# A Close look at IPC X-Ray Inspection Guidelines for BGAs

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**ABSTRACT**
BGA defects can be challenging to detect when images are not taken from the appropriate perspective or with the correct equipment. While IPC's recommended tests are effective in certain situations, recent improvements in CT technology offer a more comprehensive analysis of each solder ball within seconds. Utilizing a genuine 3D CT method, defects such as Voiding, Non-Wetting, and Head-in-Pillow are distinctly visible, enabling engineers to conduct accurate root-cause analyses. 3D CT X-Ray inspection offers exceptional clarity when comparing defects against IPC standards and removes many of the visible obstructions introduced by other advanced X-Ray Technologies.

Key words: X-Ray, IPC, 3D, BGA, CT, Computed Tomography, Void, Head in Pillow, HiP

**INTRODUCTION**
As our electric cars, computers, and phones advance, they require increasingly complex circuits. This forces manufacturing facilities to continuously adapt and meet these demands. Unfortunately, traditional bulky components do not support the development of slim, power-efficient devices. Designers are thus compelled to seek efficient and innovative solutions. In the semiconductor space, advancements have facilitated the miniaturization of components. The Ball-Grid-Array (BGA) has emerged as an optimal solution to these challenges. Its compact form factor allows solder balls to establish thousands of electrical connections in a confined space, connecting an electrical pad on the PCB to the underside of the component. The BGA's low profile ensures a shorter path length, leading to lower resistance and improved electrical performance. Additionally, this package is robust and challenging to dislodge, making it suitable for rugged applications [Source 1].

Like any component in the SMT assembly process, the BGA must adhere to IPC guidelines to ensure that the integration of these sophisticated devices does not compromise the quality of the final product. Traditional optical methods pose significant challenges in inspecting BGAs. While engineers can use high-resolution microscopes or endoscopes to inspect the solder balls at the package's perimeter, these methods cannot inspect most connections. Occasionally, it may be necessary to remove a BGA sample from production and section it to inspect the solder balls along the cut line for defects. However, this approach only provides data about the quality of connections along that specific line and is not ideal for making general assumptions about an SMT assembly line. Consequently, manufacturers are exploring alternative inspection methods.

**ADVANCED X-RAY INSPECTION**
Enter X-Ray inspection, which relies on a technology similar to that used for detecting human bone fractures. SMT X-Ray inspection equipment enables engineers to examine the smallest components and each solder joint individually. There are various X-Ray inspection methods, each with unique features [Figure 1]. The simplest 2D transmission captures a top-down or angled image of every metallic feature within the field of view, offering high resolution and sharp images. However, its limited perspective can obscure defects or features behind other dense objects. Tomosynthesis, a more complex method, captures several 2D images from different angles and overlays them to create a 2D representation that reveals aspects of 3D features. While this can quickly identify major defects, it generally lacks the clarity and detail of 2D transmission.

Laminography, slightly more complex, captures multiple angled images and processes them to produce 3-5 cross-sectional slices across the Z direction of the Field-Of-View (FOV), allowing users to isolate several layers and eliminate artifacts or obstructions. Its limitation, however, is that the limited number of slices can make it challenging to accurately compare and measure different areas of a single PCB due to PCB warpage. The most advanced method, Computed Tomography (CT), captures a large number of angled 2D images, sometimes over 1000. Sophisticated algorithms then process these images to produce hundreds of cross-sectional slices for each solder joint in a FOV. Unlike any other approach, this method compensates for PCB warpage, automatically, ensuring accurate measurements of each area of interest, regardless of obstructions or its location on the PCB.

**Common Defects in BGA Components**
To help guide SMT manufacturing facilities, the IPC association has made extensive efforts to analyze process defects and potential issues that may arise during the assembly of BGAs (among many other topics). The first IPC-7095 article was published in August 2000 and has been updated as recently as June 2019. This document provides a lengthy amount of images, measurements, observations, and crucial information important to any facility working with

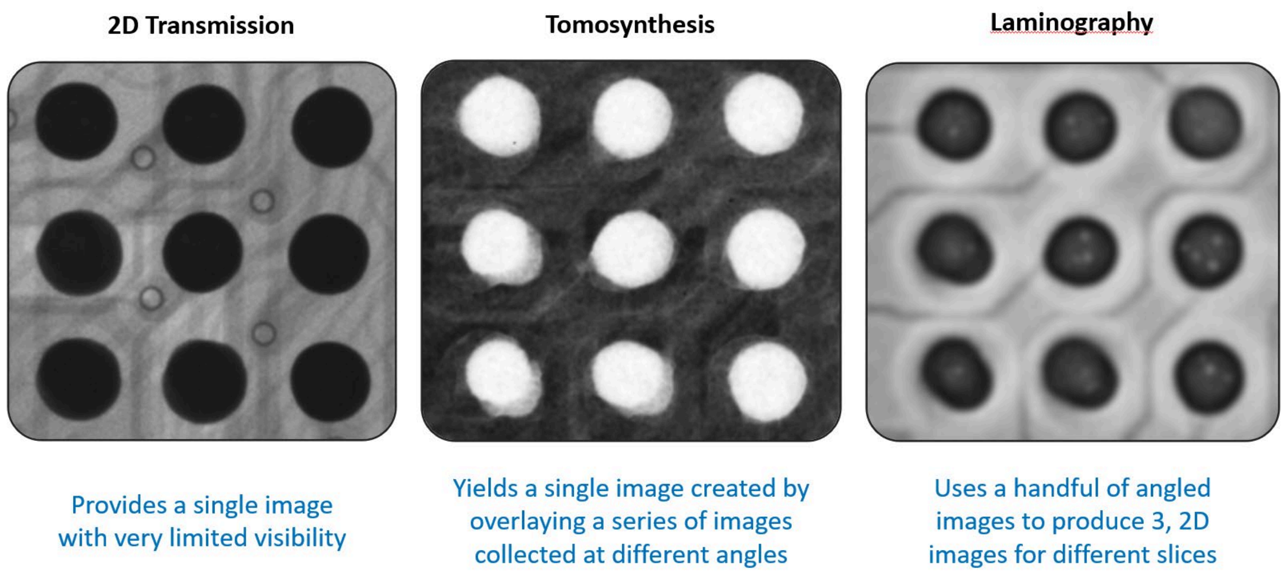


**Figure 1:** Examples of X-Ray Inspection Technology

BGAs. Among this extensive collection of content, there are a few sections which describe some of the most common forms of defects that one may encounter when reflowing BGAs. Some of the most popular and noteworthy defects to prevent include bridging, voiding, Head-in-Pillow (HiP), or non-wetting balls.

Bridging is one of the most obvious defects and would describe a situation in which a solder ball is connected to one of its nearby neighbors, whether by a trapped foreign material, or if an excessive amount of solder paste was dispensed. For this type of defect, any of the above mentioned X-Ray inspection approaches can be used to easily identify its location and severity. Once an image is captured (2D or 3D) algorithms can simply measure the amount of dense material in a field-of-view (FOV) and determine whether it spans the distance between multiple solder balls. It is worth noting however, that 2D transmission can make solder joints appear as if there is a bridge, should there be dense objects, such as capacitors, above or below the BGA of interest and in the direct line of the captured X-Rays.

Voids are a complicated type of defect that can occur in a variety of forms. In fact, IPC-7095D classifies them in 6 different categories: macro, planar, shrinkage, microvia, intermetallic, and pinhole. Interestingly, the actual impact that a void may have on a solder joint is heavily dependent on its size and location. Therefore, when inspecting and reviewing voids in an SMT assembly process, a simple set of acceptable criteria must first be defined. IPC offers manufacturers a starting point by suggesting that the allowable cross-section of a void not exceed 30-35% of the cross-section of the solder ball. It also recommends that no single void possess a diameter larger than 50% of the diameter solder ball.

To help, it is best to visualize a void as an empty space trapped within a solder ball. [Figure 2] offers two examples of what can be considered as excessive voiding, both of which should prevent a BGA or circuit from advancing in the manufacturing process. It is quite easy to review these images and visualize the relative size of void that could have a negative impact on a product's quality. However, the rules also apply for a situation in which the total amount of voiding, otherwise thought of as the percentage sum of voids, exceeds 30-35% [Figure 2]. This last scenario is both unique and interesting because it does not appear to be one that heavily studied or well understood. Though IPC clearly states that voids should not exceed a specific area percentage, it only casually mentions that “voids may impact reliability by weakening solder balls and reduce functionality because the reduced cross-section will have lower heat transfer and current carrying capabilities”. Upon closer review of the IPC-7095D document, it is clear that most of the test and images it refers to, are taken from either a 2D optical or 2D X-Ray perspective.

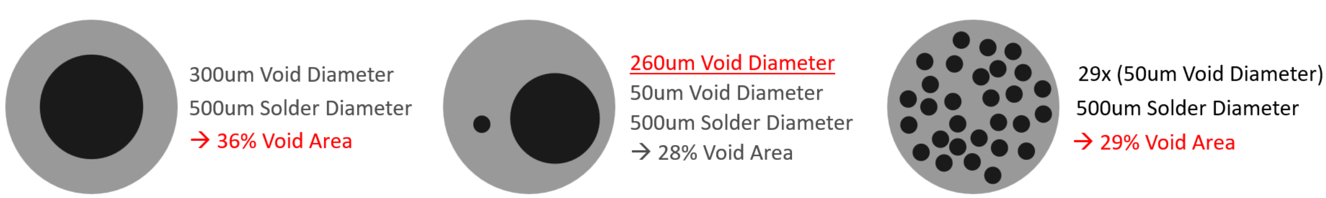


**Figure 2:** Examples of voids which do not meet IPC 7095D guidelines

This should raise some concerns because if an approach such as 2D transmission or Tomosynthesis is used, the resulting 2D image may show the outline of a void inside a solder ball, but one can only assume the dimensions of the void in the Z-dimension; it is also impossible to know if there are additional voids stacked above or below. There is no mention of specifically what void percentage should be allowed on a single plane within the solder ball. Furthermore, the IPC 7095 document may be slightly outdated, as it states that "Algorithms for X-Ray tomography do not perform summation of the voids", a statement which is completely untrue.

To better address concerns regarding voids, a method which provides access to multiple cross-section slices, such as CT, should be preferred since it allows for complete analysis of a solder ball's internal void topography without its sacrifice. As an example, [Figure 3] shows two different perspectives of the same joint for review. The first is a top-down X-Ray image taken with a true 2D approach, meaning that any features above or below the solder ball affect the brightness and contrast. In this scenario, only the XY view may be obtained. The second image is a single cross-section slice from a full 3D X-Ray inspection. This method offers multiple perspectives (virtually any perspective). While the XY images are very similar between the two approaches, the XZ perspective from the CT data shows a significantly different measurement. Here it can be seen that the actual volume of the void is close to 27% of the entire solder ball. Ultimately this begs the question of whether a new suggested criteria be introduced or if CT X-Ray inspection is recommended to truly identify the severity of a void defect.

This comprehensive analysis of void defects using CT X-Ray inspection sets the stage for addressing other subtle issues, such as the Head-in-Pillow defect, which arises from complex processing challenges. A Head-in-Pillow (HiP, Head-on-Pillow, or Ball-in-Cup) is a undesirable result of a processing issue and is extremely difficult to correctly detect, depending on its severity.

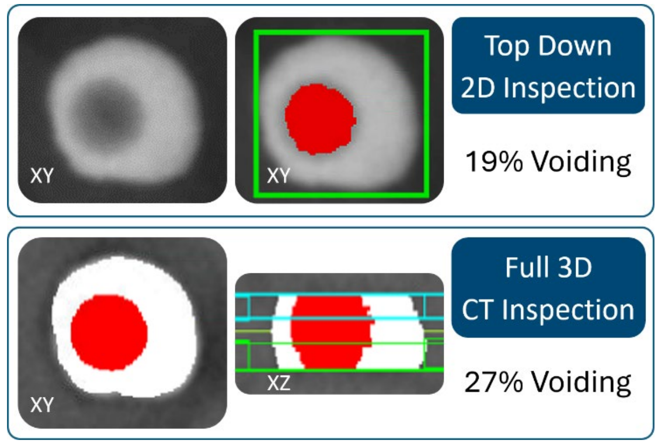


**Figure 3:** X-Ray Images with void measurements

These defects are typically introduced when the solder ball from the BGA does not correctly coalesce with the paste during the reflow process. The result is a poor electrical and thermal connection between the two, which typically presents itself a ball resting on squished bed of paste…often resembling a head pressed into a pillow [Figure 4]. From a top-down perspective, the ball often appears slightly shifted off-pad in the X and Y direction, however it may also be perfectly aligned. Usually, the better approach in identifying this issue is to inspect the profile from a ZX or ZY perspective. Under review, the ball generally exhibits a narrowing of the "waist" somewhere in the center region of the joint. This "narrowing" is the same interface where a single hairline crack can form and compromise the electrical, thermal, and mechanical properties of the joint.

Interestingly, IPC mentions that manufacturers should inspect for HiP defects and remove or rework appropriately. However, IPC does not specify the criteria or approach to do so. Of course, X-Ray is the only technology which can realistically meet the challenge, since it would be impractical to physically cut every sample in a production line.

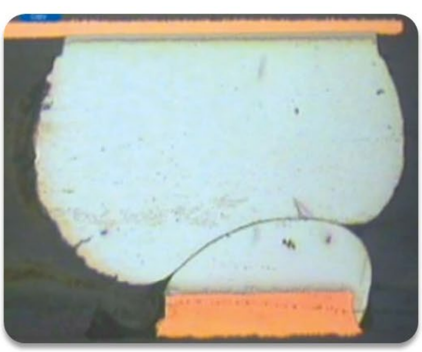

*Figure 7-74: Example of Head-in-Pillow (HiP) showing ball and solder paste that have not coalesced
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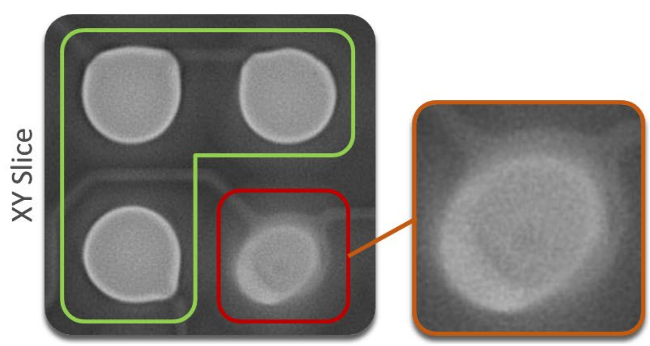


Cross-section slice near pad interface of HiP Defect

**Figure 4:** Examples of HiP Defects

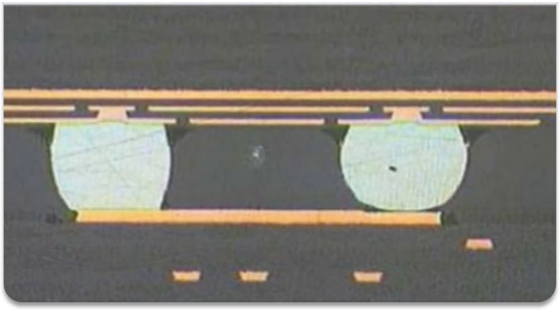

*Figure 7-79: Examples of Hanging Ball Defects

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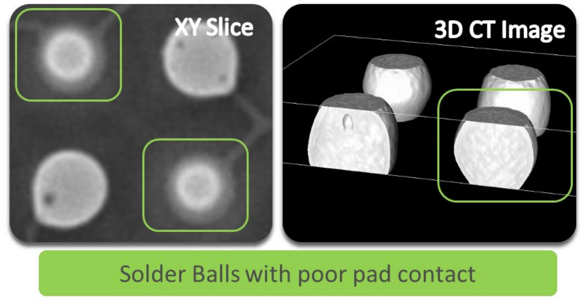


**Figure 5:** Examples of poor wetability

Spotting the defect with a 2D manual technique is quite difficult for every joint since it requires the operator to pan and tilt enough to completely study each ball. Therefore, when all solder joints must be inspected for HiP defects, a fully 3D CT X-Ray inspection approach is the only solution. An automated CT system can capture over 300 cross-section slices of every solder joint and apply inspection criteria offering repeatable and consistent results. With the addition of intelligent solder highlighting and defect logic tests, individual HiP defects can be identified amongst thousands of other solder balls within a matter of seconds. Furthermore, the repeatable and systematic nature of a CT scan also provides engineers with the ability to monitor their production such that they can predict when a HiP defect may occur.

While a HiP defect is often the first one referenced when discussing a solder ball's wettability, there are situations when a solder ball simply does not wet to the pad. These non-wets are similar to HiP, but rather than having a poor interface between the ball and paste, they have a poor connection to the pad. These defects can be even harder to identify since they do not necessarily have a shift in any direction. In most cases the ball has a simple round shape and shares most of the same characteristics as its neighbors. Similar to the HiP, a ball with wetting issues can be seen if physically cut along a plane perpendicular to the surface of the PCB, which is something that only 3D CT X-Ray can provide. From a quantitative or measurement perspective, the cross-section slices in the region of the solder ball closer to the pad, will show less solder, indicative of a ball that does not properly wet to the PCB. In fact, depending on the severity of the defect, it may even be possible to see the bare copper pad Figure 5.

**Benefits of 3D CT X-Ray Inspection**

Electronic applications have become too complicated for 2D X-Ray inspection alone. To meet IPC's standards while accommodating busier assembly lines with a limited amount of experienced operators, SMT manufacturers are forced to rely more on intelligent equipment. A fully automated 3D CT X-Ray inspection machine is an ideal solution, as it is well equipped to automatically detect and measure the same defects mentioned in IPC's 7095 standards guide. With the ability to capture full volumetric information and over three hundred cross-section slices for each solder joint, there is little opportunity for a defect to be missed. Voiding no longer needs to be limited to results from a single perspective, since the volume ratio of void to solder can be easily calculated. The contour and shape of a solder ball can be analyzed across the complete solder interface to ensure that defects like HiP, Non-Wets, or bridging are quickly identified in a matter of seconds and removed from the line.

The massive amount of measurements and qualitative information provided by CT-Xray systems can now enable more inspections to be easily automated, ultimately reducing the burden on engineers. With access to this impressive technology, tighter processing parameters can be maintained to ultimately ensure higher quality electronic products for a variety of markets. The adoption of fully automated 3D CT X-Ray inspection technology marks a pivotal advancement in electronic manufacturing, ensuring products meet the rigorous IPC standards. This technology enhances defect detection and analysis, significantly boosting production efficiency and product reliability across various markets.

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