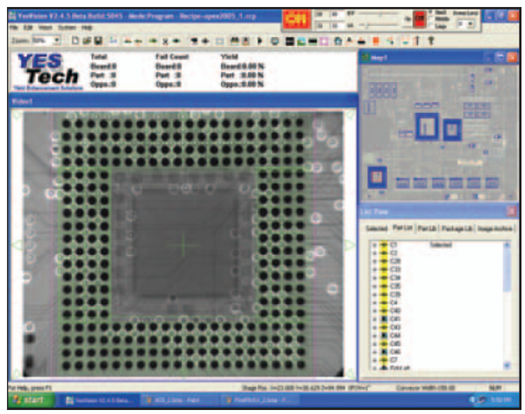
NASA-DoD Lead-Free Electronics Project

Automated X-Ray of Circuit Card Assemblies

Machine:
YESTech YTX-5000 model in-line x-ray machine
X-Ray Tube: Sealed reflection target
130 Kv, 5 micron spot size
39-watt max. output
X-Ray FOV 0.2” to 1.5” variable



Program settings:
All x-ray inspections are performed at 75kV and 40μA.
Inspection set-up:

QFN

1. Inspect each lead bank for joint presence and bridging
   Threshold = 172
2. Inspect center pad for voids (flag if > 25%)
   Threshold = 151

CSP-100

1. Inspect blocks of balls (5 x 5) for presence and bridging
   Threshold = 120
2. Inspect shape of individual balls for consistency
   Threshold = 120
   Shape Limit = 1.45
3. Inspect size of individual balls
   Threshold = 120
   Size Range = .125 mm^2 - .175 mm^2
   Translates to ∅ range of approx. 0.40 mm – 0.47 mm
   Loose component ball size is 0.46 mm
   Average x-ray ball size is 0.45 mm
4. Inspect individual balls for voiding (flag if > 10%)

Threshold = 100

BGA-225

1. Inspect blocks of balls (3 x 3 and 3 x 4) for presence and bridging Threshold = 95
2. Inspect shape of individual balls for consistency
   Threshold = 95
   Shape Limit = 1.45
3. Inspect size of individual balls
   Threshold = 95
   Size Range = .400 mm² - .525 mm²
   Translates to ∅ range of approx. 0.71 mm – 0.82 mm
   Loose component ball size is 0.75 mm
   Average x-ray ball size is .81 mm
   This range was extended to .390 mm² - .550 mm² as various batches were run – a single batch tended to push one end of the range or the other, but would not vary over the entire range
4. Inspect individual balls for voiding (flag if > 10%)
   Threshold = 75

Shape Limit: For a perfect circle, the shape value will be 1. As a shape deviates from a perfect circle, the shape value will increase. It is unknown exactly how the value is calculated, but the equipment/software vendor recommends using a shape limit of 2 or less.

Ball Size: The measured size of the ball in the x-ray image is dependent on several factors:

- Original component ball size
- Amount of solder added at assembly
- Weight of component (squish factor)
- X-Ray parameters (power)
- Background (extent to which ball contrasts with surrounding image)
- Threshold value (ball edges are ‘feathered’, and affected by small changes in threshold)

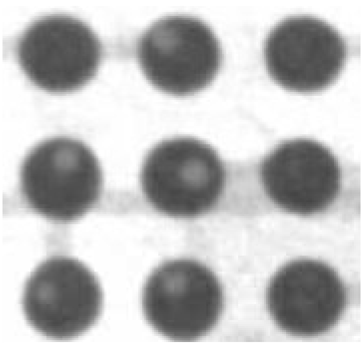
With some degree of effort, the measured balls size from the x-ray image may be adjusted to match the actual ball size by manipulating the power and threshold settings. This is not necessary, however, and setting relative limits to detect defects on an optimized image is suitable. The limits are not necessarily at the defect level, however, and many balls flagged by the system were in fact not defects.

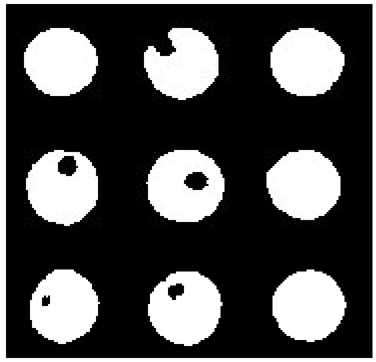
The automated x-ray system applies inspection algorithms to binary images to determine the presence of defects. The inspections include:

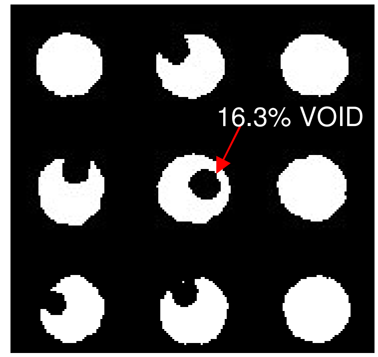
- Looking for the expected number of distinct shapes within the inspection area, within a range of the expected size, and at the expected locations (pitch)
- Checking the overall size (diameter / pixel count) of the shapes found
- Checking the ‘roundness’ of the shapes found

- Looking for and evaluating size of voids within those shapes found

The algorithm requires that a threshold value be set to define what is, and what is not, solder. This will be used to create the binary images from the raw x-ray images. This value is determined by the programmer.

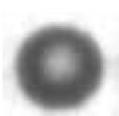

Raw X-Ray Image

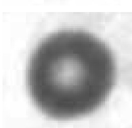

Binary Image for Ball Inspection

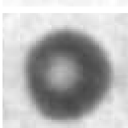


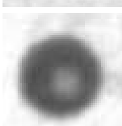
Binary Image for Void Inspection

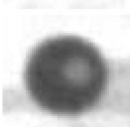
The first image above is the raw x-ray image of part of a BGA. Voids within the solder ball are clearly visible as lighter spots within the joints. The second image is the binary image used to determine the presence, size, and shape of the solder balls. A threshold value has been set (based on the contrast between solder and surrounding areas) for this image such that the resulting shapes in the binary image match the size of the solder balls in the raw x-ray image. The third image is the binary image used to evaluate the presence and size of voids. Because the contrast between the voids and the surrounding solder is different from the contrast between the solder ball and the surrounding area, the threshold level is different, and a different image is created. This threshold value is set such that the resulting voids in the binary image match the size of the voids in the raw x-ray image

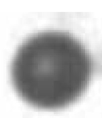

31.9%

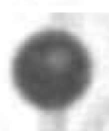

26.7%

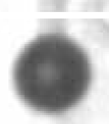

25.0%

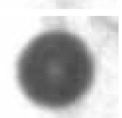

20.9 %

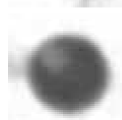

16.3%


13.2%

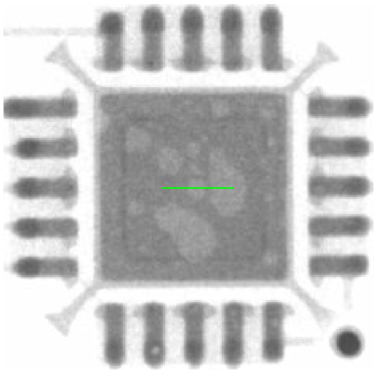

11.8%

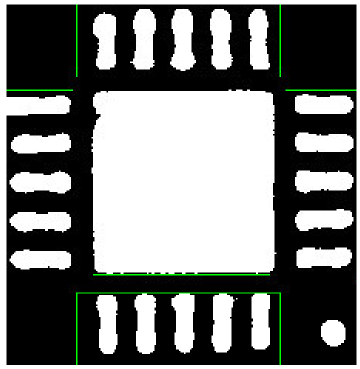

7.9%

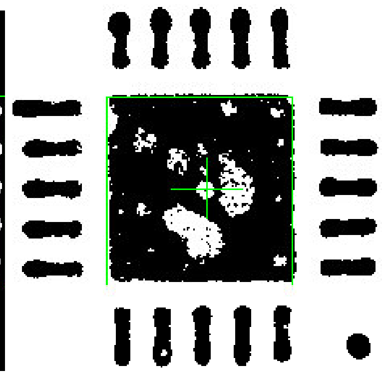

3.2%


Bad Shape Defect

Similar to the BGA inspection, the images below of for QFN x-ray inspection. The first image is the raw x-ray image, the second is the binary image for lead bank inspection, and the third is the binary image for void detection. The combined area of the voids shown in this example was calculated at 16%.


Raw X-Ray Image


Binary Image for Lead Inspection

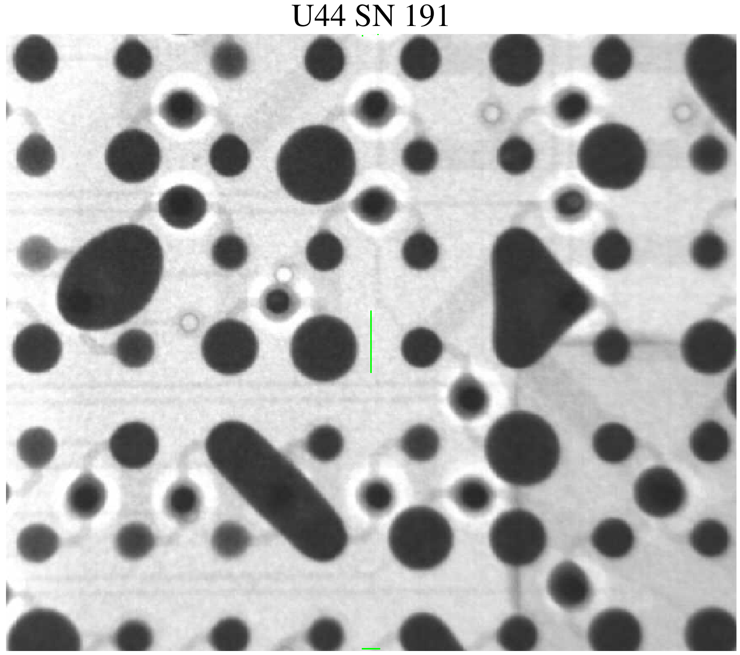

Binary Image for Void Inspection

Results:

Batch A

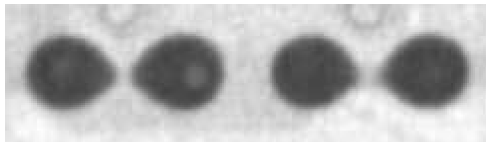
Bridging: The only obvious voids identified were on U44 of SN191, where something apparently went wrong:

U44 SN 191



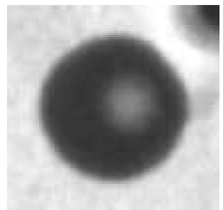
There was also some implied bridging. This tear-drop shape (below) was not uncommon and fell along the paths of electrical connection on the bottom side of the package:

U35 SN 193

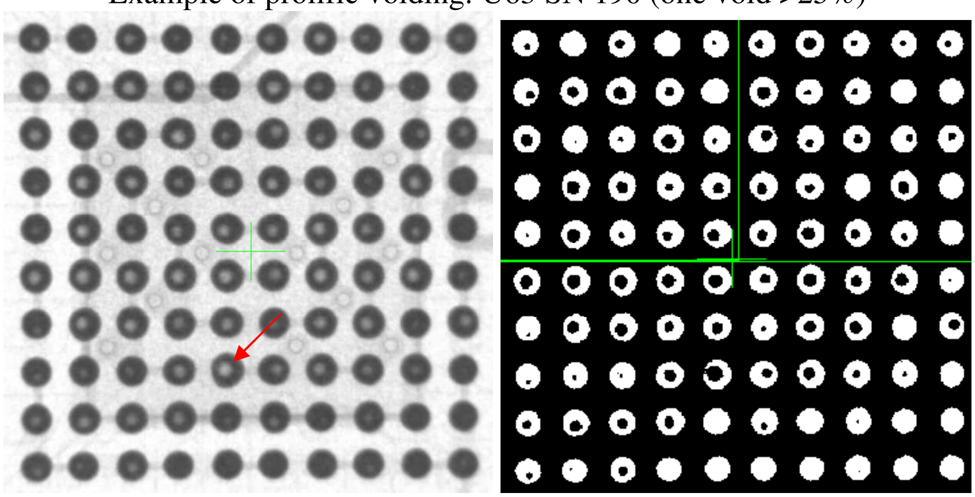


Voids: Several voids >25% on BGAs, low voiding (~20% or less) on QFNs
There were numerous voids in both the CSP-100 and BGA-225 packages.
Voids up to 16.4% were seen in the BGA-225 balls.

U55 SN 165

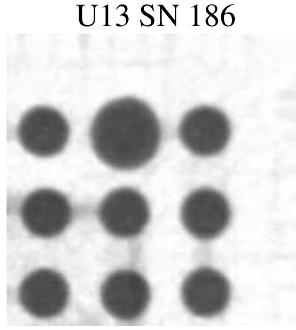


Example of prolific voiding: U63 SN 190 (one void >25%)



Other: An excessively large solder ball was found. The diameter of this ball is 0.65 mm (average is about 0.45 mm for this package)

U13 SN 186

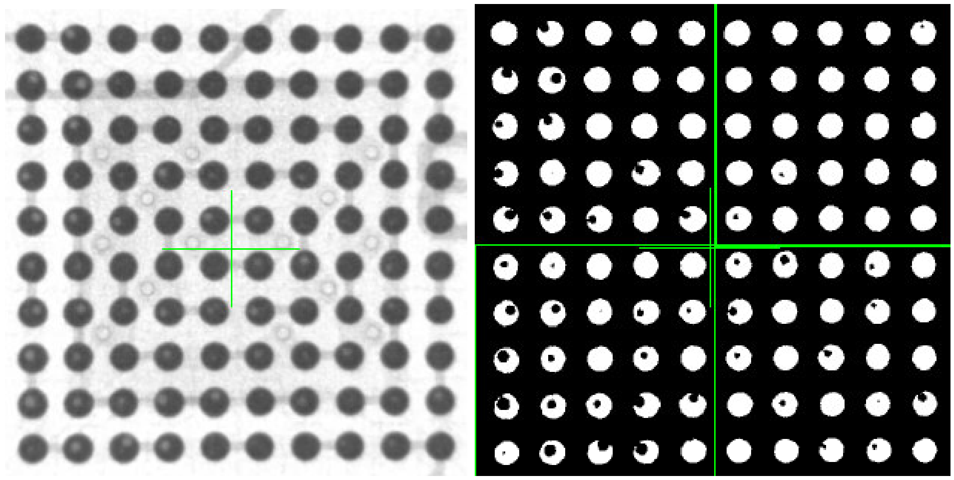


Batch B1

Bridging: No bridging detected

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

SN 138 exhibits the most voiding (none >25%):



Other: No other anomalies detected.

Batch B2

Bridging: No bridging detected

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

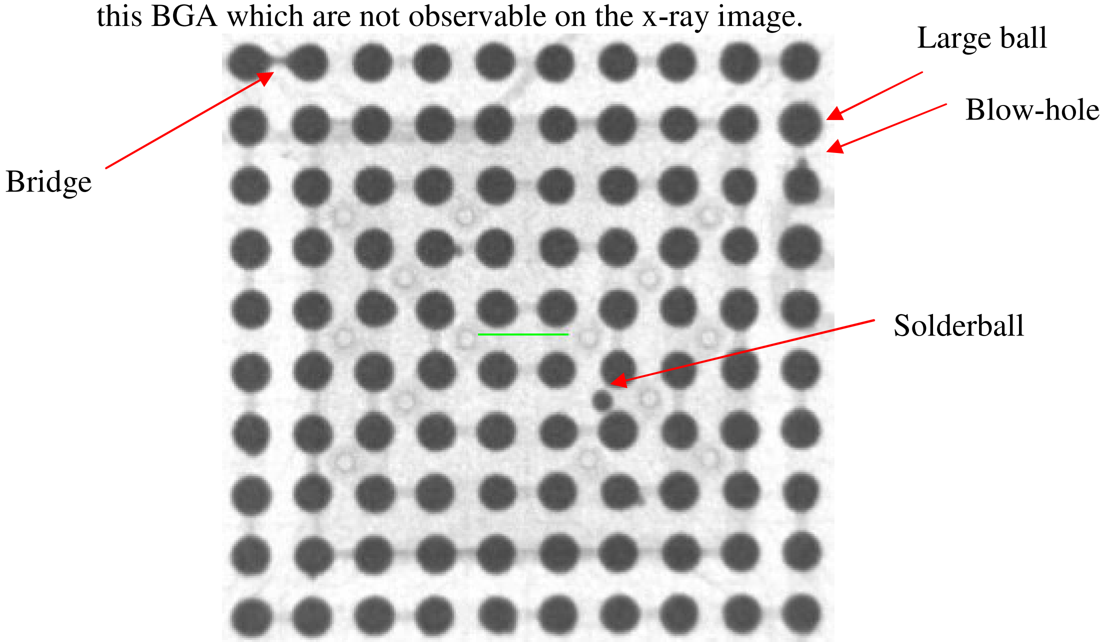
Other: No other anomalies detected.

Batch C

Bridging: No bridging detected.

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

Other: SN 1, U63 has a solder ball (extra) violating minimum electrical clearance(?), a solder ball larger than normal (not excessive), a blow-hole on a ball, and a bridge. There were also several small solderballs under this BGA which are not observable on the x-ray image.



Batch D

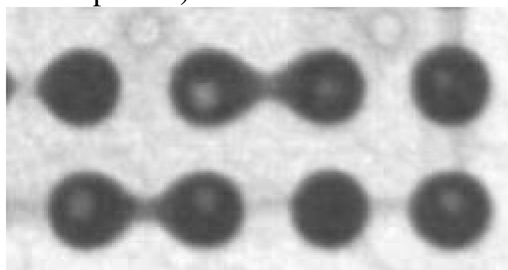
Bridging: One board had bridging on one component (12 bridges on U36)

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

Other: No other anomalies detected.

Batch E

Bridging: One board had bridging on one component (bridges appear to be along the metallization of the component)



Voids:Low voiding (~20% or less) on QFNs
4 units have voids greater than 25% on U63

Other: No other anomalies detected.

Batch F

Bridging: No bridging detected

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

Other: No other anomalies detected.

Batch G

Bridging: No bridging detected

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

Other: No other anomalies detected.

Batch H

Bridging: No bridging detected

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

Other: No other anomalies detected.

Batch I

Bridging: No bridging detected

Voids: No voids >25% on BGAs, low voiding (~20% or less) on QFNs

Other: One slightly larger ball (diameter of .54mm) on SN 107 U33, not excessive.

SUMMARY:

There were several true defects found, from both special causes (misinstalled parts) and common causes (voiding, solder ball variation, etc.).

The amount of voiding in BGA and CSP solder joints varied greatly, although the most common and worst cases of voiding were typically found in the U35 and U63 locations of the CSP component.

Near bridging, implied bridging, and true bridges were common on the CSP components. It appears that the physical geometry of the components and the traces running between pads on the bottom of the component promoted bridging along these traces (despite the presence of solder mask covering the traces).