Presented at IPC SMEMA Council APEX® 2002
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Paste Inspection Study

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Abstract
Many papers and articles are claiming that a majority of the defects detected after reflow are coming from the solder paste application process. However, very little real data seems to be available to support this claim. To investigate the paste process impact on defects after reflow, Nokia in Finland and Agilent Technologies decided to do a joint study. The study was designed to use a paste inspection system to measure paste volume directly after the paste application process and to use an automated X-ray inspection system to measure defects after reflow. The first part of the study was to correlate the paste and the X-ray systems to each other using a small number of PCAs. After this correlation study, one week of production volume was analyzed and more than 680,000 solder paste bricks and later solder joints were measured. In this sample, 46 defects were detected and confirmed after reflow but, very surprisingly, none of those was detected by the paste inspection. Also very surprisingly, over 2,000 paste bricks had below 65% of nominal paste volume, which in normal production would have triggered a repair action, but none of these -- over 2,000 "defects" at paste inspection -- created a "defect" after reflow.

It is important to note that the result was surprising, but at the same time keep it in perspective. It is just one study and in other cases other results may occur.

Nokia objective with the study:
"To see if there is any correlation between the defects seen at Automated Paste Inspection(API) and Automated X-Ray Inspection (AXI). The results should help Nokia optimize its inspection and test processes to maximize throughput."

Agilent objective with the study:
"To gain deeper knowledge of where defects are introduced in the manufacturing process. In this specific study the objective is to see defect levels introduced by paste application. The results should help Agilent optimize the solutions we provide to our customers."

As can be seen, both companies' objectives were very similar and it made sense to work together. The study was planned during the spring of 2000, was performed during one week of August 2000, and data analysis and compilation of results were done in late August and early September.

This paper will present the methodology used in this study, and present a significant amount of real data. The paper will end with a conclusion and recommendation.

Methodology
In the study a Cyber Optics API was used in production for paste inspection and an Agilent AXI x-ray laminography system was used after reflow of the second side of the printed circuit board assembly (PCBA). Nokia developed the paste inspection program for the API system. Nokia also had developed the x-ray program that was used to inspect the boards after reflow. The AXI x-ray system can also be used as a paste inspection system. Agilent developed the AXI paste inspection program for the PCBA. That program was developed with paste on one side and no components on the other side. The first step in the study was to compare the paste inspection capability of both systems and to verify that pad identification reporting was correct for both machines. This was done using one PCBA with paste on one side and no components on the other side. To verify the pad identification, around 10 pads had all the paste removed before the measurement.

The study entailed running approximately one week's production through the paste inspection system, then doing normal pick-and-place operation of components, then reflowing the boards. This was done for both sides of the PCBA. After reflow of the second side, the boards were inspected using the x-ray system and all calls from this operation were analyzed by normal repair operators. All measurement and defect data from both the paste inspection system and the x-ray system were logged automatically. Also repair operations after the x-ray operation were automatically logged. In addition a manual log was made during the study of a manual visual inspection step, just before the reflow oven. The only difference in this experiment compared to normal production was that no repairs were done after the paste inspection. Our main objective was to see how many of the defects detected by the paste inspection were later diagnosed as defect after reflow.

Correlation study

The first objective was to investigate the correlation between the paste inspection system and the x-ray system used in paste inspection mode. To do that we used one PCBA blank board with paste on one side and no components on the other side. Four IC packages were selected for this study and also for the production study.

The key characteristics of the pads and the later placed components can be seen in Table 1. There were two dual-in-line components and two QFP components and the pitch ranged from 20 mils to 50 mils. A total of 408 solder paste pads per board were included in this study. The reason for selecting the rather few pads to be inspected was that the production time was around a minute and the paste inspection system could only do around 500 per minute.

Table 1 - Key Characteristics Of Components And Pads In The Study

				Pad dimensions	
Name	Pins	Type	Pitch (Mils)	Width (Mils)	Length (Mils)
D1601	44	DIL	50	19	69
D1904	56	DIL	25	12	59
D1401	176	QFP	20	11	39
D703	132	QFP	25	15	79

For this study and particularly for the main study it was very important to have a correct understanding of the pin numbering on each of the two systems. We wanted to compare the paste volume measured by the API on, for example, D1601 pin 1 with the measurement by the AXI on the exact same pin or pad, and we wanted that for all 408 pads (pins) in the study. To check this, we deliberately removed the solder paste on a few pads for each component.

There is another point that is important to understand when comparing the paste results from the paste inspection system and the x-ray system. In this part of the study we were measuring solder paste height, area, and volume. The paste inspection system is measuring the metallic content, the flux, and the carrier content. The x-ray system is only measuring the metallic content of the paste. Therefore it should be expected that paste height and volume should be significantly lower reported by the x-ray system compared to the solder paste system. The area measurement should be similar but there is also one item that should be considered for small measurement discrepancies. This item is where the measurement system locks on when it is determining the slope of the solder paste. (See figure 1.) The key fact is that the solder paste brick does not have a vertical edge of 90 degrees. Instead it is more like a steep slope. Now one inspection system could “lock on” very deep on this slope, resulting in larger area measurements, while the other system can “lock on" almost at the top of the solder paste brick, resulting in smaller area measurements.

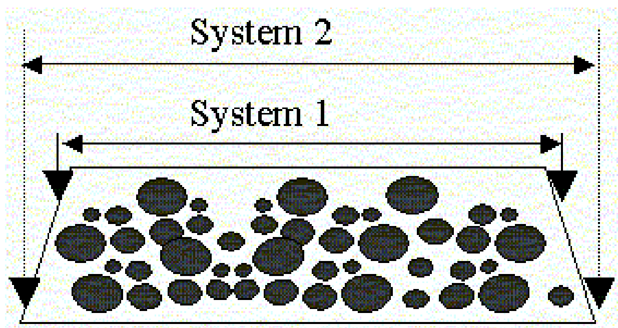


Figure 1 - Why The Two Systems Have Small Discrepancies In Area Measurement

The volume measurement, Figure 2, by the x-ray system is significantly lower than what is measured by the paste inspection system. (Figures 2 to 5 are at the end of the paper.) This is to be expected as explained above. The overall correlation between the two systems was 0.9915, which indicates a very good correlation. (1 is perfect correlation and 0 is no correlation at all.) The pads with solder paste removed are shown as removed in Figure 2, and the resulting correlation number is presented. The height measurement was around 0.2 mm measured by the API system, which was to be expected since a 200-micron stencil was used. The AXI system measured the height to 0.05 mm and again a significantly lower height measurement is to be expected as explained above.

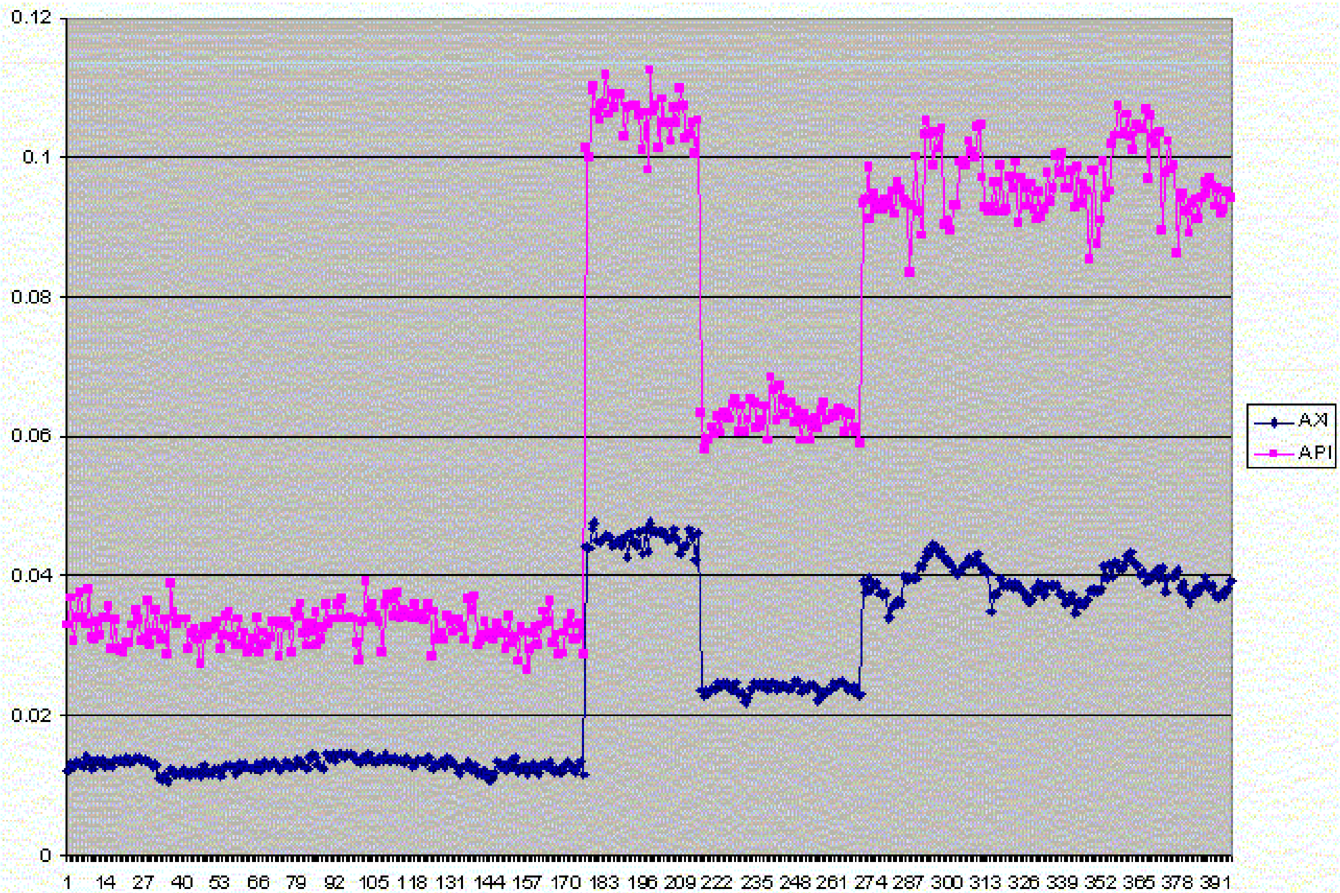
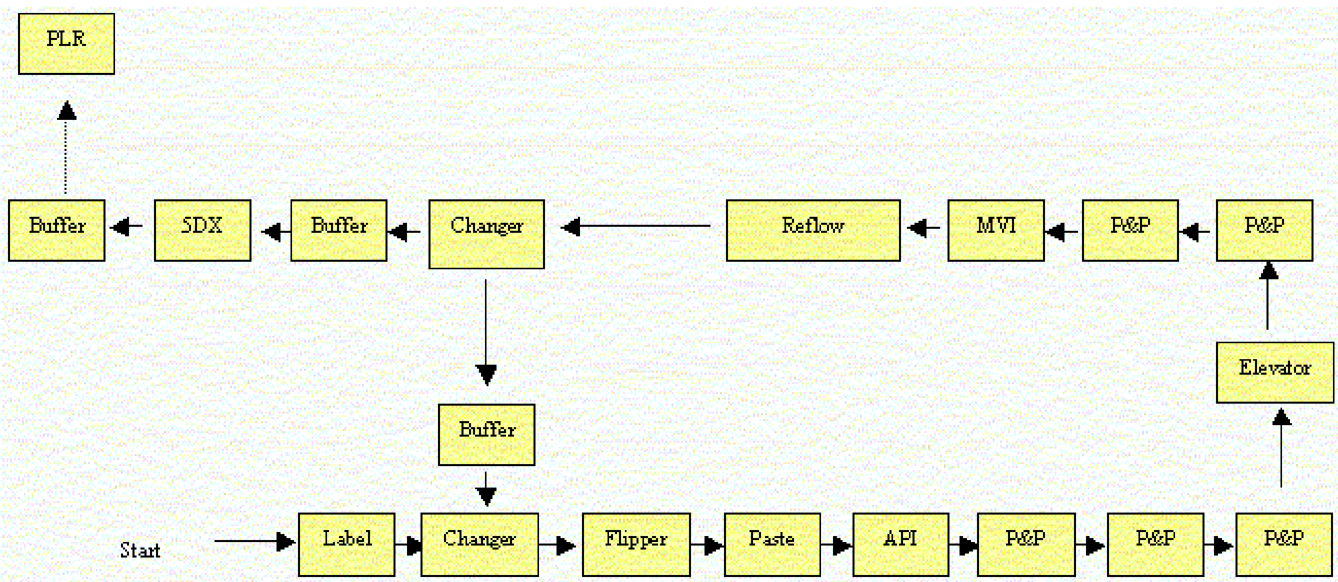
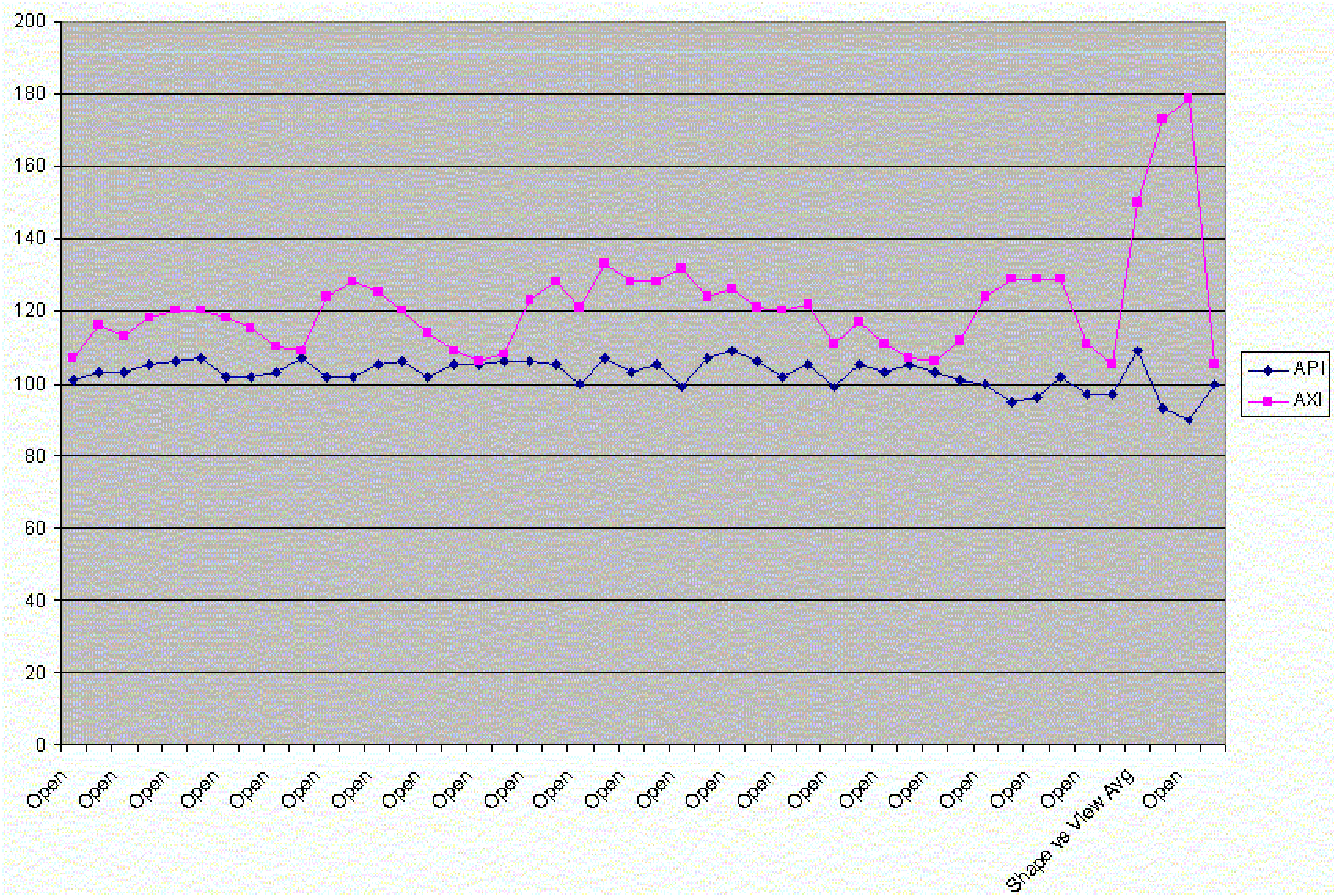


Figure 2 - Average Paste Volume (AXI Lower Curve, API Upper Curve) - Correlation between the Two Data Sets are 0.9915 - Pads Where Paste were Removed are Excluded





Note that paste volume for all defects are over around 90%

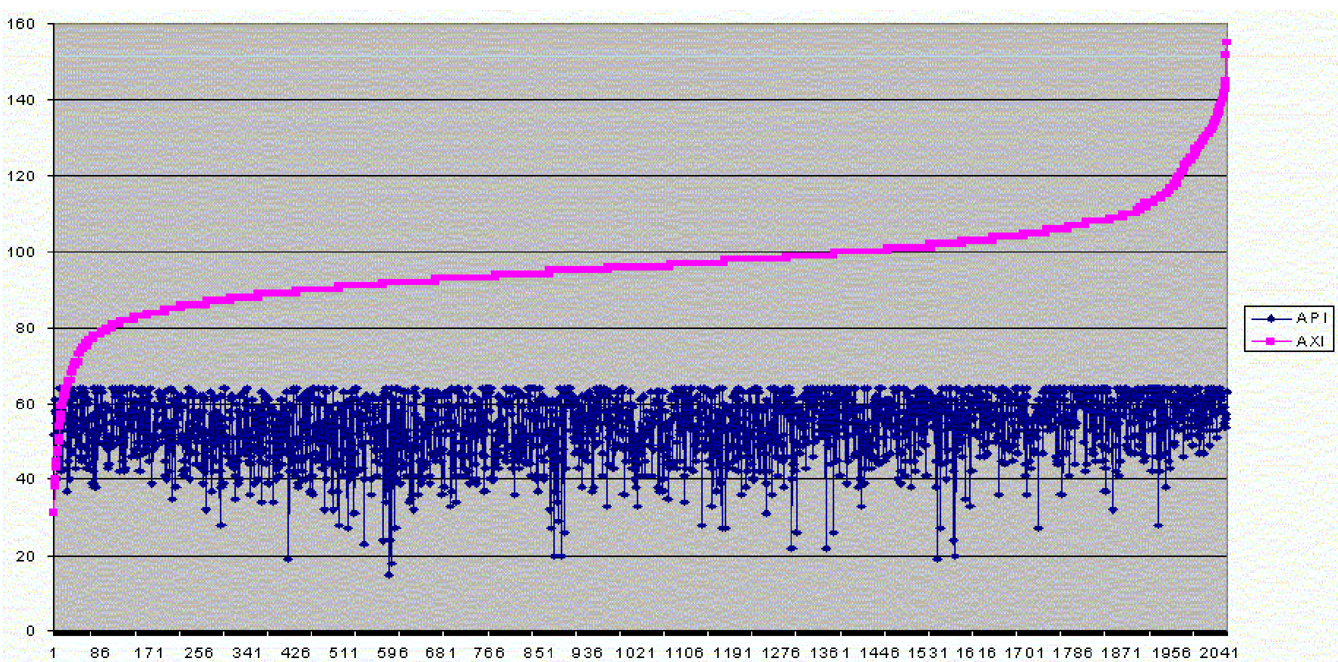


Figure 5 - All 2,053 Pads with Paste Volume Under 65% - Data is Sorted in Increasing Solder Volume Measured at X-X-ray

The AXI area measurements were slightly larger than the API area measurements but both Nokia and Agilent were both comfortable with this rather small discrepancy based on the explanation made above in the text and in Figure 1.

Based on this result we felt that the paste inspection system was doing an acceptable job of measuring the solder paste and that we could rely on the result in the main study.

Correct Pad Identification

When one or several defects occur at paste inspection, the normal repair action is to clean the whole side of paste. There is no direct need to know the exact location of the defect. However in this study it was very important to establish that information. We started with a theory that if we started to inspect the pad at component pin 1 and then moved the Field Of View (FOV) around the pads in increasing "pin number order" we should accomplish this automatically. The technician that normally programs the API was very certain that it was done as described. Since we had manually removed paste on around 5-10 pads per component we were able to realize that in fact that was not the case. To further confuse us, one component had the pads numbered correctly according to our first theory. The errors on the three other components were very different. The numbering is assigned in a certain way in each field of view and we had to build a lookup table to be able to create the correct pin / pad numbering.

Repeatability Study

We used this board, with paste on one side and no components on the other side, to also do a repeatability study. We measured the board five times on the paste inspection system and five times on the x-ray system. For each pad we calculated average and standard deviation for height, area, and volume measurements. We then analyzed how big the standard deviation was compared to the average value. For both the paste inspection system and the x-ray inspection system the standard deviation was around 1-2% of the average value. We decided that repeatability for each system was reasonable and should not impact the major study in a significant way.

The Main Study

The main study was to analyze the results of close to four days of production. The line layout could be seen in Figure 3. The line was very automatic, and human hands touched very few boards. Note the Manual Visual Inspection (MVI) station just before the reflow oven. Even at this station the boards were not touched. If there were any adjustments done here, only the component that needed adjustments was touched, and then only with tweezers.

During the main study the bottom side of the board was manufactured first. At this time the bottom side went through paste, pick-and-place, manual visual inspection, refold and buffering. When a certain number of boards were manufactured with components on the bottom side, the line was switched over for topside manufacturing. On the bottom side no paste inspection was done. However on the topside, the paste inspection station was active.

During the topside manufacturing, normal production steps were taken, with one exception: no repairs were made at the paste inspection step. Normally if any pad had less than 65% paste volume or if any paste was misplaced the board would be removed. All paste would be cleaned off, and the board would have been re-pasted. In this study, that did not happen. On all boards, a log of all paste inspection results was kept automatically by the paste inspection machine but no repairs were done.

The boards were then sent through the pick-and-place operation, then through the manual visual inspection step and then through the reflow. At the MVI station a manual log was kept during the experiment to keep track of whether any components in the study were adjusted at this step.

After reflow the boards went to the AXI x-ray inspection system. A majority of solder joints were inspected, including all solder joints on the four components whose pads were paste-inspected. After the x-ray inspection a normal paperless repair station was used. At this repair station all calls from the x-ray inspection system were evaluated and for some calls repair action was taken and some calls were determined as false calls. After x-ray inspection the boards went to in-circuit test and functional test, but no data from these two test steps were included in this study.

During this experiment automatic data logging was done at the paste inspection machine, at the x-ray inspection, and at the x-ray repair station. A manual log of repair actions at the manual visual inspection was also kept.

The boards used in this study were manufactured from Monday afternoon to Friday morning, the week of the study. For a board to be included in the study we needed log records for that board from paste inspection, from MVI, from x-ray inspection, and from x-ray inspection repair. There were 1,677 boards manufactured where all log records are available.

Results

On these 1,677 boards a total of 684,216 solder pads were inspected. On these 1,677 boards, there were 46 confirmed defects after reflow on the four ICs included in the study. The 46 solder joint defects were on 6 different boards and on each defective board there was one component with either one defective solder joint or in most cases multiple defective solder joints on one component. 46 defects on 684,216 defects opportunities results in a defect level of 67 PPM, a very low defect level. Table 2 shows all the confirmed defects.

Table 2, - List Of Confirmed Defects.

Board Serial Number	Component	Pins	Defect
6245	D1601	1-10, 14-22	Open
6399	D1601	2-5, 39-41, 43	Open
6381	D1601	3, 5-8, 11-21	Open
6872	D1601	23	Open
6802	D1401	34, 37	Open
6786	D1904	40	Bad solder joint

Of the 46 confirmed defects, 43 were on device D1601 and were opens. None of the 46 defects had insufficient paste. D1601 is a programmable device. Nokia's process to program these components is to take them out of the tube they are delivered in, place them in a special programming unit, and then put them back in the tubes again after programming. The handling of the devices at this station is a manual process. The most likely cause of these opens is bent pins resulted from the manual handling at the programming step. This conclusion is also based on data that can be seen in figure 4, which shows the paste volume and solder volume measured after reflow for the confirmed defects. None of the 46 defects had paste volume under around 90%.

So were there any pads with solder paste below the Nokia specification, of 65% solder volume, or any other paste defects detected at the paste inspection stage?

Yes, there were 2,053 pads with solder paste volume below 65% on 209 different boards. None of these 2,053 pads was later classified as bad solder joints. Of the 2,053 calls that the paste inspection system made, 5 of those were also called by the x-ray inspection system, but were classified by the repair operator as good solder joints.

This is a very surprising result. Both Nokia and Agilent had expected that around 20-25% of all defects should have been present and detected at paste inspection. However that was not the case in this study. It is important to keep in mind that this is one study and the Nokia manufacturing process was very well under control with a very low defect level of 67 PPM. This defect level should be compared with a typical industry level of 600 to 1,100 PPM.[1]

The x-ray system was inspecting a total of 4,006 solder joints on these boards, resulting in a total of 6,718,062 solder joints inspected. On this larger sample there was a total of 974 confirmed defects, resulting in a PPM level of 145 PPM -- again an extremely low defect level compared with other studies Agilent has performed in the industry.[1]

Figure 5 shows all of the 2,053 pads with paste volume below 65%. Average solder volume was also measured at the x-ray inspection. In this figure the pads / solder joints have been sorted by increasing solder volume measured at x-ray. Note that there is very little correlation between the paste volume measured and solder volume after reflow. Since Agilent did the data analysis after leaving the Nokia test site, no additional measurements have been done to investigate this further. Also note in figure 5 that the paste volume for some pads were below 20%, but still resulted in good solder joints.

There were no other defects detected at paste inspection than insufficient solder paste. Also another interesting observation is that we did not see any shorts or solder bridges after reflow. Usually a significant amount of defects are shorts.

Summary

A general industry perception is that a majority of solder defects after reflow has its root cause in the paste application process. Many papers and articles have made this claim, but very seldom is this substantiated with real data.

Nokia and Agilent wanted to investigate this further and decided to do a paste inspection study jointly. The main objective was to see how many of the defects existing after reflow were also detected as defects immediately after solder paste application.

The first step in the study was to verify the accuracy of the paste inspection. One board was measured several times on the paste inspection machine and also on the x-ray system using the paste measurement method. Good correlation between the two systems was achieved and also good repeatability was noticed.

We already had very good confidence in the x-ray system, from many test effectiveness studies. Results from some of these studies have been presented in a paper.[2]

Around one week's production of one board type was used for the study. To our surprise, no defects found after reflow were identified at paste inspection and had its root cause from the paste application process.

Conclusion

There are limited conclusions made from just one study, however it is fair to make some observations.

First, there are probably significantly fewer defects with root cause from the solder paste application than is commonly believed.

Second, even if there were zero defects coming from paste application in this study, a general conclusion that it will always be zero is not correct.

Third, the poor correlation between applied paste volume and solder volume should be further investigated.

Fourth, we encourage other companies to do this type of study and present the data in technical papers.

Fifth, also further studies should be done and presented in technical papers, of where defects are introduced in the manufacturing process, and also of whether defects prior to reflow are "self-correcting" and disappear during the normal process.

Reference

1. Stig Oresjo, "Year 1999 Defect level and Fault Spectrum Study", Proceedings of SMTA International 2000.
2. Joe Kirschling, "Improved fault coverage in a combined x-ray and in-circuit test environment", Proceedings of EtroniX 2001.