

COMMON PROCESS DEFECT IDENTIFICATION OF QFN PACKAGES USING OPTICAL AND X-RAY INSPECTION

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ABSTRACT

The Quad Flat Pack No Leads (QFN) style of leadless packaging [also known as a Land Grid Array (LGA)] is rapidly increasing in use for wireless, automotive, telecom and many other areas because of its low cost, low stand-off height and excellent thermal and electrical properties. With the implementation of any new package type, there is always a learning curve for its use in design and processing as well as for the Process and Quality Engineers who have to get to grips with the challenges that these packages bring. Therefore, this paper will provide examples of the common process defects that can be seen with QFNs /LGAs when using optical and x-ray inspection as part of manufacturing quality control. Results of trials conducted on four PCB finishes and using vapour phase and convection reflow will be discussed. In addition to optical inspection, the use of high resolution, high magnification x-ray inspection provides a non-destructive test for the optically hidden aspects of the package so as to highlight open joints and the excessive voiding that can often be seen under the central part of the package. Such excessive voiding can not only affect the package's thermal performance during operation, it can also modify the stand-off height. Therefore, monitoring this voiding provides a valuable method to qualify the presence of unsuitable stand-off heights which, in turn, may increase the propensity for open joints during production.

Key words: QFN, quad flat pack no leads, LGA, land grid array, x-ray inspection, optical inspection, defect

INTRODUCTION

The Quad Flat Pack No Leads (QFN) style of leadless packaging is becoming ever more used for many applications in printed circuit board assembly. This is because of its low cost, compared to other package types; its low stand-off height, enabling thinner final products; and its excellent thermal and electrical properties. Although most commonly known as QFNs, the same, or similar, package types are also known under other names. The most common alternative is Land Grid Array (LGA). However, other terms that can be used to describe the same thing

include Plastic Quad Flat No-Lead (PQFN), Micro Lead Frame Plastic (MLFP), Small Outline No-Lead (SON – two sides) and Micro Leadframe Package (MLP). A simple common description of all of these packages is of a number of planar connections around the edge with the bulk of the joint termination running back under the package. Often, the edge termination continues a small way up the vertical side of the moulded exterior. There may also be a further single large termination/heat sink under the majority of the central portion of the device (see image 1). As will be discussed later, it is not just the quality of the edge connections that must be ensured during board assembly, but also the level of voiding within the central, large pad in the centre (if present). If such a central pad is being used for removing heat from the component, then any reduction in the thermal efficiency, caused by the voids producing a poor thermal contact, may not only result in device overheating but also likely failure.

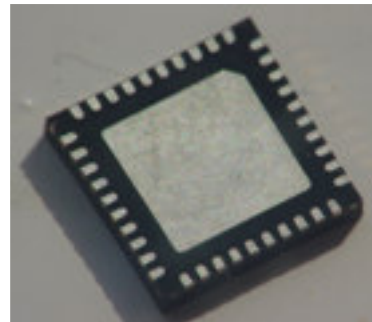


Image 1: Optical image of QFN package terminations

As the package terminations are all located under the device, it makes traditional Automated Optical Inspection (AOI) very difficult, if not impossible, as the main bulk of the edge joints, and the entire central joint, are hidden from view. In addition, should the side terminations on the package not wet during reflow then this will further mitigate the efficiency of AOI with these packages. Manual use of an edge viewing optical microscope does offer some good information as to the quality of the edge joints in these packages, as will be seen later, but, once again, the

central joint is unable to be evaluated. In contrast, using x-ray inspection within the production environment offers a non-destructive method for investigating all of the package terminations, including the voiding under the central pad.

The use of x-ray inspection for investigating QFN packages has been helped by recent developments made in 2-dimensional (2D) x-ray inspection equipment [1 – 3]. In particular, the improvements in resolution magnification and greyscale sensitivity, especially when inspecting at oblique angle views. In addition, new x-ray systems include digital x-ray imaging detectors, which have enhanced greyscale range as standard, that enables far better visual separation of similarly dense features [3] so as to ensure the best effective identification and analysis (see image 2).

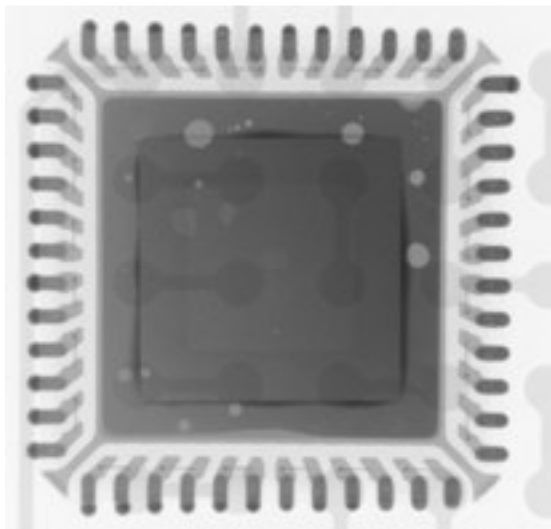


Image 2: X-ray image of QFN post reflow

Together, these x-ray developments allow a relatively inexperienced operator to quickly assess and quantify the analysis within the production environment. With lesser x-ray inspection equipment, that lacks good magnification, resolution and contrast sensitivity, the clarity of the analysis may be more difficult to achieve.

EXPERIMENTAL DETAILS

During the four years of running the Lead-Free Experience ('Experience') [4], lead-free processing trials were conducted using convection and vapour phase reflow on boards with different surface finishes. The boards were 1.6mm thick and contained a range of different surface mount components and the through-hole connectors. During the most recent 'Experience', two 40-pin QFN packages 6 x 6 mm square were included in the design. Two different package configurations were used, so as to have different types of side terminations. Trials were also conducted for QFNs processed onto flexible circuits using similar design rules and process parameters as for the rigid boards.

Two types of rigid laminate construction were used:

- ISOLA 410 Materials - 1.08 mm cores 35/35 um + 2 x 7628 pre-pregs
- ISOLA 104 (Standard FR4) Materials - 1.00 mm cores + 2 x 7628HR pre-pregs

The flexible circuit construction was:

- 0.05mm Copper 18/18um ESPANEX from Holders Technologies
- Liquid Solder Mask - MPR80 Amber from Nippon Steel

The flexible circuits and the rigid boards were divided into four batches. One of the four main surface finishes typically considered for lead-free manufacture was then applied to each batch. This provided a stock of identical boards where the only difference was the surface finish. The surface finishes used were:

Immersion Nickel/Gold - Aurotech, from Atotech
Immersion Tin - Stannatech from Atotech
Immersion Silver - Sterling from MacDermid
OSP - Gliccoat SMD P2 from Shikoku

Both the flexible and rigid circuit boards were then assembled with the following process steps:

Electroform nickel stencil
Siemens placement
Convection & vapour phase reflow
IR and convection rework

Further details and the process parameters used can be found in the Lead-Free Experience Report [4]. For the 'Experience 4' experiments, the sample boards were additionally thermally cycled between -55°C and +125°C; initially for 2000 cycles and subsequently for a further 900 cycles. The cycle duration was 48 minutes. The temperature cycling was kindly conducted by Milos Dusek at the UK National Physical laboratory (NPL) where free space was available in one of their test chambers. Each of the experimental boards was visually examined and selected examples micro-sectioned. This part of the exercise was primarily associated with testing micro-via hole reliability and is discussed in a separate paper [5].

X-ray examination of the QFN joint quality was conducted after the soldering processes and after 900 thermal cycles. A digital x-ray inspection system was used for this analysis. The x-ray system had a 'sealed transmissive' type of x-ray tube with sub-micron resolution that provided 16-bit greyscale sensitivity with a real-time x-ray image size of 2.0 Mpixels on-screen. The x-ray images were acquired at 30 frames per second. The system was able to provide oblique angles of up to 70° at any point 360° around any position on the test board without compromising the available magnification. This is achieved through tilting the x-ray detector instead of tilting the board.

ANALYSIS – OPTICAL INSPECTION

Optical inspection of the QFN joints within the test boards showed that the majority of joints were of good quality, irrespective of whether convection or vapour phase reflow was used. However, the few defects that did occur have provided a range of pictures that offer good reference images as to good and 'good bad' examples of QFN edge terminations. Images 3 – 8, provide typical examples of the results and offer some comparison benchmark for those who may be less familiar with using QFNs.

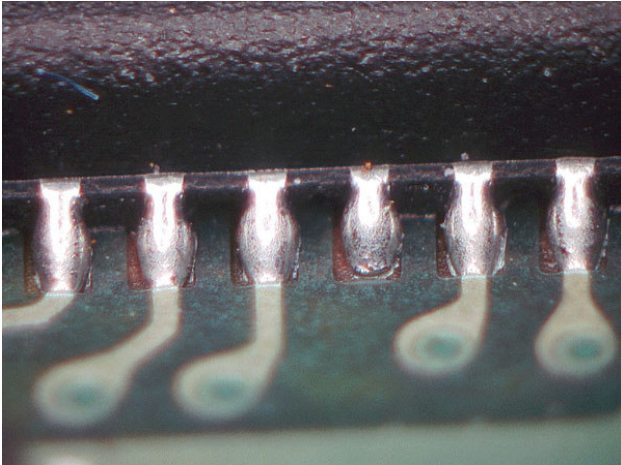


Image 3: Optical image of edge termination solder joints on a QFN component. The component supplier has managed to achieve an optimum plating finish on the terminations which has allowed a 'classically perfect' fillet to form during reflow, which includes coverage of the side terminations.

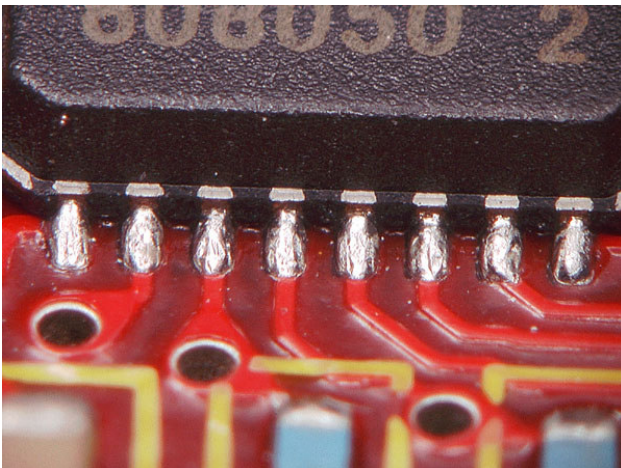


Image 3a: Optical image of edge termination solder joints on a QFN component. This shows satisfactory solder fillets on the edge terminations but there is no substantial wetting of the side terminations. This type of view is far more commonly found during real manufacture.

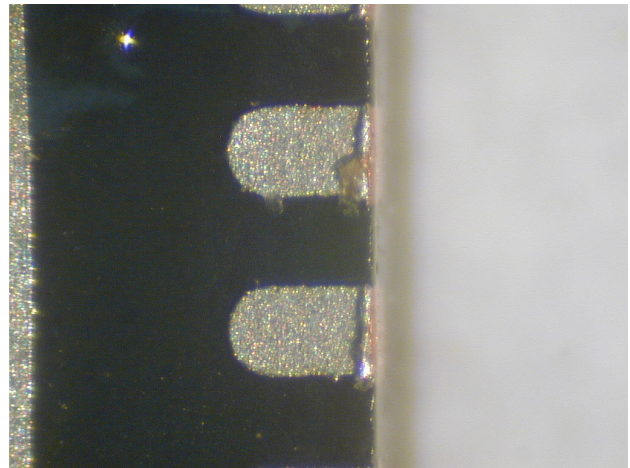


Image 4: Optical image of the base of a QFN showing typical pad burring that may be seen on edge-terminations. This is caused by poor component singulation of the lead-frame during device manufacture.

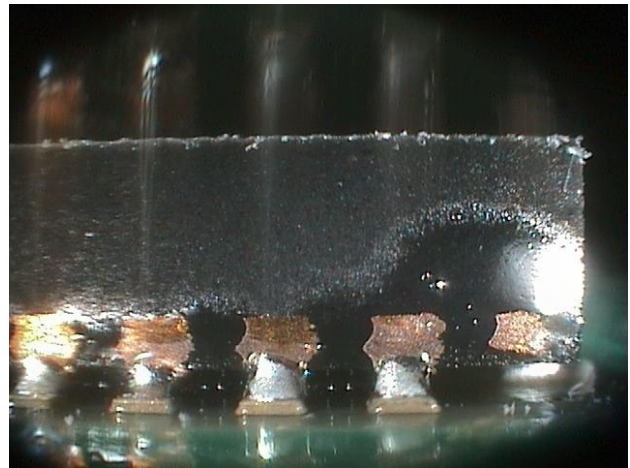


Image 5: Optical image of the edge of a QFN post reflow. The right most joint has not been made successfully and should be compared to the other joints shown. This has been caused by excessive paste being applied to the central QFN pad and/or excessive voiding occurring in the central pad during an inadequate reflow profile. These conditions make the QFN 'float' on the central pad during reflow, which raises the package above the board more than normal, and so interferes with the capillarity action of the reflow process. These issues have also led to variation in the solder quality on the side fillets. Issues with the QFN central pad cannot be seen by visual inspection and it is possible that other factors may also cause failed edge terminations. X-ray inspection (see later) allows a non-destructive view of the central QFN pad to confirm, or otherwise, the analysis.

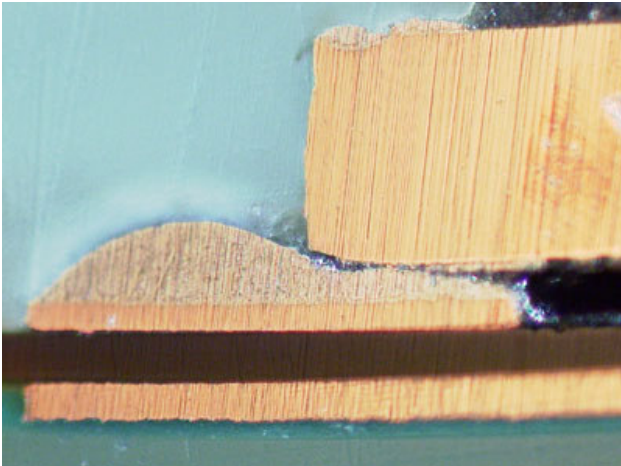
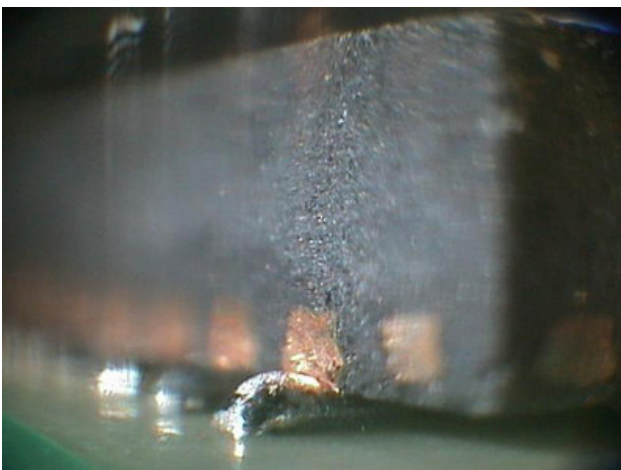
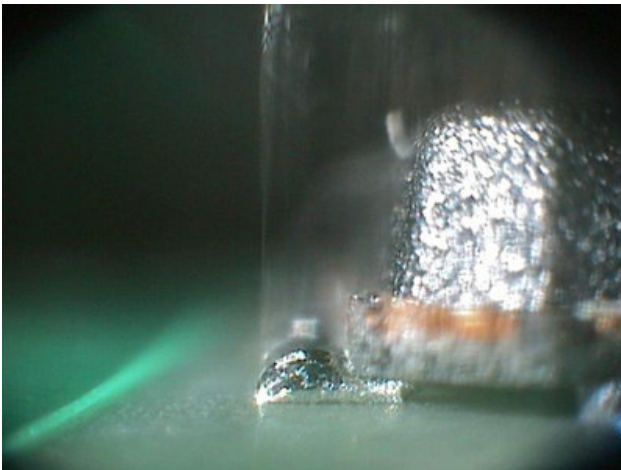


Image 6: Micro-section of a QFN on a flexible circuit. The QFN has 'floated' due to excessive paste deposited on the central pad and/or excessive voiding in the centre pad. This has caused an open joint. This failure may have been exacerbated by solderability or burring issues in the component plating.



Images 7 & 8: Optical images of a QFN showing that solder joints have formed on the base of the device. However, if the side terminations do not wet then the visual appearance of the joints may vary making it very

difficult for AOI inspection. The land pattern should still extend outside of the component footprint and the length of the pad designed under the part should extend to the end of the metalisation. Although good wetting of the side terminations is not required to make a good QFN edge joint, if they are present then it is often a great help to inspecting their quality in the real world of manufacturing.

ANALYSIS – X-RAY INSPECTION

As with the optical inspection images, the test boards have provided useful reference x-ray images to show the difference between good and bad QFN joints (see images 9 and 10). The defects were more likely caused by the rush to produce boards from an ad hoc assembly line at an exhibition rather than by any underlying issues with the use of QFN packages under convection or vapour phase reflow. The good joints remained good, even after the thermal cycling.

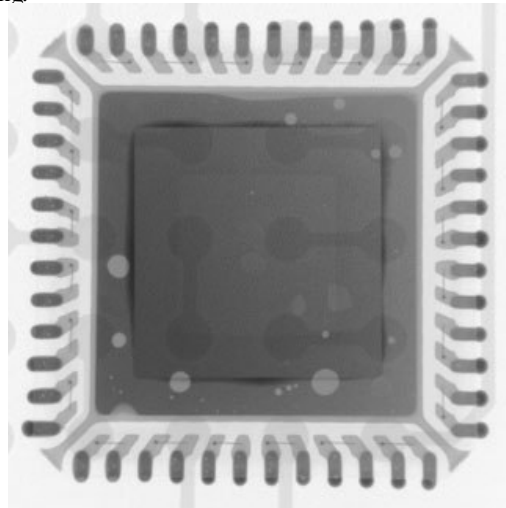


Image 9: X-ray image of a QFN reflowed onto a flexible circuit showing good, consistent edge joints and very little voiding under the central pad.

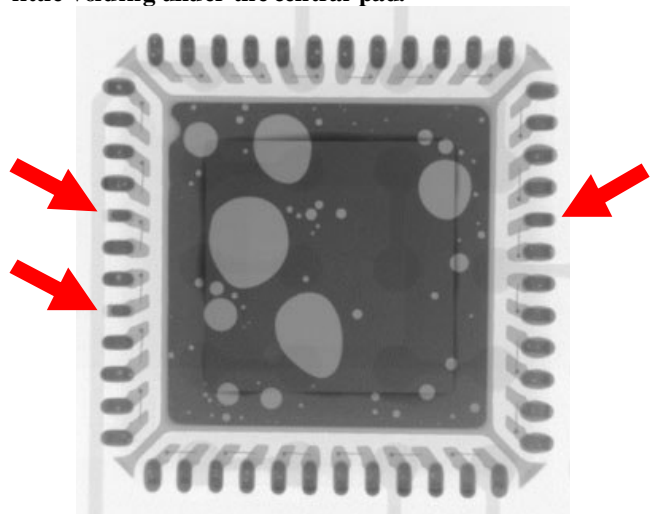


Image 10: X-ray image of a QFN reflowed onto a flexible circuit showing open edge joints (as seen by the shape of, and less material in, the joint – see arrows and

compare with image 9 and the substantial voiding under the central pad.

It was in the central pad however, clearly seen under x-ray inspection, where the voiding levels varied dramatically across all the test boards. This was irrespective of the reflow method used on the board and this variation was especially marked on the QFNs placed on the flexible circuits (see images 9 and 10).

As described previously (image 5), the most likely cause of this voiding variation is because of solder paste deposition variability during printing owing to the un-optimised nature of the production line used at the 'Experience'. An excess of solder paste may cause the QFN to 'float' over the pad and, as a result, impact on the heat dissipation and/or the efficiency of operation of the package. It should be noted that the excessive voiding levels were slightly more pronounced on convection reflowed boards compared to vapour phase. However, the difference was small and there were many convection reflowed boards that showed little, or no voiding. Any discrepancy in the data may have been caused instead by the wetting efficiency of the PCB solder finish and/or the stencil design.

Optical Inspection Criteria for QFNs

Optical inspection criteria for QFNs are suggested by the IPC-A-610D document [6]. In particular, it suggests that the maximum side overhang of the termination relative to the pad be at most 25% of the pad width for class 2 and 3 products. It also suggests that the minimum end joint width is at least 75% of the total pad width for class 2 and 3 products (see diagram 1).

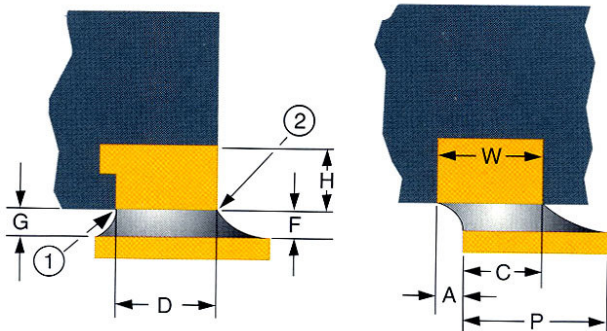


Diagram 1: Optical inspection criteria for QFNs (from IPC-A-610D – see reference 6).

To provide a simpler understanding of the visual appearance of acceptable and unacceptable QFN joints in manufacturing, shop floor inspection posters are available [7]. Images 11 – 13, show typical examples

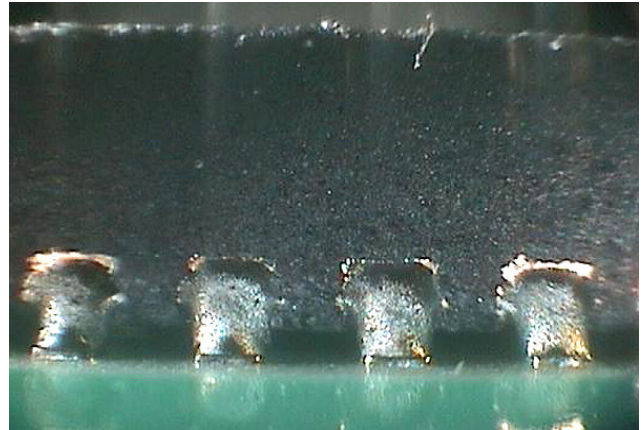


Image 11: Optical image of acceptable QFN edge terminations. Solder fillets should exist if the design incorporates pads that extend beyond the package width.

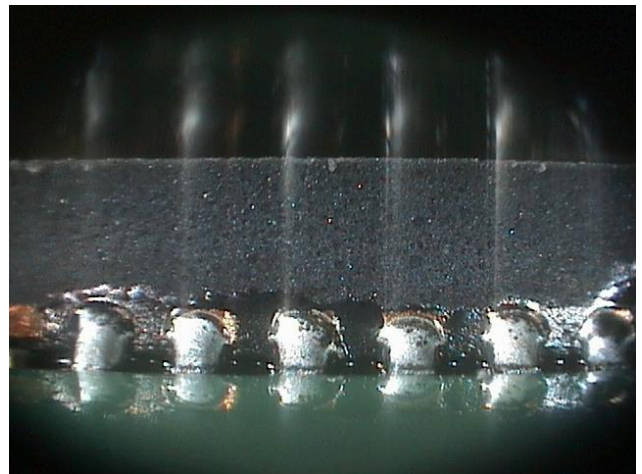


Image 12: Optical image of acceptable QFN edge terminations. Solder fillets should be visible to a minimum of 75% of the width of the termination.

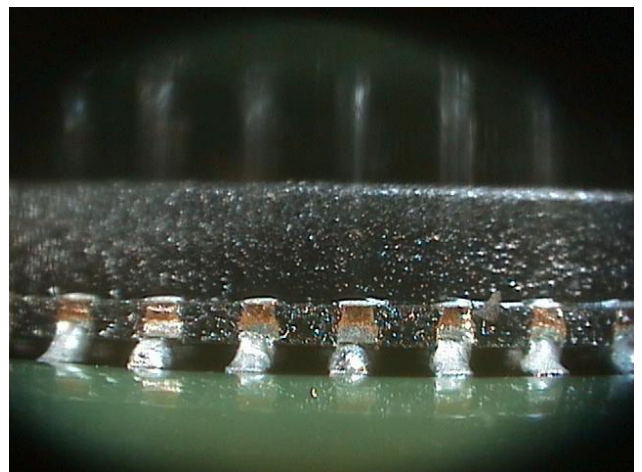


Image 13: Optical image of unacceptable QFN edge terminations. The solder rise is limited and an open joint can be seen. The package is also 'floating' above the surface of the pads.

X-ray Inspection Criteria for QFNs

As there is no explicit recommendation in the IPC-A-610D as to acceptable x-ray inspection criteria for QFNs, the following are suggested as a guideline. Further information on suggested x-ray inspection guidelines for a range of typical components used in production can be seen in reference 8. A comparison between x-ray images of a good and a bad QFN are shown in images 9 and 10 as well as in image 14.

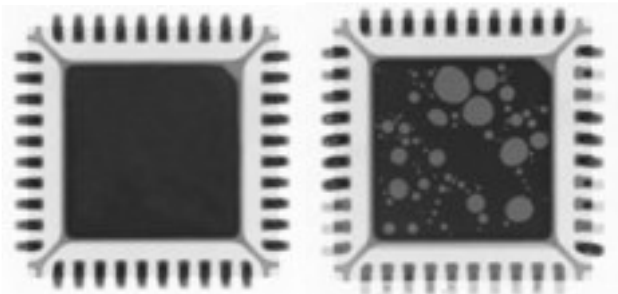


Image 14: X-ray images of QFNs following reflow showing an ideal example (left) and an unsatisfactory one. Note the joint variations in the unsatisfactory example which can be clearly seen, even at low magnification, and therefore, with this x-ray system, does not require additional higher magnification or oblique angle views to be taken.

X-ray inspection should commence at one corner of the device and scan around all four sides. Attention should be paid to the presence of fillets, if they exist, on extending lands.

The maximum void percentage in any one termination, including the central pad, should be less than 20% of the joint area. In the case of multiple voids, the maximum void percentage should be also less than 20%. It should be noted that blind vias in the centre pad area, or through-vias with solder mask capping the opposite side of the board, are likely also to contribute to voiding.

Images 15 – 17 and 18 – 20 show three example x-ray images of QFNs. Each indicates a different level of joint condition acceptability for the edge and central terminations respectively. These are:

1. Target Condition – An image of the ideal solder joint when inspected with x-ray.
2. Acceptable Condition – An image of the joint appearance in the x-ray system that is at the maximum permitted level of deviation from that set as the target condition. These joints will not require rework but suggest a process review be considered to improve the joint quality towards the target condition. This level is the minimum condition for the production process.
3. Defect Condition – An image of the joint appearance in the x-ray system indicating an unacceptable joint. The

cause(s) of this condition should be investigated and necessary corrective action to the process applied. Possible rework of such joint conditions should wait until the process has been corrected.



Image 15: Target Condition of QFN edge joints where showing a moderate level of voiding within joints is acceptable. All joints have reflowed.



Image 16: Acceptable Condition of QFN edge joints showing an increased level of voiding within the joints but well within any action level.

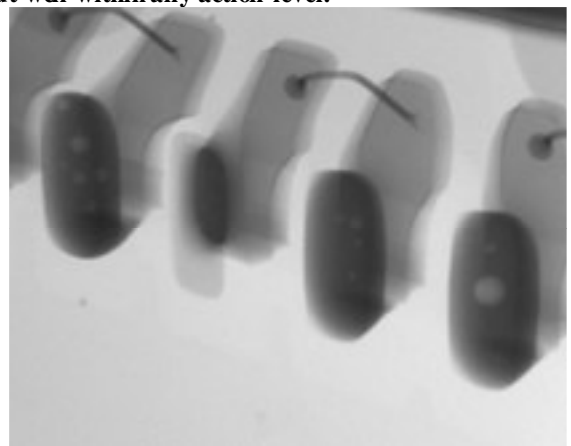


Image 17: Defect Condition of QFN edge joints showing insufficient solder in a joint (this example) or voiding exceeds 20% of the joint area of a single joint.

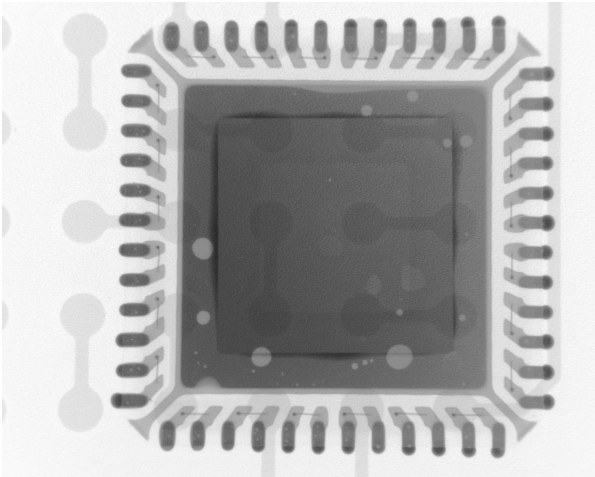


Image 18: Target Condition - Moderate level of voiding under the central termination is acceptable. All edge terminations are consistent.

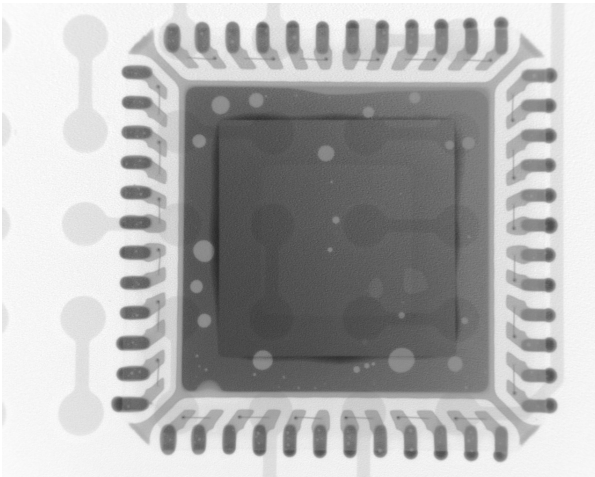


Image 19: Acceptable Condition –An increased level of voiding is seen in the central termination.

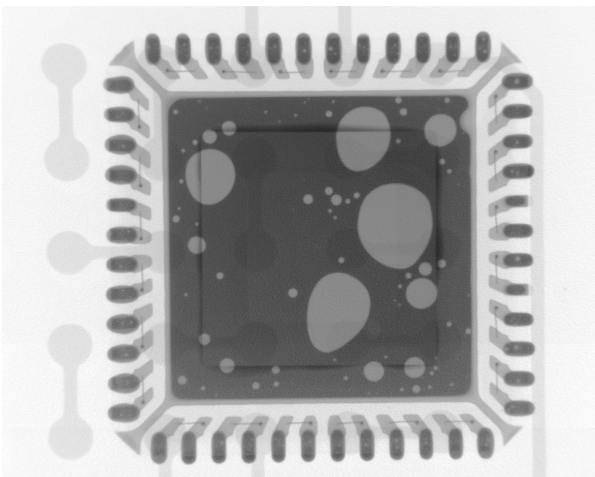


Image 20: Defect Condition - Excessive level of voiding is seen both in total quantity and for individual voids. Open joints are also seen in the edge terminations.

CONCLUSIONS

Manual optical inspection for QFNs (LGAs) or similar packages is possible provided the Design Engineers include lands that protrude outside the footprint of the package. This permits the formation of visible solder fillets. However, it is not practical to manually optically inspect these joints in quantity. Therefore, implementing proper process control and good process engineering practice is the best solution to getting good joints in the first place.

Automatic optical inspection systems can inspect joints formed around the QFN devices provided that suitable footprints are used by Design Engineers. However, defining the best criteria for automated testing of QFNs can be challenging due to the variations that can exist on the edge of the package. These variations can be caused by limited wetting of the side terminations and/or burring produced following singulation of the components during their manufacture.

It is not possible for optical inspection to check for variation in the height of the package above the pads, which may occur if the device ‘floats’ owing to the deposition of excess solder paste and/or excessive voiding under the central termination.

X-ray inspection can easily show, and measure, the level of voiding under the central termination, allowing quick and practical confirmation, or otherwise, of a good manufacturing process. It will not check the height variation directly, but if there are substantial volume changes in the conductive material underneath the device then this will be seen as discrete density differences in the x-ray image. Excessive voiding levels will also be clearly visible. Together, these observations can be correlated with the likelihood of the device ‘floating’ above the surface of the pads and its potential for failure when in use.

Changes in the density and shape of the edge terminations can also be quickly observed in QFNs by x-ray inspection. Such variation will strongly indicate the presence of open and partial joints, especially when compared to the other terminations in the device and to comparison images from ‘golden’ reference samples.

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