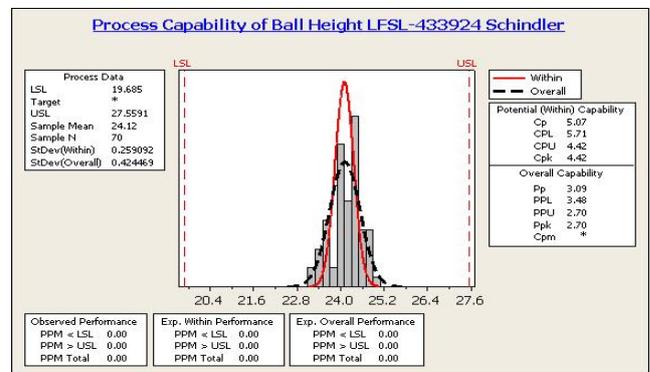
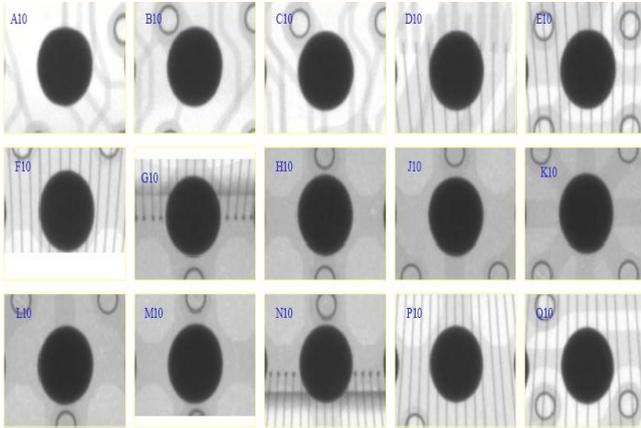


Figure 6 Process Capability of Ball Height

### X-Ray Inspection

2D X-ray inspection was performed on all reballled BGAs to identify any defects, such as bridging and voiding related issues. Voiding has been reported as a reliability

concern in the case of reballed components [3]. This is due to the amount of flux that needs to be applied for both ball removal and the attachment process. If the flux residue is not cleaned completely, the residue can become the source of voids after either reballing or PCB assembly. Through X-ray inspection, it was determined that voiding was not a concern for the reballed components (see Figure 7).



**Figure 7 2D X-ray Images Showing No Voiding Issues**

#### Cold Ball Shear Test

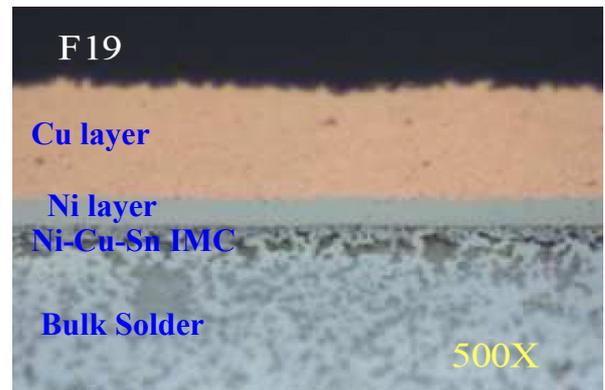
To identify the effect of the reballing process on the mechanical properties of solder joints, the ball shear test was performed on the reballed solder joints, using a Dage® Series 4000 tester. The ball shear tests were conducted at a shear speed of 1 mm/s (results in Table 1). The failure mode was identified as complete ductile fracture of solder. The shear strengths obtained were inline with that seen with other SnPb components of a similar size.

**Table 1 Shear Strength of Reballed Solder Joint**

	Mean	StDev	Minimum	Maximum
Shear Strength (kg)	1.57	0.082	1.45	1.70

#### Cross-Section and Microstructure Analysis

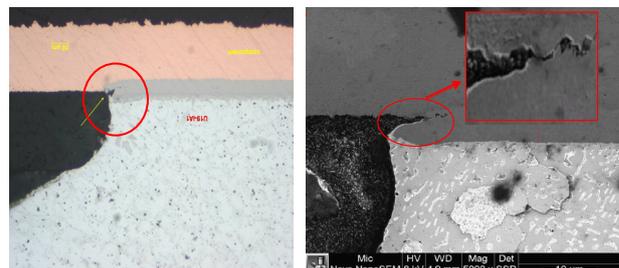
One concern in the case of reballed BGA components is excessive IMC growth due to multiple reflow cycles during the reballing process [1, 2, 6]. Because of the rigid and brittle nature of the IMC layer, excessive IMC formation could weaken the solder joint's strength, especially under certain high impact loading conditions. The joints were cross-sectioned to study the IMC structure. Compared with the original IMC layer, the increase in IMC layer thickness in reballed balls was not readily obvious. The thickness was within a reasonable range, between 1.2  $\mu\text{m}$  to 2.7  $\mu\text{m}$ , as shown in Figure 8. This could be due to the Ni layer in ENIG surface finish, which serves as a good barrier and inhibits the accelerated growth of IMC layer.



**Figure 8 IMC structure for reballed BGA**

Cross-section images show micro cracks at the corner of the solder joints within the Ni layer. Surprisingly, nearly every joint had such cracks, which was quite abnormal if the cracks were due to damage caused by the reballing process. In addition, as Figure 9 shows, the cracks showed a curve pattern, which was not similar to the cracks generated by certain stresses. Further analysis was conducted by using Scanning Electron Microscope (SEM). Besides Ni and Au, high levels of both barium and sulfur were detected on the crack surface, which could be principal constituents of the solder mask layer. The evidence indicates that the cracks were possibly due to contamination. Fresh components were cross-sectioned and similar crack patterns were also observed. Therefore, it was confirmed that the reballing process was not the source of the cracks and they were introduced during the component manufacturing process.

In order to confirm whether these micro-cracks can become a reliability issue or not, reballed components were cross-sectioned after the ESS test. It was observed that the micro-cracks did not propagate further and retained the same pattern. Component suppliers have also confirmed that the main reason for this issue was due to excessive etching while plating the Ni layer. According to their evaluation, the micro cracks should not result in any reliability issue.



**Figure 9 Cracks in the Nickel Layer Due to Contamination**

#### Reliability Evaluation After Assembly

After populating the reballed BGA components on PCBs, the assemblies were subjected to ESS tests, followed by in-circuit and functional tests. The temperature range was set as -20 to 100  $^{\circ}\text{C}$ , with 20 min dwell time and 5  $^{\circ}\text{C}$  /minute ramp rate. Figure 10 shows the test profile for the test. ICT and functional tests were conducted after 24 hours of running the ESS test. All assemblies passed both the ICT and the functional tests.

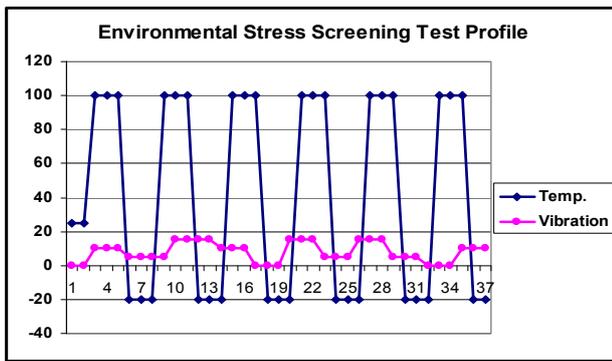


Figure 10 ESS Test Profile

## CONCLUSION

Because of the reliability concerns and the challenges in developing backward compatible process, BGA reballing was considered as an alternative option for the mixed system assembly process. The main focus of this study was to comprehensively evaluate the reliability of reballed BGAs. Several potential issues that could impact the use of reballed BGA components were evaluated. The sizes of reballed spheres were measured and the process  $C_{pk}$  values indicated a high consistency in both ball diameter and height. As reported, voiding could be a major concern for reballed components. However, in this study, this was not the case. According to cross-section images, excessive growth in the IMC layer was not seen. Besides, solder joint strength did not degrade, as indicated by shear strength data. After populating the BGA components on PCBs, it was seen that all assemblies passed ESS testing, ICT and functional tests. All the evaluations mentioned above showed that the reballed components exhibited adequate performance and can be recommended as a solution for the mixed system assembly process.

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