



X-ray / Bondtester Reliability Study of BGA Devices - Impact of Interfacial Voiding

John Tingay and Evstatin Krastev, Nordson DAGE

Abstract

The impact of voiding on BGA/CSP joint reliability has been discussed actively during the last several years. IPC610-A and J-STD-001 state that voiding greater than 25% of the area of the solder joint as seen by top down view 2D X-ray inspection should be considered as a defective joint. Several studies during the last years have tried to find a correlation between the void size and BGA solder joint reliability (References 3-5). All these studies have utilized 2D X-ray voiding calculations that provide very precise quantitative measurement of the total voiding within the solder joint. However, this type of measurement does not provide information on the exact location of the voiding within the joint. Therefore, the impact of the void location on the joint reliability has not been studied so far.

Naturally, if the voiding is concentrated predominantly at the joint interfaces, we are much more concerned that a field failure will occur in the near future.

As discussed, so far there have been no quantitative studies that explain the impact of interfacial voiding on joint reliability and compare this to the impact of the voiding that is located within the bulk of the solder joint. A novel technique called Large Board Computer Tomography, Large Board CT or PCT, as described in Ref. 1, is capable of providing quantitative and precise information for void location and size, while performing the testing in a completely non-destructive fashion. This previous study also suggests that there is a poor correlation between total voiding as per 2D X-ray measurements and interfacial voiding as determined by Large Board CT. Thus, we decided to combine the Large Board CT together with the well-established technique of Bondtest Shear in an effort to study the impact of interfacial voiding on the bond strength as determined by the shear force.

For this study, we concentrated on a single BGA device that consisted of 374 joints. We found that interfacial voiding does degrade the strength of the BGA joints. Interfacial voiding of 6% to 10% resulted in about 10% weaker bonds. As a future work, we plan to expand the study using large set of BGA devices to achieve better statistical significance. To speed up the testing we plan to employ various levels of automation for both the Bondtester and X-ray measurements.

Key words: X-ray inspection, Bondtester, Shear, Voiding, IPC-610, J-STD-001, AXI, Automated X-Ray Inspection, X-ray technology, Computer Tomography, CT, PCT, CT without cutting, Large Board CT.

Introduction

Calculation of voiding percentage is a standard quality assurance procedure within the testing regime of the microelectronics/PCB manufacturers. It is 'regulated' by IPC-A-610 that states that voiding less than 25% as determined using top view provided by regular 2D X-ray inspection is acceptable for certain class of BGA devices-see Figure 1-1.

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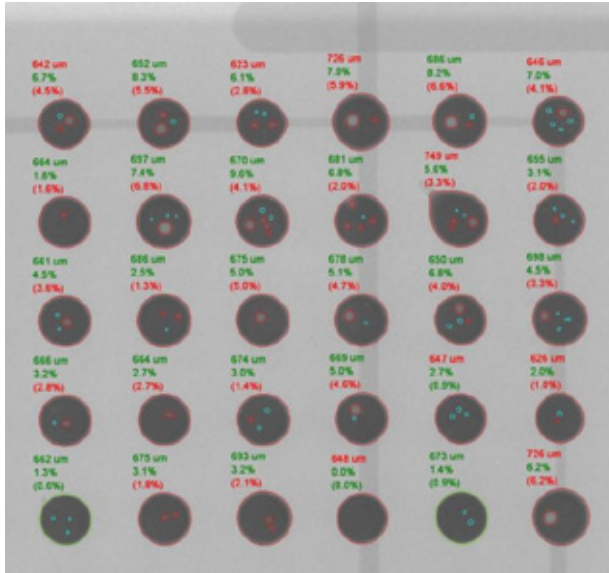


Figure I-1. 2D voiding calculation of a BGA device as per IPC-A-610

This procedure gives us an indication of total voiding within the solder joints but does not give a good representation of the interfacial voiding that is at the BGA joint to PCB interface. It is suggested in the literature that the interfacial voiding could be crucial for the joint strength/quality and does not correlate well to the total voiding as calculated by IPC-610 (Figure I-2).

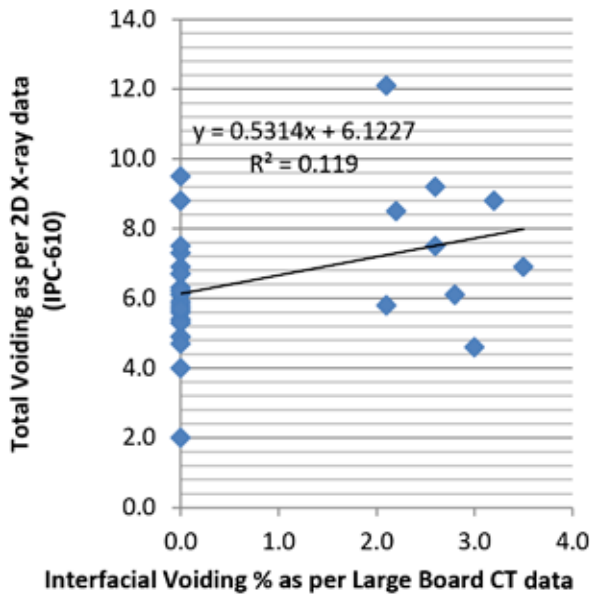


Figure I-2. Total Voiding vs. Interfacial Voiding of BGA device as per study [1]. Very weak correlation between Interfacial voiding and Total Voiding (IPC-610) is evident ($R^2=0.12$)

The only way to study interfacial voiding in a nondestructive fashion is by employing Large Board CT. This novel technique is described in detail in References [1] and [2]. Basic principle is shown in Figure I-3 and I-4.



Figure I-3. μ CT limitations for larger samples

It is obvious from Figure I-3 that the standard CT technique employed for the Electronics industry is not suitable for large samples like PCB assemblies. As the sample needs to be rotated between the X-ray source and the detector, the large size of the PCB places the BGA device of interest very far away from the X-ray source that results in very low Magnification/Resolution. This is pure Physics consideration that is valid for all X-ray CT systems.

In order to overcome this problem, the Large Board CT technique (also called PCT) keeps the PCB flat and close to the X-ray source while turning the detector at an angle. This permits very good resolution images to be collected without cutting down the valuable PCB. See Figure I-4.

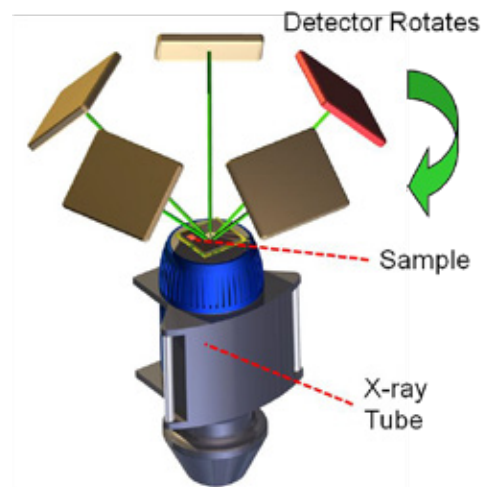


Figure I-4. Basic principle of Large Board CT also called limited angle CT or PCT.

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In this study we are presenting a technique that combines the strengths of the Large Board CT with the mechanical testing capabilities of a standard Bondtester machine.

Current Bondtesters are extremely capable machines that can perform a very large variety of material testing applications like a 3 and 4 point bend test. We measure bond strength using mechanical shear testing and try to correlate the results to interfacial voiding as observed by Large Board CT.

Experiments

Using Large Board CT we examined a large a number of PCBs looking for a BGA device suitable for our tests. This was accomplished completely non-destructively as the technique permits the use of a very large PCB sample. We needed to find a device that possessed significant levels of interfacial voiding. Finally, we were able to identify a BGA device that had a significant number of pins that exhibited 6% to 10% interfacial voiding as well as many pins that did not have voiding or had very low levels of interfacial voiding - up to 1% on average. Total number of joints is 374, average ball diameter 0.65 mm and pitch 1 mm. We carefully scanned the device in question using Large Board CT in order to produce a detailed map of the interfacial voiding percentage at the PCB interface. Once done, we started polishing down the device in order to reveal the solder joints and prepare for the shear testing. This process needs to be carried out very slowly and carefully in order not to disturb the joint's integrity. Before proceeding with the shear testing, we grouped the pins in two groups: Group 1 - pins that exhibited 6% to 10% interfacial voiding and Group 2 - pins with up to 1% on average interfacial voiding. In order to do this we used electronic cross section data as obtained by Large Board CT. Figure 1 shows a typical electronic cross section or e-section of the interfacial area of a BGA device. On Figure 1a the voids appear as the black oval areas within the joint represented in white. On Figure 1b we show a typical voiding calculation carried on an e-section at the interfacial area of the BGA device.

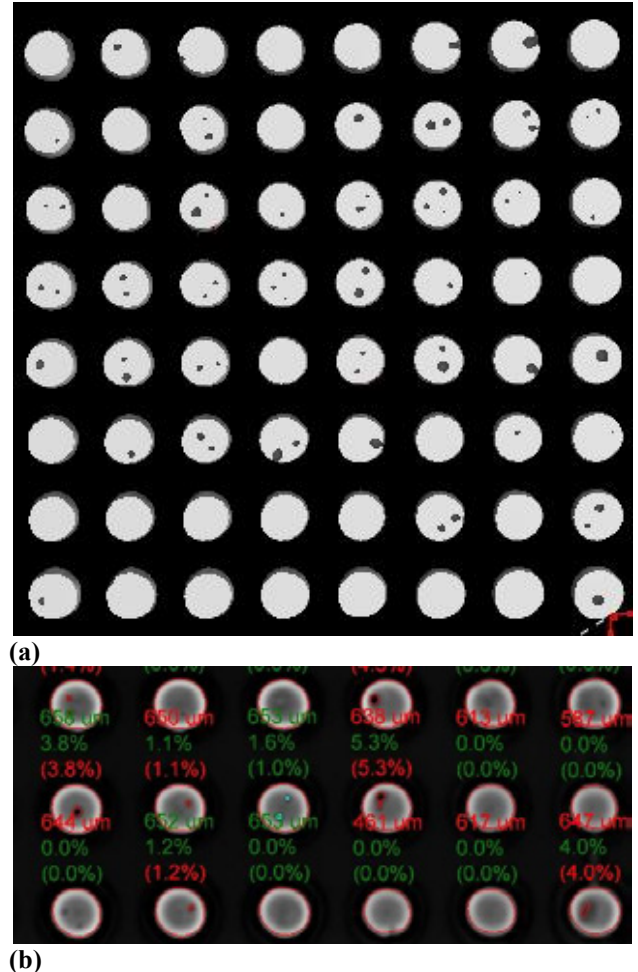


Figure 1. Electronic cross sections (e-sections) of interfacial area of a BGA device. Black oval areas represent the voiding (a), (b) BGA voiding calculation on an e-section at the PCB interfacial area. These sections are obtained in a completely non destructive way.

The shearing of the bonds was performed using a standard Dage 4000 Plus bondtester. Contemporary bondtesters are very versatile and accurate machines that perform a very wide variety of mechanical tests both in a destructive and non-destructive way. These include shear, pull, peel, and also a large set of material tests like 3 and 4 point bend tests. For certain testing conditions these machines can be automated in order to achieve speed, productivity or better accuracy.

Typical shear test results are shown on Figure 2. It is obvious the joints in Group 2 (less than 1% interfacial voiding on average) show more consistent and higher results for break force compared to the joints in Group 1 (6% to 10% interfacial voiding).

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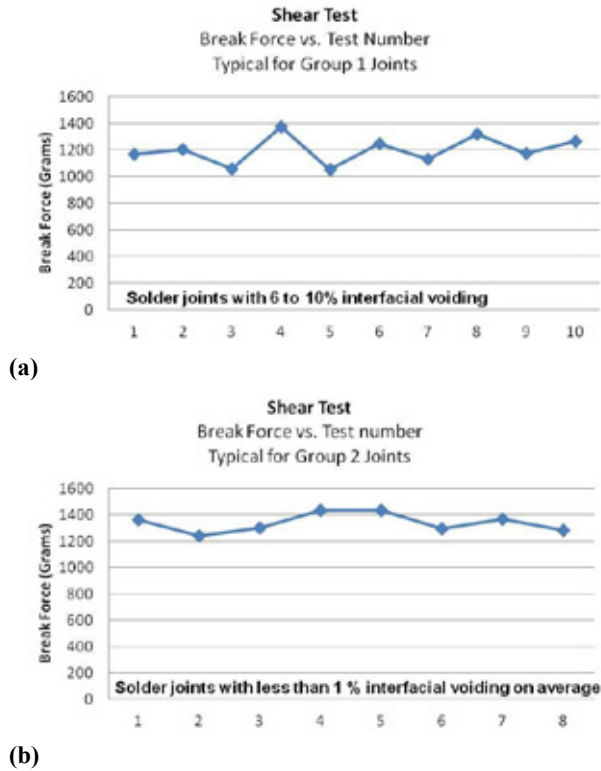


Figure 2. Typical shear results for Groups 1 and 2 solder joints. Group 2 joints (less than 1% voiding) show better joint strength.

We observed two types of failure mechanisms due to the shear testing - ductile and pad cratering, with the ductile failure being significantly more proliferated. A ductile failure is shown on Figure 3 and corresponds to a failure that occurs in the solder bulk.

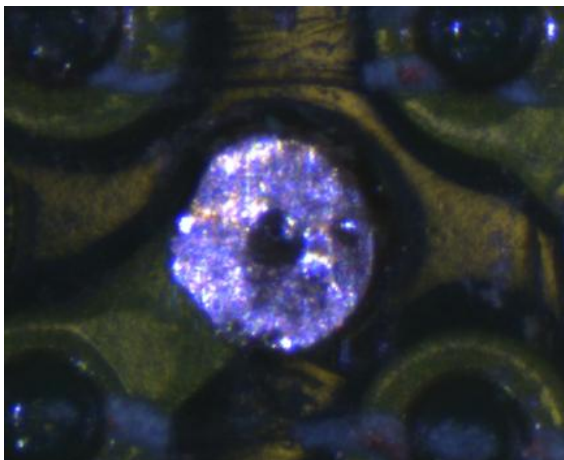
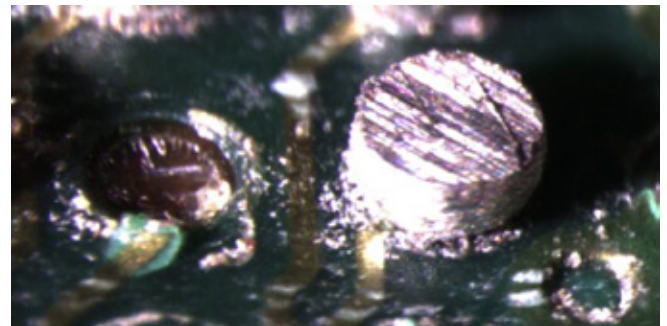
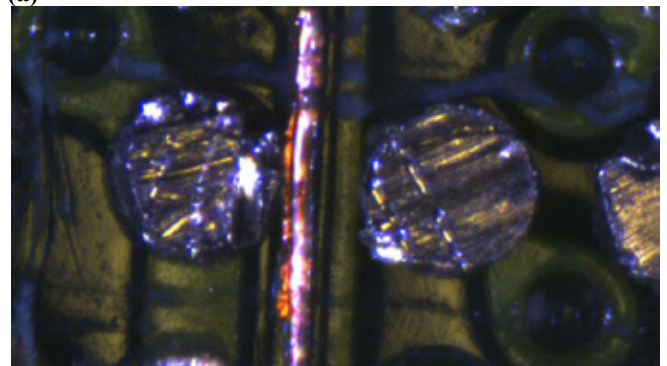


Figure 3. Example of a ductile or solder failure due to shear test. The dark area in the middle is an interfacial void.

The other type of failure observed during the shear testing was a pad crater. This type of failure is shown on Figure 4 and - the break occurs in the PCB material and it looks like a crater.



(a)



(b)

Figure 4 - Pad crater failure due to shear test. The break occurs in the PCB material; (a) side view, (b) top view. A comparison between pad crater and a ductile failure is shown on figure 5.

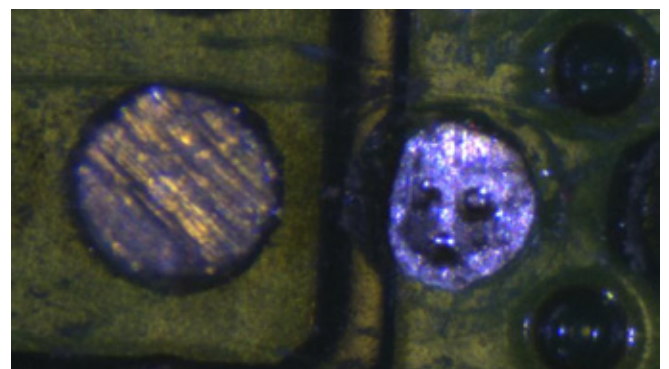


Figure 5 - Comparison between pad crater (left) and ductile failure (right). Interfacial voiding seen in the solder

After completing the shear testing, we averaged the results and found the average value for break force for Group 1 joints (interfacial voiding 6% to 10%) to be 1192 grams. For this study

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Conclusion

we considered only data points that represented solder failure. The corresponding result for Group 2 joints (less than 1 % voiding on average) was 1317 grams. This indicates that the joints of Group 2 showed 9% to 10% higher values for break force on average. This result is in a good agreement with the hypothesis that interfacial voiding affects negatively the bond strength. The device we used for testing exhibited moderate levels of interfacial voiding and we were still able to observe a negative impact on solder strength. It was also very interesting to observe that the weakest link for this device were pad crater failures that occur around 800 grams shear force.

In this paper, we describe a testing procedure that combines non destructive X-ray examination combined with destructive shear testing in order to study the impact of interfacial voiding on joint strength of BGA devices. We used a X-ray Large board CT technique that permits a virtual e-section to be taken at the BGA to PCB interface and revealed the interfacial voiding. Previous study [1] has indicated that the correlation between interfacial voiding and total voiding as per IPC-610 can be very weak for certain devices. Thus, being able to quantify the exact amount of interfacial voiding is crucially important and can be carried out only by employing Large Board CT. The shear experiments were executed using a multi-purpose Bondtester system that is capable of doing a large variety of Bondtest experiments as well as many material tests like 3-4 bend test.

We found that interfacial voiding negatively impacts joint strength up to 10% for a very moderate amount of interfacial voiding (6% to 10%). We expect higher levels of voiding to produce much stronger negative effect.

As a future work project we plan to expand our testing to include a larger number and different types of BGA devices in order to gain statistical significance and a better accuracy. We hope to be able to study the effect of higher level of interface voiding (15% and more), as we speculate that the impact on the joint integrity would be more significant and therefore critical.

Acknowledgments

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Europe, SEA, Africa

ti-sales-eu@nordson.com

China

ti-sales-cn@nordson.com

Singapore

ti-sales-eu@nordson.com

Korea

ti-sales-korea@nordson.com

Americas

ti-sales-us@nordson.com

Japan

ti-sales-jp@nordson.com

Taiwan

ti-sales-tw@nordson.com