DELPHI

Impact of BGA Warpage on Quality

Mike Varnau

5-11-06

Contents

- What is a Ball in Cup Failure
- Case Study
  - Background
  - Problem Identification
  - Solution
  - Results
- Assembly Related Factors Causing Ball in Cup
- Component Related Factors Causing Ball in Cup
- Trends from Technology Changes
- Summary

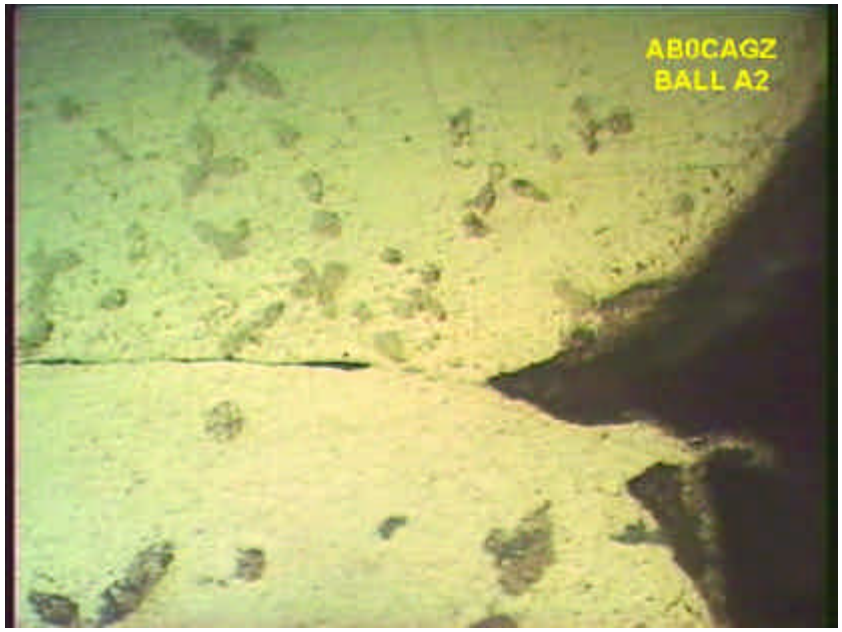
DELPHI

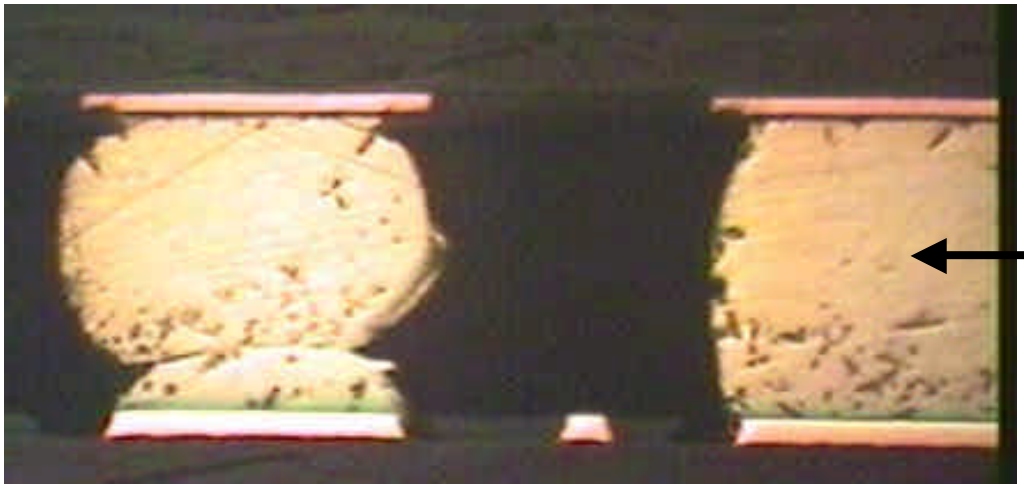
388 PBGA Interconnect Issue
Ball & Cup Interconnect Failure

Also known as “Ball and Socket”

There is a gap between the ball and solder paste.

The gap contains flux residue.





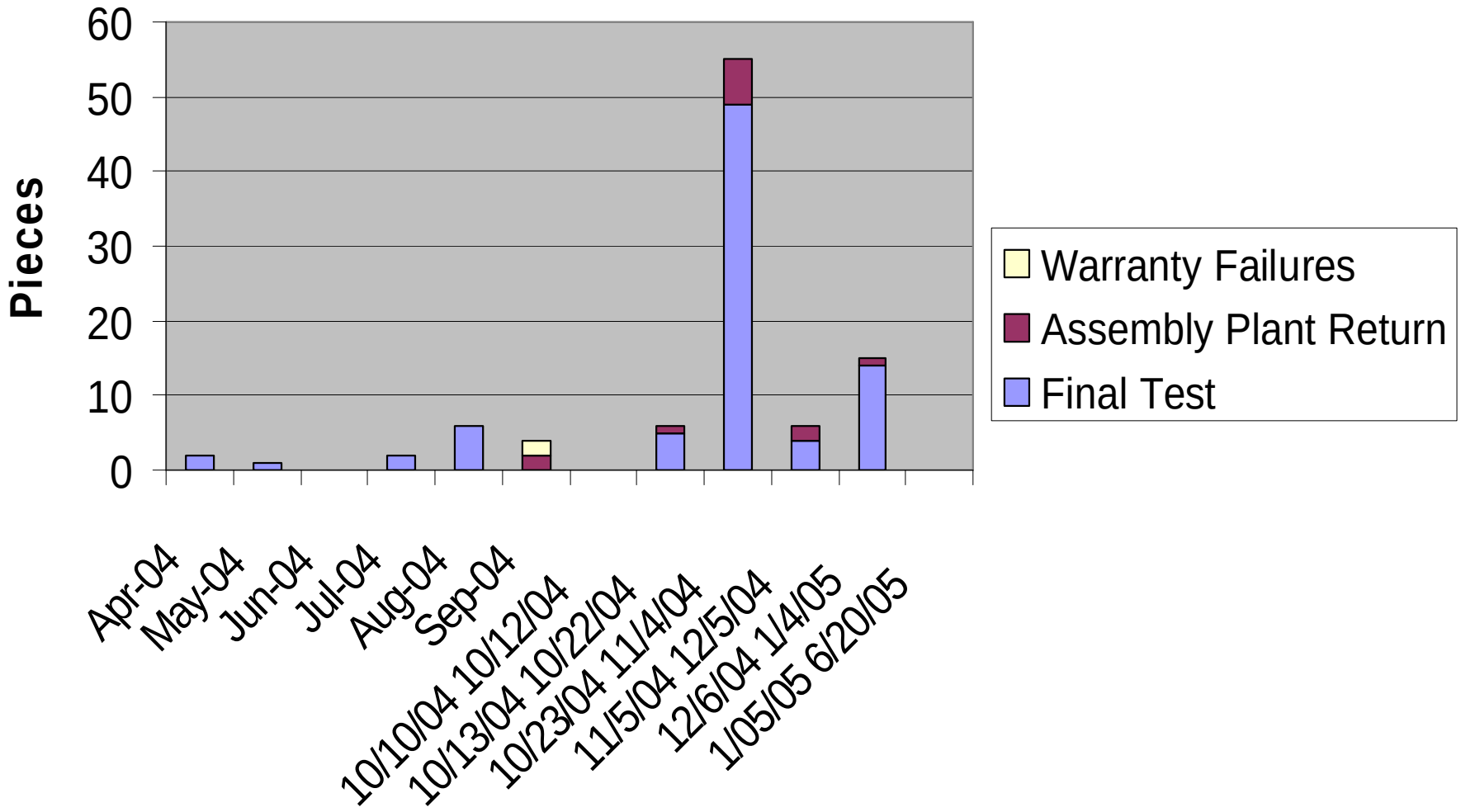
Note how neighbor joint looks stretched rather than round

DELPHI

388 PBGA Interconnect Issue
Background

- **Microprocessor in 388 pin 27 x 27 mm PBGA**
- **High volume production in Automotive Engine Controls**
  - **Liverpool – 3,500 / week**
  - **Singapore – 4,000 / week**
  - **Milwaukee – 10,000 / week**
- **Problem was significant only in Milwaukee**
  - **Product being built in each location was different but similar technology**
  - **Differences identified**
    - » **More "discriminating" customer for Milwaukee product**
      - **More aggressive test methodology and limits**
    - » **Solder paste (lower flux activity) – Shown not significant**
    - » **Solder stencil 125 micron thick in Milwaukee, 150 micron elsewhere**
      - **Driven by presence of 0402 chip components on Milwaukee product**

388 PBGA Interconnect Issue
Ball & Cup Failures in Milwaukee



DELPHI

388 PBGA Interconnect Issue
Concentration Diagram / Warpage Map

151 total defects

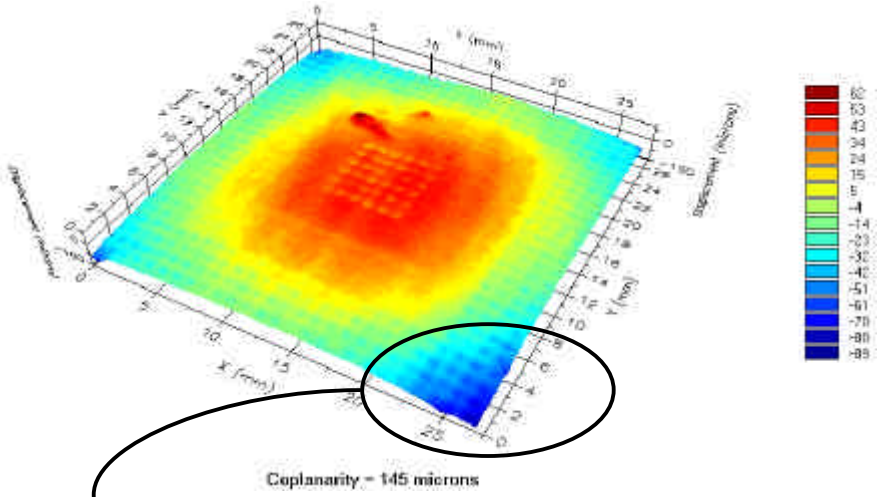
12 defects = 8%

26 defects = 17%

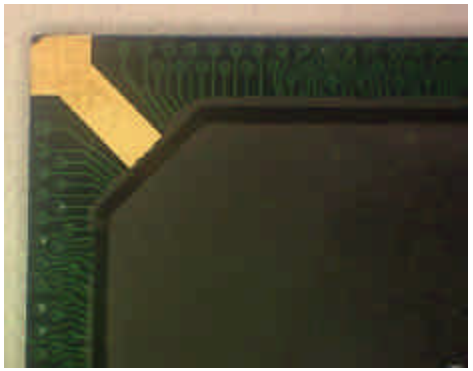
	Z	Y	X	W	V	U	T	S	R	Q	P	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
26	)		2	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	4	9
25	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
24	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
23	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
22	0	0	0	0																			0	0	0	0
21	0	0	0	0																			0	0	0	0
20	0	0	0	0																			0	0	0	0
19	0	0	0	0																			0	0	0	0
18	0	0	0	0																			0	0	0	0
17	0	0	0	0																			0	0	0	0
16	0	0	0	0							0	0	0	0	0	0							0	0	0	0
15	0	0	0	0							0	0	0	0	0	0							0	0	0	0
14	0	0	0	0							0	0	0	0	0	0							0	0	0	0
13	0	0	0	0							0	0	0	0	0	0							0	0	0	0
12	0	0	0	0							0	0	0	0	0	0							0	0	0	0
11	0	0	0	0							0	0	0	0	0	0							0	0	0	0
10	0	0	0	0																			0	0	0	0
9	0	0	0	0																			0	0	0	0
8	0	0	0	0																			0	0	0	0
7	0	0	0	0																			0	0	0	0
6	1	0	1	0																			0	0	0	1
5	0	0	0	0																			0	0	0	0
4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	15	
1	1	4	6	1	5	0	0	0	0	0	0	2	0	1	0	0	0	0	1	1	0	0	4	10	19	21

21 defects = 14%

84 defects = 56%



Au/Cu trace over Pin 1 causes more warpage in that corner of package

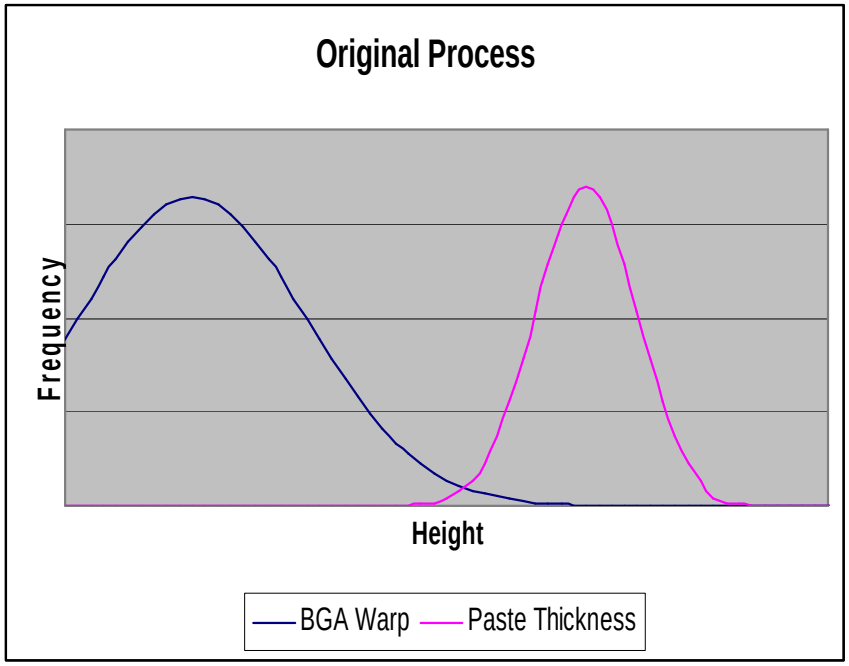


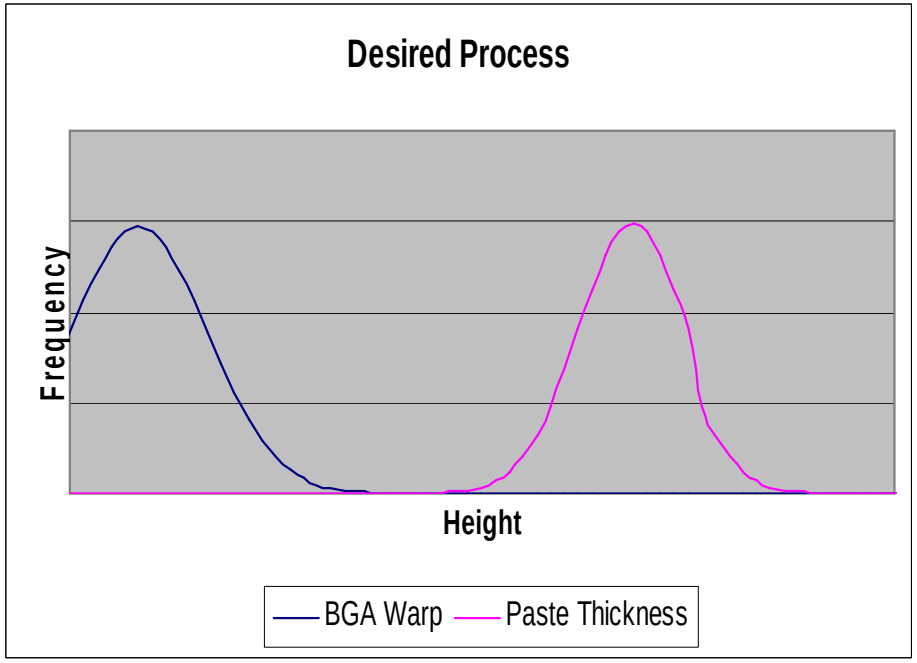
DELPHI

388 PBGA Interconnect Issue
Original vs Desired State

- Yield loss due to overlapping of process distributions
- BGA Warpage during reflow rises out of printed paste
- Solder solidifies before part flattens out as it cools

Concept Diagram



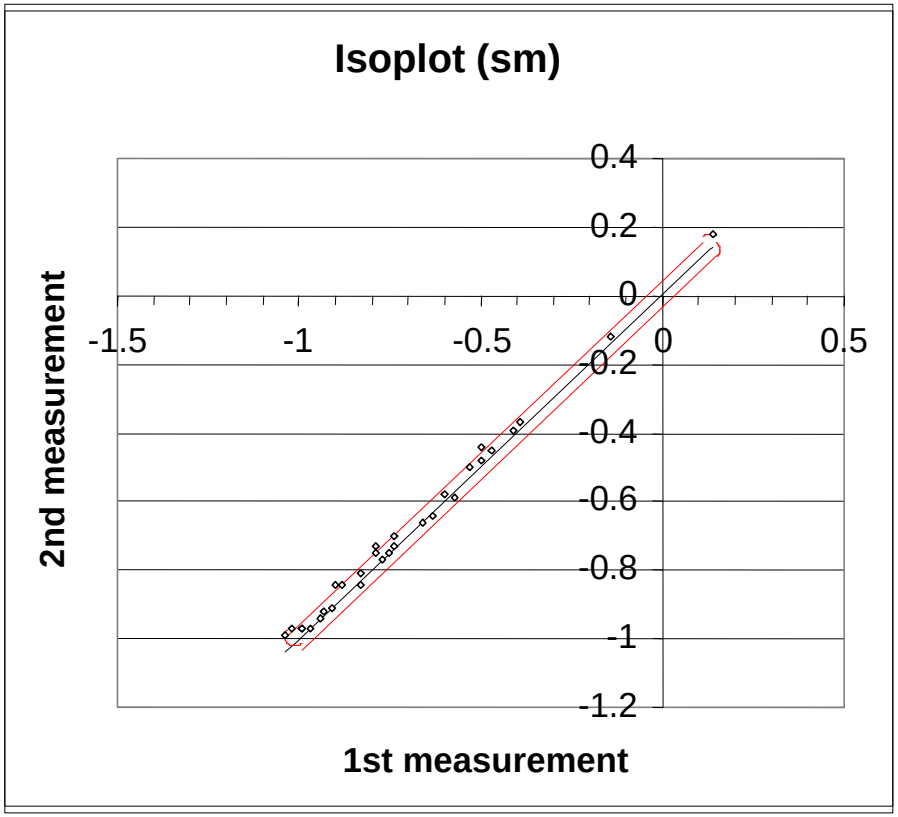


DELPHI

Isoplot of Warpage Measurement using Coplanarity Measurement System

part id	1st meas	2nd meas
1	-0.74	-0.75
2	-0.94	-0.96
3	-0.39	-0.39
4	-0.77	-0.79
5	-0.75	-0.77
6	-0.79	-0.77
7	-0.63	-0.66
8	-0.41	-0.41
9	-0.5	-0.46
10	-0.66	-0.68
11	-0.79	-0.75
12	-0.6	-0.6
13	-0.53	-0.52
14	-0.57	-0.61
15	-0.14	-0.14
16	-0.74	-0.72
17	-0.97	-0.99
18	-0.83	-0.86
19	-0.5	-0.5
20	0.14	0.16
21	-0.47	-0.47
22	-0.83	-0.83
23	-0.99	-0.99
24	-1.02	-0.99
25	-1.04	-1.01
26	-0.9	-0.86
27	-0.91	-0.93
28	-0.93	-0.94
29	-0.88	-0.86
30	-0.99	-0.99

Discrimination Ratio	
L	1.674051
? M	0.055656
? P	1.183079
D.R.	21.25687
Pass	



Conclusion: Warpage measurement at the supplier is good enough to discriminate BOB and WOW parts.

DELPHI

Comparison of Known Good and Bad Lots using Moiré Interferometry

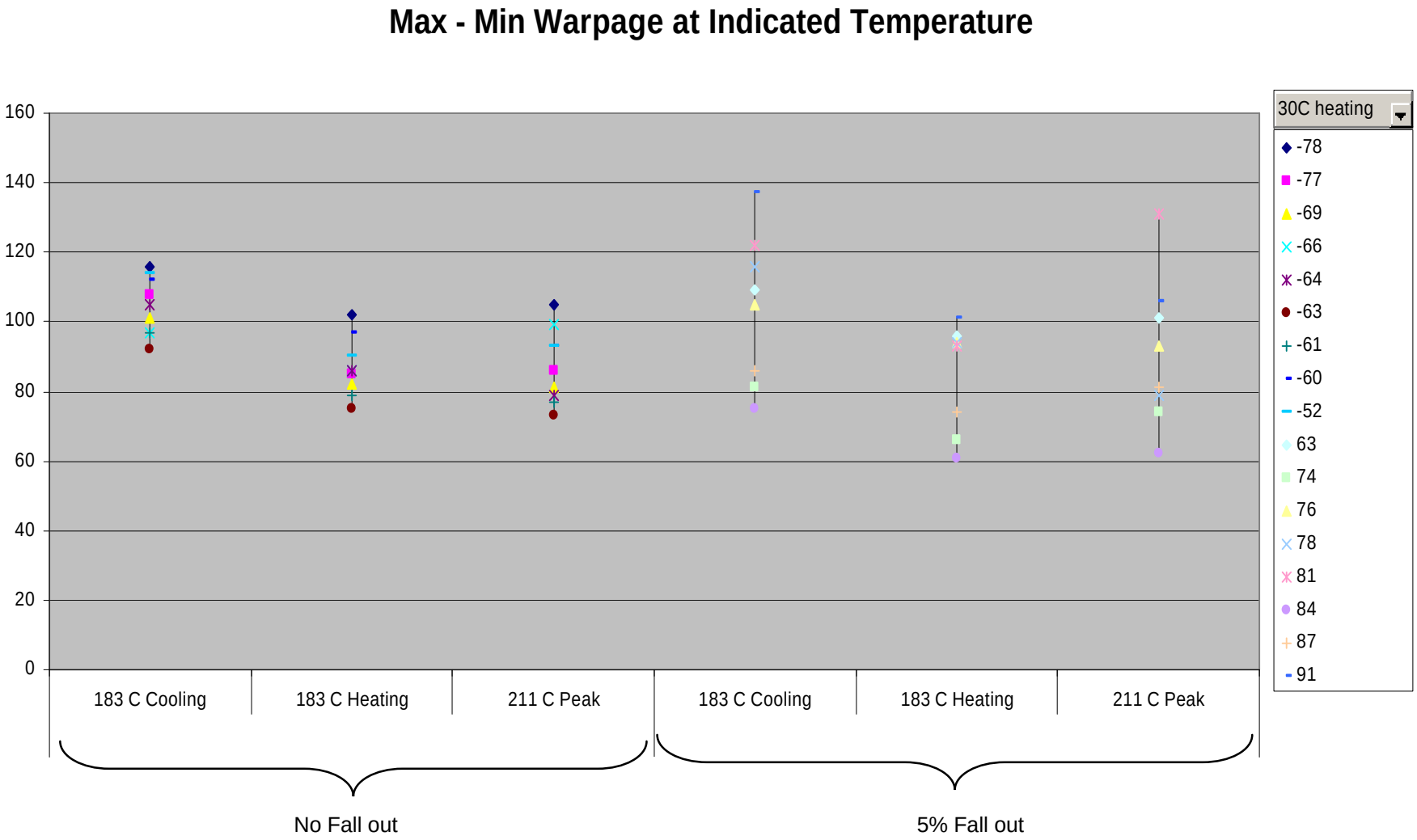
Max – Min Displacement on Part (microns) (Note that this is referred to as "coplanarity" on the 3D plots)						
30C heating	150C heating	183C heating	211C peak	183C cooling	150C cooling	30C cooling
-78	89	102	105	116	103	-72
-77	67	80	82	100	94	-67
-77	79	90	90	116	112	-65
-69	74	82	81	101	97	-59
-66	69	86	99	97	89	-56
-64	77	86	79	105	109	64
-63	60	75	73	92	89	-56
-61	70	79	77	97	95	-60
-60	88	97	93	112	112	68
-52	76	90	93	114	105	60
63	95	96	101	109	112	71
74	60	71	88	89	95	70
74	60	61	60	73	73	72
76	90	94	93	105	104	78
78	88	94	79	116	112	80
81	69	93	131	122	96	74
84	55	61	62	75	75	76
87	67	74	81	86	88	75
91	94	101	106	137	123	77

Samples from lot with no fall out from Ball and Cup defects

Samples from lot with ~ 5% fall out from Ball and Cup defects

DELPHI

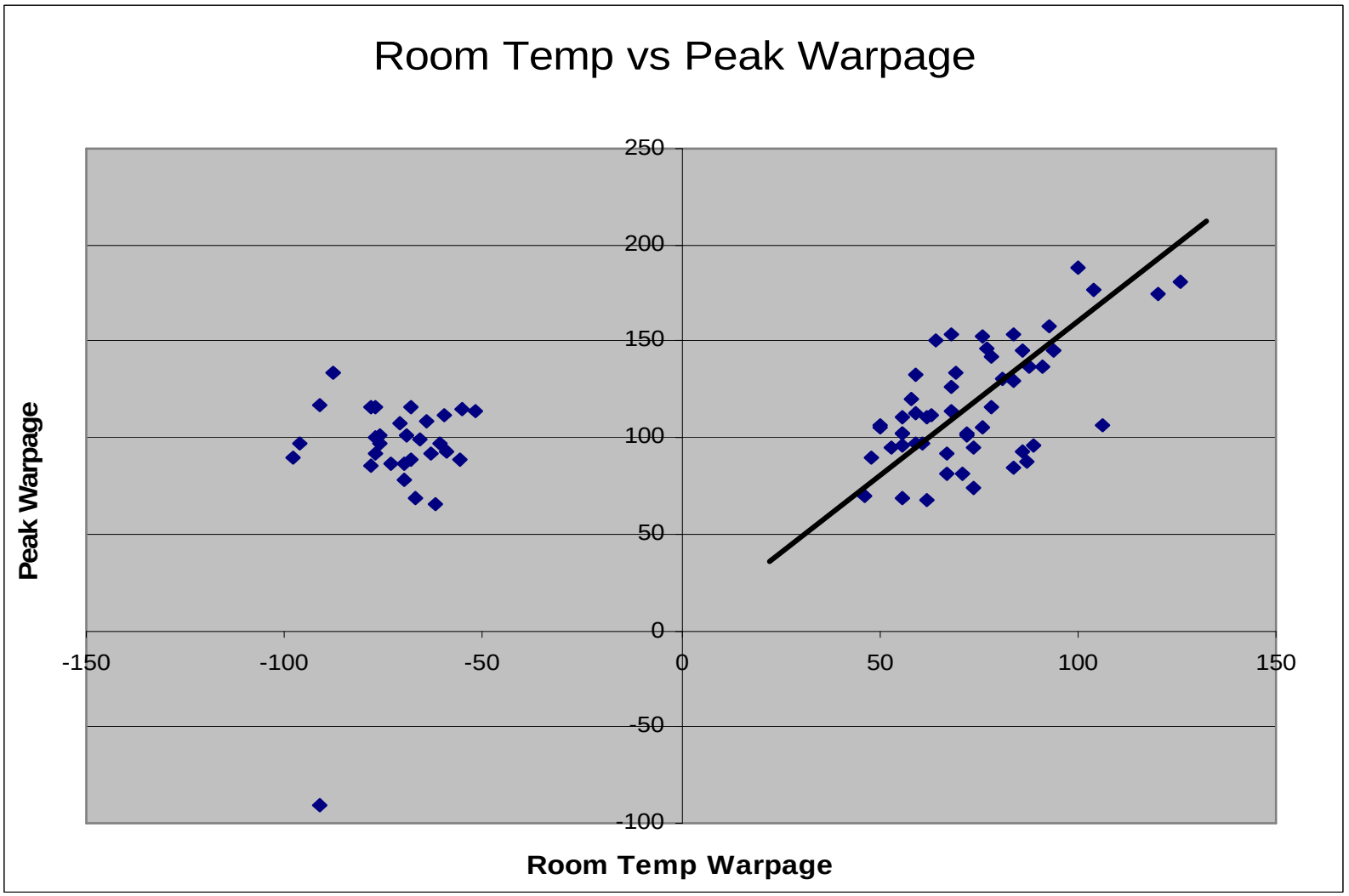
388 PBGA Interconnect Issue
Warpage vs Temperature



DELPHI

Correlation of Room Temperature vs Peak Warpage

(Data from Assorted Production & Engineering Lots)



No Fall Out

5% Fall Out

DELPHI

Comparison of Known Good and Bad Lots using Moiré Interferometry

Max – Min Displacement on Part (microns) (Note that this is referred to as "coplanarity" on the 3D plots)						
30C heating	150C heating	183C heating	211C peak	183C cooling	150C cooling	30C cooling
-78	89	102	105	116	103	-72
-77	67	80	82	100	94	-67
-77	79	90	90	116	112	-65
-69	74	82	81	101	97	-59
-66	69	86	99	97	89	-56
-64	77	86	79	105	109	64
-63	60	75	73	92	89	-56
-61	70	79	77	97	95	-60
-60	88	97	93	112	112	68
-52	76	90	93	114	105	60
63	95	96	101	109	112	71
74	60	71	88	89	95	70
74	60	61	60	73	73	72
76	90	94	93	105	104	78
78	88	94	79	116	112	80
81	69	93	131	122	96	74
84	55	61	62	75	75	76
87	67	74	81	86	88	75
91	94	101	106	137	123	77

Conclusion: Complete separation between No Fallout and 5% Fallout parts at 30°C!

This can be used as a sort at supplier.

Samples from lot with no fall out from Ball and Cup defects

Samples from lot with ~ 5% fall out from Ball and Cup defects

Separation of Data

No Separation of Data

DELPHI

388 PBGA Interconnect Issue
Impact of Controlling Warpage (r.t.)

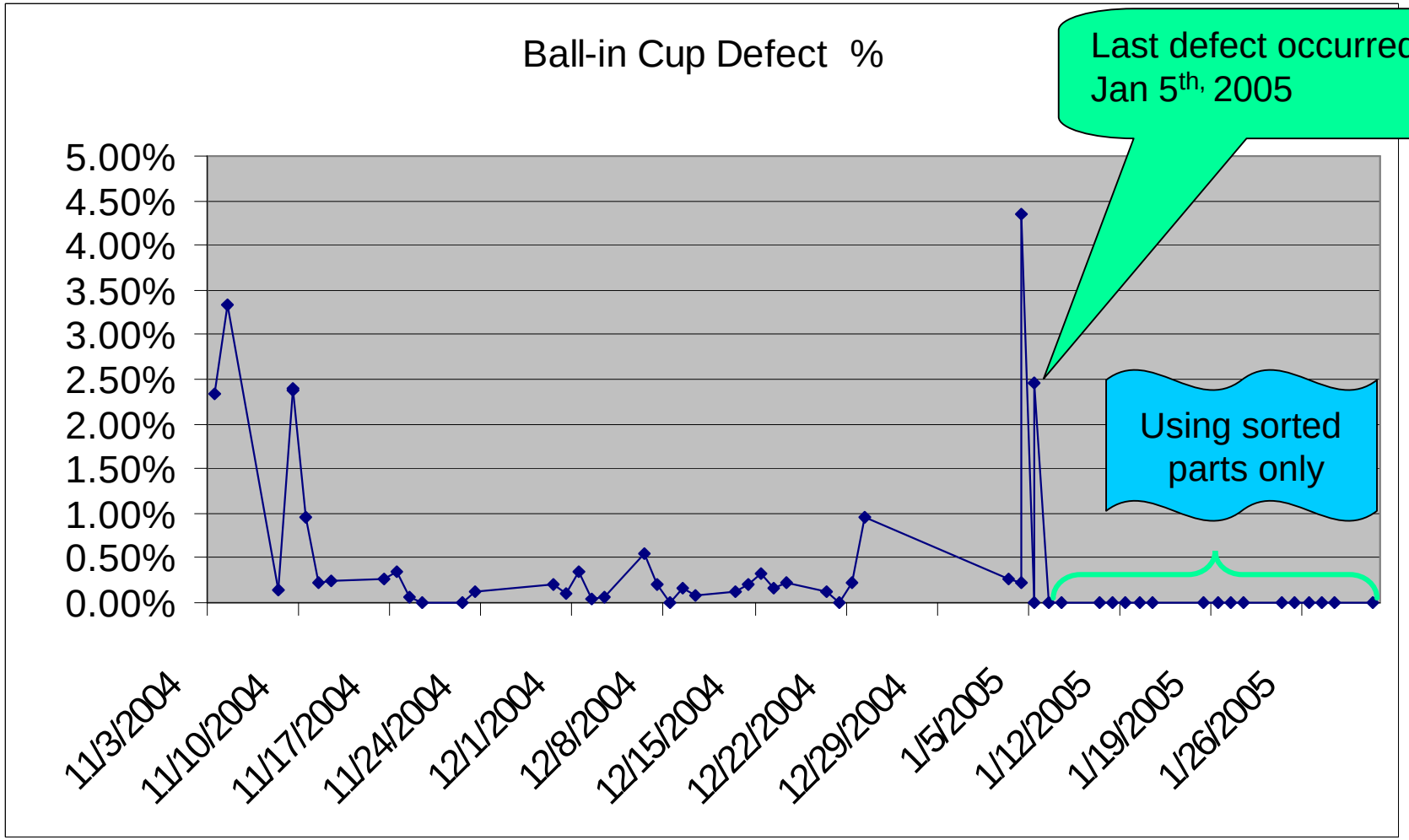
- **Failure Analysis of Defects showed maximum room temperature warpage of +0.46 mils**
- **Negotiated a 0.3 mils Positive (corners up) Maximum warpage specification**

Acceptable Warpage

Max Warpage Limit Set	Yield Loss Due to Sorting	
	Original Process	Improved Process
<= 0.0 mils (up)	19.0%	0.9%
<= 0.1 mils (up)	12.6%	0.2%
<= 0.2 mils (up)	7.6%	0.0%
<= 0.3 mils (up)	4.8%	0.0%
<= 0.4 mils (up)	3.3%	0.0%
<= 0.5 mils (up)	1.7%	0.0%
<= 0.6 mils (up)	0.9%	0.0%
<= 0.7 mils (up)	0.5%	0.0%
<= 0.8 mils (up)	0.2%	0.0%

DELPHI

388 PBGA Interconnect Issue
Defects found at visual and functional Test



DELPHI

388 PBGA Interconnect Issue
Long Term Results

- **No additional Ball-in-Cup failures have been found on original Milwaukee Product / Process with tightened specification**
  - **Assembly Process**
  - **Assembly Plant**
  - **Field Warranty**
- **Supplier's Process has Drifted with Time**
  - **Stable for 6 Months**
  - **Gradual Increase in Warpage Level Over 3 Months**
  - **Sharp Increase in Warpage Level Over 2 Months**
    - **Significant Decrease in Yields**
    - **Large Lot to Lot Variability**
    - **No Assignable Cause Found**
    - **Structured Problem Solving Effort Underway**

388 PBGA Interconnect Issue
Assembly Factors Leading to Ball-In-Cup Defects

- Non-optimized Reflow Profile
- PCB
  - Flatness
  - Stability during Reflow
  - Pad Design
- Solder Paste
  - Thickness
  - Stencil Pattern
  - Rheology
    - » Printability / Release
    - » Slump during Reflow
  - Flux Activity
- Placement Force
- Moisture Absorption of Parts Before Reflow
- PBGA Warpage During Reflow

388 PBGA Interconnect Issue
Significant Factors for BGA Warpage

Design

- **Package Geometry**
  - Package Size
  - Package Dimensions
  - Die Size / Thickness
- **Substrate**
  - Thickness / Number of Layers
  - Design of Layers
  - α_1, α_2, T_g
  - Modulus
  - Flatness / Residual Stresses
    - » Laminate
    - » Plating
- **Mold Compound**
  - α_1, α_2, T_g
  - Modulus (Filler Content)
  - Cure Shrinkage

Process

- **Molding**
  - Pre-heat Temp & Uniformity
  - Clamping Pressure & Uniformity
  - Mold Temp & Uniformity
  - In-Mold Cure Time
- **Post Mold Cure**
  - Temperature
  - Duration
  - Fixturing
- **Solder Ball Reflow Process**
- **Burn-In Process**
- **Data Retention Bake**

388 PBGA Interconnect Issue
Impact of Technology Directions

- **Worsening of Problem**
  - PB Free Process
    - » Higher Reflow Temperatures
    - » Higher BGA Warpage Due to Lower Tg Molding Compounds
    - » Lower wetability of SnAgCu solder
  - Packaging Trends
    - » Larger Packages
    - » Thinner Packages
    - » Smaller Die (with Semiconductor Technology Shrinks)
    - » Finer Pitches ? Smaller Balls ? Less Collapse
- **Improvement of Problem**
  - Improved BGA Designs
  - Improved Substrate Designs
  - Improved Molding Processes / Equipment
  - Improved Molding Compounds

DELPHI

388 PBGA Interconnect Issue
Future Changes

- **JEDEC Proposal to Constrain Warpage**
  - **J-Std-020D** Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices
  - Require part to maintain coplanarity up through peak reflow temperature
    - » Baked dry condition
    - » After moisture Conditioning for rated MSL
  - JEDEC Ballot Complete
  - IPC Ballot Pending

6.3 Moisture Induced Body Warpage - **Substrate Based Packages (e.g. BGA, LGA etc.):** Moisture Induced warpage could result in solder bridging or open connections during board assembly solder attachment operations. It is known that ingressed moisture can either increase or decrease the total package body warpage depending on the specific design of the component. Total package body warpage can be a function of the moisture content and can be affected by the ramp rates and dwells used to measure the total warpage effect at elevated temperatures. (Exceedingly slow ramp rates or long dwells at elevated temperatures will begin to dry the package). Care should be taken to ensure ramp rates and dwells used for the warpage measurements appropriately represent board assembly conditions. Package body warpage measured per JESD22-B112 should be characterized during package development and/or qualification to determine if warpage exceeding co-planarity and standoff dimension tolerances at any temperatures above the solder melting point, including the designated peak-reflow temperature exists. Both dry and moisture soaked components at the MSL being tested should be utilized for warpage measurements at temperatures above the solder melting point, including the designated peak reflow temperature.

388 PBGA Interconnect Issue
Summary

- **Failure Mode is Real**
  - Defect level from low ppm to 5% seen in volume production
  - Opens and Intermittent Connections
    - » Intermittent connections are very difficult to find electrically
    - » Possible, but expensive to find with automated visual inspection
  - Aggravated by Product & Process Design
- **Defect Mode Greatly Aggravated by Package Size**
  - Seen with 27 mm body size from 2 suppliers
  - Significant problem above 35 mm body size
- **Defect Level Aggravated by Many Process Factors**
  - Assembly Processes
  - BGA Assembly Processes
  - Process Variation Impacts Defect Level