Head-on-Pillow I

Mitigating Head-in-Pillow Defects: An Experimental Approach to Identify No-Clean Soldering Materials

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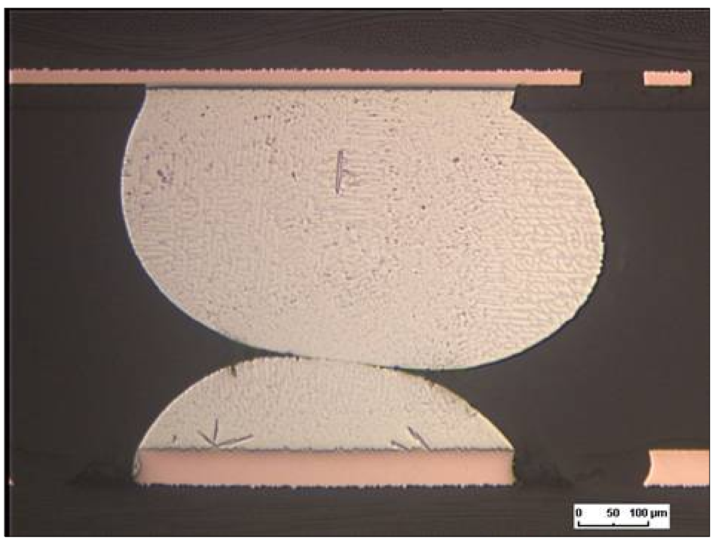
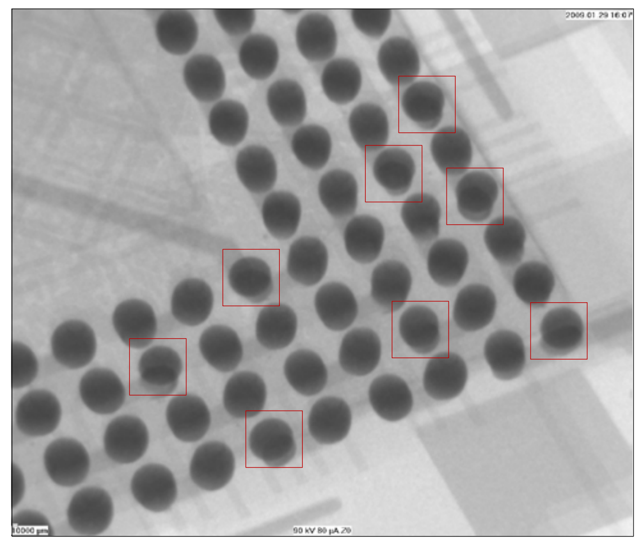
Overview

Head-in-Pillow (HIP) defects occur when the solder ball doesn't coalesce with the solder on the PCB pad. The mechanism for Head-in-Pillow (HIP) defect formation is fairly well understood. Component warpage is one of the primary causes for this defect. However, it's difficult to eliminate component warpage because of various design, construction and material constraints.



Head-in-Pillow Defect / Non-coalescence Example



Head-in-Pillow Defects observed on a 14 mm PBGA, 0.4 mm Pitch, SAC305

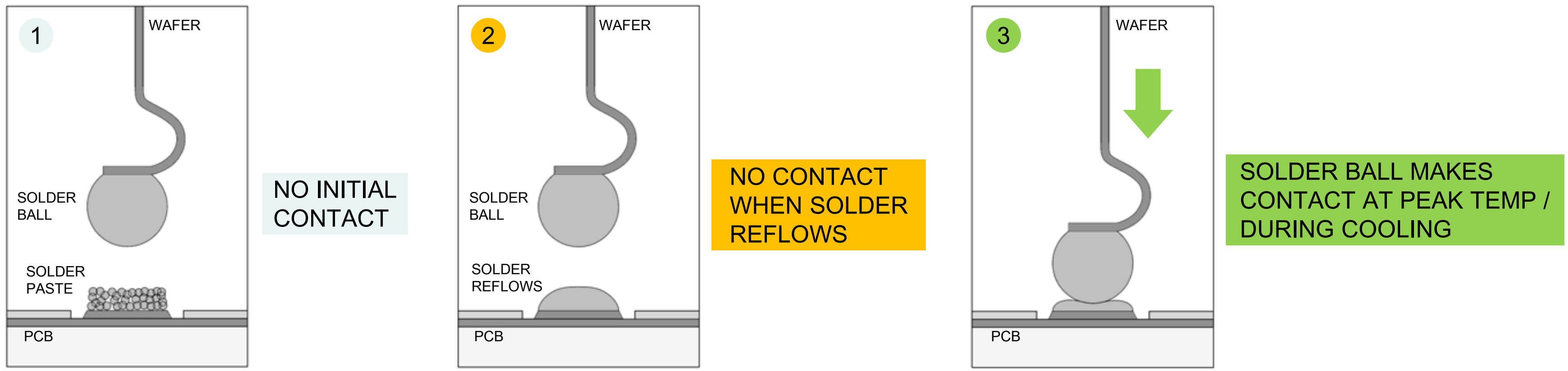
Test Method Considerations

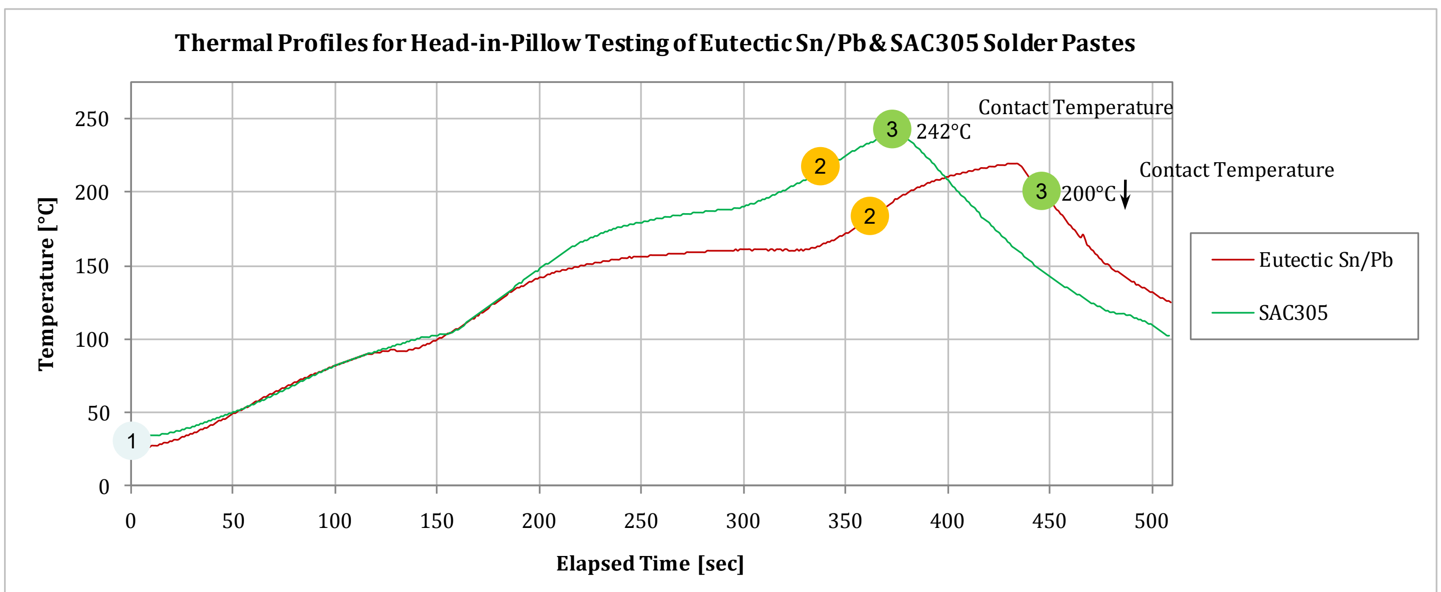
- Solder paste formulations that are high heat resistant and promote faster wetting can help mitigate HIP defects to some extent. In order to evaluate the effectiveness of these formulations, an experimental test method was looked at.

- The intent of this test method was to simulate the conditions needed to form a HIP joint. In addition to testing different solder pastes, this also helps identify the key factors or parameters in the process that influence the most, with respect to HIP defects.

- This approach would also eliminate the use of problematic components which could get expensive, considering the sample size needed to obtain a fair degree of confidence.

Proposed Test Methodology





PCB, Stencil and Part Information

PCB Pad Design Details

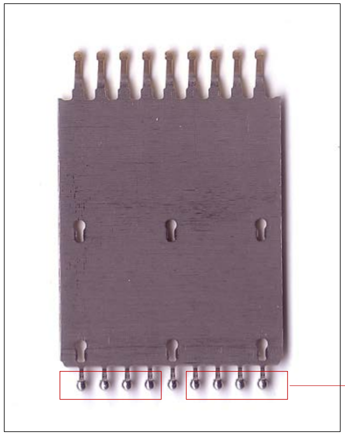
Pad Dimension	Ø0.024" / 0.61 mm Diameter
Solder Mask Opening	Ø0.028" / 0.71 mm Diameter

Stencil Aperture Design Details

Foil Thickness	0.006"
Fabrication Method	Laser-cut
Aperture Shape	Circular
Aperture Opening	Ø0.024" / 0.61 mm Diameter
Area Ratio	1.00
Solder Paste Volume Target	2,714 cubic mils

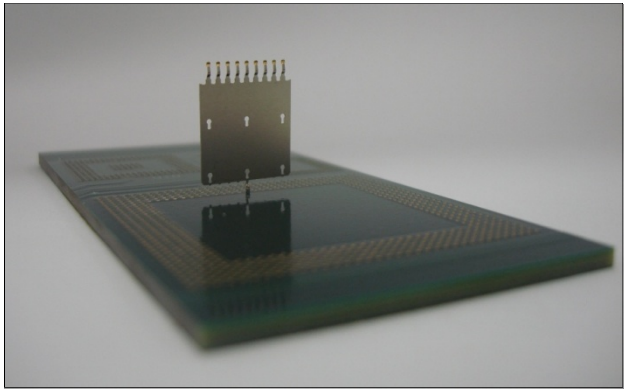
Part Details*

Part Type	Wafer extracted from a BGA Mezzanine Connector (Receptacle Version)
Wafer Type	Ground Wafer
Solder Ball Alloy Composition	Eutectic SnPb, Sn/3.0Ag/0.5Cu
Solder Ball Diameter	Ø0.030" Diameter
Solder Ball Height	0.023"



Solder balls within the red outline are to be trimmed off

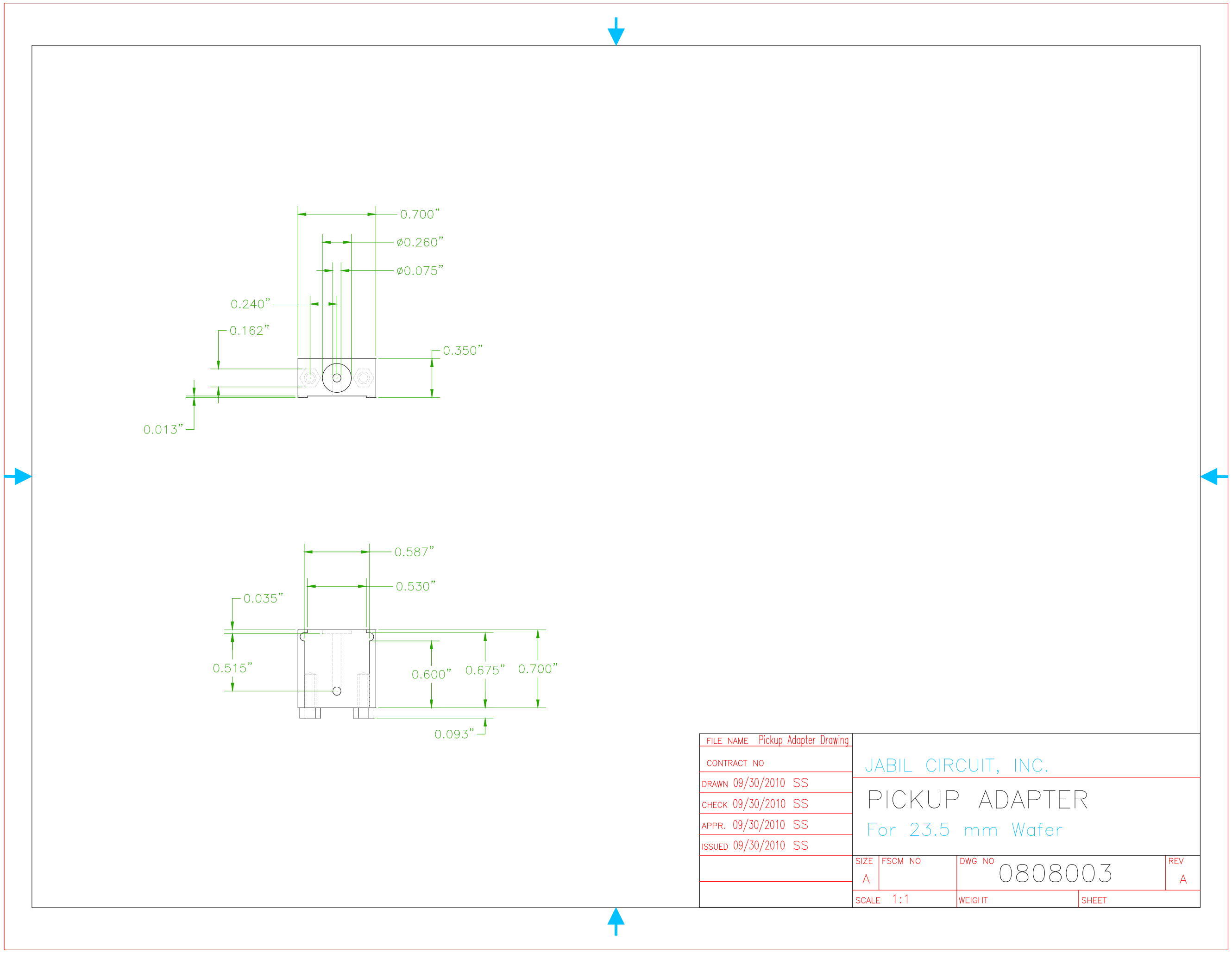
Ground Wafer from a BGA Mezzanine Connector



Wafer soldered to the PCB Coupon

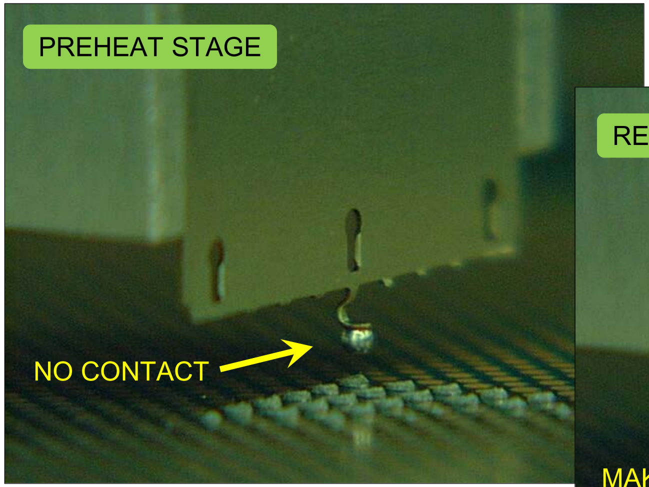
***Note:** The wafer used in this study was selected primarily for ease of testing, as it provides a single BGA sphere pre-mounted on a pedestal/post. Other part types could also be used.

Pickup Adapter Design for holding the Wafer

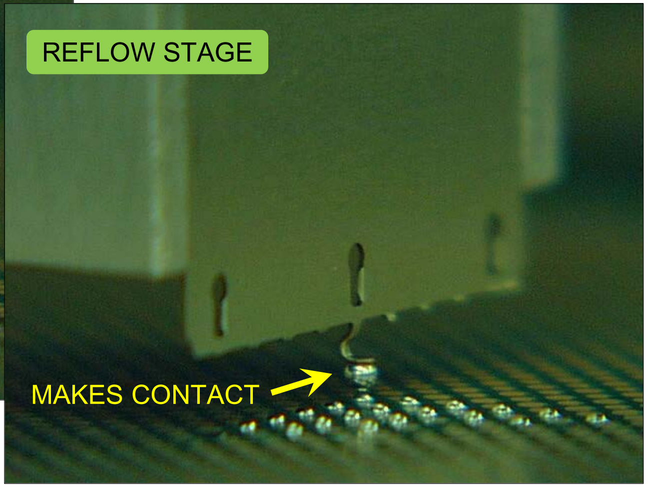


Test Setup Overview

- This test is performed on a BGA rework station. With the help of a custom fixture, a single wafer with one solder ball is held by the vacuum pick-up tube. The time and temperature at which the solder ball makes contact with the solder on the PCB pad is controlled by moving the pick-up tube. The entire sequence is recorded on video in order to determine the wetting time.



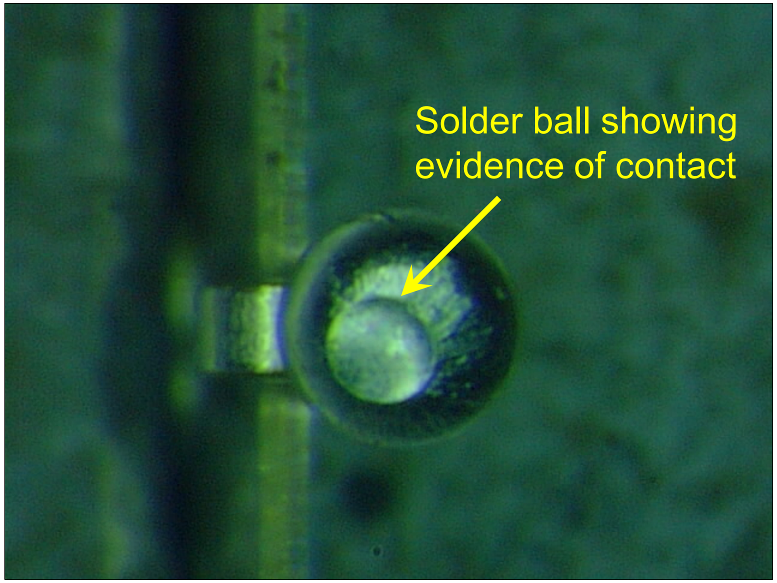
Wafer Position during Preheat Stage (No contact between Solder ball and Solder Paste)



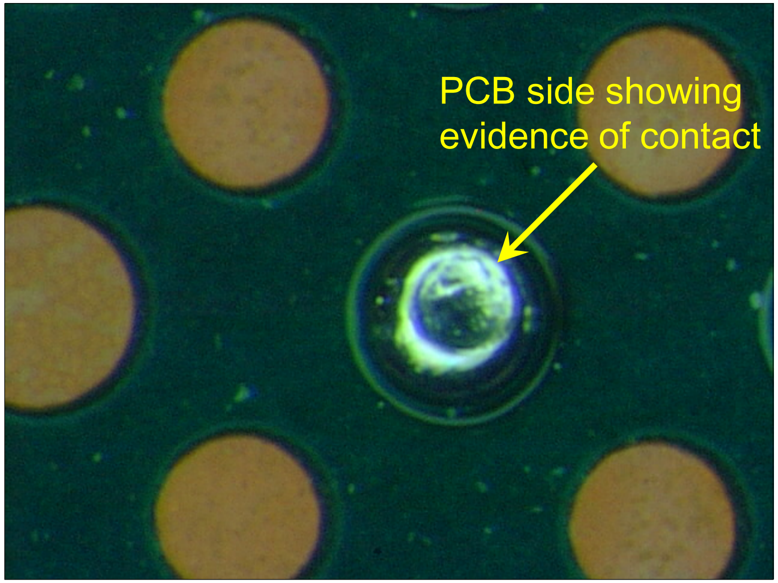
Wafer Position during Reflow Stage (Solder ball makes contact with solder on the PCB pad)

Head-in-Pillow Defect Detection

- When there is a head-in-pillow defect, the wafer would separate from the PCB after reflow. Both the solder ball and solder on the PCB pad would show evidence of contact.



Head-in-Pillow Defect (Solder Ball Side / Bottom View)



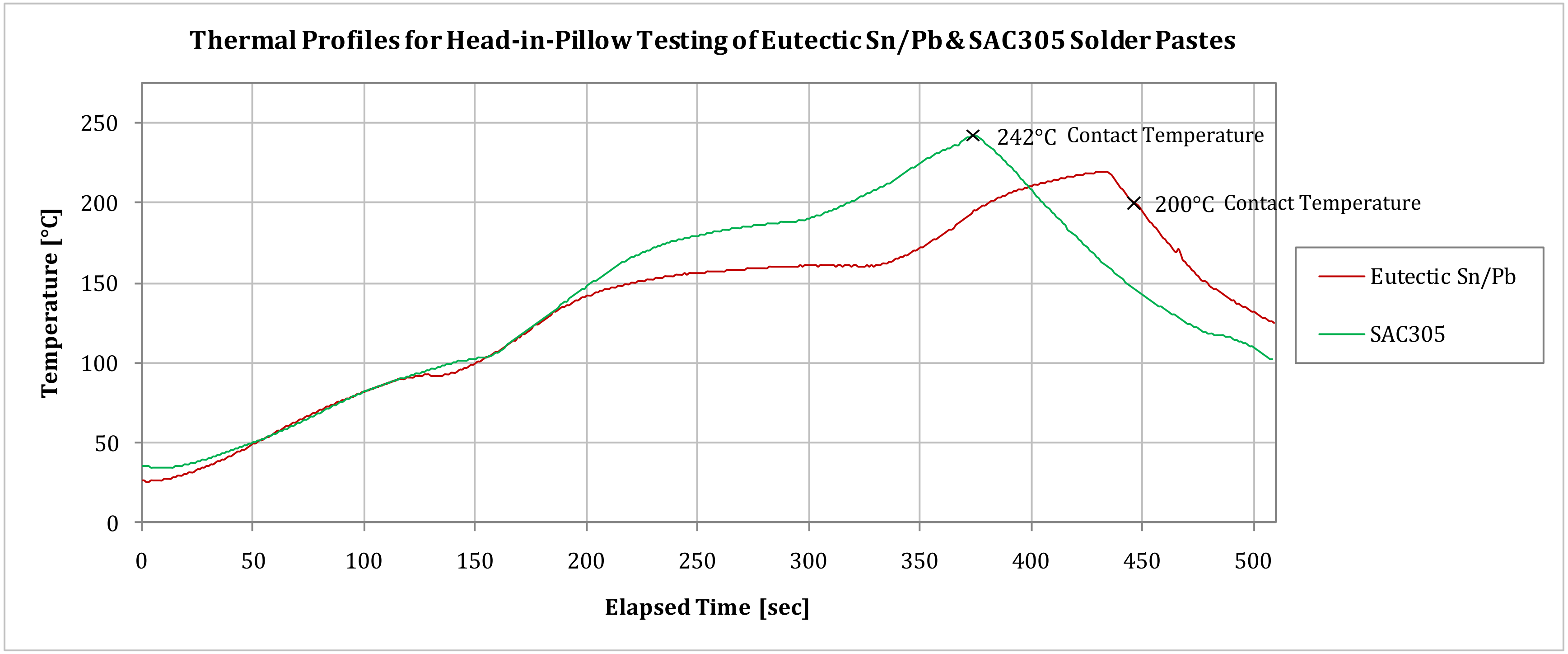
Head-in-Pillow Defect (PCB Side / Top View)

Test Parameters

- Trial runs were performed to establish a process and identify the critical test parameters. Both optimized and non-optimized solder paste formulations were used for these trials. Test parameters for SnPb and Pb-free SAC305 solder pastes are listed below.

Test Parameters	Eutectic SnPb Solder Paste	Pb-free SAC305 Solder Paste
Solder Paste Height	6 – 8 mils	6 – 8 mils
Solder Ball Preheat Position	1 mm above the PCB pad surface (No initial contact with solder paste)	1 mm above the PCB pad surface (No initial contact with solder paste)
Solder Ball Contact Height	4 mils above PCB pad (controlled by a spacer)	4 mils above PCB pad (controlled by a spacer)
Solder Joint Peak Temperature	220 – 222° C	240 – 242° C
Time above Liquidus	90 – 100 sec	50 – 60 sec
Contact Temperature	200 – 202° C while cooling (Test Condition 1) 190 – 192° C while cooling (Test Condition 2)	240 – 242° C (same as Peak Temperature)
Reflow Environment	Air	Air
Sample Size	10 Samples	10 Samples

Thermal Profile Comparison



Thermal Profile Targets for Eutectic SnPb and Pb-free SAC305 Solder Pastes

Reflow Parameters	Eutectic SnPb	SAC305
Soak Temperature Range	150 – 170° C	170 – 217° C
Soak Time	100 – 120 sec	100 – 120 sec
Solder Joint Peak Temperature	220 – 222° C	240 – 242° C

Reflow Parameters	Eutectic SnPb	SAC305
Time above Liquidus	90 – 100 sec	50 – 60 sec
Contact Temperature	200 – 202° C	240 – 242° C
Average Cooling Rate	1 – 1.2 ° C/sec	1 – 1.2 ° C/sec
Reflow Environment	Air	Air

Test Results Classification

The test results are categorized into following 4 groups:

(a) Full Coalescence (Fast Wetting) **100% Weight**

Full wetting occurs instantaneously, within 2 sec after contact

(b) Full Coalescence (Slow Wetting) **80% Weight**

Full wetting occurs between 2 sec and 10 sec after contact

(c) Partial Coalescence **20% Weight**

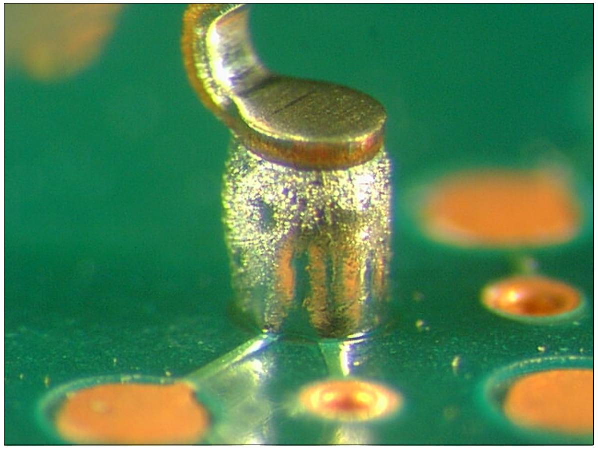
Partial wetting occurs more than 10 sec after contact

(d) Head-in-Pillow Defect / No Coalescence **0% Weight**

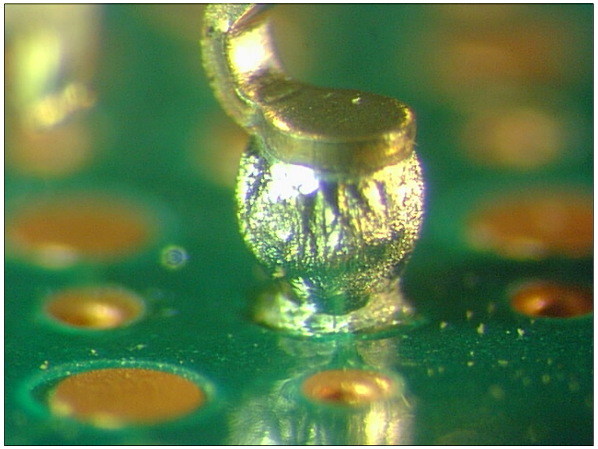
No wetting, No Solder Joint Formation

An overall weighted score is computed based on the test results from 10 samples.

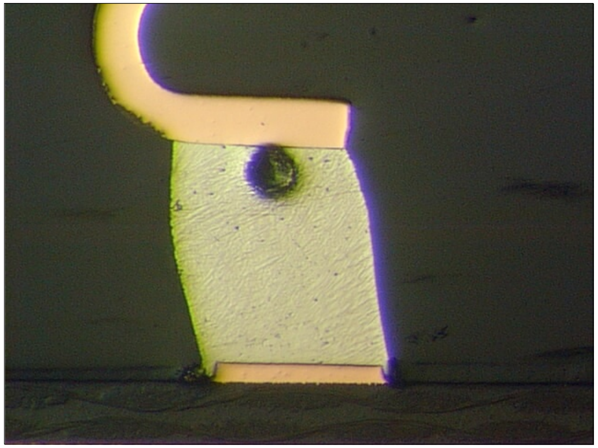
Full and Partial Coalescence Example



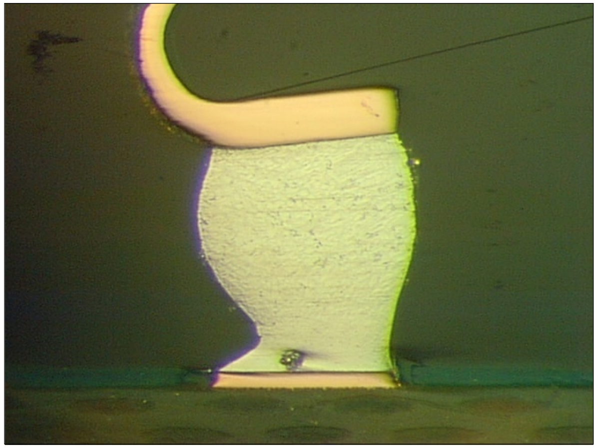
Fully Coalesced Solder Joint Example - Category A/B



Partially Coalesced Solder Joint Example - Category C

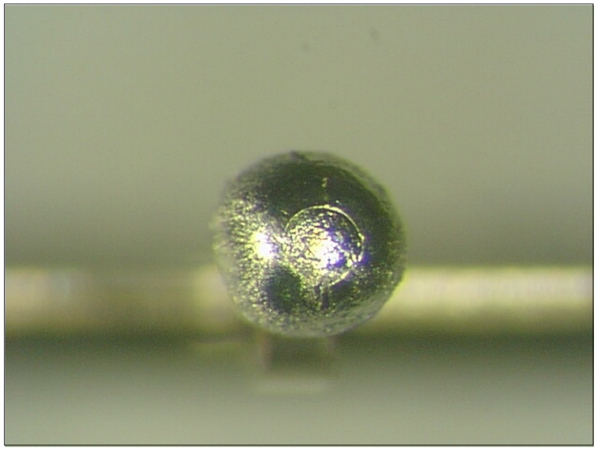


Fully Coalesced Solder Joint Example - Category A/B

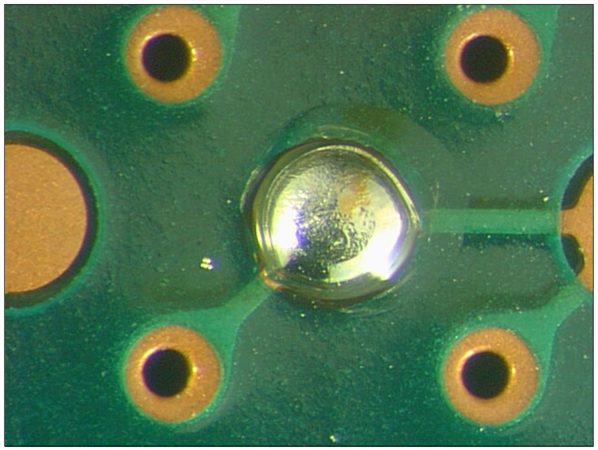


Partially Coalesced Solder Joint Example - Category C

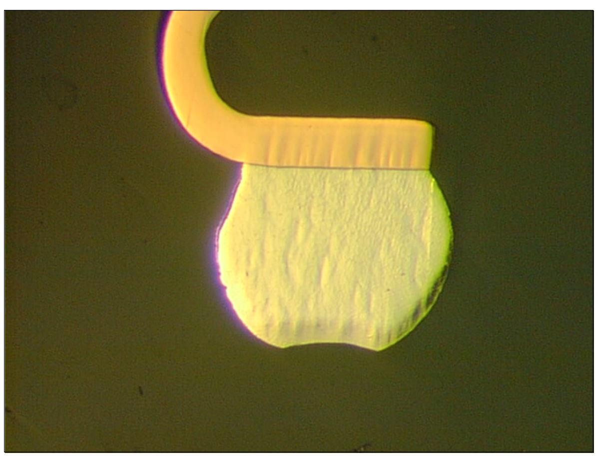
Head-in-Pillow / No Coalescence Example



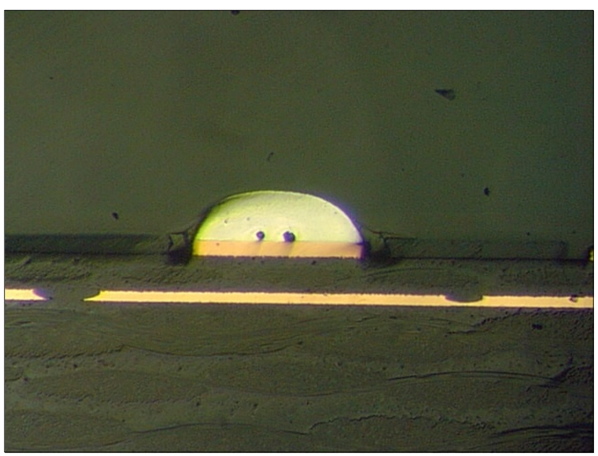
Head-in-Pillow Defect Example - Solder Ball Side (Category D)



Head-in-Pillow Defect Example - PCB Side (Category D)



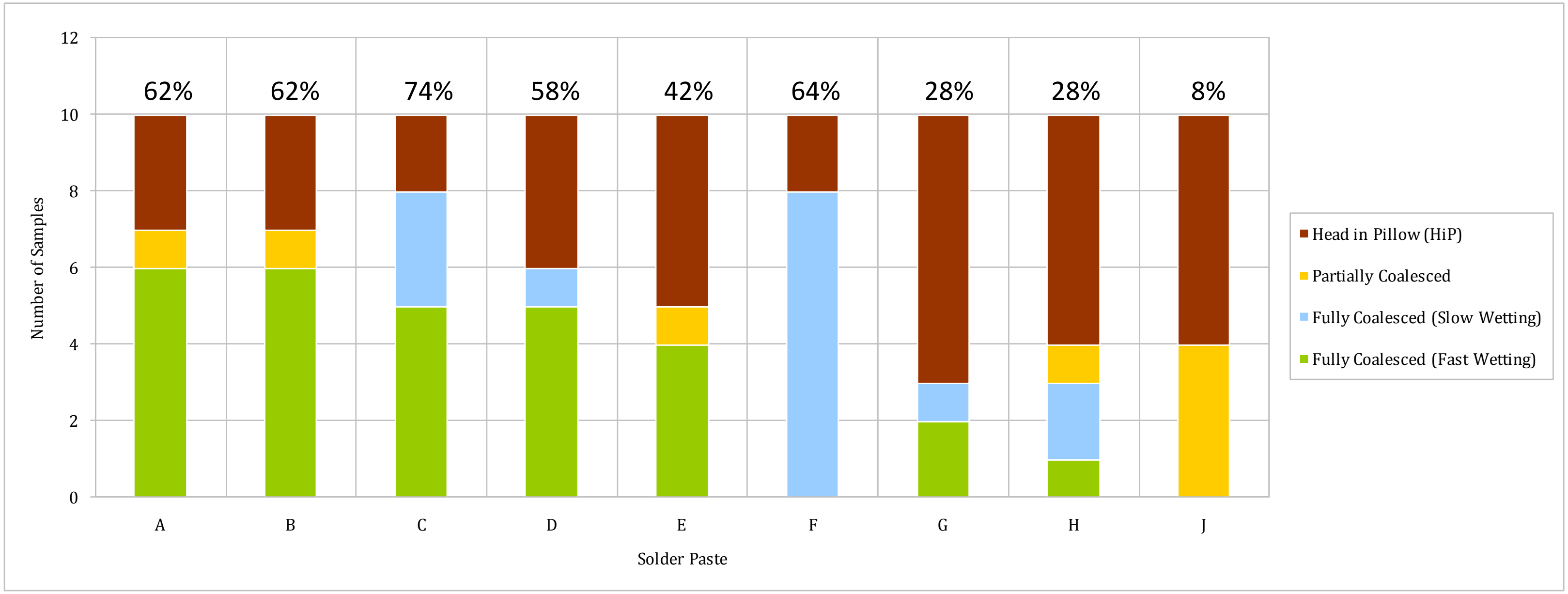
Head-in-Pillow Defect Example - Solder Ball Side (Category D)



Head-in-Pillow Defect Example - PCB Side (Category D)

SnPb Solder Paste Results for Test Condition 1

- Of the 9 No-clean SnPb Solder Pastes tested, four of them with a weighted score of above 50% were selected. Solder Paste F was not selected due to its slow wetting characteristics. The weighted score calculations are shown in the next slide. There were 10 samples tested for each solder paste.



** 10 samples tested for each solder paste*

SnPb Solder Paste Results for Test Condition 1

Solder Paste	Full Coalescence (Fast Wetting)*	Full Coalescence (Slow Wetting)*	Partial Coalescence*	Head-in-Pillow Defects*	Weighted Score (%)
A	6	0	1	3	62%
B	6	0	1	3	62%
C	5	3	0	2	74%
D	5	1	0	4	58%
E	4	0	1	5	42%
F*	0	8	0	2	64%
G	2	1	0	7	28%
H	1	2	1	6	28%
J	0	0	4	6	8%

4 SnPb Solder Pastes Selected from TC1

** 10 samples tested for each solder paste. Solder paste F was not selected due to its slow wetting characteristics.*

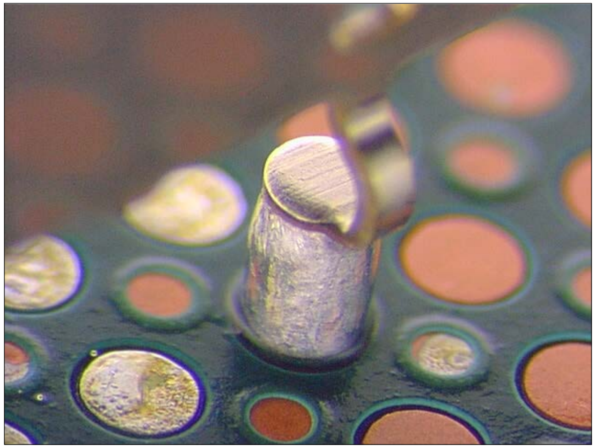
Sample Weighted Score Calculation:

For Solder Paste A,

Overall Weighted Score (%) = [(6 Samples x 1.0) + (0 Samples x 0.8) + (1 Samples x 0.2) + (3 Samples x 0)] x 100% / (10 Samples)

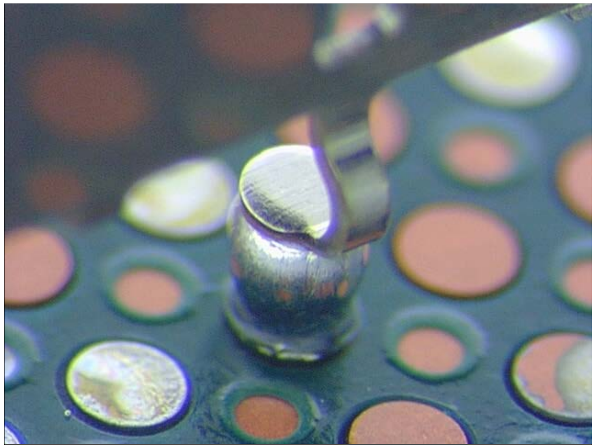
= 62%

SnPb Solder Paste Results for Test Condition 1

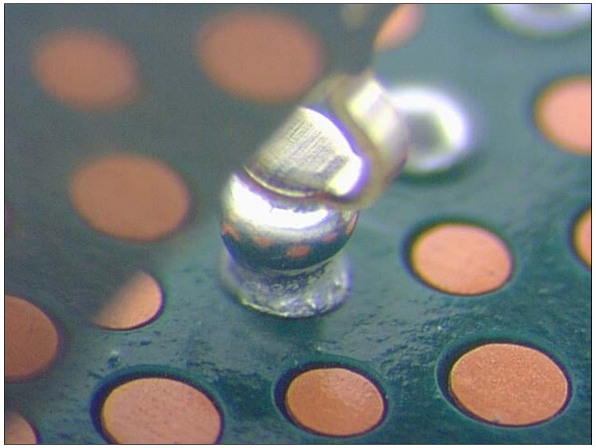


Fully Coalesced Solder Joint (Fast Wetting) – Solder Paste H

Fully Coalesced Solder Joint (Fast Wetting) – Solder Paste A



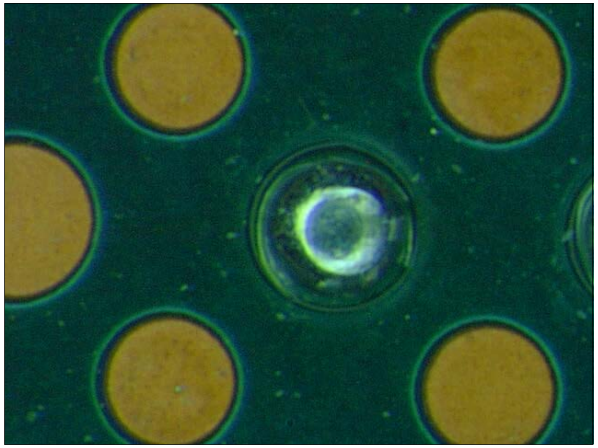
Partially Coalesced Solder Joint – Solder Paste J



Partially Coalesced Solder Joint – Solder Paste J

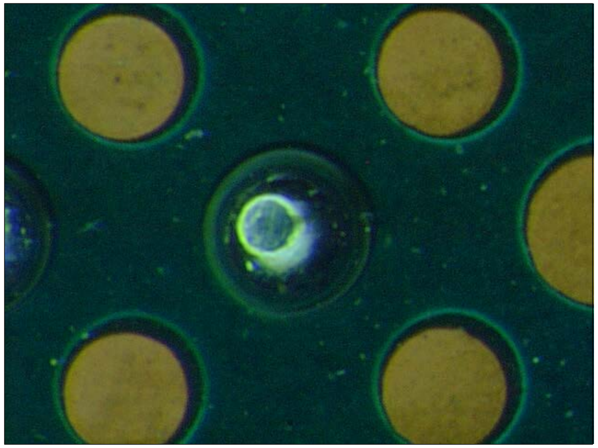
SnPb Solder Paste Results for Test Condition 1

Head-in-Pillow Solder Joint (Solder Ball Side) – Solder Paste A



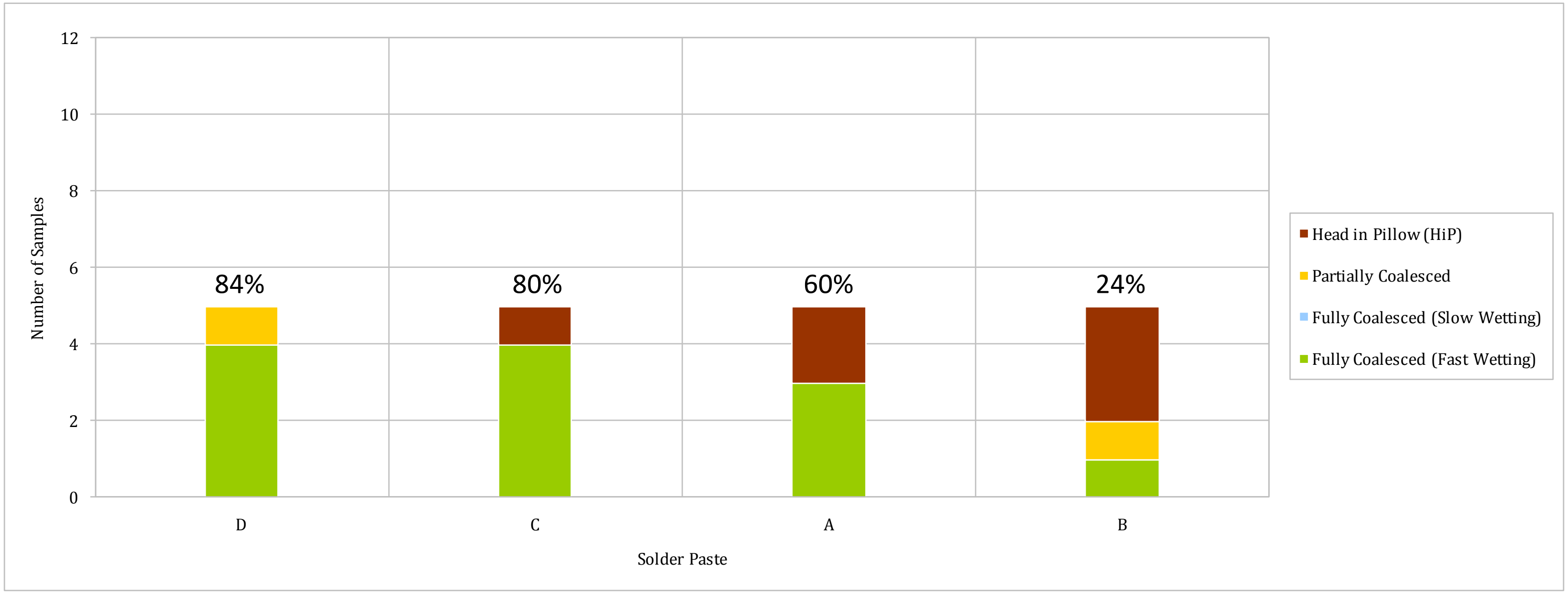
Head-in-Pillow Solder Joint (PCB Side) – Solder Paste A

Head-in-Pillow Solder Joint (Solder Ball Side) – Solder Paste B



Head-in-Pillow Solder Joint (PCB Side) – Solder Paste B

SnPb Solder Paste Results for Test Condition 2

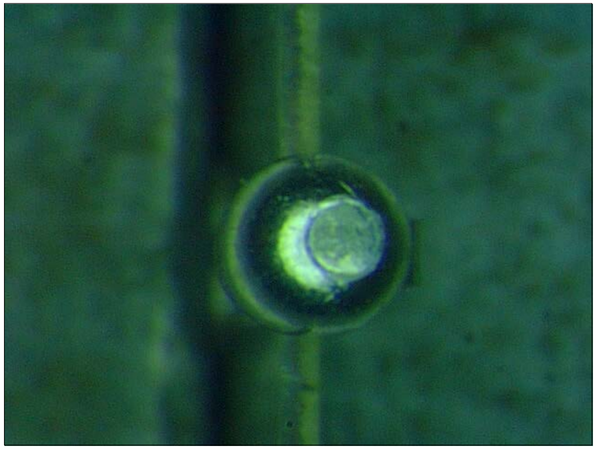


Solder Paste	Full Coalescence (Fast Wetting)*	Full Coalescence (Slow Wetting)*	Partial Coalescence*	Head-in-Pillow Defects*	Weighted Score (%)
D	4	0	1	0	84%
C	4	0	0	1	80%
A	3	0	0	2	60%
B	1	0	1	3	24%

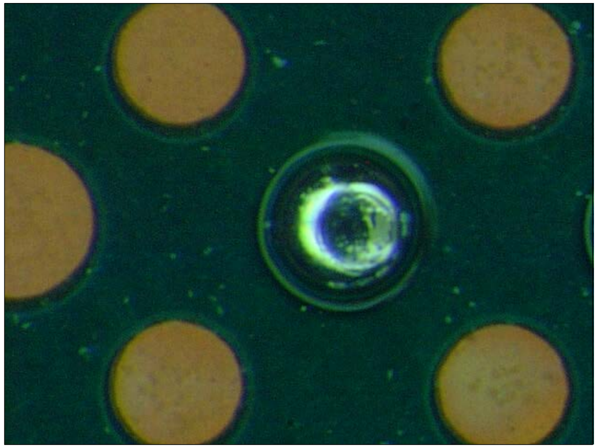
Top 3 SnPb Solder Pastes Selected from TC2

** 5 Samples were tested for each solder paste.*

SnPb Solder Paste Results for Test Condition 2

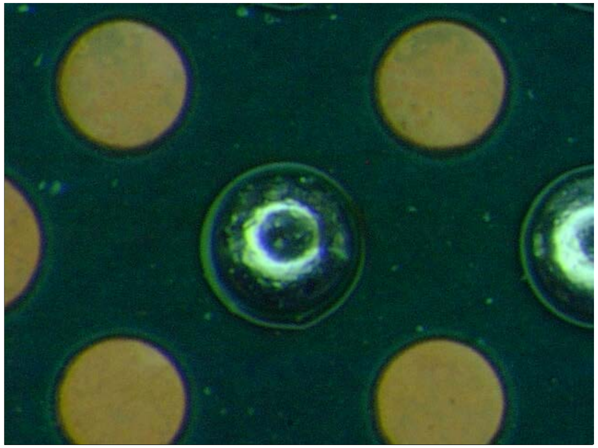


Head-in-Pillow Solder Joint (Solder Ball Side) – Solder Paste B



Head-in-Pillow Solder Joint (PCB Side) – Solder Paste B

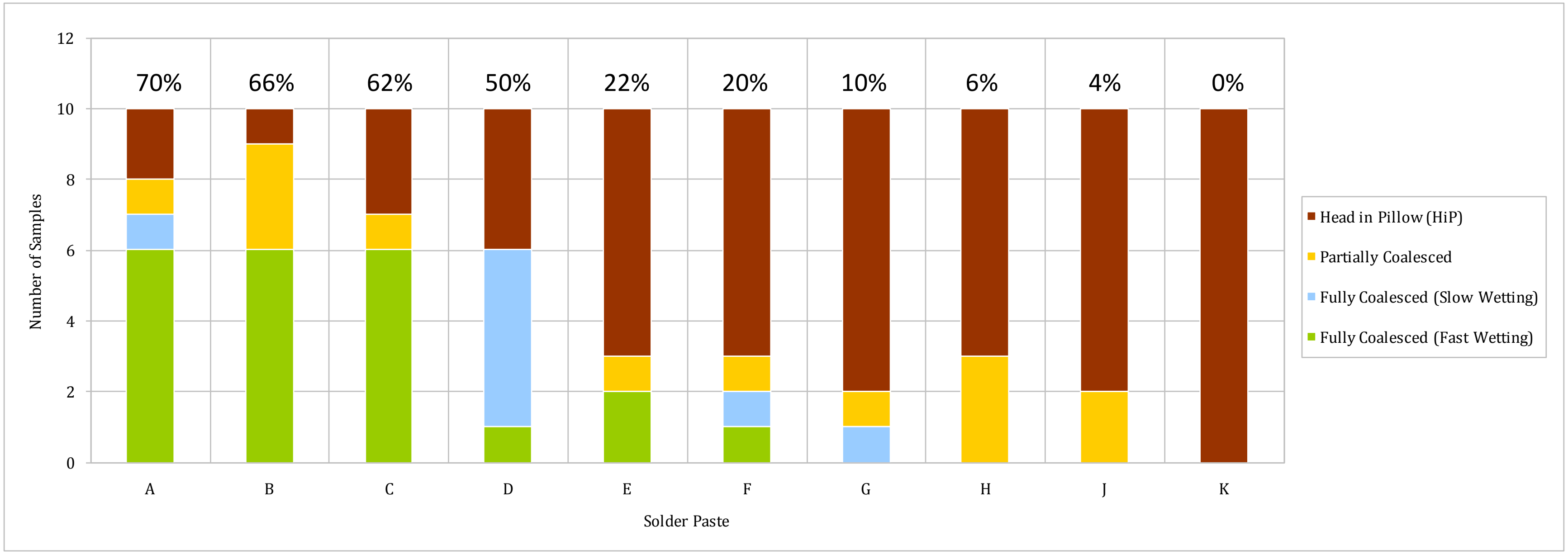
Head-in-Pillow Solder Joint (Solder Ball Side) – Solder Paste C



Head-in-Pillow Solder Joint (PCB Side) – Solder Paste C

Pb-free Solder Paste Results

- Of the 10 No-clean Pb-free SAC305 Solder Pastes tested, the top three Solder Pastes with a weighted score of above 60% were selected. The weighted score calculations are shown in the next slide. There were 10 samples tested for each solder paste.



** 10 samples tested for each solder paste*

Pb-free Solder Paste Results

Solder Paste	Full Coalescence (Fast Wetting)*	Full Coalescence (Slow Wetting)*	Partial Coalescence*	Head-in-Pillow Defects*	Weighted Score (%)
A	6	1	1	2	70%
B	6	0	3	1	66%
C	6	0	1	3	62%
D	1	5	0	4	50%
E	2	0	1	7	22%
F	1	1	1	7	20%
G	0	1	1	8	10%
H	0	0	3	7	6%
J	0	0	2	8	4%
K	0	0	0	10	0%

Top 3 Pb-free Solder Pastes Selected

** 10 samples tested for each Solder Paste.*

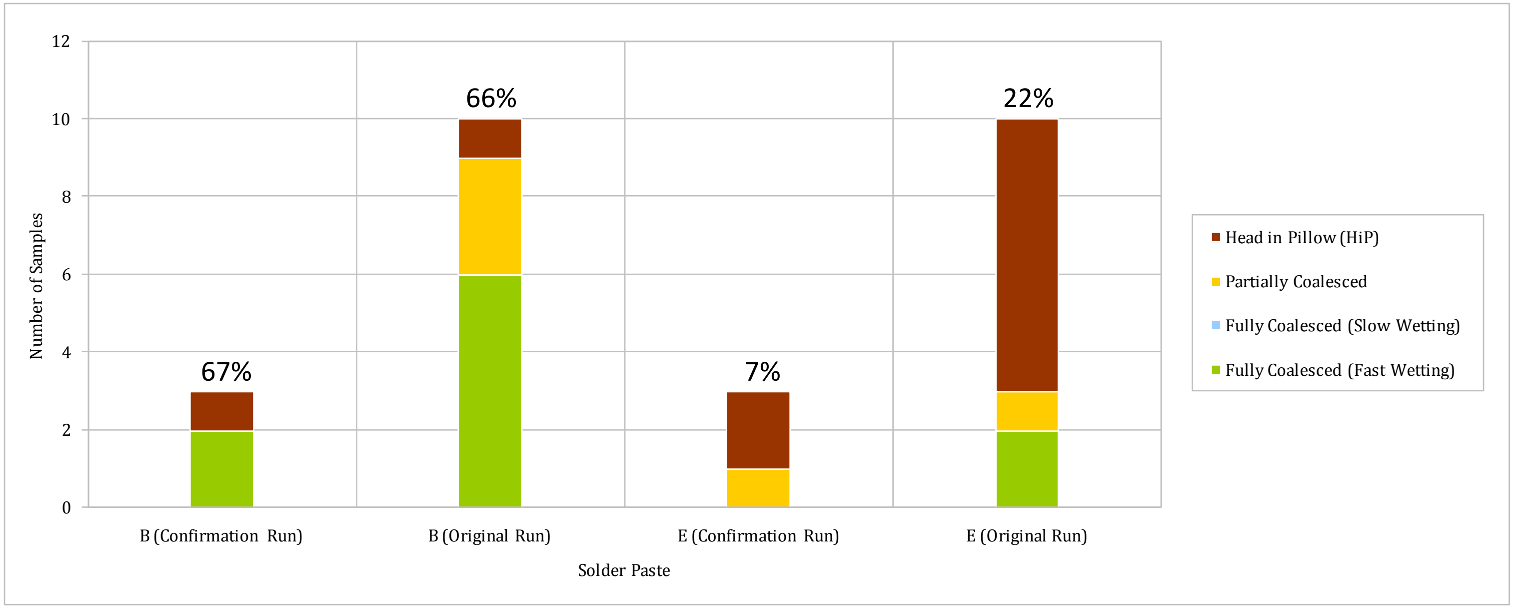
Sample Weighted Score Calculation:

For Solder Paste A,

Overall Weighted Score (%) = [(6 Samples x 1.0) + (1 Samples x 0.8) + (1 Samples x 0.2) + (2 Samples x 0)] x 100% / (10 Samples)

= 70%

Pb-free Solder Paste Confirmation Run



Solder Paste	Full Coalescence (Fast Wetting)*	Full Coalescence (Slow Wetting)*	Partial Coalescence*	Head-in-Pillow Defects*	Weighted Score (%)
B (Confirmation Run)	2	0	0	1	67%
B (Original Run)	6	0	3	1	66%
E (Confirmation Run)	0	0	1	2	7%
E (Original Run)	2	0	1	7	22%

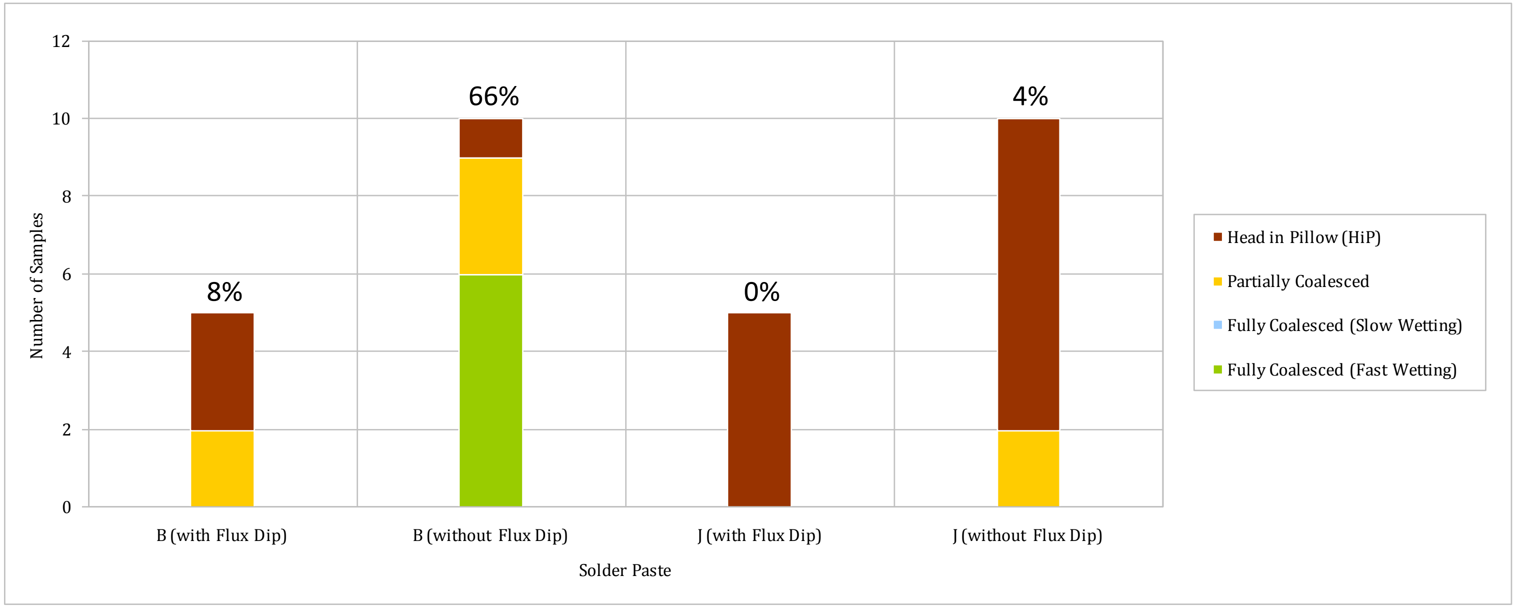
** For confirmation run, 3 samples were tested for each solder paste. Results of the original run shown for reference. Same test conditions were used.*

Influence of Flux Dip with Pb-free Solder Paste

- Follow-up testing was done on a small subset to see if there is any influence due to flux dip of the solder balls. One solder paste from top 3 (Solder pastes B) and one from the bottom 3 (Solder paste J) were picked for this run. 5 samples were run for each solder paste.

Test Parameters	Pb-free SAC305 Solder Paste (with Flux Dip)	Pb-free SAC305 Solder Paste (without Flux Dip)
Solder Paste Height	6 – 8 mils	6 – 8 mils
Flux Material	No-clean Tacky Flux B & J	No Flux Dip
Flux Dip Height	4 mils (Solder ball dipped in flux at time zero)	N/A
Solder Ball Position during Preheat	1 mm above the PCB pad surface (No initial contact with solder paste)	1 mm above the PCB pad surface (No initial contact with solder paste)
Solder Ball Contact Height	4 mils above PCB pad (controlled by a spacer)	4 mils above PCB pad (controlled by a spacer)
Solder Joint Peak Temperature	240 – 242° C	240 – 242° C
Time above Liquidus	50 – 60 sec	90 – 100 sec
Contact Temperature	240 – 242° C (same as Peak Temperature)	240 – 242° C (same as Peak Temperature)
Reflow Environment	Air	Air
Sample Size	5 Samples	10 Samples

Test Results for Flux Dip with Pb-free Solder Paste



Solder Paste	Full Coalescence (Fast Wetting)*	Full Coalescence (Slow Wetting)*	Partial Coalescence*	Head-in-Pillow Defects*	Weighted Score (%)
B (with Flux Dip)	0	0	2	3	8%
B (without Flux Dip)	6	0	3	1	66%
J (with Flux Dip)	0	0	0	5	0%
J (without Flux Dip)	0	0	2	8	4%

** 5 Samples tested with flux dip & 10 samples tested without flux dip for each solder paste*

Summary

- The test method was found to be effective in evaluating the performance of both SnPb and Pb-free no-clean solder pastes, with respect to mitigating Head-in-Pillow defects.

- Some of the key benefits identified with using this test method.
  - Generic PCB coupons could be used (no electrical connections needed).
  - Quick and easy visual Inspection for Head-in-Pillow defects.
  - Wetting time can be captured with use of video.
  - Contact Height & Temperature can be precisely controlled.

- Based on this testing, the top three SnPb & Pb-free solder pastes were selected for further testing and verification.

- Preliminary testing indicate that flux dip process is not effective in reducing the occurrence of Head-in-Pillow defects.

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