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Development of Image Analysis for Detection of Defects of BGA by Using X-Ray Images

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Abstract- ***In the surface mount technology, Ball Grid Array (BGA) has been used in a production of PC boards, because of their excellent characters such as high density of the lead pin pitch, better lead rigidity and self-alignment during re-flow processing. This paper deals with the development of image analysis for the detection of defects at BGA solder joints in PC boards by using X-ray images. In the conventional IC boards, it is possible to detect defects of solder joints by visual inspection, because the lead of IC package is set on its outside. However, we can't detect visually defects at BGA solder joints, because they are hidden under the IC package. In a production line, the inspection of BGA in PC boards depends on the function test of electric circuits in the final process. To improve a cost performance and the reliability of PC boards, an inspection of BGA is required in the surface mount process. Types of defects at BGA solder joints are solder bridge, missing connection, solder voids, open connection and miss-registration of parts. As we can find mostly solder bridge in these defects, we pick up this to detect solder bridge in a production line. The problems of image analysis for the detection of defects at BGA solder joints are the detection accuracy and image processing time according to a line speed of production. To get design data for the development of the inspection system, which can be used easily in the surface mount process, it is important to develop image analysis techniques based on X-ray image data. At the first step of our study, we attempt to detect the characteristics of the solder bridges based on an image analysis.***

I. INTRODUCTION

In a conventional IC package, the lead pin of IC is set on the outside of IC package and the defects of the solder joints of lead pin to the PC board has been done by the visual inspection [1]. Recently according to the high density surface mount, Ball Grid Arrays (BGA) and Chip Scale Packages (CSP) are used in PC boards, because they are easily mounted to the surface of PC boards [2,3]. However, we can't inspect directly the solder joints of BGA, because these are hidden under IC package. In a production line, many companies that product the PC board with BGA have done the inspection of BGA in the function test of electric circuits in the final process. To improve the cost of performance in manufacturing IC packages, it is required to detect defects at BGA solder joints in the process of surface mount. Therefore, it is important to develop image analysis techniques for the inspection system in a production line. Types of defects at BGA solder joints are solder bridges(short of two balls), missing connection, solder voids, open connection and miss-registration of parts. In actual production line, we can find mostly the solder bridges. In order to prevent a bad package is sent to the next process, it is required to detect solder bridges in the surface mount process. We pay attention to detect solder bridges in a production line.

In this paper, we propose to develop image analysis techniques for the detection of defects at BGA solder joints by X-ray imaging. The problems of image analysis for the detection of defects of BGA are summarized in the following, one is the detection accuracy, that is, BGA is very small and we must inspect many BGA according to a production line speed. The solder ball diameter is 0.76 mm and one IC package has three hundred solder balls. The other is the processing speed, that is, huge image data must be analyzed in the real time manner. At the first step of our study, it is important to develop image analysis techniques for the detection of defects at BGA solder joints. We attempt to detect BGA bridges based on X-ray images.

II. FUNDAMENTAL EXPERIMENT

In order to get design information of defects at BGA solder joints for the development of inspection system, which can be used easily in a production line, we need the fundamental experiment with the test of IC package.

A. Test IC Package

BGA is an important technology for utilizing higher pin counts, without the attendant handling and processing problems of the peripheral leaded packages. They are used in manufacturing PC boards, because of their higher ball pitch(1.27 mm pitch), better lead rigidity, and self-alignment characteristics during re-flow processing. Fig 1 shows the flow of a surface mount process with BGA. PC board comes into this process. At the first step, solder paste is printed in the circuit and at the next step BGA with fine pitch are mounted and solder joints between IC package and the surface of printed circuit are made by re-flow process. BGA solder joints could not been inspected and reworked using the conventional methods. In Chip Size Packages (CSP), Mondou et al. have proposed to measure precisely the surface structure by using the co focal optics before re-flowing[4,5]. In BGA, the ability to inspect visually the solder joints is desired in a production line to provide confidence in solder joint reliability.

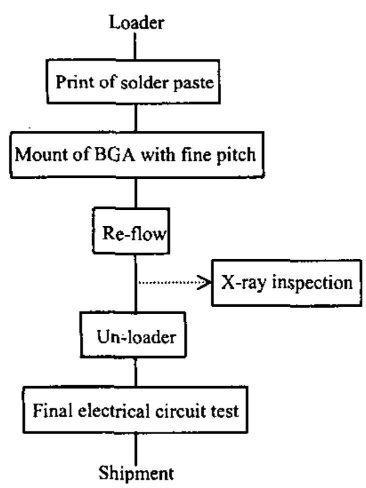

Fig.1 Flowchart of surface mount.

In the most case of defects at BGA solder joint, the solder bridges between two balls are founded in a production line. This results from excess solder or misplaced solder, because dirty solder paste stencils are often founded in a production line. In manufacturing PC boards, IC package used with BGA is CPU for main function in an electronics circuit. In the actual production line, we can find the test IC packages based on the final electrical circuit test. Fig.2 shows a photograph of one example of a test IC board. The thickness of PC board is 2 mm and it has six layers. IC package is mounted with BGA to the surface of the PC board. The solder ball diameter is 0.76 mm and the ball pitch is 1.27 mm and the number of BGA is two hundred and fifty six. The size of IC package is 27x27 mm. This test package does not pass the electrical function test. We consider this package has defects at BGA solder joints.

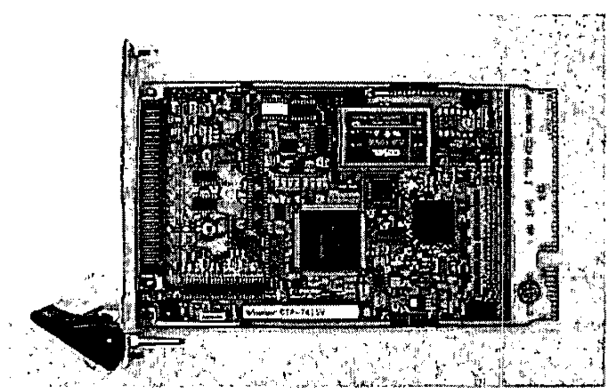

Fig.2 Photograph of one example of test board.

B. Capture of X-ray Image Data of BGA

We try to capture X-ray image data by using an X-ray computed tomography (CT) [6]. To detect the inner defects, this apparatus was made to get computed tomography of mechanical parts such as a ball bearing, a cylinder and a battery. In these parts, the object for measuring is one unit. In this apparatus X-ray focus is 4 μm and resolution is 68 lines pair/cm. The X-ray source and the detector of image are fixed. Besides, a test sample is set on the stage. Then, we can get images data by rotating the stage. We can adjust an image size of the test sample by changing the distance between the X-ray focus and the test sample. X-ray radiated from the focus transmits the test sample on the stage and comes to the detector. X-ray detection system consists of an image intensifier of 23 cm diameter and a CCD camera of four hundred thousand pixels. X-ray image is converted to the visible light by the image intensifier and image data is captured by 2/3 inch CCD camera as 8 bit gray levels.

It is difficult to capture the X-ray image at one scene, because a solder ball is small. Thus the number of it amounts over two or three hundred. We tried to change the image size of a solder ball to analyze the characteristics of an abnormal solder ball. It is impossible to get computed tomography data of each solder ball, because there are many solder balls in one IC package. Therefore, we have captured a projection X-ray image of a IC package. We set vertically the test package on the stage and rotated the test table from 0 degree to ±50 degrees on every 10 degrees as shown in Fig.3. By rotating the test package, we can take X-ray image with inclined penetration and attempt to detect BGA bridges from different direction. When the angle of inclination is over 50 degrees, we can not distinguish each solder balls, because of overlapping of images. The condition for capturing image data is as follows.

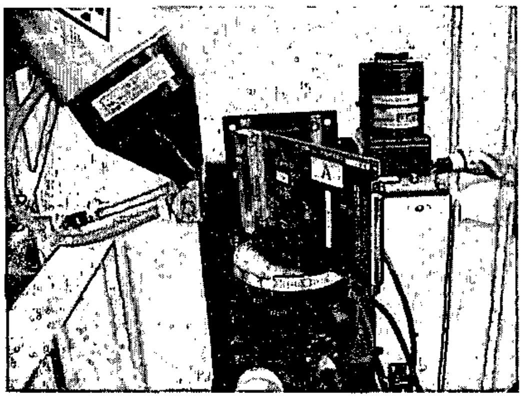

Fig.3 Apparatus for capturing X ray-image.

X-ray tube voltage: 185 KV, X-ray tube current: 160mA, exposure times: 30 seconds.
We did three hundred times to smooth out image data and to improve image quality.
We got a series of X-ray image data and captured data is stored in the Magnetic Optical Disk as bit map data.

III. ANALYSIS OF X-RAY IMAGE DATA

In the actual X-ray image data in PC boards, the image data of each solder ball is very small and we must process huge data. It is very difficult to process directly the image data of BGA. Therefore, at the first step, we need image analysis of BGA to get fundamental data for the development of an inspection system used easily in a production line. We propose the following image process techniques.
Fig.4 shows a flowchart of an image processing for X-ray image data obtained by the above apparatus. Image data is an input data to the personal computer for analysis. It is converted to the binary data to detect accurately the counter of a solder ball. Threshold level is determined based on signal profile on horizontal line. We selected 54 count gray levels as the threshold level and converted to black and white image data to measure accurately the following factors of BGA. After labeling, first we measure the area of each solder ball and center of X axis and Y axis. Next we measure the perimeter and the radius ratio of each solder ball. A normal pattern of a solder ball is a circle. If a solder ball has defects such as bridge, the shape of the object separate from a true circle. In the case of solder bridges, two solder balls are shorted with the narrow path and we can observe the different pattern such as connected with the bridge.

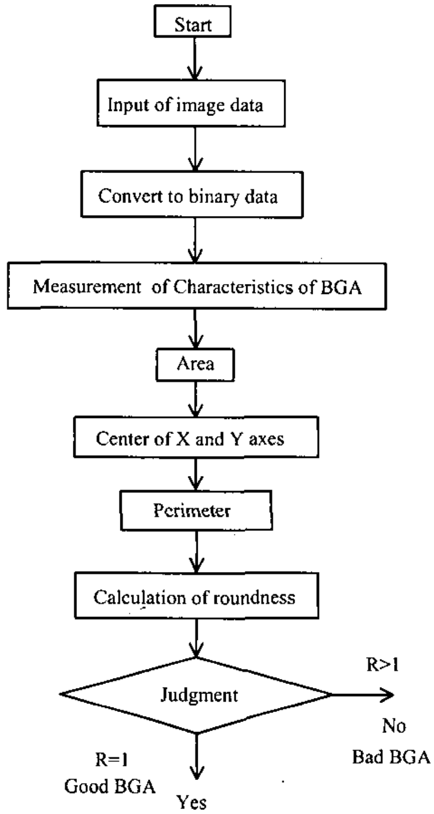

Fig.4 Flowchart of image analysis.

In order to judge whether the solder joints are connected normally to the base pad in a surface mount process or not, we pay attention to the radius ratio and the roundness of a solder ball. Roundness R is calculated by the following equation.

$$R = L^2/4\pi S \quad (1)$$

Where L (m) is the perimeter of a solder ball, S (m^2) is the area of a solder ball.

If the object is a true circle, the radius ratio and the roundness equal to 1. According as the shape of the object separate from a true circle, the radius ratio and the roundness become lager than 1. The judgment whether BGA is good or not is determined by the radius ratio and the roundness. If the value of these terms equals to 1, we judge BGA is normal. Then, if the value of these terms overrun equal to 1, we judge BGA is abnormal.

IV. RESULT AND DISCUSSION

Fig.5 shows an example of the original image data series captured by the above apparatus with inclined penetration of X-ray (inclination angle :–37 degrees). In this picture, we can observe one abnormal BGA. We analyzed this image data based on the above method. Fig.6 shows the binary image data after labeling. Fig.7 shows the radius ratio of each solder ball. Fig.8 shows the roundness. The roundness is one for the true circle by equation (1). The actual radius ratio and the roundness of a solder ball is a little over one as shown in Table 1. This table shows an example of the result of the image analysis.

Fig.5 Original image data (minus 37 degrees).

When the radius ratio is below 1.5 and the roundness is below 1.1, we judge BGA is normal and if two terms overrun these values, we judge BGA is abnormal. In this table, we can find one abnormal solder ball as shown in the data number 58. The radius ratio is over 1.5 and the roundness is over 1.2, namely, 1.97657 and 1.22408 respectively. Therefore, we can warn this solder ball is abnormal. This abnormal image data is shown as number 58 in Fig.6. This test package is inspected in the function test of the electrical circuit and determined as an abnormal board. Except only one or two solder balls, we can't find another abnormal point in this test board. In the X-ray image, we could not find obviously two balls short but can find a ball having tail. The radius ratio of number 33 overruns 1.5 but the roundness is below 1.2. Then we judge this BGA is normal in this table.

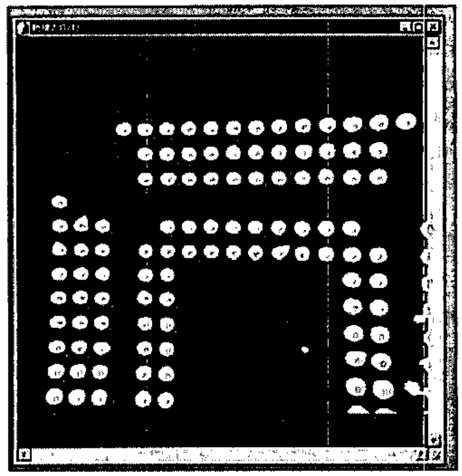

Fig.6 Binary image data (minus 37 degrees).

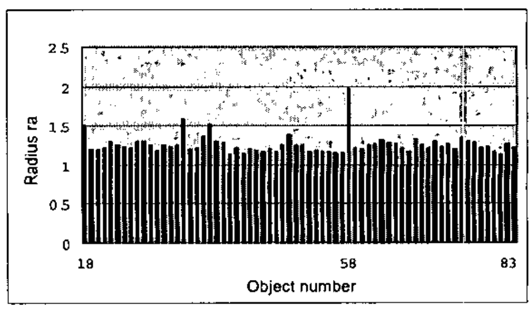

Fig.7 Radius ratio.

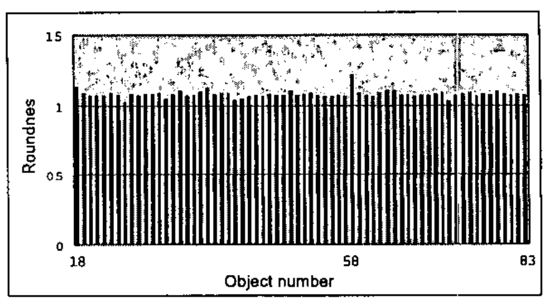

Fig.8 Roundness.

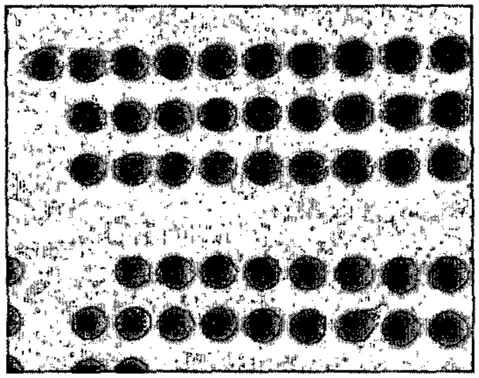

Fig.9 Original image data (minus 43 degrees).

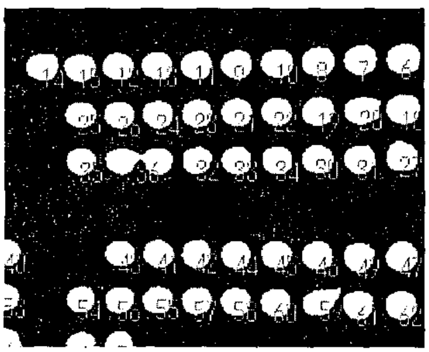

Fig.10 Binary image data (minus 43 degrees).

Table 1 Example of result of image analysis.

No.	Area	Center-X	Center-Y	Perimeter	Radius Ratio	Roundness
33	306	187.5784302	175.51634	61.16638	1.58526	1.10902
54	305	213.17705	265.90491	59.94811	1.17490	1.06369
55	313	240.88179	266.03833	60.24455	1.16527	1.06428
56	315	268.49841	266.46350	61.08346	1.14968	1.07758
57	313	296.71567	267.30670	60.28836	1.14730	1.06398
58	350	327.91714	266.46286	68.88228	1.97657	1.22408
59	340	354.92648	268.49118	63.77168	1.21310	1.08722
60	346	385.23410	268.96820	64.75266	1.20893	1.07690
61	378	417.09259	269.78571	66.70914	1.24465	1.06314

By rotating this test board, we can find another solder bridge with the inclination angle of minus 43 degrees, as shown in Fig.9. Fig.10 shows the binary image data after labeling. We can observe that the bridge connects two balls. This bridge is observed in the inclination angle between minus 40 degrees and minus 47 degrees. In this case, two balls are labeled as one pattern. The radius ratio and the roundness are 20.71083 and 1.98948 respectively. If this bridge connects two balls completely, we can observe this bridge in any inclination angle. In this case, it is considered that two balls have excess solder under the solder ball and we can observe the bridge in the penetration angle between minus 43 degrees and minus 50 degrees. It is reasonable that the radius ratio and the roundness of a solder ball are effective to detect the solder ball bridge based on X-ray image data. Besides, we can detect defects under the solder ball by changing the inclination angle of X-ray.

In the actual production line, we founded some abnormal PC boards based on the functional test of electrical circuit. Each board has only one or two solder bridges. We wonder if every joint on every board needs inspection. We hope to inspect everything to provide higher confidence of reliability of PC boards. But members of a company that products PC boards say that they need to inspect every BGA, when the condition of a production is changed. Once a process runs well, a manufacturer could inspect only a test sample of PC boards.

V. CONCLUSION

For a practical purpose of developing the inspection system to detect defects at BGA solder joints in a production line, we have proposed the image analysis techniques, in order to carry out the inspection of the IC package having BGA. At the first step of our study, we deal with an image analysis of the test package, and significant results are obtained as follow.

1) To find BGA bridge, the radius ratio and the roundness of a solder ball is effective. For a normal solder ball, we can get these values equal to nearly 1. On the other hand, for an abnormal solder ball, it is cleared that the radius ratio and the roundness overruns 1.

2) To analyze accurately the radius ratio and the roundness of a solder ball, it is enough to get image data having 20 pixels diameter in each solder ball.

3) To detect defects under the solder ball, it is effective to change the penetration angle of X-ray.

It is concluded that the image analysis based on X-ray image data proposed in this study is an effective method for the detection of defects of BGA bridge. To realize the inspection system of BGA in a production line, further studies are desired such as the construction of control system of X-ray focus for covering all BGA in one IC package and image analysis algorithm according to a line speed of production.

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