As originally published in the SMTA Proceedings.

COLLABORATION BETWEEN OEM AND EMS TO COMBAT HEAD ON PILLOWING DEFECTS: PART 1 – AXI CAPABILITY FOR HOP DETECTION

Alex Chan[1], Paul Brown[1], Lars Bruno[2], Anne-Kathrine Knoph[2], Thilo Sack[3], David Geiger[4],
David Mendez[4], Mulugeta Abtew[5], Iulia Muntele[5], and Michael Meilunas[6]
[1]Alcatel-Lucent, Ottawa, ON, Canada; [2]Ericsson, Katrineholm, Sweden;
[3]Celestica Inc., Toronto, ON; Canada, [4]Flextronics International, Milpitas, CA, Austin, TX, USA;
[5]Sanmina Corporation, San Jose, CA, Huntsville, AL, USA;
[6]Universal Instruments Corporation, Binghamton, NY, USA alex.l.chan@alcatel-lucent.com

ABSTRACT

It is an ongoing battle in the OEM and EMS world to eliminate Head on Pillow (HoP) defects in every day assembly activities. Recent effort in the industry has been primarily focused on defect mitigation, while limited investment has been made to understand the true capability of HoP detection using Automatic X-ray Inspection (AXI). For this reason, the study presented here focused on evaluating the HoP detection capability of four different AXI platforms using assemblies with known HoP defects.

Key words: HoP, BGA, AXI, x-ray

INTRODUCTION

Head-on-Pillow (HoP), Head-in-Pillow (HiP), Head-andPillow (HnP); regardless of the terminology, it is a defect that is growing in prevalence. HoP is particularly problematic because the intimate contact between ball and paste in PCB assembly can easily escape current x-ray inspection processes and, in many instances, adequate electrical continuity exists to pass initial electrical testing. Eventual separation of what was never a proper metallurgical bond can lead to late stage manufacturing defects and even early stage field return issues.

Significant effort has been invested in the study of HoP. As a result, the defect mechanism and its contributing factors have been substantially described in the literature [1, 2, 3]. There is wide recognition that package warpage is a primary factor in the formation of HoP. In fact, several industry consortia efforts are currently in progress to help characterize factors influencing package warpage behavior in an attempt to define mitigation measures. These include the iNEMI Package Warpage Qualification Criteria and the HDPUG FCBGA Package Warpage projects.

In addition to warpage acceptance criteria, the industry also needs a reliable method for detecting the HoP defect. When HoP occurs along BGA outer rows and/or at corner pins it is quite easy to confirm using simple visual inspection. However, if HoP occurs closer to the center of the BGA, the defect cannot be readily observed and 2D transmissive x-ray imaging is typically used for validation. Unfortunately, such processes yield variable results depending upon both the inspection equipment and, more importantly, the operator's interpretation of the images.

The project discussed in this paper was designed to evaluate not only AXI results from different machine platforms, but also by analyzing results from similar platforms operating at different facilities.

From the outset, it was clear that a project like this would require collaboration between OEM and EMS. Indeed, initial brainstorming meetings revealed many unique perspectives on HoP which helped drive follow-on work. These included:

- Typical feedback from suppliers regarding HoP defect with their part was, “we've never had an issue with the part … you are the only one … it must be the poor profile from your EMS!”
- OEM and EMS frequently point fingers at each other, especially when the issue becomes highly visible
- Some factories went so far as to claim that no such defects occurred in the products they assembled
- HoP defects are not limited to Pb-free, they occur in SnPb products more often then one might think
- Significant defect mitigation has already been achieved through changes in the soldering process
- A need exists to better understand AXI capability to catch different types of HoP defects
- Two years+ ago, most EMSs shared the view that HoP detection could not be done effectively with AXI in production
- There isn't much that users can do on the 5Dx for HoP detection without Agilent's support for algorithm changes
- This was an opportunity for AXI suppliers to test new algorithms and an opportunity for AXI users/customers to push this as a requirement to supplier
- At the end of the day, both OEM and EMS were eager to catch this defect before it gets to the field!!!

Regardless of whether the reader agrees with any of the reasons above, it is the belief of the authors that the industry shares a common interest in preventing the occurrence of the HoP defect on products that ship to customers. X-ray inspection is one of the key processes to minimize HoP going to the field. The intent of this study is to quantify the effectiveness of the most common AXI platform (5Dx), while also increasing knowledge about the new AXI platforms and their effectiveness to tackle the HoP detection challenge.

HEAD ON PILLOW DESCRIPTION

HoP is “characterized by complete melting of both the solder paste and the BGA solder ball but with insufficient coalescence to produce well-formed solder joint”[2].

KNOWN HOP MITIGATION SOLUTIONS

It is not the intent of this paper to focus on process mitigation strategies, as these have been adequately described in previous papers. However, it is worth listing here the three most common process modifications employed for HoP mitigation:

a. Stencil aperture modification is by far the most common method applied by the EMS to mitigate the risk of HoP. A stencil aperture with bigger openings [2] will deliver more paste to targeted areas to help increase the chance of proper soldering in the areas most affected by component warpage. The image shown in Figure 1 is just one of many stencil designs in use in the industry which illustrates progressively larger stencil openings in the 4 corners of the component land.

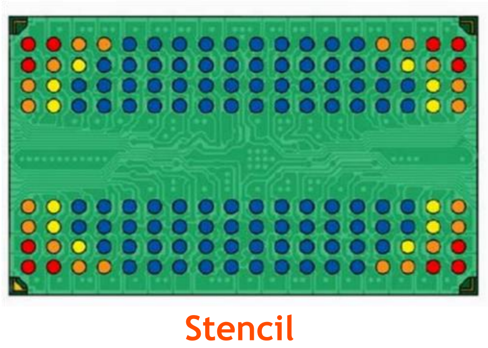


Figure 1: Mitigation through stencil aperture modification [2]

b. Reflow profile adjustment is another solution used by the EMS. By varying the profile type (soak or ramp), dwell time, and/or atmosphere (air or nitrogen), different assembly houses have found varying degrees of success in decreasing the prevalence of HoP on the assembly.

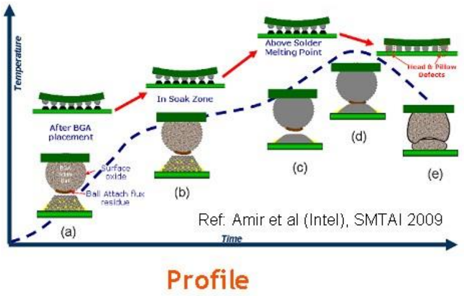
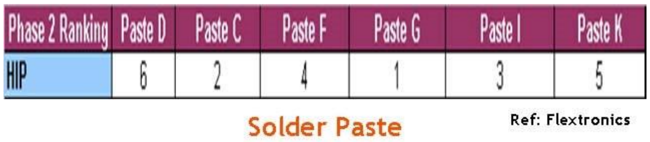


Figure 2: Mitigation through reflow profile adjustment [5]

c. Solder paste type has also been tested in order to understand which solder paste properties can be more effective in mitigating the HoP defect. As shown in Figure 3, multiple types of solder paste can be considered for evaluation.



Phase 2 Ranking	Paste D	Paste C	Paste F	Paste G	Paste I	Paste K
HIP	6	2	4	1	3	5

Figure 3: Mitigation through paste type

HOP INSPECTION

In 2011 a study was published at APEX renewed the interests of the authors to further evaluate AXI capability which was previously considered to be incapable of detecting HoP. This study suggested that HoP “detection rate on the 5Dx AXI averages about 70% …” [4]. With a large number of OEMs and EMSs still using the 5Dx for high complexity product inspection, a quantifiable understanding of the inspection accuracy with regards to HoP is still necessary. At the same time, multiple new AXI suppliers are interested in taking on this inspection challenge with a new set of AXI equipment and dedicated engineers to work on algorithms specifically designed to provide more reliable detection.

In this study, an attempt is made to quantify the effectiveness of multiple AXI equipment in HoP detection by using cards with known HoP defects.

TEST CARD AND PROGRAM SETUP

The test cards used for this experiment came from the Advanced Research in Electronics Assembly (AREA) consortium and were originally assembled for a project unrelated to HoP. However, one of the coincidental findings of the project was that the cards in question had a surprisingly high number of HoP defects on a PBGA. Ten such cards were set aside for the HoP AXI inspection project with AREA performing failure analysis on two cards to confirm the presence of HoP through cross-sectioning. The remaining eight cards were then divided into two groups (Group A and Group B). For this paper the results from Group B only are presented.

The test card utilized for the experiment (is shown in Figure 4) measured 210x180mm and was 2.0mm thick. The card contained 12 signal layers and had an ENIG surface finish.

Figure 4: AREA test card used for HoP AXI inspection

The component of interest in this experiment was the 1156 pin, full grid, 35x35mm PBGA with daisy chain, located on the left side of the test card.

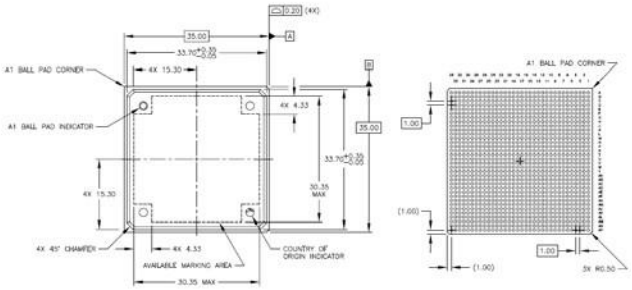
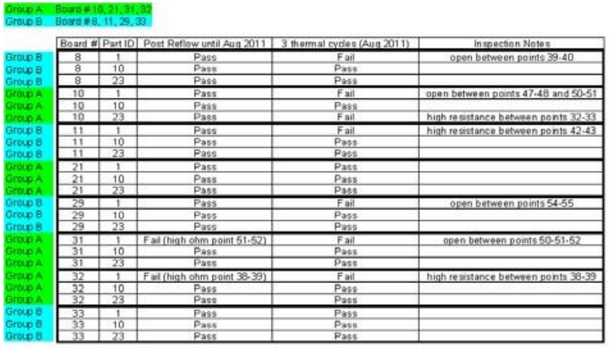


Figure 5: 35x35mm PBGA with HoP defects

The cards were assembled using a typical process. Paste was screen printed over each test card using a 1.27mm thick stainless steel stencil. The solder paste selected was a type 3, no-clean, SAC305 formulation. The test vehicles were then reflow soldered in an air atmosphere using a forced convection oven. Peak solder joint temperature was measured to be approximately 240°C at the PBGA and time above 217° was approximately 70 seconds.

The eight boards used for this project were numbered as Board # 8, 10, 11, 21, 29, 31, 32, and 33. Each board contained three PBGA assemblies and each PBGA was electrically inspected by probing the daisy chain test points located around the perimeter of the package. Testing was performed by the AREA engineers and the results were provided to Alcatel-Lucent (ALU) in order to develop the test plan. The results were intentionally withheld from the EMS sites that performed the actual x-ray inspections in order to avoid bias and keep the testing as objective as possible. Please note that two of the 24 PBGAs failed initial inspection while five additional failures were detected after the cards were subjected to three burn-in thermal cycles (-40 to 125°C). The electrical probe test results are shown in Table 1.

Table 1: Electrical probe test results of the test cards



Group A Board # 10, 21, 31, 32
Group B Board # 8, 11, 29, 33

	Board #	Part ID	Post Reflow until Aug 2011	3 thermal cycles (Aug 2011)	Inspection Notes
Group B	8	1	Pass	Fail	open between points 39-40
Group B	8	10	Pass	Pass	
Group B	8	23	Pass	Pass	
Group A	10	1	Pass	Fail	open between points 47-48 and 50-51
Group A	10	10	Pass	Pass	
Group A	10	23	Pass	Fail	high resistance between points 32-33
Group B	11	1	Pass	Fail	high resistance between points 42-43
Group B	11	10	Pass	Pass	
Group B	11	23	Pass	Pass	
Group A	21	1	Pass	Pass	
Group A	21	10	Pass	Pass	
Group A	21	23	Pass	Pass	
Group B	29	1	Pass	Fail	open between points 54-55
Group B	29	10	Pass	Pass	
Group B	29	23	Pass	Pass	
Group A	31	1	Fail (high ohm point 51-52)	Fail	open between points 50-51-52
Group A	31	10	Pass	Pass	
Group A	31	23	Pass	Pass	
Group A	32	1	Fail (high ohm point 38-39)	Fail	high resistance between points 38-39
Group A	32	10	Pass	Pass	
Group A	32	23	Pass	Pass	
Group B	33	1	Pass	Pass	
Group B	33	10	Pass	Pass	
Group B	33	23	Pass	Pass	

The cards were divided into the two groups shown in Table 1. Each group contained four cards: three which had suspected HoP defects and one which did not (i.e. a decoy).

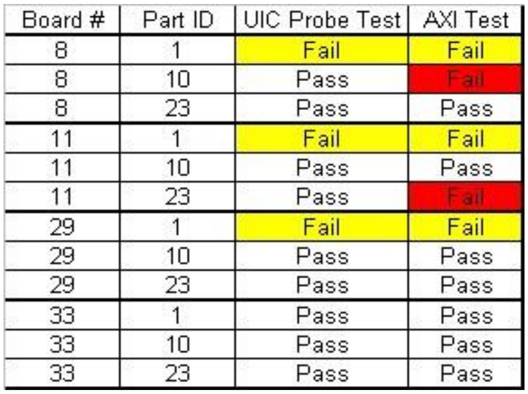
The two groups were then circulated among five different assembly sites where AXI inspection took place over a period of six months. These assembly sites are label as S1, S2, S3, S4, and S5. At these five sites, four different AXI platforms were used with some sites using just one platform and others using up to three platforms to test the same cards. The machines used in the study are labeled M1, M2, M3, and M4. Once completed, all the test sites provided the raw data to ALU for analysis.

DATA COLLECTION AND ANALYSIS

The team decided to perform the detailed analysis on the four cards in Group B first, given that all sites had completed testing on this group while the cards in Group A were set aside for inspection validation and further algorithm development. The data for this paper is based solely on results of the Group B cards: Board # 8, 11, 29, and 33.

The first step in the data analysis was to correlate the electrical test results to the AXI inspection results. As shown in Table 2, electrical testing had indicated that three out of twelve devices (Group B) were defective, while AXI indicated that two additional devices (five in total) were defective. The importance of this finding cannot be stressed enough; the AXI systems flagged two potential failures that went unnoticed with the electrical test, even after three burn-in thermal cycles.

Table 2: Probe test results versus the AXI test results



Board #	Part ID	UIC Probe Test	AXI Test
8	1	Fail	Fail
8	10	Pass	Fail
8	23	Pass	Pass
11	1	Fail	Fail
11	10	Pass	Pass
11	23	Pass	Fail
29	1	Fail	Fail
29	10	Pass	Pass
29	23	Pass	Pass
33	1	Pass	Pass
33	10	Pass	Pass
33	23	Pass	Pass

Based on these results, three boards were identified by AXI with potential HoP defects. Board #29, which was suspected of containing five or six HoP defects, was then subjected to additional physical analysis by the AREA consortium team. The program then focused on part ID 1 and 10 on board #8; and part ID 1 and 23 on board #11. Cross-sectioning of the test cards was the key technique used to verify all the AXI results. Parts with ID's 10 and 23 were the first to be sectioned since they had a very low number of HoP reported, and because these two parts had passed electrical probe test.

The tedious process of cross-sectioning each device row by row was used in order to observe any potential HoP defect that may have escaped both electrical probing and AXI. As expected by the team, the HoP defects identified were more toward the center rather than in the corners of the PBGAs, owing to the device warpage which is described as concave down during reflow. As shown in Figure 5, the pin map shows the locations of the two defects from part ID 10 and 23.

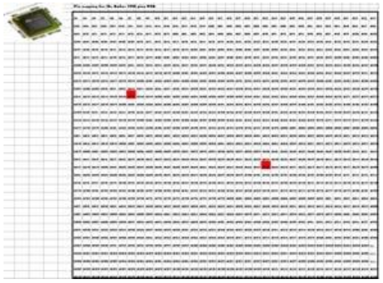


Figure 5: Pin map of the two failing pins on the part ID 10 on board SN8 and 23 on board SN11

Images of the two HoP defects from part ID 10 on board #8 and part ID 23 on board #11 are shown in Figure 6. As described in Coyle’s paper [2], some HoP failures might even pass electrical testing depending on the HoP joint type and how it was formed. From an inspection and statistical point of view, this may not be a big concern because a small percentage of defects are expected to escape any algorithm that is not yet completely mature. However, from a product point of view, this type of one pin defect escaping inspection is the worst enemy of the OEM as it is expected to fail after a period of time in the field.

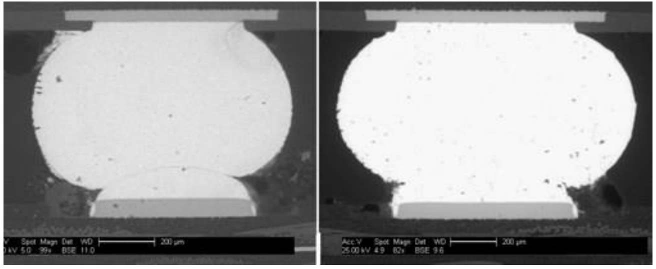


Figure 6: The single HoP defect of the part ID 10 from board SN8 on the left, and the part ID 23 from board SN11 on the right

The next part to be cross-sectioned was part ID 1 on board #11 since the inspection results from every site were largely in agreement. The cross-sectioning was once again performed row by row and the results confirmed each of the six HoP reported by the AXI systems.

Finally, the focus turned to part ID 1 on board #8 as the last part for cross-sectioning in this program and the pin mao of HoP is shown in Figure 7. This part ID had a large number of HoP reports by each EMS site. In addition, the results from the different sites varied quite a bit between the number of escape calls (defined as a real defect that was not caught by the inspection) versus the number of false calls (defined as a good joint reported as a defect by the AXI). For part ID 1 board #8, cross-sectioning shown in Figure 8, was performed row by row and the pin map diagram shown in Figure 7 illustrates where the defects were located on the part. All the pins highlighted in RED are those that were confirmed by cross-section and are considered to be real defects. All the pins highlighted in GREY are those that have been confirmed as false calls from one or multiple machines.

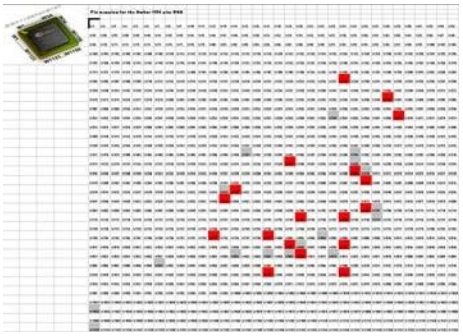


Figure 7: Pin map of HoP on part ID 1 on board SN8

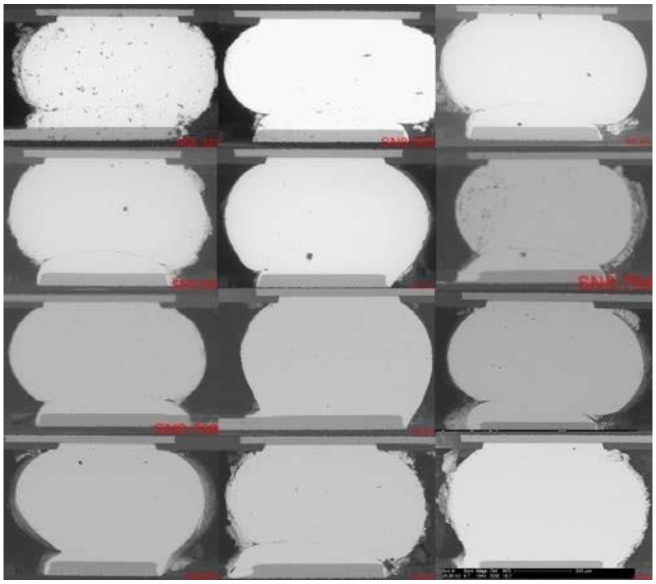


Figure 8: HoP images of different pins from part ID 1 on board SN8

INSPECTION RESULTS VS. CROSS-SECTION

The data from each site and machine was compared. Each site provided their results independently to ALU. The results of the four key parts are listed in Table 3 below.
They are referred to as S1M1 (Site 1 using Machine 1), S2M1, etc… which in some cases shows that multiple machines were used at one site.

Pin number	S1M1	S2M1	S2M2	S2M3	S3M1	S3M3	S3M4	S4M3	S5M2	X-section Notes
SN 8, ID_1										
228	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
300	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
363	HoP	HoP	HoP	HoP		HoP		HoP	HoP	Did Not Observe HiP
369	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
491	HoP	HoP	HoP	HoP	HoP	HoP		HoP	HoP	Did Not Observe HiP
501	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	Did Not Observe HiP
529	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
535					HoP	HoP				Did Not Observe HiP
569	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
570		HoP								Did Not Observe HiP
604	HoP	🟥	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
625		HoP			HoP	HoP				Did Not Observe HiP
626	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
659	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
706	HoP	HoP	HoP	HoP	🟥	HoP	🟥	HoP	HoP	Unusual shape, may be Partial HiP
707		HoP								Did Not Observe HiP
734	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
738	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
741	HoP	HoP	HoP	HoP		HoP		HoP	HoP	Did Not Observe HiP - Joint Shape is similar to HiP on one side
794	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
799	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
804	HoP	HoP	HoP	HoP		HoP		HoP	HoP	Did Not Observe HiP
835	HoP	HoP	HoP	HoP	HoP	HoP		HoP	HoP	HiP Confirmed
836						HoP				Did Not Observe HiP
840	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
864				HoP						Did Not Observe HiP
867				HoP						Did Not Observe HiP
869						HoP				Did Not Observe HiP
870	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
873			HoP			HoP		HoP	HoP	Did Not Observe HiP
891		HoP								Did Not Observe HiP
901	HoP	🟥	HoP	HoP	HoP	HoP	🟥	HoP	HoP	Initial section seemed to confirm HiP Fine Polishing seemed to remove HiP features. I believe Partial HiP
935	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HoP	HoP	HiP Confirmed
942	HoP	HoP	HoP	HoP	🟥	HoP	🟥	HoP	HoP	HiP Confirmed
1055							HoP			No HiP Observed
1123							HoP			No HiP Observed
SN8, ID_10										
347	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
801							HoP			No HiP Observed
1123			HoP	HoP		HoP	HoP	HoP		No HiP Observed - Joint has slightly odd shape
SN11, ID_1										
7		HoP								Did Not Observe HiP
727	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	🟥	HiP Confirmed
728	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
732	HoP	Insuf	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
790	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
803	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
897	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
SN11, ID_23										
668	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HoP	HiP Confirmed
1123						HoP				Did Not Observe HiP
ESC	0	2	0	0	2	0	14	0	1	
FalseC	5	10	7	8	4	12	5	7	6	
ESC%	0.00%	7.41%	0.00%	0.00%	7.41%	0.00%	51.85%	0.00%	3.70%	
FalseC%	10.42%	20.83%	14.58%	16.67%	8.33%	25.00%	10.42%	14.58%	12.50%	

Table 3 summarizes the Group B results after crosssectioning was performed. The term "HoP" appears in each cell where AXI identified a potential HoP. White cells indicate correctly identified HoP. Escapes, where AXI failed to find the HoP defect are highlighted in RED and false calls are highlighted in GREY.

Table 3: Cross section results on the four key parts that performed the in-depth analysis and compared to AXI results

SITES AND MACHINES COMPARISON

It was noted that S3M4 resulted in a 50% escape rate on the 27 confirmed HoP. The authors considered this an outlier of the overall data set because the result was largely inconsistent with that of the other machines, and because there was only one attempt with each machine to identify the HoP, which brings into question the algorithm maturity and experience of that machine and/or operator.

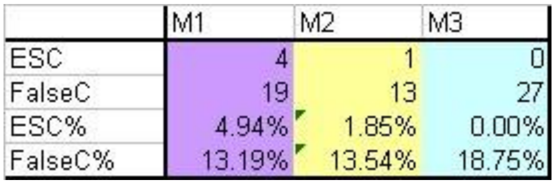
Overall the data shows (with the exception of S3M4), that three different machines have up to an 8% escape rate, and as high as a 25% false call rate.

Machine M2 showed consistency, producing the smallest delta between the results from two different sites. It had similar false call rate as M1, but with an overall lower escape percentage.

Machine M3 was able to detect all HoP defects from the three different sites in this project with the catch that the false call rate was notably higher.

All the M1 machine results were grouped and shown in Table 4 below. It was observed that this machine is capable of producing very good results, and in fact best overall in all nine data sets with zero escape and low false call rate from S1M1 as shown in the bottom of Table 3. However, it was also suggested that different users with different level of experience and thresholds setting in algorithm could allow as much as an 8% escape rate for the 27 HoP defects.

Table 4: Combined AXI machines results from the different sites



	M1	M2	M3
ESC	4	1	0
FalseC	19	13	27
ESC%	4.94%	1.85%	0.00%
FalseC%	13.19%	13.54%	18.75%

Normally in production, the standard practice to calculate the false call rate is to use the number of false defect found in the entire population that was inspected and present data in the format of Defect per Million Opportunity (DPMO). In this study not all the devices and pins were cross-sectioned for confirmation. To simplify the view for the ease of comparison, the authors used the 48 pins shown in Table 3 that had been reported by at least one of the machines for the analysis to calculate false call and present the results in percentage. The 27 pins that had confirmed HoP from crosssection are used for the analysis to calculate escape.

Table 3 provides all nine combinations of sites and machines and their respective inspection results. Notes from the engineer who performed the actual cross-sections are also shown beside each pin on the right hand side of the table. Ultimately, the engineer who performed the crosssection made the decision of whether the pin was HoP or not (some pins were not clearly identifiable as either HoP or good).

CONCLUSIONS AND SUGGESTED FUTURE WORK

HoP is not an easy defect to detect in production. The industry's perception of the problem has come a long way from believing that HoP is an isolated phenomenon to now understanding and accepting that HoP is a much more prevalent defect in BGA soldering in the SMT process. In this collaborative study between the OEM and EMS, the overall results are very encouraging. It suggests that with focused engineering effort between the EMS and the AXI suppliers, a reliable HoP detection capability is achievable. This project was able to quantify the effectiveness of the HoP detection through a lengthy experiment that culminated with a tedious cross-sectioning effort. The results suggested that some machines can potentially catch 100% of the HoP defect while other less effective machines are still capable of catching 90%+ of the HoP defect. Depending on the machine type used, adding HoP inspection to production may potentially result in a small increase in AXI inspection time. However, with the quantifiable results demonstrated in this study, such an increase is easily justifiable on the grounds that it will help to avoid 90%+ of the HoP defect escapes. By extension, implementation of AXI for HoP detection in volume production on high risk BGAs is now a common practice in some of the OEM and EMS involved in the project.

Despite the very promising results that have come from this project, several other aspects require further study and follow-on investigation to improve HoP detection through the AXI process.

- Algorithm fine tuning. Knowing the results of the cards in Group B, the sites involved in the study can further improve the algorithms and threshold settings through re-inspection of the Group A cards that have not been subjected to destructive analysis.
- More work is needed to understand the effect that BGA joint size, pitch and shape may have on different thresholds in the algorithm settings.
- Identifying BGAs that are at higher risk of HoP was not part of this study but it is a key to successful implementation of HoP detection with AXI.

  Component warpage and its relationship to HoP defects will be discussed in Part 2 of this collaboration effort between the OEM and EMS.
- Finding a known HoP defect card is not an easy process -especially without destructive analysis. A more reliable laboratory type of tool is needed especially when HoP is not on the outside row of the BGA. Once a known HoP BGA is found, using such a card to fine tune the AXI will lead to a much more successful HoP detection of that same BGA type.
- Much of the work that has been done previously has been focused on mitigation steps to minimize HoP, rather then addressing the root cause. The industry will need to focus more efforts on how to address the root cause of HoP (as will be discussed in the Part 2 of this paper).

ACKNOWLEDGEMENTS

The authors would like to acknowledge the help of a very large extended team from the different companies involved in this project. These included the Celestica team in the Thailand factory, Flextronics team in the Austin factory, and the Sanmina team in the Guadalajara factory.

The authors would also like to thank Tony Chien, Vincent Yang, Liang Chen, Haolee Yang from TRI; and Wee Kan Khim, Seow Zi Yang, Lim Seng Yew, Tracy Elliason, Dr Tan Chun Aun Dr Rick Gaudette from Vitrox for their support in this project.

REFERENCES

[1] Chris Oliphant, Bev Christian, Kishore Subba-Rao, Fintan Doyle, Laura Turbini, David Connell and Jack Q. L. Han, "Head-On-Pillow Defect – A Pain in the Neck or Head-On-Pillow BGA Solder Defect," APEX 2010.

[2] Richard Coyle, Russell Nowland, Peter Read, George Wenger, "Telecommunications Case Studies Address HeadIn-Pillow (Hnp) Defects and Mitigation through Assembly Process Modifications and Control," APEX 2010.

[3] Peng Su and Guhan Subbarayan, "Effects Of Component Warpage On Board Assembly Defects And Effective Mitigation Measures," Proceeding SMTAI 2010. [4] Joseph Lee, K.Y. Tsai, Chin Choo, "Detection of Headin-Pillow Defects Using 5DX Method," IPC-APEX 2011. [5] Dudi Amir, Raiyo Aspandiar, Scott Buttars, Wei Wei Chin, and Paramjeet Gill, "Head – and – Pillow SMT Failure Modes," Proceedings SMTAI 2009.