IEC 61191-6

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour
inside

Printed board assemblies –
Part 6: Evaluation criteria for voids in soldered joints of BGA and LGA and measurement method

Ensembles de cartes imprimées –
Partie 6: Critères d'évaluation des vides dans les joints brasés des boîtiers BGA et LGA et méthode de mesure

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FOREWORD

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The text of this standard is based on the following documents:

FDIS	Report on voting
91/897/FDIS	91/909/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

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INTRODUCTION

The necessity for the evaluation of voids in soldered joints increases in the industry because the voids may affect the reliability of joints as the devices get smaller. As the number of interconnections increases the reliability per joint must also increase.

This subject has been discussed in some countries and trade organizations, and specific proposals have been made for classification or evaluation of voids to develop process guidelines. The same subject is also studied in academia to find correlation between voids and reliability of a joint. Appreciable findings are now available from the reliability study including relation between shapes of voids and degradation of life due to voids in a joint in thermal cycle stress.

Based on the information available, we developed evaluation criteria of voids in soldered joints for BGA (Ball Grid Array) and LGA (Land Grid Array) and a measurement method.

PRINTED BOARD ASSEMBLIES –

Part 6: Evaluation criteria for voids in soldered joints of BGA and LGA and measurement method

1 Scope

This part of IEC 61191 specifies the evaluation criteria for voids on the scale of the thermal cycle life, and the measurement method of voids using X-ray observation. This part of IEC 61191 is applicable to the voids generated in the solder joints of BGA and LGA soldered on a board. This part of IEC 61191 is not applicable to the BGA package itself before it is assembled on a board.

This standard is applicable also to devices having joints made by melt and re-solidification, such as flip chip devices and multi-chip modules, in addition to BGA and LGA. This standard is not applicable to joints with under-fill between a device and a board, or to solder joints within a device package.

This standard is applicable to macrovoids of the sizes of from 10 µm to several hundred micrometres generated in a soldered joint, but is not applicable to smaller voids (typically, planar microvoids) with a size of smaller than 10 µm in diameter.

This standard is intended for evaluation purposes and is applicable to

- research studies,
- off-line production process control and
- reliability assessment of assembly

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-1:1998, *Environmental testing – Part 1: General and guidance*
Amendment 1:1992

IEC 60194:2006, *Printed board design, manufacture and assembly – Terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60194 and the following apply. The terms and definitions for BGA and LGA have been added for the benefit of the reader, see also IEC 60194.

3.1
ball grid array
BGA
surface mount package wherein the bumps for terminations are formed in a grid on the bottom of a package

[IEC 60194, definition 34.1096]

3.2

land grid array

LGA

surface mount package with termination lands located in a grid pattern on the bottom of the package

[IEC 60194, definition 33.1891, modified]

3.3

void occupancy

ratio of the void cross-section area in a joint to the maximum cross-section area of the joint

NOTE Practical calculation for a void evaluation is specified in 6.1.

3.4

macrovoid

the most widely occurring voids in solder joints; these are caused by volatile compounds that evolve during the soldering processes, and they are typically larger than 10 µm in diameter

3.5

planar microvoids

series of small voids located at the interface between the PCB (Printed Circuit Board) lands and the solder; they are caused by the surface condition of the board

4 Voids in solder joints

4.1 General

A change in void size or frequency of voids may be an indication that the manufacturing parameters need to be adjusted. Two reported causes of voids are trapped flux that has not had enough time to be released from the solder paste, and contaminants on improperly cleaned circuit boards. Voids appear as a lighter area inside the X-ray picture of solder joints and are usually found randomly throughout the package.

4.2 Sources of voids

There can be voids in a BGA solder ball, in the solder joint to LSI (Large-Scale Integration) package interface, or in the solder joint to PCB interface. Various sources or reasons can be responsible for these voids. Voids can be carried over from original voids in BGA solder balls, which could be the result of the ball manufacturing process. Voids can be induced into the reflowed solder joint by either the voids in the original component solder ball, or during the reflow attachment process. Voids can also form near the PCB interface during attachment. These voids are typically formed during the reflow soldering process by flux volatiles trapped during the solidification of the molten solder. The source of flux volatiles can be either from applied flux itself (typically rework), or flux which is one of the constituents of the solder paste used in the reflow assembly process.

In addition to voids formed from via-in-pad construction, some voids are detected in the middle to top (ball/device interface) of the reflowed solder joint. This is expected because the trapped air bubble and the vaporized flux, which is applied to the PCB lands, rises during the reflow profile. This occurs when the applied solder paste and the BGA's collapsible solder balls melt together during the reflow profile. If the reflow profile cycle doesn't allow sufficient time for either the trapped air or vaporized flux to escape, a void is formed as the molten solder solidifies in the cool down area of the reflow profile. Therefore, the development of the reflow profile is extremely important as a contributor to the formation of voids.

Voiding can also be a result of surface contamination at the component land or at the PCB land, inter-metallics forming between solder ball and land, or un-expelled flux residues from the assembly process.

4.3 Impact of voids

How many and what size of voids should be allowable in the product before they impact the product's required reliability? Voids may impact reliability by weakening the solder balls and reducing functionality because the reduced cross-section will have lower heat transfer and current carrying capabilities. Large voids are more detrimental but small pre-existing voids can merge during reflow to create larger voids. The elimination of voids, or at least a substantial reduction, is generally preferred.

4.4 Void detection

X-ray is required for the detection of voids in BGA and LGA solder joints. Higher cost equipment is based on X-ray tomography or laminography. Both types of these systems provide valuable techniques for void detection and location.

X-ray systems tend to distort the size of voids depending on measuring conditions and the capability of the X-ray system used. It is possible to accurately measure the true volume of a void but the procedure can be involved and requires a known reference for radiometric calibration of the X-ray film or detector. In most cases the effort is better spent on identifying and eliminating the cause of the voids.

4.5 Void classification

In order to assess different conditions, voids have been given a specific identifier, based on location, to establish a method of void identification and the possibility of corrective action for process improvement. The details are provided in Table 1 which shows the classification criteria for the location of voids in the BGA solder ball structure.

The following descriptions identify the three different void types.

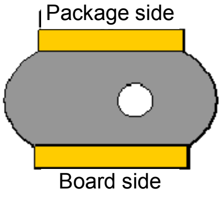
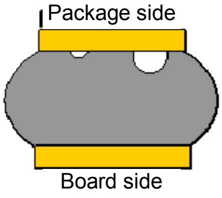
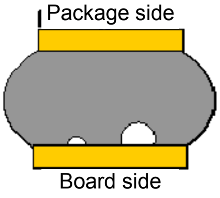
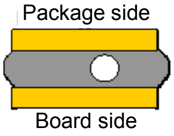
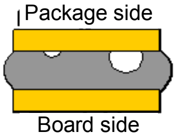
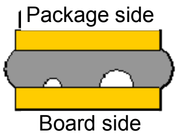
Type C: Void(s) within the ball after the board level assembly process.

Type D: Void(s) at the ball/package substrate interface after the board level assembly process.

Type E: Void(s) at the ball/board substrate interface after the board level assembly process.

This standard specifies evaluation criteria for voids in soldered joints and the reliability of the joints of devices assembled on a board. This standard is not applicable to the voids in the BGA package as received (refer to type A and type B in Table C.1), because any correlation between voids as received and voids after assembling has not been confirmed yet.

Table 1 – Void classification

	Type C **Void within the joint**	**Type D** **Void at the package interface**	**Type E** **Void at the board interface**
Void in BGA soldered joint			
Void in LGA soldered joint			

5 Measurement

5.1 X-ray transmission equipment

Micro-focus X-ray transmission equipment is such that it can observe a BGA or LGA mounted on a board from above or below the board. X-ray computer tomography (CT) equipment may also be used, if necessary.

The test equipment should have the following specification and performance. An example of the specification of available equipment is described in Annex B.

a) Maximum voltage: not less than 120 kV
b) Feature recognition size of X-ray: typically 2 µm
c) Maximum geometric magnification: more than 100×

Commonly available transmission X-ray systems can vary in the grayscale sensitivity that they provide in the image which, in turn, can have an effect on the precision of the area calculation. It should be noted that systems with lower grayscale sensitivity may cause the void(s) to appear at a reduced size (and hence at a lower value) within the solder joint, as there is insufficient sensitivity to observe the true edges of the spherical void, and the smallest voids may not be visible at all. It is suggested that an X-ray system used for this standard has sufficient capability to be able to see a 20 µm diameter void (for a 6 layer double sided board).

5.2 Measuring environment

Unless otherwise specified, measurements should be made in the standard atmospheric condition, as specified in IEC 60068-1, after keeping the specimen in the condition for an appropriate period.

NOTE The standard condition is the following.

Temperature:	15 °C to 35 °C
Relative humidity	25 % to 75 %
Atmospheric pressure	86 kPa to 106 kPa.

5.3 Measurement procedure

The following procedure is recommended for reference measurement of joint size and void size, using X-ray transmission equipment with area calculation function. Different procedures may be applied for higher throughput with minimum accuracy required.

a) Detect an image of solder joints and identify the solder joints with voids to be measured. Multiple joints may be detected in a screen for higher throughput.
b) Determine geometric magnification for measurement. It is recommended that only one solder joint is detected in a screen for precise measurement. For example, approximately 80x is recommended for the measurement of a joint with diameter of 500 µm. When a higher resolution of an image digitizing system is available, multiple solder balls may be detected in a screen. Each ball in the screen is recommended to have more than 400 pixels in diameter.
c) Detect an image of void, with enough X-ray intensity to pass through the joint (for example, tube voltage is 100 kV), and adjust X-ray intensity and imaging condition.
d) Capture the void image and calculate the cross-section area.
e) Repeat procedure c) and d), when there are multiple voids. Measurement for smaller voids may be skipped, according to 6.2.
f) Detect an image of joint, with enough X-ray intensity to be identified (for example, tube voltage is 40 kV), and adjust X-ray intensity and imaging conditions.
g) Capture the solder joint image and calculate the cross-section area.

h) Calculate the void occupancy for the solder joint.

i) Repeat procedures c), d), e), f), g) and h) when there are multiple solder joints to be measured.

In procedure f), the same condition as in procedure c) may be applied, if there is no significant difference between calculated results under those conditions.

Predetermined conditions may be applied repeatedly in the procedures c) and f), if similar measurements are repeated as the measurement of the different points of the same LSI package.

5.4 Record of the measured value

Unless otherwise specified, the following measurement results should be recorded for each solder joints.

a) Void occupancy (O_v)

b) X-ray image

The following supplemental data may be recorded, if necessary.

c) Cross-section area of voids (A_{v1}, A_{v2}, A_{v3} …..A_{vn})

d) Maximum cross-section area of soldered joint (A_{smax})

5.5 Considerations on measurement

5.5.1 X-ray intensity for void detection

Sufficient intensity of X-ray (for example, tube voltage is 100 kV) to pass through the joint, is required for detection and measurement of voids in a soldered joint. When the X-ray intensity is insufficient (for example, tube voltage is 40 kV), X-rays are attenuated almost completely, whether there is a void or not in the path, and they can't make any image of the void, but only the shadow of the joint.

5.5.2 Detection of real edge

The thickness of solder in the path of X-rays changes gradually in the periphery of a void and joint. An X-ray transmission image of a void and joint is detected with the gradation of black and white in its periphery. It is very important to detect the outer edge of the gradation and to measure the maximum size of the outline image to obtain a precise measurement.

5.5.3 Verification of measurement results

The user should have some procedure that provides a reasonable correlation between the measurement and the actual void size. The verification with a specimen of a known dimension, or an observation of the cross-section is recommended.

6 Void occupancy

6.1 Calculation of void occupancy

The void occupancy, O_v, defined in 3.3 is calculated from the maximum cross-section area of the soldered joint, A_{smax}, and the cross-section area of a void, A_v. The maximum cross-section area of the joint, A_{smax}, is measured from the projected image of a joint. The cross-section area of the void, A_v, is also measured from the projected image of a void, regardless of its location in the joint.

$$O_{\mathrm{v}} = \frac{A_{\mathrm{v}}}{A_{\mathrm{s\,max}}} \qquad (1)$$

where

O_{v} is the void occupancy,

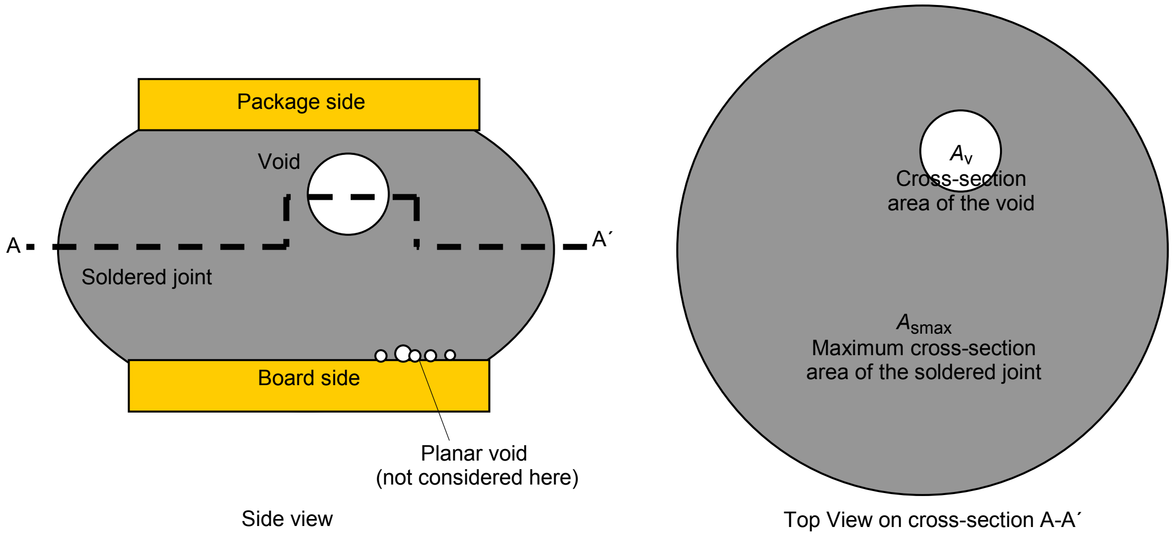
A_{smax} is the maximum cross-section area of the soldered joint,

A_{v} is the cross-section area of the void.

For example, if the solder ball size = 300 μm and void size = 50 μm in diameter and the cross-section of void and joint is approximated by a circle, the void occupancy is calculated as follows:

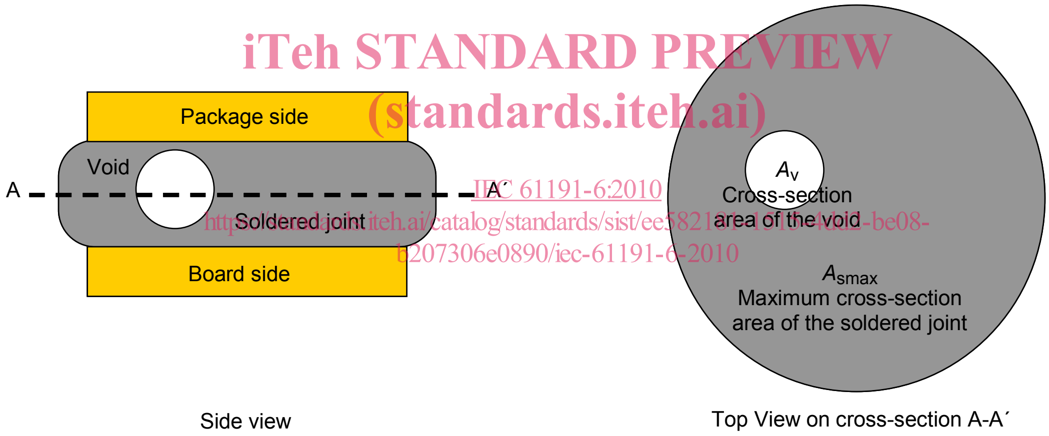
void occupancy $$O_{\mathrm{v}} = \frac{A_{\mathrm{v}}}{A_{\mathrm{s\,max}}} = \frac{\frac{\pi}{4}(50)^2}{\frac{\pi}{4}(300)^2} = 0{,}028 \cong 3\ \% \qquad (2)$$

The relationship between cross-section image detected by X-ray and void occupancy is shown in Table 2.



IEC 011/10

Figure 1a – BGA soldered joint



IEC 012/10

Figure 1b – LGA soldered joint

Figure 1 – Void occupancy