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-Case Study-

Post Reflow Open/Intermittent BGA Solder Connections

('Head in Pillow' Effect)

This is a report of findings concerning an investigation of the three (3) 492 ball BGA's and one (1) bare motherboard that were submitted for failure analysis. Electrical opens were being detected after final assembly when ICT is performed.

The investigation of the submitted BGA samples consisted of the following, and generated the associated observations, recommendations, and conclusions.

- **Initial Inspection and Observations**

1. **Initial microscopic inspection of the motherboard, using a stereomicroscope, revealed no obvious defects that would prompt concerns with regard to its solderability.**
2. **Subsequently conducted solderability testing confirmed that no solderability issues existed with the submitted motherboard.**
3. **Microscopic inspection of the BGA's revealed a large number of questionable solder connections along the periphery of package (See first four photographs attached hereto).**
4. **Some of the connections appeared to be somewhat stretched or elongated, but still possessed an obvious bond that was continuous between the solder sphere and the reflowed solder paste on the motherboard attachment site (See first four photographs attached).**
5. **Other sites revealed much more doubtful solder connections, appearing as though the solder spheres were just resting on the reflowed solder paste on the attachment pads (See first four photographs attached hereto).**
6. **At the sites described in item 5, it appeared that the solder spheres were somewhat deformed, some appearing to have even been deflected slightly to one side.**

7. **In addition, the BGA substrate revealed visible warpage; the amount observed not appearing to be too extensive.**

- ## Metallographic Investigation and Observations

In order to investigate the initial observations further, and attempt to discover clues as to the mechanism that has resulted in the open connections, the BGA's were prepared metallographically in cross-section for a thorough microscopic examination. A large number of connections along the failure prone periphery of all three (3) BGA's were examined in this fashion. Microscopic examination of the carefully prepared cross-sections revealed the following observations.

1. **As illustrated in the bottom left photomicrograph on the first page of attachments, the separation in the open solder connection is confirmed and is quite clear. This was observed in several connections on all three (3) BGA's submitted. The appearance of these opens strongly suggests that the connections have become molten again after initial package attachment to the motherboard, probably during the second soldering operation.**

2. **The deformation and deflection of the solder spheres is also confirmed and very apparent in this same photomicrograph and strongly supports the proposal put forth in item 1.**

3. **The bottom right photomicrograph on the first page of attachments clearly confirms the stretched and elongated appearance suggested by the initial observations. Note the appearance of the small voids along an apparent "ghost" boundary.**

4. **The photomicrographs on the second page of attachments illustrate several connections from each of the three (3) submitted BGA's. Notice the variety of appearances they reveal.**

5. **The separations in the open solder connections, along with the variations in the connection heights, are also evident in these photomicrographs.**

6. **The interfaces of the apparent separations, when examined at very high magnifications did in fact confirm distinct separations with slight surface irregularities. This can be seen in the photomicrographs on the third page of attachments.**

7. **Extensive examination of the solder interfaces with both the component substrate and the motherboard clearly revealed very good solderability. This was evidenced by the formation of a significant intermetallic compound (IMC) reaction layer formed at these interfaces.**

8. **The IMC reaction layer formed between the solder and the Ni layer at the BGA component interface was measured to be approximately 20 micro-inches on the average. This is a significant thickness for an IMC reaction layer between Ni and solder. The photomicrographs on the fourth page of attachments, illustrate the typical appearance of the IMC reaction layer observed between the solder and the Ni layer.**

9. **The IMC reaction layer observed at the solder interface with the Cu attachment pad on the motherboard was measured to have an average thickness of approximately 70 micro-inches. This is quite extensive, even for a substrate that has experienced two reflow operations, and strongly**

suggests quite an extensive thermal exposure. Typically each reflow results in an IMC layer thickness of approximately 20 micro-inches between the solder and a Cu surface. The photomicrographs on the fourth page of attachments illustrate the very thick IMC reaction layer formed between the solder and the Cu surface on the motherboard attachment sites.

- **Conclusions**

Based on the evidence brought to light by this investigation, along with previous experiences and other known phenomena as related to this type of assembly, the following conclusions have been proposed.

The electrical opens discovered during ICT are very likely the result of two or more of the following conditions acting in concert.

1. The most predominant factor found to be associated with such failures is the warpage of the thin BGA substrate occurring during the soldering operations and other thermal excursions such as curing cycles, preheats, and bakes. Obviously, the greater the thermal excursion, the greater the degree of warpage.

2. The warpage is greatly influenced by the initial amount and direction of the "as received" substrate 'set' that already exists as well as its moisture content. The edges of the BGA substrate could either be turned up and away from the motherboard (Smiley face), or down toward the motherboard (Frowning face). Based on experience and information gathered thusfar, this initial 'set' usually determines the direction of further movement. This warpage and the associated opens therefore, are generally found to occur around the periphery of the package where it is not held more rigid by the encapsulated chip.

3. The warpage experienced by the motherboard during the soldering operations is relatively less of a factor, but still a significant contributor.

4. The variation in sizes of the solder spheres also come into play. This is generally in the range of $\pm$ 0.001".

5. And finally, the variations associated with solder paste deposits. These are influenced by paste properties and condition; ambient conditions (temperature and humidity); stencil quality, cleanliness and condition; and with the various printing equipment parameters.

- **Failure Mechanism**

Based on all of the accumulated information and observations gathered from the metallographic investigation, it is most likely that the failures have occurred as a result of the controlling factors described in the following synopsis.

It appears most reasonable that the opens have actually been created during the second soldering operation. This can be easily confirmed by comparing electrical test results on some BGA's before and after the second soldering operation. During this second soldering operation, warpage has been experienced by the BGA package due to initial package conditions (amount and direction of 'set' and moisture content), and the thermal conditions of the soldering process (preheat and reflow temperatures and times).

The extensive thermal environment during the second soldering operation has resulted in the liquification of the previously reflowed connections, and along with the extreme warpage in certain areas, particularly around the BGA package periphery, has extended the now molten solder connections beyond their cohesive limits. The separations thereby created, along with the lack of active flux at these locations, have resulted in a skin of oxide on the two surfaces resulting from the separation. Upon cooling, reduction of the warpage condition, and depending upon the exact timing of solidification, these two separate solder globules have made contact and have resulted in the various conditions observed during the microscopic investigation of their microstructures.

The observed separations have occurred where the generated oxide films on the two solder surfaces have not fractured upon reinitiation of contact and allowing them to rejoin into one continuous globule. Instead, the significant oxide film has created both a physical and electrical barrier as detected during ICT.

The observed deformation of the larger globule on the component side, is the result of the slightly faster solidification of the small solder globule left on the motherboard attachment site. Upon subsequent contact of the 'oxide enveloped', and 'still molten' larger globule, deformation and deflection of this larger globule takes place as it is pressed against the now solid mass on motherboard attachment site.

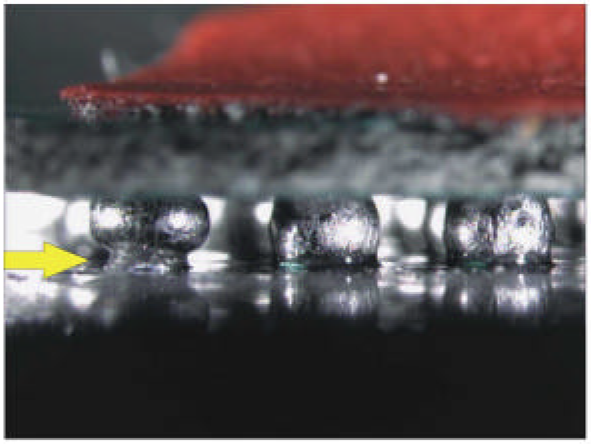
Where the oxide layers have broken, the two globules have merged to varying degrees again, forming a number of peculiar shapes as observed during microscopic examination of the microstructures and as illustrated also in the attached photomicrographs.

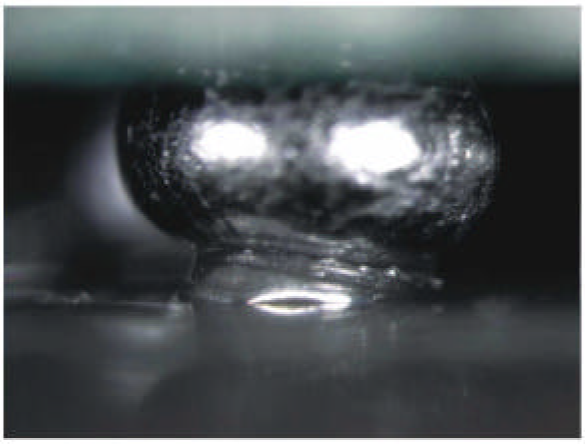
- ## Recommendations

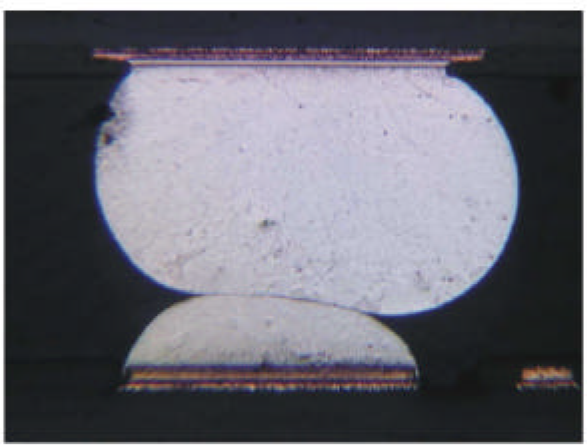
In order to minimize, and hopefully eliminate the occurrence of the electrically open connections being experienced, the following recommendations are made. It is suggested that each recommendation be attempted individually so as to determine the exact degree of impact on reducing the defects encountered.

1. **Minimize preheat on the BGA side during the second soldering operation. This will reduce warpage somewhat and minimize the chances of reflowing the BGA connections during the second soldering operation.**
2. **Reduce the soldering parameters (temperature and time) on second soldering operation. This will also have the same effect as previously put forth in recommendation 1.**
3. **Optimize solder deposition consistency. Minimizing incomplete or light deposits will obviously decrease the probability of this defect, as well as the generation of others.**
4. **Increase solder paste deposition volumes within reasonable limits in order to better compensate for substrate warpage and solder sphere variations.**

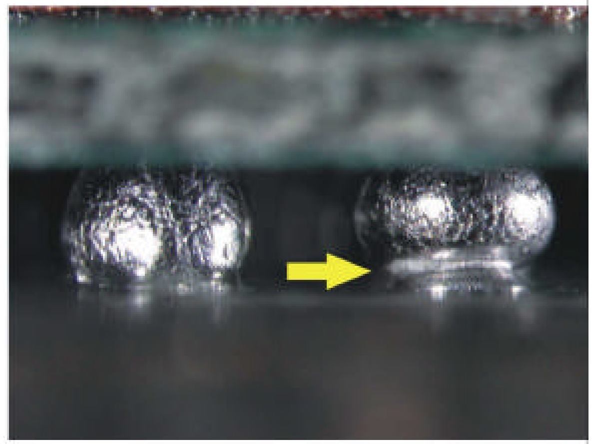
OPEN CORNER CONNECTION

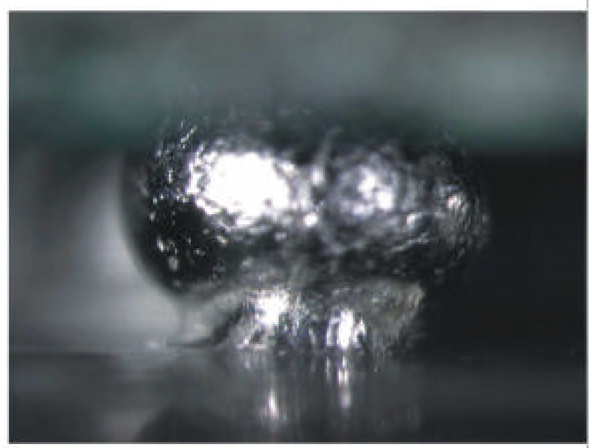


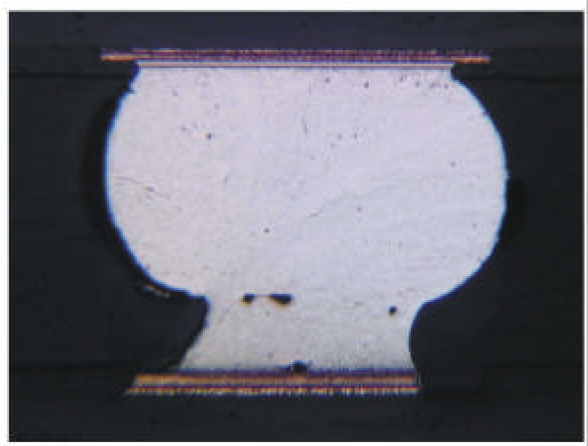




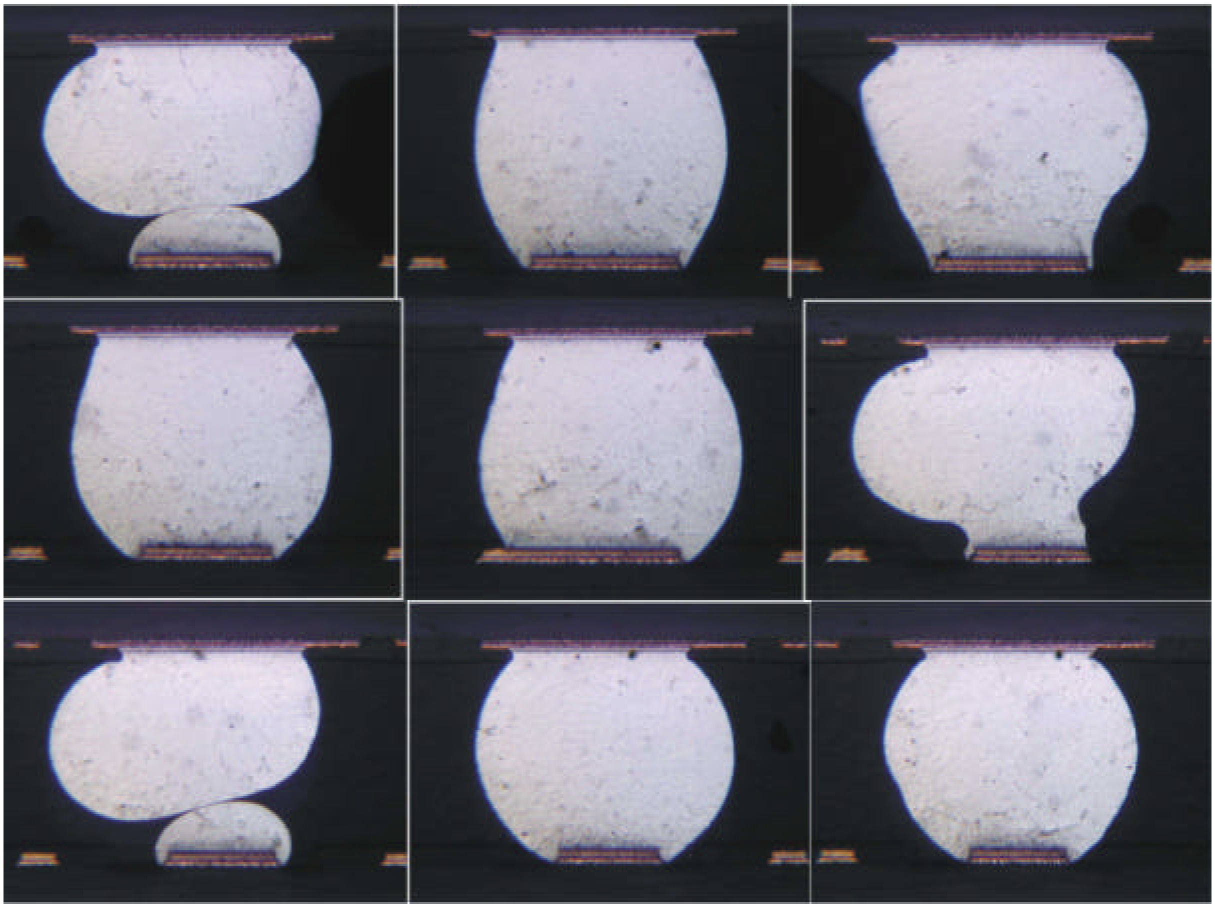
ELONGATED CONNECTION







BGA ASSEMBLY #1



HIGH MAGNIFICATION OF OPEN CONNECTIONS SHOWING DISTINCT SEPARATION