X-ray Inspection of Voids in BGA Joints with Respect to the IPC-7095A Specification

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Abstract
With the introduction of Lead-free solder, voiding within BGA joints is potentially a major issue during PCBA manufacture. With BGA components sometimes costing hundreds or even thousands of US Dollars, there has to be an understanding about when voiding within the joint is excessive.

There are a number of specifications that a manufacturer can refer to but with respect to BGA joints, IPC-7095A is probably the most comprehensive. It has an entire section on voiding within the BGA ball and limits on when the void size becomes either a Process Control issue or a Corrective Action Indicator. However, some of this information seems to conflict with other IPC specifications, for example IPC-A-610D. Instead of trying to set a global specification, this paper investigates whether the limits specified within IPC-7095A were acceptable to a particular Contract Manufacturer and their OEM customer.

Introduction
With the introduction of the IPC-7095A in October 2004, there has been a great deal of interest among OEMs and CMs on the voiding specification therein. This paper is a study using two different X-ray Inspection systems – one a Laminography and the other a transmission type – to inspect BGA joints that exhibit voids.

These two X-ray systems were used purely as a means of measuring the size of the voids within the BGA ball. With the 3-D Laminography system, the voids were measured within the ball, at the ball-package interface and at the ball-pad interface. It was not possible to isolate the location of the void using the Transmission X-ray system and the pass/fail criteria were set according the IPC-7095A specification.

IPC Specifications
IPC-7095A is the Specification for the Design and Assembly Process Implementation for BGAs. Chapter 7 deals with the Assembly of BGAs on the printed circuit board and has extensive information on voiding.

Where possible, it is important to know the location of the void within the ball. Voids at the package or PCB interfaces are more likely to cause failures or weaknesses in the joint compared with voids completed within the ball.

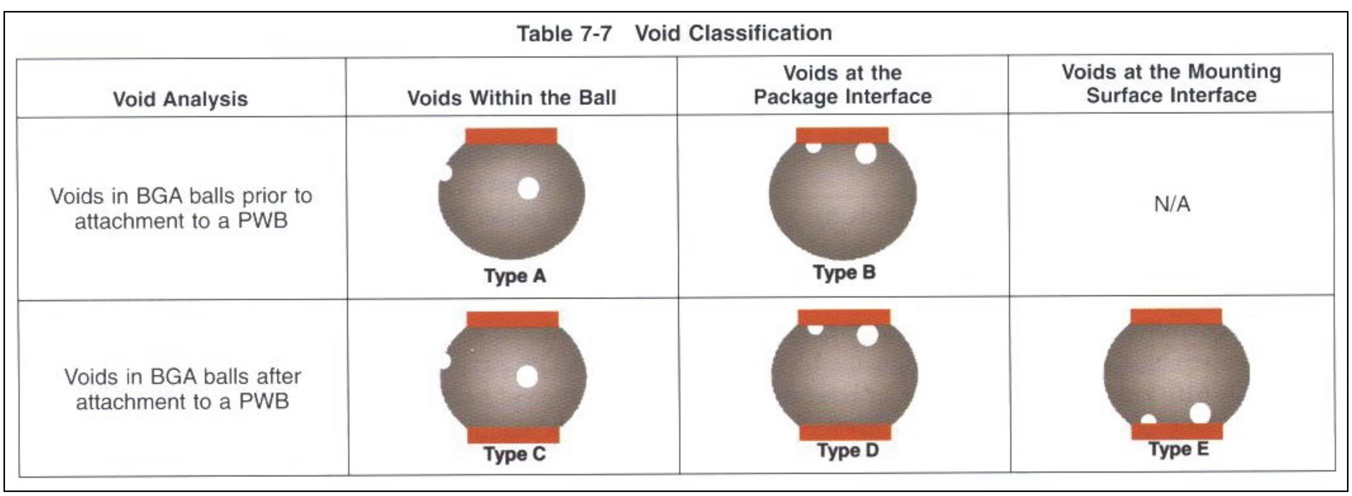


Table 7-7 Void Classification

Void Analysis	Voids Within the Ball	Voids at the Package Interface	Voids at the Mounting Surface Interface
Voids in BGA balls prior to attachment to a PWB	Type A	Type B	N/A
Voids in BGA balls after attachment to a PWB	Type C	Type D	Type E

Figure1 – IPC-7095A Table 7-7

Though IPC-7095A does specify criteria on the size of the voids before attachment (Type A and Type B) to the Printed Circuit Board, all the work done was only after attachment as shown in Type C, D and E in Figure1 shown above.

Type C voids
As shown in the figure above, these voids are found within the ball and not at either attachment interface. These voids may be wholly or partially contained with the ball.

Type D voids
These are voids at the interface between the ball and the package. These are typically, though not exclusively formed when the solder ball is attached to the component during the packaging process.

Type E voids
These are voids at the ball and PCB (pad) interface. These are formed during the reflow process when attaching the component to the Printed Circuit Board.

Type D and E voids being at a mounting interface have the potential of creating weaker joints due to the fact there may be less solder to lend strength to the joint. Another potential problem could be a decrease in the ability to dissipate heat due to the air gap instead of having a continuous layer of solder.

Type C voids are generally less critical as they are not on an attachment interface. However, if the void is too large, the strength integrity of the entire joint may be compromised. There is an argument that multiple micro-voiding within the ball actually increases joint strength by creating a flexibly spongy structure, however, at this stage the validity of this theory is unknown. Plus it is not possible to consistently create the spongy micro void structure.

Table 7-8 Void Size Limitations

Void Type	Void Description	Process Control Criteria			Determined By
		Class 1	Class 2	Class 3	
A	Voids within the solder ball at incoming	36% of area = 60% of dia	20% of area = 45% of dia	9% of area = 30% of dia	Transmission or cross section X-ray (sampling)
B	Voids at Package Interface at incoming	25% of area = 50% of Dia.	12% of area = 35% of Dia.	4% of area = 20% of Dia.	Transmission * or Cross section X-ray (sampling)
C	Voids within the Ball after PCA reflow	36% of area = 60% of dia	20% of area = 45% of dia	9% of area = 30% of dia	Transmission * or cross section X-ray (sampling)
D	Voids at the package interface after PCA reflow	25% of area = 50% of Dia.	12% of area = 35% of Dia.	4% of area = 20% of Dia.	Transmission * or Cross section X-ray (sampling)
E	Voids at the mounting surface/ Printed Board after PCA reflow	25% of area = 50% of Dia.	12% of area = 35% of Dia.	4% of area = 20% of Dia.	Transmission * or Cross section X-ray (sampling)

If Transmission X-ray is used to evaluate the occurrence of voids the tightest criteria (% allowable at ball or interface) must be used for the evaluation since transmission X-ray cannot determine the location of the void. This would be the criteria for a type "D" void.

Figure2 – IPC-7095A Table 7-8

Within IPC-7095A, Table 7-8 (shown above) is the relevant specification as to the maximum void size permitted. Class 1 products are high volume, very low cost and typically X-ray inspection is not carried out. If these products fail at functional test, they are typically scrapped instead of being repaired. Computers and cell phone PCBAs are examples of products that fall within the Class 2 rating. Class 3 products are where high reliability is required, for example in Aerospace and Defense applications, hence the much tighter limit on allowable voids.

Using the Laminography X-ray system, it is possible to "slice" the BGA to determine whether the void is contained within the ball or whether it is at a connecting interface. Traditional Transmission X-ray systems can only inspect the BGA from above and hence all voids need to be evaluated using the Type D void criteria irrespective of the location of the void. However, many Transmission X-ray systems now have the capability of moving the X-ray source where it is possible, using an off-angle view, to determine whether the void is within the ball or at an attachment interface. In these circumstances, it should be permissible to judge the void depending on its location, and hence use Void Type C, D or E criteria.

IPC-7095A does allow for the CM and the OEM to set other criteria as shown in:

7.5.1.7 Accept/Reject Criteria The accept/reject criteria for BGA assemblies is being considered by the J-STD-001 and IPC-A-610 Task Groups at the time of release of this standard. Those documents provide the final accept/reject criteria used in contractual agreements. The recommended accept/reject conditions have been supplied to those stan-

Figure3 – IPC-7095A Section 7.5.1.7

However, IPC-A-610D has a different specification on allowable voids:

8.2.12.4 Surface Mount Area Array – Voids

Design induced voids, e.g., microvia in land, are excluded from this criteria. In such cases acceptance criteria will need to be established between the manufacturer and user.

Manufacturers may use test or analysis to develop alternate acceptance criteria for voiding that consider the end-use environment.

Acceptable - Class 1,2,3

- 25% or less voiding of the ball x-ray image area.

Defect - Class 1,2,3

- More than 25% voiding in the ball x-ray image area.

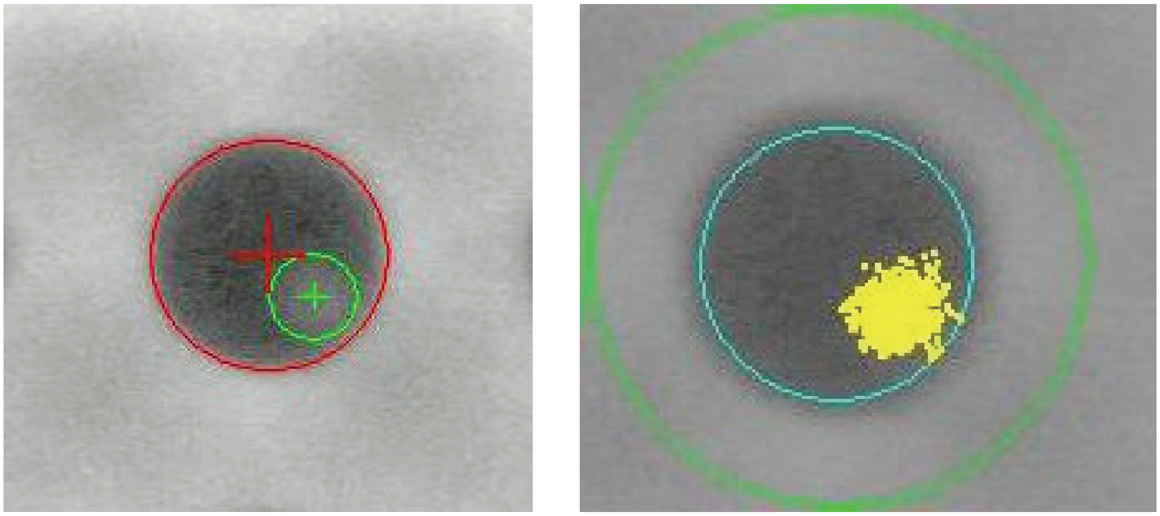
Figure4 - IPC-A-610D Section 8.2.12.4

IPC-A-610D does not differentiate between the different Classes of products nor on the location of the void. And furthermore, IPC-A-610D also allows the CM and the OEM to agree on an acceptance criteria subject to the end user environment.

X-ray Inspection

At first glance it seems that the two IPC specifications conflict, however on further study both suggest that the CM and the OEM agree to a pass/fail criteria that depends on the end customer usage and the above specs are the suggested maximum permissible voiding for each class of product.

Most X-ray inspection systems have some means of measuring voids within the BGA. It could be a manual process where an operator puts cursors over the voids and measures the diameter of the joint versus the diameter of the ball. Or it could be an algorithm that automatically calculates the area of the void and compares it with the area of the ball.



Either method is valid provided that it is possible to accurately measure the diameter/area of the void compared with the diameter/area of the ball.

Test Conditions

The manufacturer was trying to characterize the oven profile best suited for Lead free manufacture. 10 PCBAs were selected to be inspected using the two X-ray Inspection systems. Each board had three 736-pin BGA's. Not all the balls had voids and only those with voids greater than 9% by area (30% by diameter) were inspected further. This gave us data from 229 balls with significant voiding. 10 of these balls were diced open to visually confirm the size of the voids and compare with the results obtained from the X-ray systems

Both the OEM and the CM made a joint decision on the measurements to arrive at a pass/fail criterion for the size of voids that would be unacceptable for the end use of the printed circuit board.

Decisions

Based on the small sample size a decision was reached that, for a Class 2 product, a void at the interconnection interface of 12% or larger would be unacceptable – this is in accordance with IPC-7095A. However, for voids within the ball it was decided to tighten the criteria from 20% down to 17.5% by area.

Conclusions

The overall conclusion that the IPC-7095A limits of void size is generally the correct figure and it is not recommended to exceed these values. However, it may be necessary on a product by product basis to tighten some of these limits provided that there is consensus between the CM and the OEM.

Acknowledgements

Data from IPC7095A and IPC-A-610D were used for the purposes of validating the same.