Evaluating the Accuracy of a Nondestructive Thermo Couple Attach Method for Area Array Package Profiling

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Introduction

The oven recipe, which consists of the reflow oven zone temperature settings and the speed of the conveyor, will determine a specific time-temperature profile for a given PCB assembly. In order to achieve a good quality PCB assembly, the time-temperature profile should be within the product and process specifications. This is determined by the solder paste, components and substrate tolerances. As a result, the accuracy of the profile becomes a critical element in the quality of the electronics assembly. The methods by which thermocouples (TCs) are attached to the PCB assembly, to record the profile as the PCB travels through the oven, significantly impact the measuring accuracy of the profile.

Many electronics assemblers do not have the luxury of sacrificing production PCBs and BGAs for the purpose of measuring their profiles. Yet they need to make sure that these assemblies are processed in spec.

Area-array packages have solder balls hidden under the package, making it particularly difficult to achieve the correct thermal profile. Improper melting of solder balls will lead to poor solder joint formation and will damage the BGAs or the entire assembly. These components also tend to be expensive and, hence, represent a particular challenge for assemblers.

The goal of this study was to identify a non-destructive method for TC attachment that provides a small offset to the "actual temperature under a BGA."

Project Metric

The "gold standard" of TC attachment for a BGA is to place the TC accurately on top of a single pad and then to solder the BGA on top, without using any additional solder material beyond what exists on the pads and BGA balls. Preliminary research found that using a flattened bead TC and a BGA rework station allowed for an accurate and reliable location of the TC on a single pad/ball. This study used a flattened bead TC soldered under the BGA as the reference TC.

Furthermore, previous research reveals that aluminum tape provides both accurate and repeatable TC readings while complying with the criteria as a non-destructive attachment method. The repeatability includes measurements when the TCs are reattached numerous times. Other TC attachment methods, such as high-temperature solder or adhesives, risk small variations in the amount of material applied when needing to reattach a TC, resulting in skewed temperature readings. A second benefit with the aluminum tape is that it is already widely used in the electronics assembly industry.

The project metric included the difference in temperature between the temperature recorded by the TC attached using aluminum tape at two locations with respect to the BGA (Figures 1a and 1b), and the flat TC that measured the temperature under the BGA (Figure 2). A small delta T indicates that the particular method and location tracks very closely with the flat TC soldered under the BGA.

Results and Discussions

The different experiment phases were carried out using a forced convection oven with six heating zones and one uncontrolled cooling zone. The measurements from the cooling zone were truncated for the analysis to avoid misinterpretation of data. The oven recipe that was used for the different experiments is shown in the table.

Table 1 Oven recipe used in the study

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
80°C	105°C	143°C	183°C	223°C	253°C
Belt Speed (cm/min)					
29					

Figure 1a. TC attachment on top of the BGA

Figure 1b. TC attachment on the bottom of the PCB directly underneath the BGA location

Figure 2. Flattened TC bead located directly underneath the BGA

TC Attachment Using Aluminum Tape

16 total profile runs were conducted by using four combinations of BGA and PCB sizes, assembling two BGAs per PCB, and running two replications for each run combination. The substrate was a two-layer FR4 PCB, 0.8 mm thick and 1.6 mm thick. Both PCB sizes were same (203.2 x 139.6 mm) except for the thickness variation. The two BGA components used included BGA 160 (15 x 15 mm – 1 mm pitch) and BGA 1156 (35 x 35 mm – 1 mm pitch).

A flattened TC was soldered under the BGA to measure the true temperature under the BGA. Care was taken to place the flattened TC bead directly on a BGA pad, and with the use of a rework station, the BGA was soldered onto the pads. The bead was sandwiched between the pad and the solder ball without touching any of the other BGA solder balls/pads. Two additional TCs were attached to measure the BGA temperature by use of aluminum tape in the following locations:

- The top face of the BGA
- The underside of the FR4 PCB, below the BGA

Temperature Differences between the Reference TC and the Nondestructive TC Attachment Methods

The analysis was carried out using the temperature difference between the TCs attached with aluminum tape and the flat TC soldered under the BGA. The temperature difference was measured for the most critical part of the profile, the reflow zone, within the reflow oven. The method used to calculate the temperature difference was to take every data point generated by the KIC Explorer profiler and to subtract the reference TC data from the relevant location TC data. Figures 3, 4, 5, 6 and 7 summarize the temperature differences with various BGA sizes and PCB thicknesses.

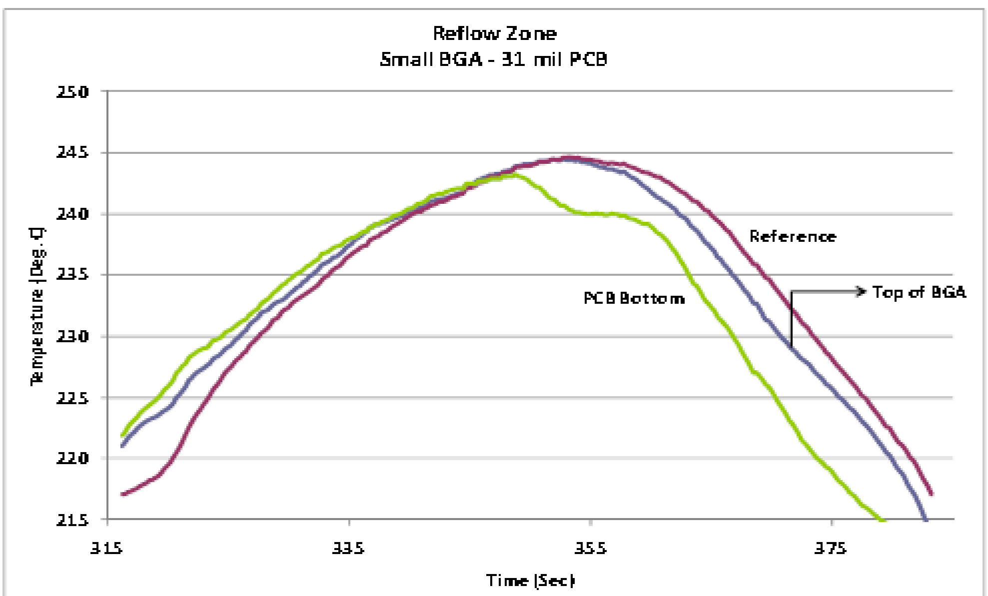

Figure 3. Profile overlay for reference TC, small BGA and 31 mil PCB

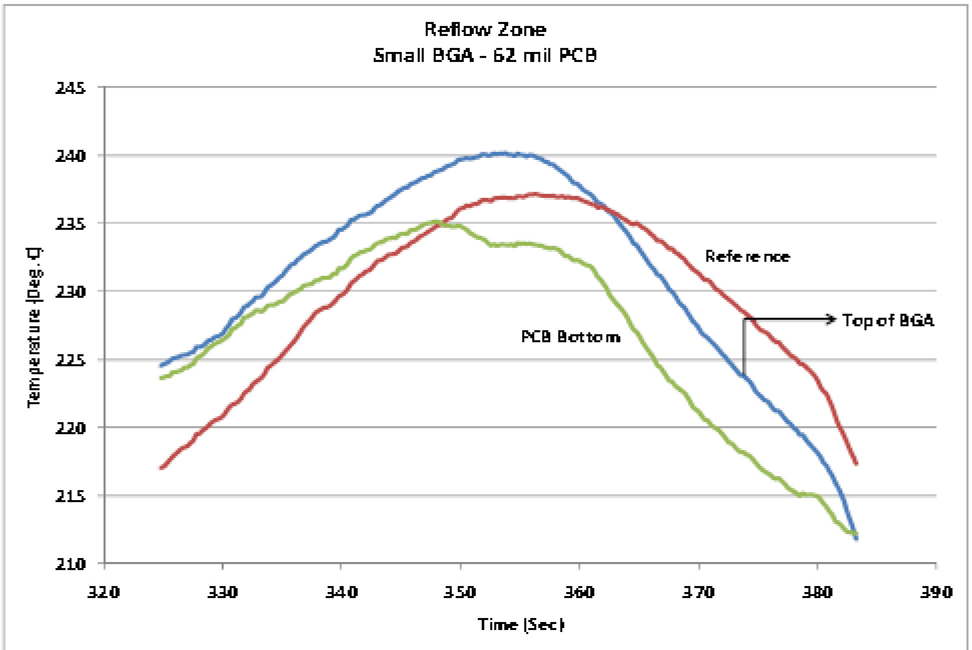

Figure 4. Profile overlay for reference TC, small BGA and 62 mil PCB

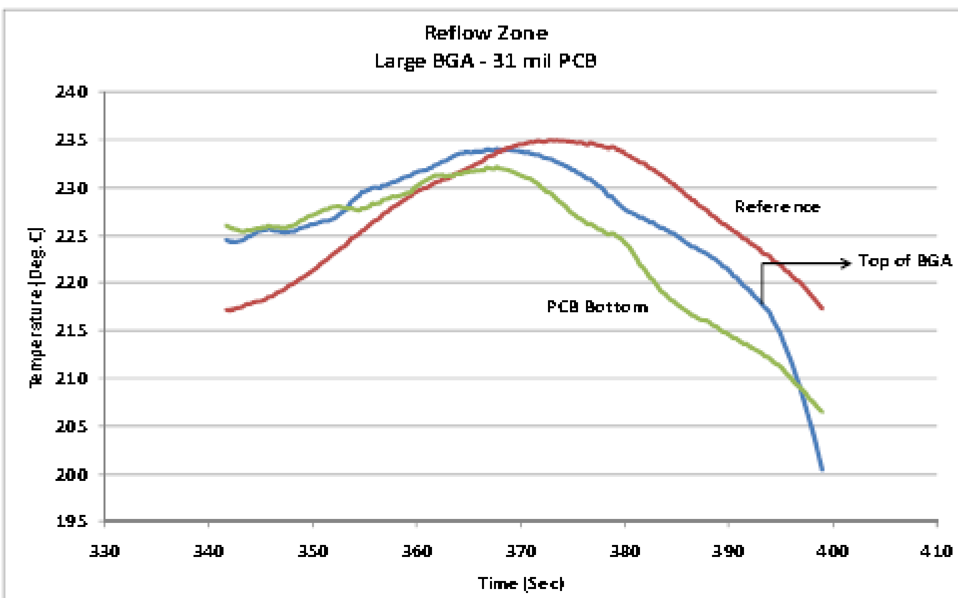

Figure 5. Profile overlay for reference TC, large BGA and 31 mil PCB

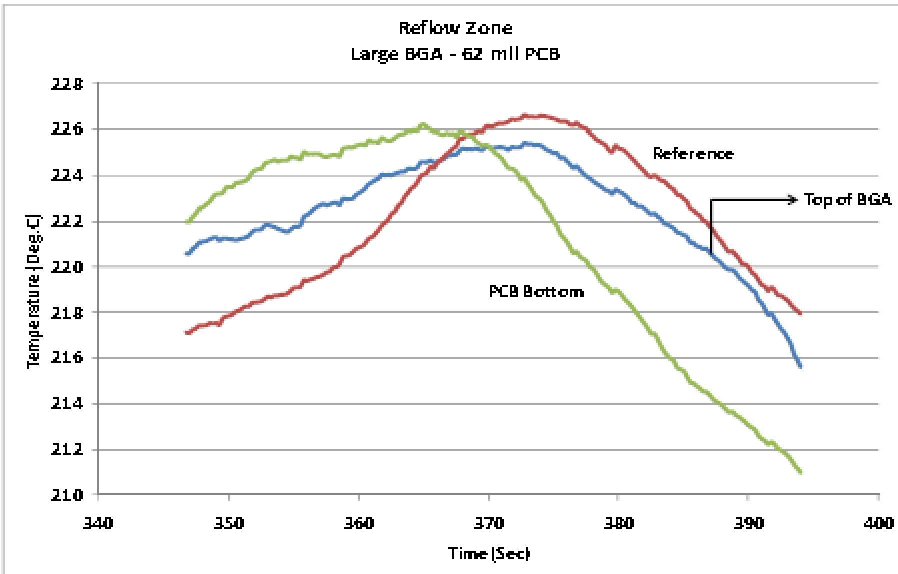

Figure 6. Profile overlay for reference TC, large BGA and 62 mil PCB

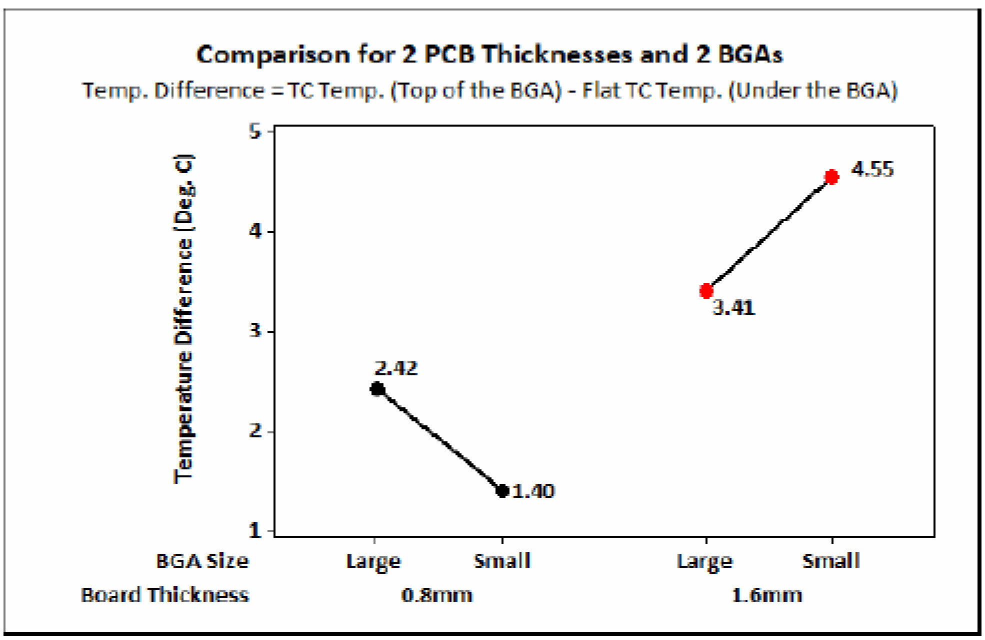

Figure 7. Temperature offset for 2 PCB sizes and two PCB thicknesses

Combining all data from this experiment and past experiments with the various BGA and PCB sizes, a generic empirical relationship (Equation) and graphs (Figure 8 and 9) were created for assembling plastic BGA packages on FR4 PCBs with TC attach on the top of the BGA and PCB bottom, using aluminum tape. Based on the experimental data, the derived empirical relationship provided a closer fit for TC attachment on the top of the BGA when compared to the TC attachment on the PCB bottom below the BGA.

Figures 8 and 9 show the predicted temperature difference for TC attach on the top of the BGA, for a given PCB/BGA combination, using the empirical relationship derived from the PCB and BGA parameters. Figure 8 is for all zones combined and Figure 9 is for the reflow zone only. In order to use the graph in Figure 8 or Figure 9, an Assembly Index (AI) needs to be calculated by making use of the PCB and BGA parameters as shown below. Additional confirmation runs need to be carried out to validate this graph.

$$AI = \frac{PT \times PW \times PA \times CP}{IOC \times CA \times CW \times CT}$$

Equation. Formula to calculate temperature offset from reference TC to non-destructive TC attachment

Where ....

- AI is the Assembly Index
- PT is PCB Thickness (mm)
- PW is PCB Weight (grams)
- PA is Full PCB Area (sq mm)
- CP is Component Pitch
- IOC is I/O Count
- CA is Component Area (sq mm)
- CW is Component Weight
- CT is Component Thickness including solder balls

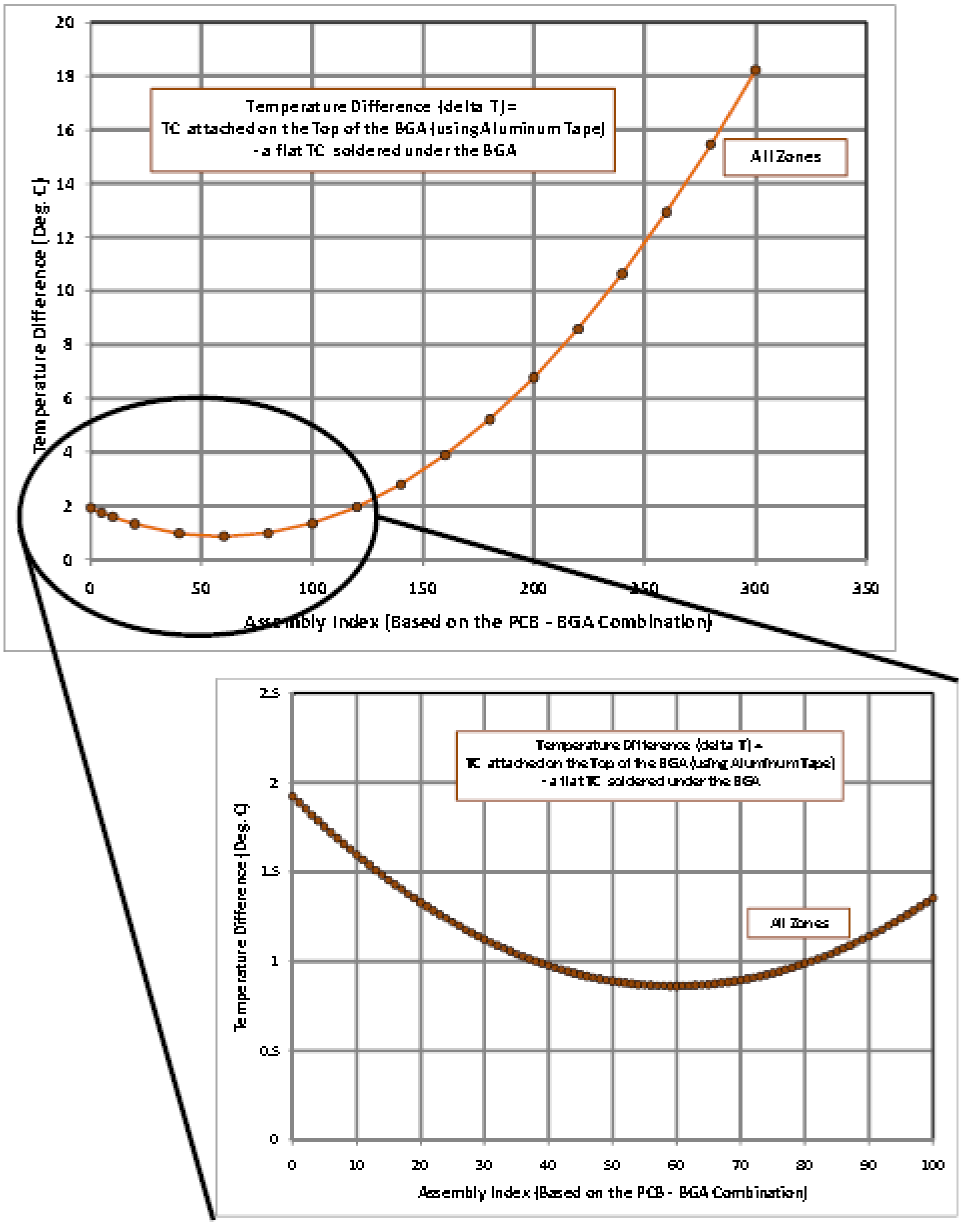

Figure 8. Graph for temperature offsets All Zones combined based on the AI formula

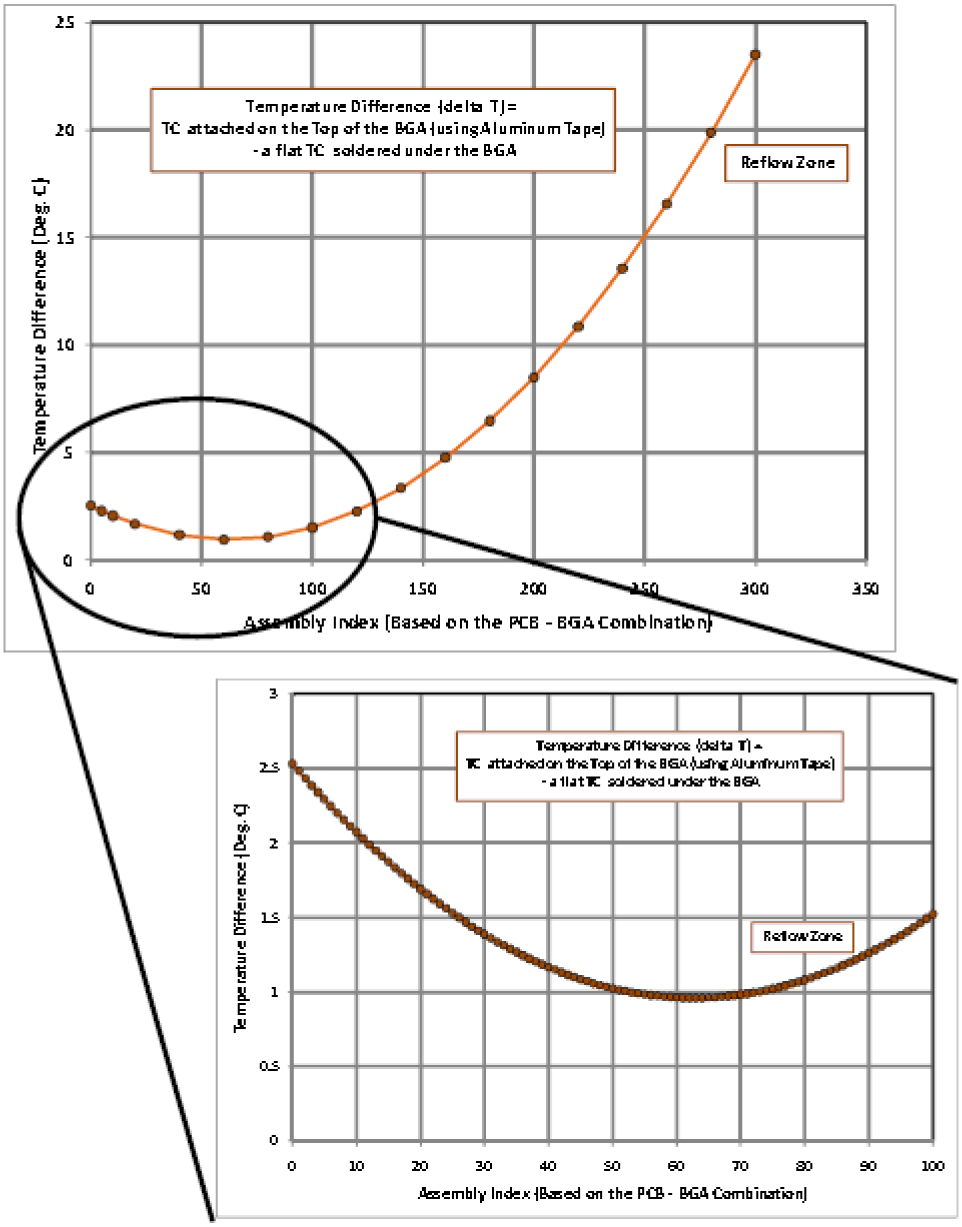

Figure 9. Graph for temperature offsets for Reflow Zone only based on the AI formula

Conclusion

Using aluminum tape to attach a TC directly onto the top of the BGA provides a good approximation of the temperature readings under a BGA. Furthermore, this offset can be calculated with a reasonable level of confidence by using a formula developed in this research and displayed in this article. For a relatively small BGA and thin PCB, that offset is less than 2 C. Thicker boards and larger BGAs produce larger offsets, which can be approximated by the referenced formula and associated graph.

Evaluating the Optimal Thermocouple Attach Method and the Optimal Thermocouple Location for Area Array Package Profiling

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Agenda

- Project Objectives
- Phase I – Preliminary Investigation
- Phase II - Investigation of Attach Methods
- Phase III - Comparison of Adhesive 2 and Tape 2 for BGA Attach
- Conclusions
- Acknowledgements
- Question & Answer

Project Objectives

- Evaluate the most optimum thermocouple (TC) attachment method
- Evaluate TC attach locations for effective and non-destructive profiling of area array packages

RIT CEMA Lab

SMT Laboratory

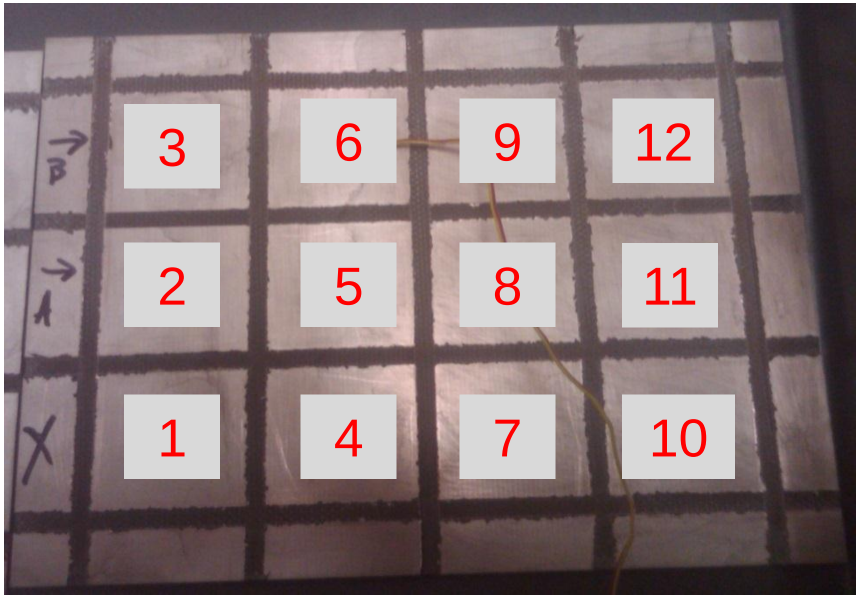
Focus Areas:
- Electronics Packaging
- Optoelectronics Packaging
- Microsystems Packaging
- Solar Power/Fuel Cell Packaging

X-ray
Ultrasonic Imaging
Shear Testing
Cross-sections
Thermal Shock
Temp. & Humidity

Failure Analysis Laboratory

Phase I – Preliminary Investigation

- Substrate
  - 62 mil thick plain copper clad laminate with silver finish
  - Routed into 12 uniform isolation zones



  - Data analysis identified that locations 2,3,5,6,8 and 9 on the substrate had the least difference from the board mean (average of all TCs)

Phase I – Preliminary Investigation

- Multiple runs were executed using a lead free profile at the following temperatures:

Reflow Oven Zones Temperatures (deg C)							**Belt Speed (cm/min)**
Zone 1	*Zone 2*	*Zone 3*	*Zone 4*	*Zone 5*	*Zone 6*		
80	105	143	183	223	253		29

- Information obtained was useful for Phase II (Investigation of Attach Methods)

Phase II – Investigation of Attach Methods

- To investigate the responsiveness of the attachment methods for a selected lead free profile

- Comparison of thermocouple readings for various attach methods in relation to the air temperature (reference)

Phase II - Attachment Methods Investigated

- Non-destructive Methods of Attachment
  - Tape 1: Kapton Tape
  - Tape 2: Aluminum Tape
  - Tape 3: ECD EZ Tape
- Destructive Methods of Attachment
  - Adhesive 1: Two Part Epoxy
  - Adhesive 2: Instant Adhesive
  - HT Solder: High-Temperature Solder

Phase II – Test Substrate

Oven Entry

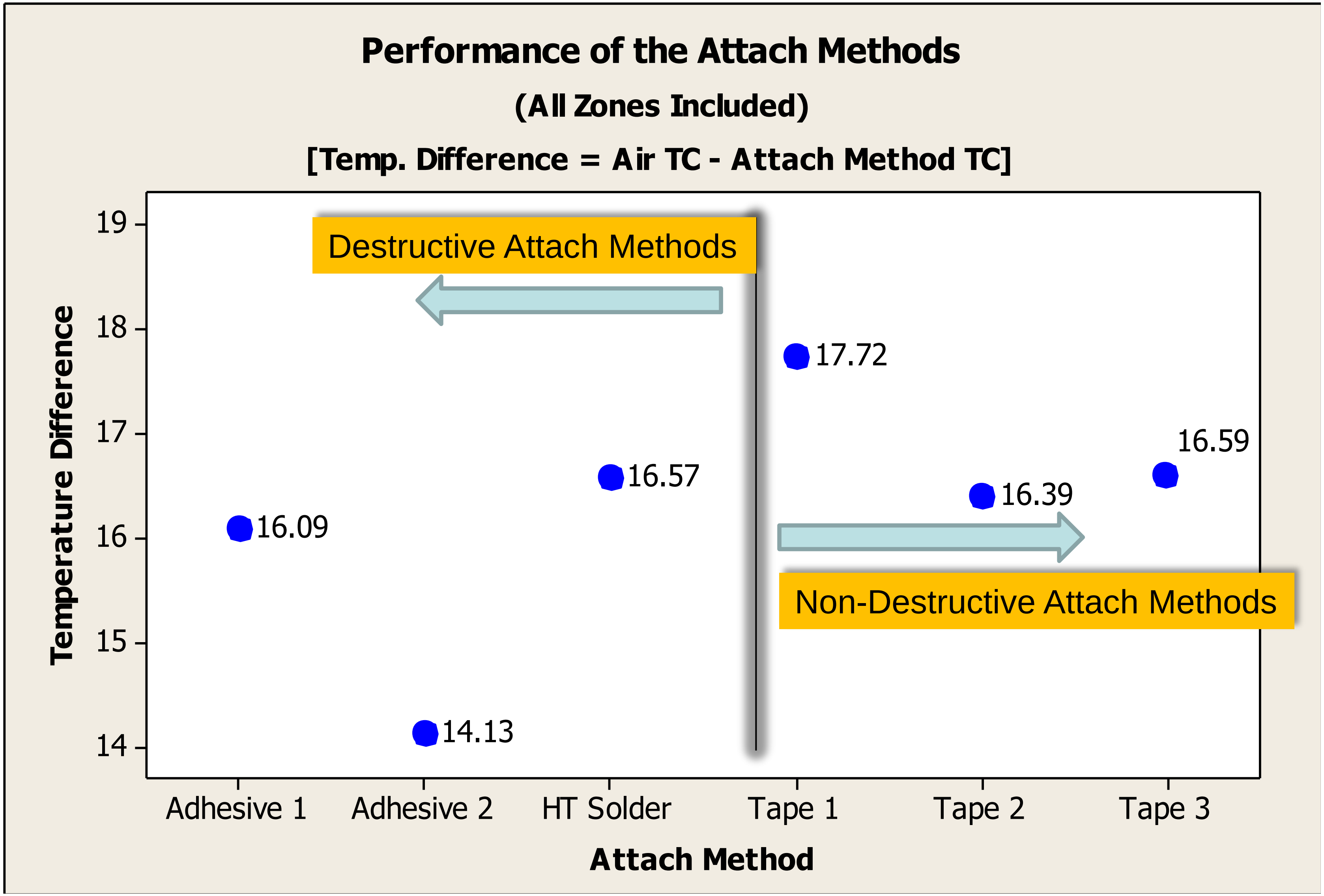
3	6	9	Omitted
2	5	8	Omitted
Omitted	Omitted	Omitted	Omitted

One TC was used for measuring the Air Temperature

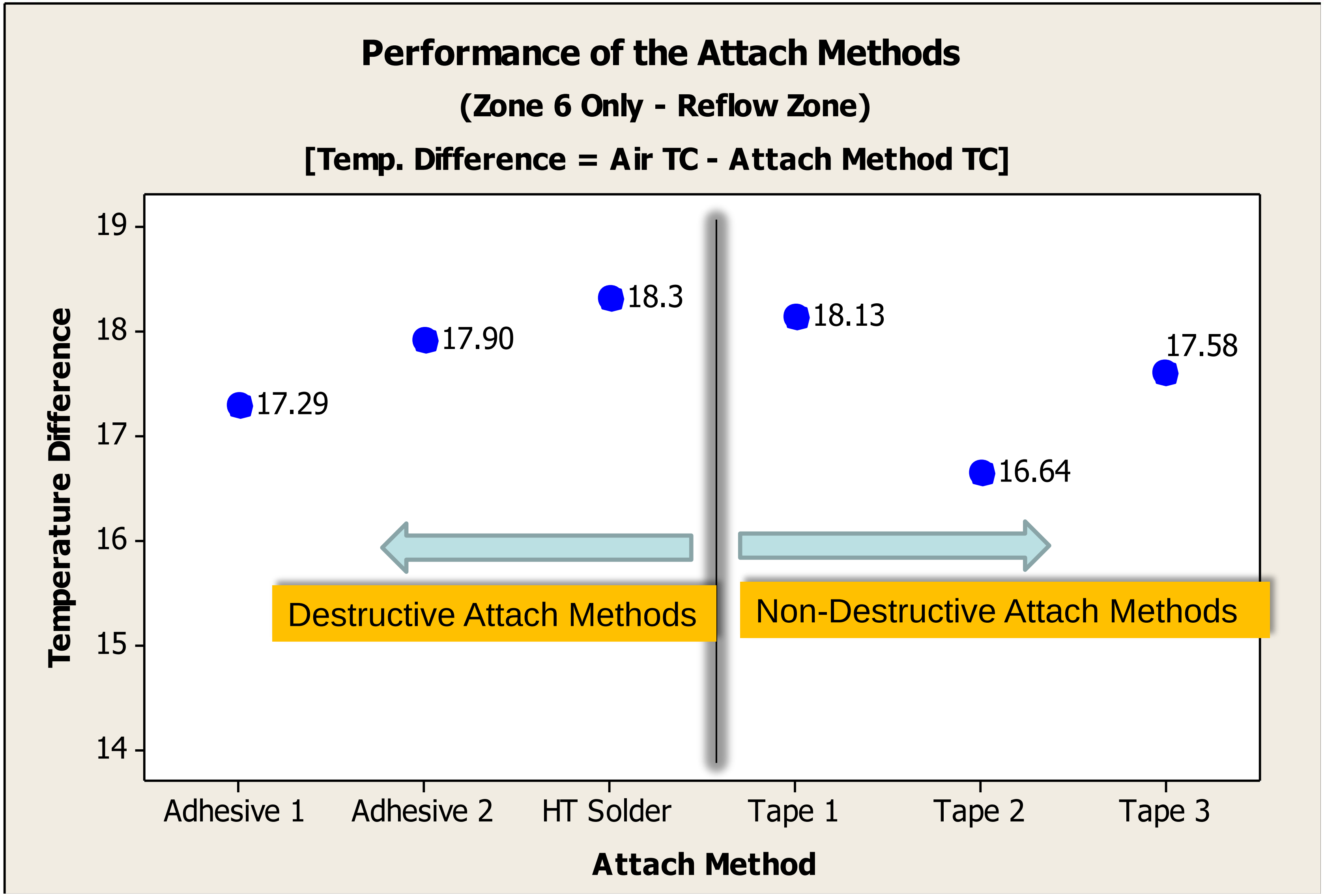
1. One TC per location (location identified on the substrate through preliminary investigation – Phase I)
2. All six attach methods were used for attaching round TCs on the test substrate – one per location
3. Six replications were carried out using six different test substrates and all six TCs attached

Response Variable for Phase II

- Temperature Difference
  - Difference between the temperature measured by the Air TC and the temperature measured by the TCs attached (Attach Method TC) on the test substrate
  - Equation: (Air TC – Attach Method TC)
    - Lower the temperature difference the better
  - The method with the closest TC temperature to that of the air TC was the best method



The instant adhesive performed the best of the destructive methods while aluminum tape was the best of the non-destructive methods.



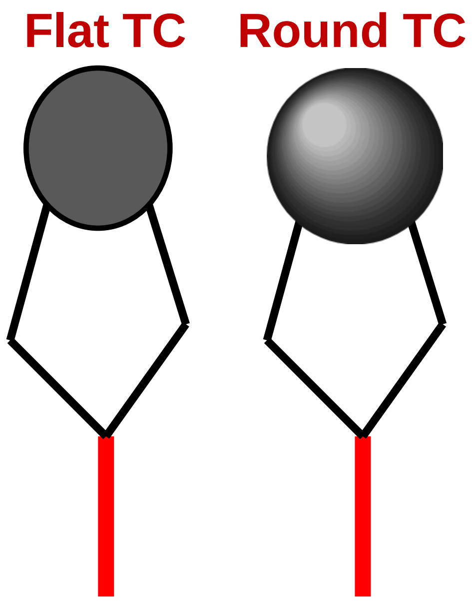
The aluminum tape (when looking at reflow zone only) has the least deviation from the air temperature and remains the most constant throughout all zones of the oven.

Phase III – Comparison of Adhesive 2 and Tape 2 for BGA Attach

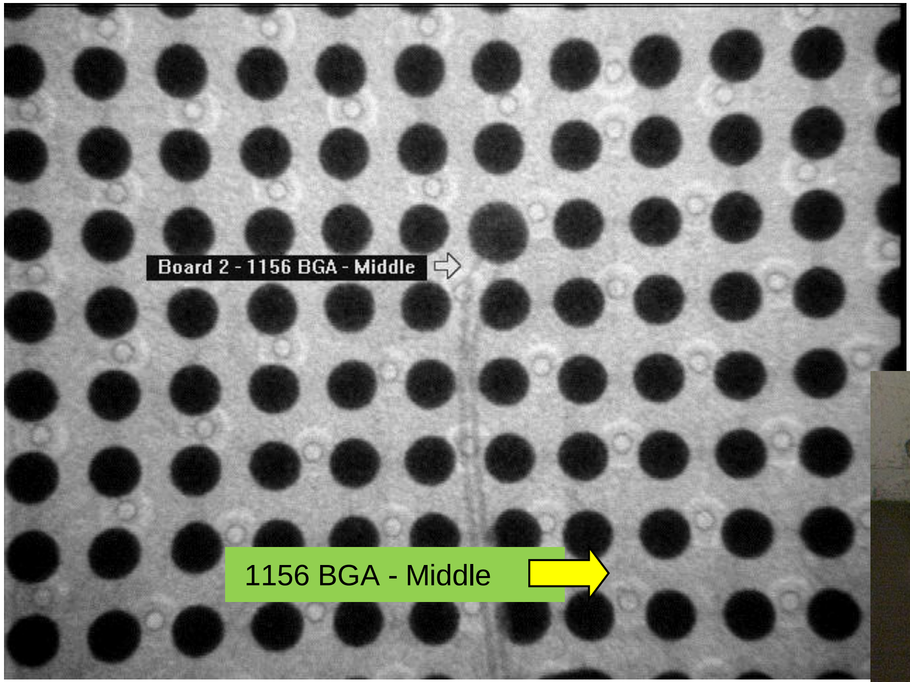
- Goal
  - To investigate the responsiveness of Adhesive 2 and Tape 2 attach methods for profiling a BGA
- Substrate
  - Dimension: 98.5mm x 136.5mm
  - Thickness: 1.6mm thick 2-layer PCB
  - Weight: 40 grams
- Component
  - Type: 169 I/O BGA
  - Package Size: 17mm x 17mm
  - Pitch: 1.5mm
  - Weight: 1.4 grams

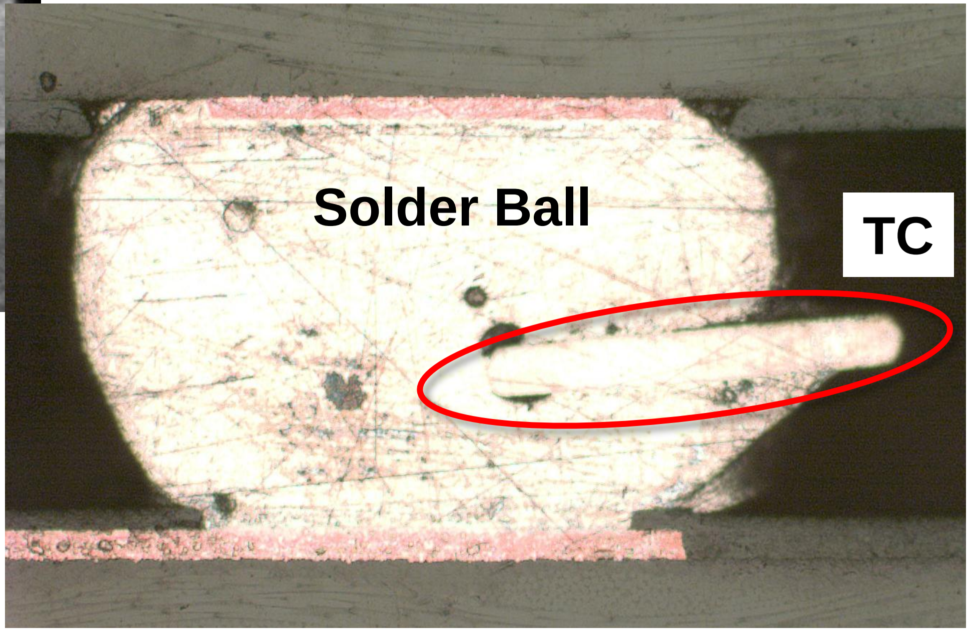
Phase III – Comparison of Adhesive 2 and Tape 2 for BGA Attach

- Thermocouples Attach Points
  - One Flattened TC
    - Under the BGA soldered to a BGA pad on the PCB
  - Three Round TC
    - Top of the BGA
    - Near the BGA on the PCB
    - Bottom side of the PCB below the BGA



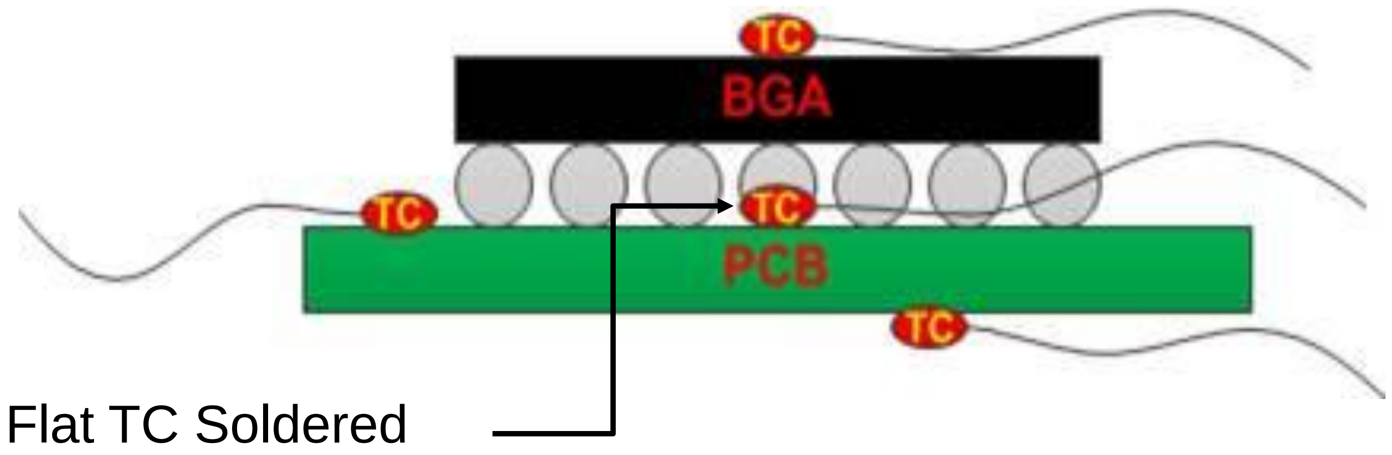
Phase III – Flattened Thermocouple

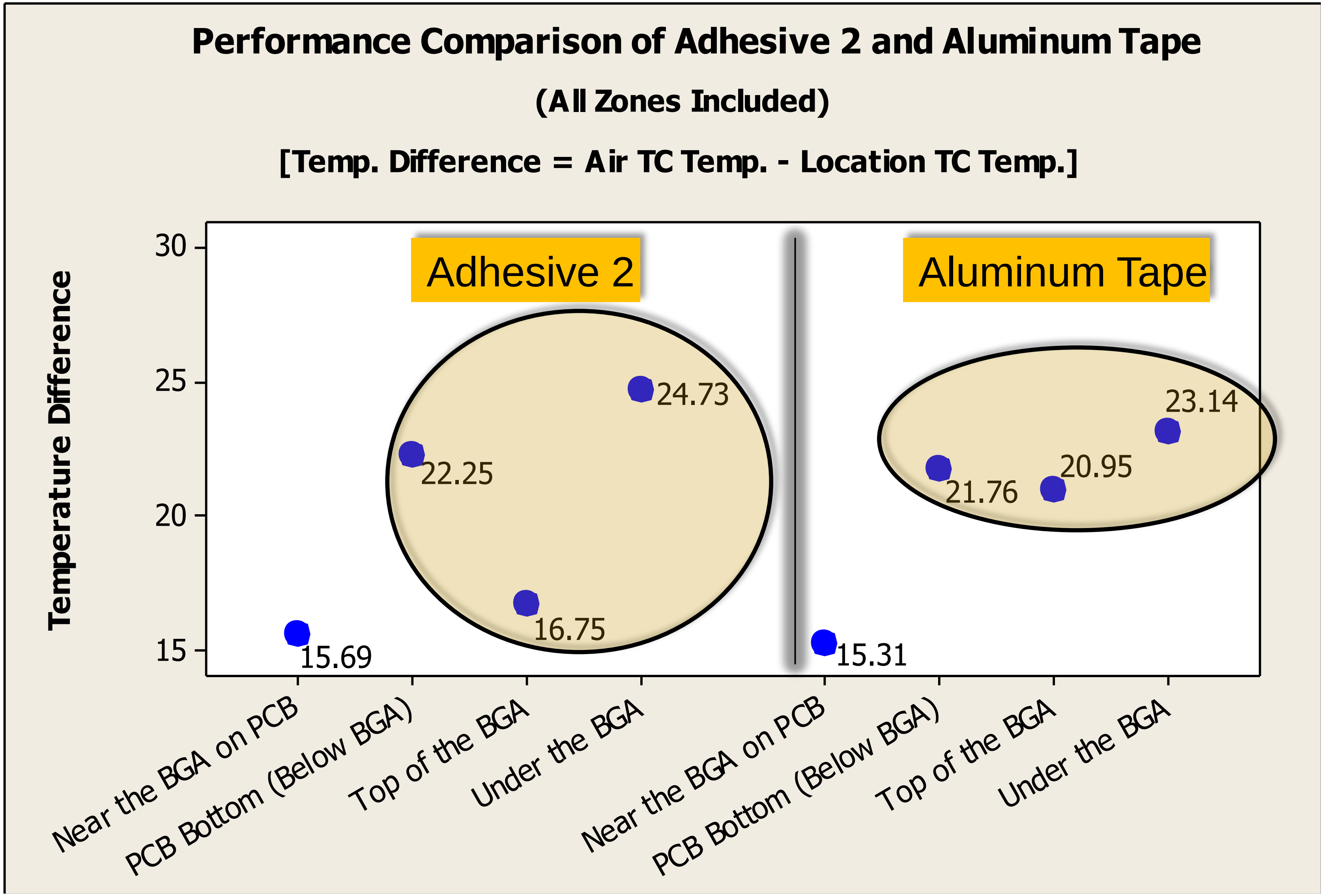




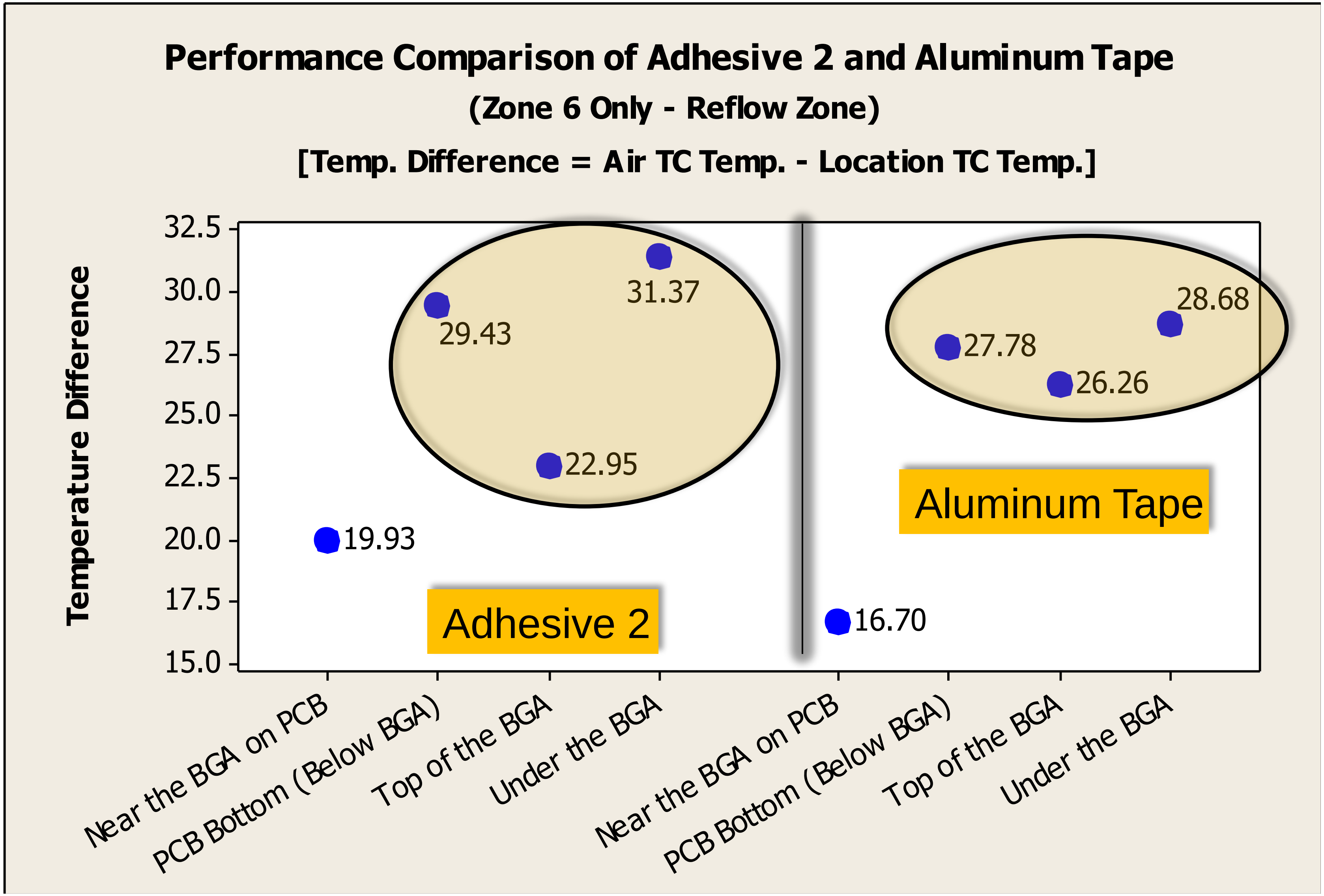
Slides 17 and 18 Reference the Following:

- Response Variable
  - Temp. Difference = Air TC – Location TC
- Location of TCs





The aluminum tape had a tighter grouping of measurements for all TC locations. In both attach methods, the TC near the BGA on the PCB showed similar readings.

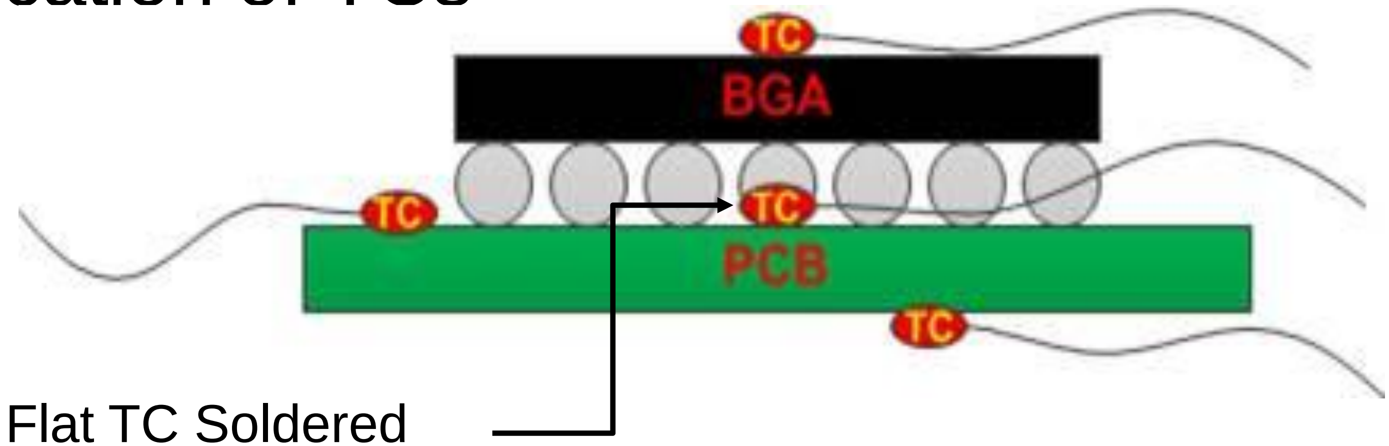


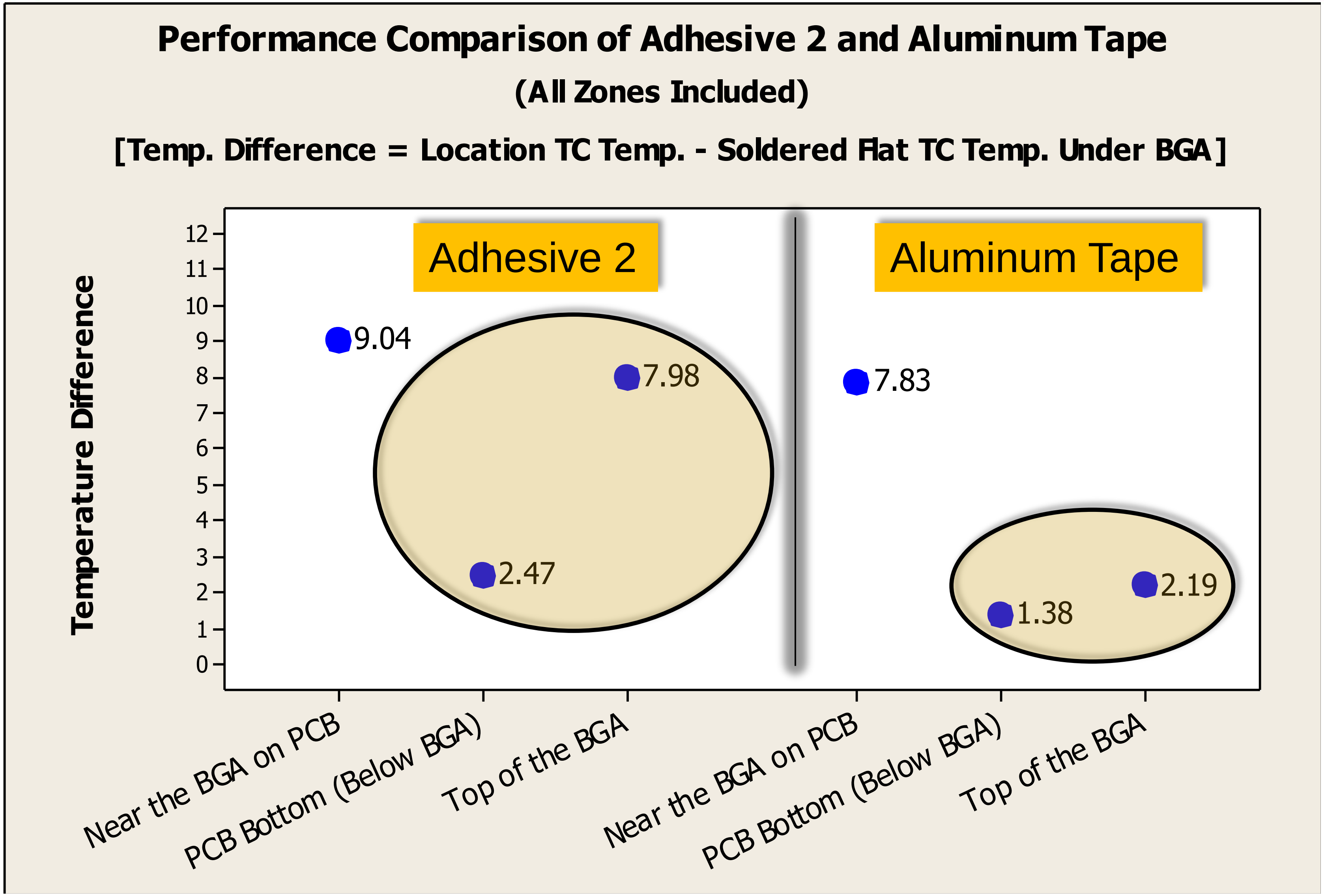
When looking at the reflow zone only, aluminum tape still showed a tighter grouping of measurements.

Slides 20 and 21 Reference the Following:

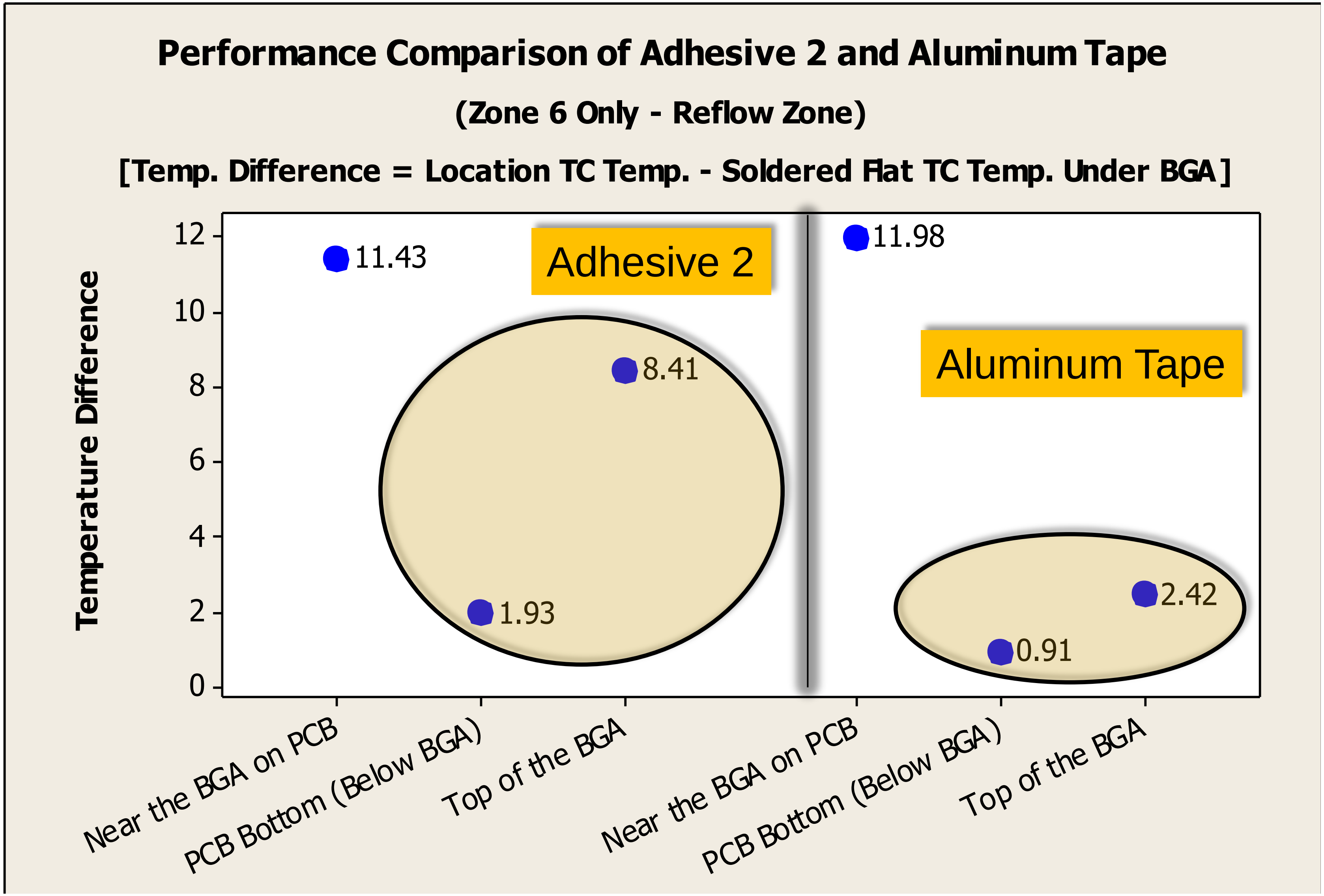
- Response Variable
  - Temp. Difference = Location TC – Flat TC Under BGA

- Location of TCs





When comparing the temperature difference of the flat TC located under the BGA to that of the other locations, aluminum tape showed the least variability.



When looking at the reflow zone only, aluminum tape still showed the least amount of variation between the actual (flat TC under BGA) and measured temperature.

Phase III - Findings

- Aluminum Tape outperforms Adhesive 2
  - Evaluated using both response variables
- Aluminum tape produced much tighter temperature readings between different locations
- Using a TC on the bottom of the PCB (using aluminum tape) is the best location for attachment
  - 1 to 2 degree C offset from a TC on top of the BGA

Phase IV - Final BGA Analysis

- Aluminum tape was selected from Phase III based on consistent performance
- 24 Experimental Runs
  - 3 BGAs
  - 2 FR4 Board Thicknesses
  - 2 Assemblies per Combination (Replications)
  - 2 Runs for Each Assembly
- Substrate – 2 Layer
  - Thin: 203.2mm x 139.6mm – 0.8mm thick – 43 grams
  - Thick: 203.2mm x 139.6mm – 1.6mm thick – 82.4 grams

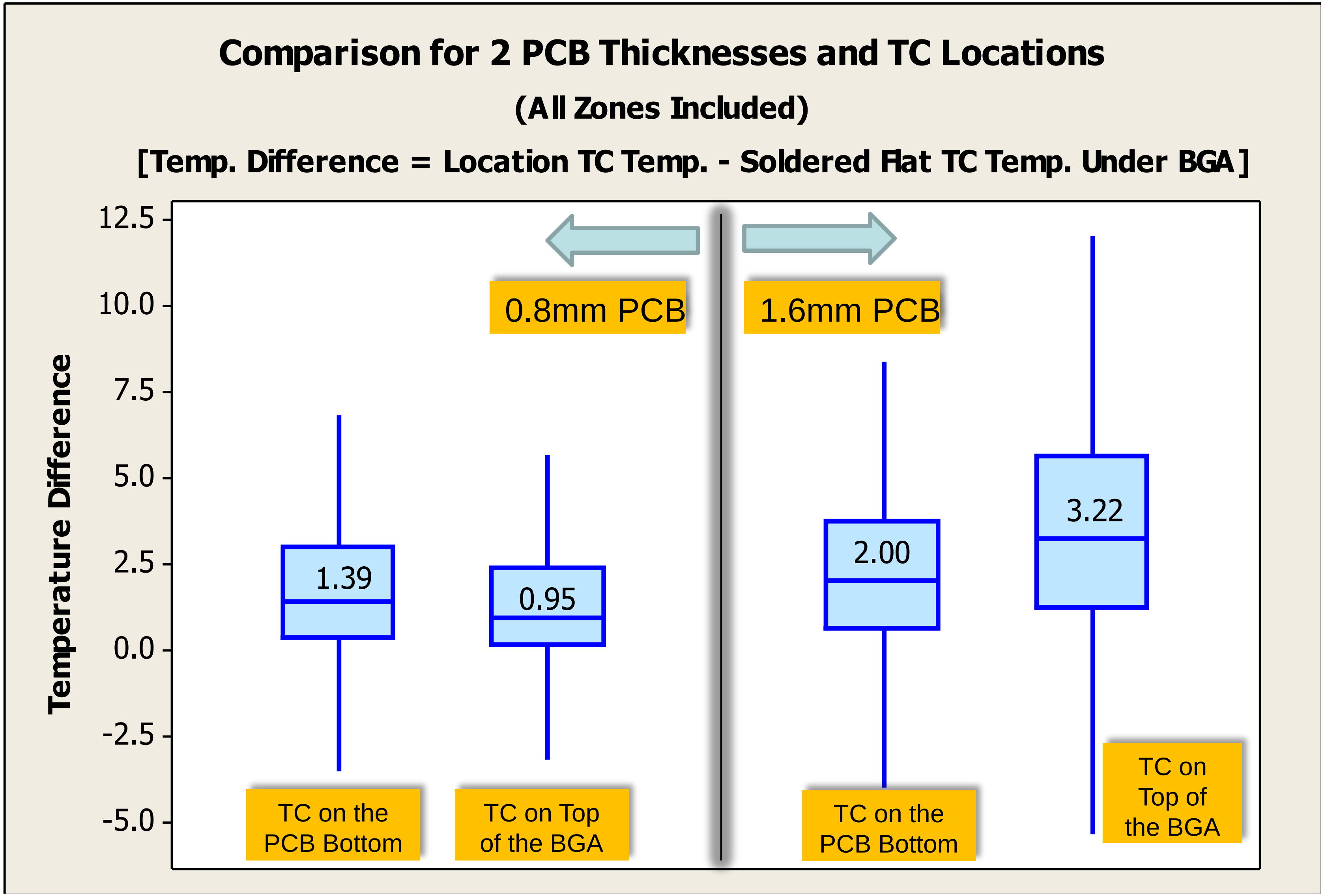
Phase IV - Final BGA Analysis

- Substrate – 2 Layer
  - Thin: 203.2mm x 139.6mm – 0.8mm thick – 43 grams
  - Thick: 203.2mm x 139.6mm – 1.6mm thick – 82.4 grams

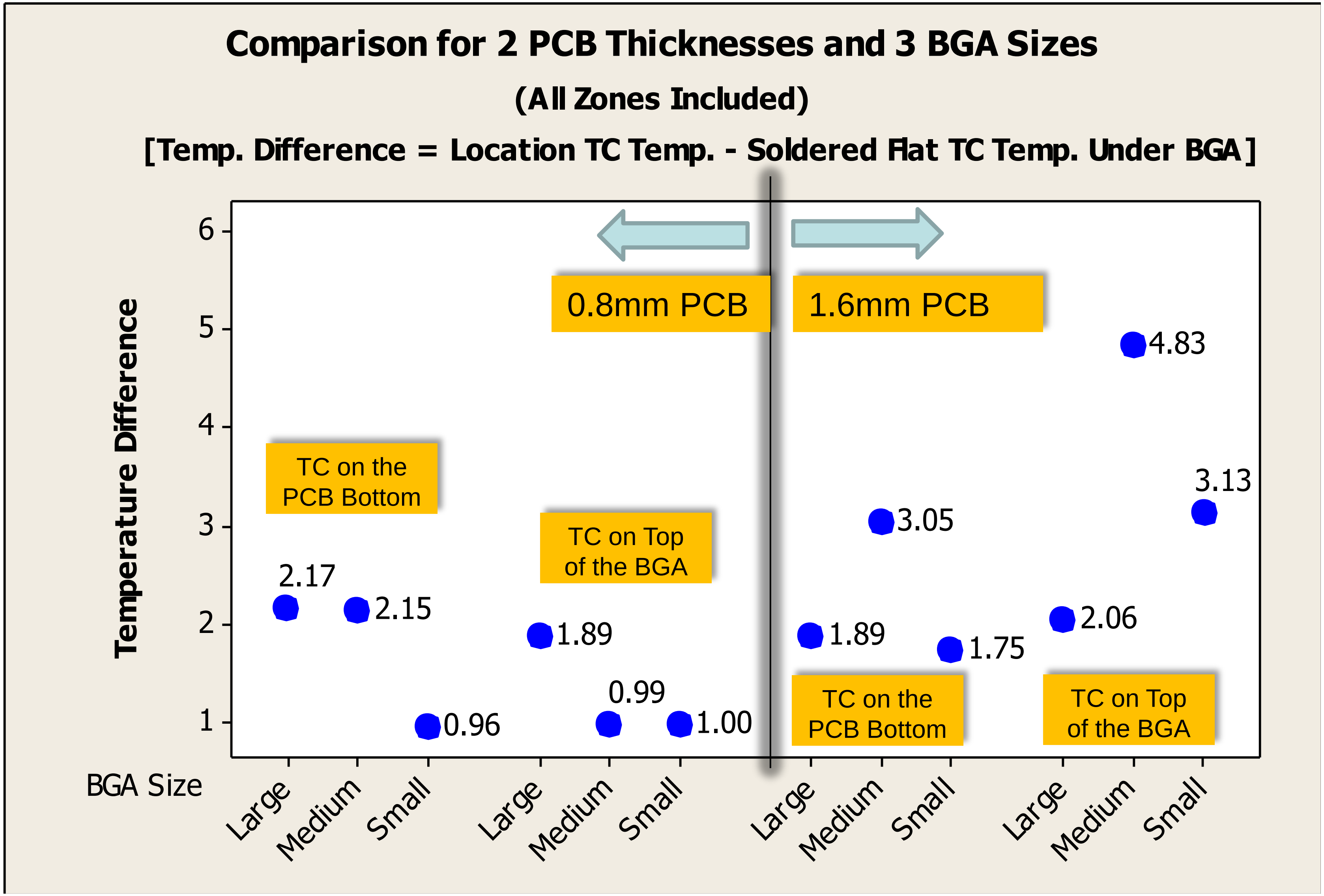
- Components
  - BGA 160 – 15mm x 15mm – 1mm Pitch – 0.4 grams
  - BGA 208 – 23mm x 23mm – 1.27mm Pitch – 1.5 grams
  - BGA 1156 – 35mm x 35mm – 1mm Pitch – 5.7 grams

Phase IV - Final BGA Analysis

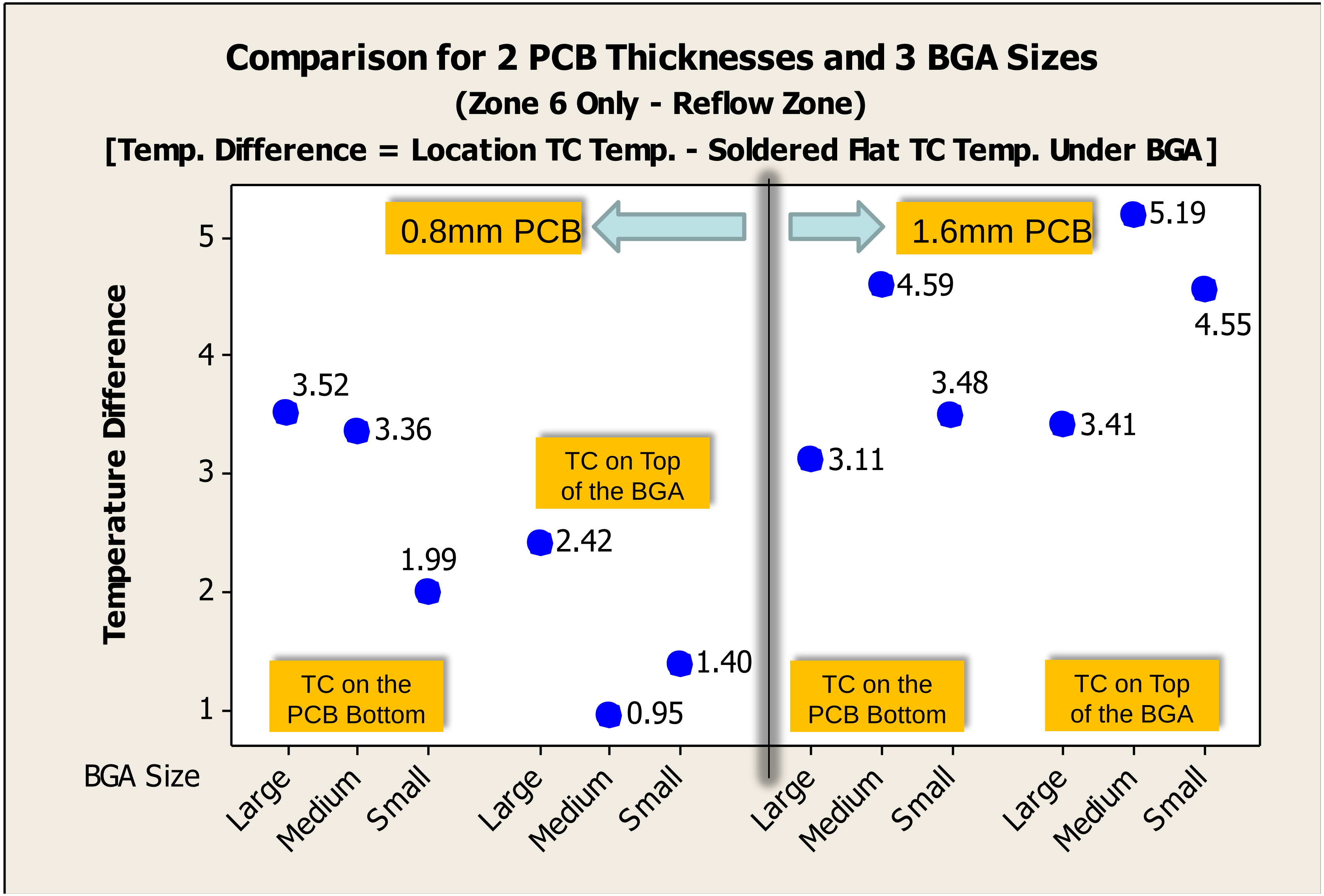
- Response Variable
  - Temp. Difference = Location TC Temp. – Soldered Flat TC Temp. Under BGA
- Location of TCs
  - PCB Bottom (Below the BGA)
  - Top of the BGA
- Flat TC Under BGA
  - Flat TC Soldered on the PCB pad Under the BGA



The thicker the PCB, the wider the temperature distribution. When looking at the TC on the bottom of the PCB the temperature was consistent regardless of thickness.



The thicker PCB showed a greater variation in the temperature difference, irrespective of the location and BGA size.



When looking at the reflow zone only, similar results were observed except that the temperature differences were higher. The thin PCB showed better performance.

Conclusions

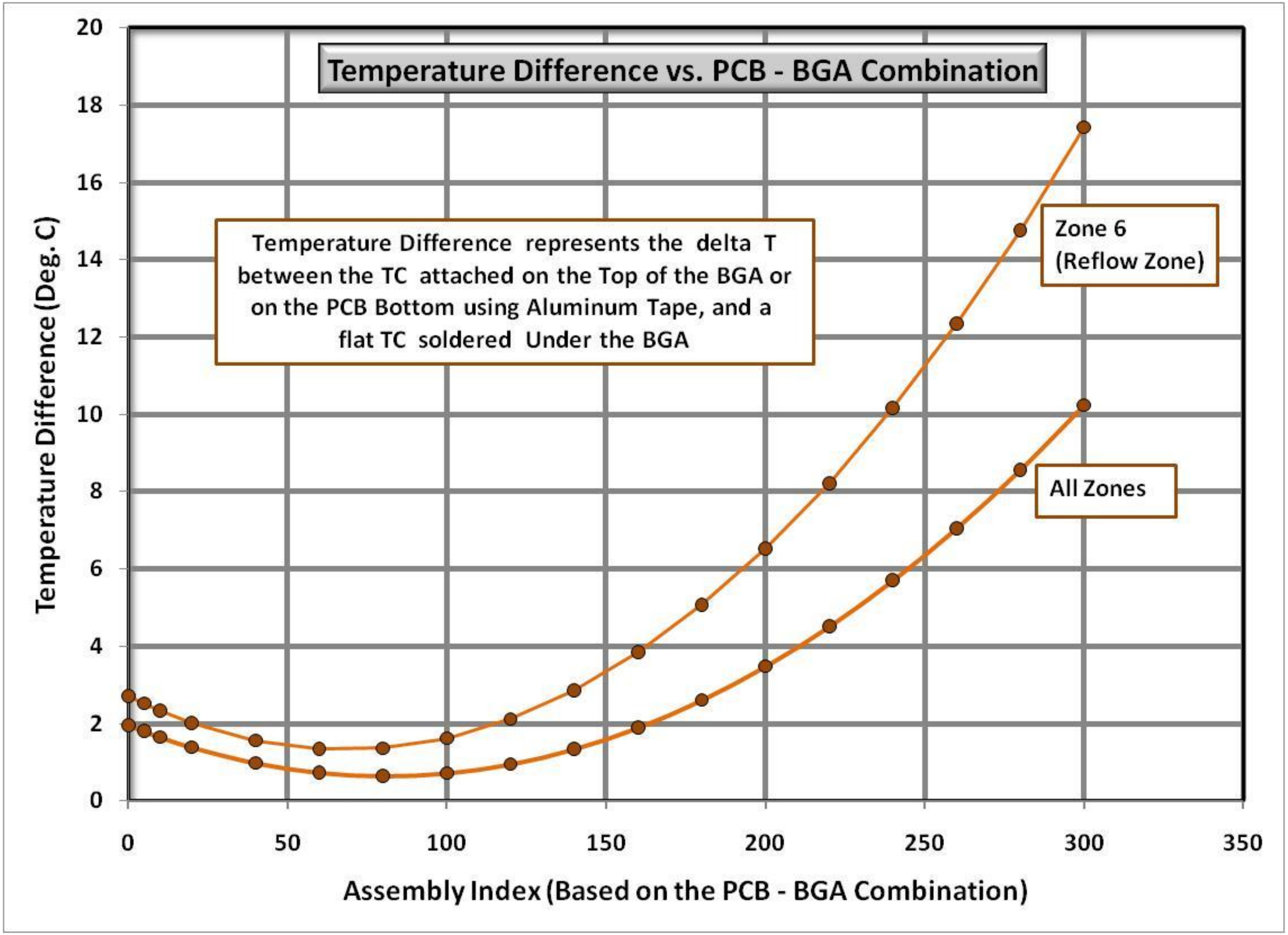
- TC attach on the Bottom of the PCB below the BGA provided more consistency irrespective of the BGA size and PCB thickness.
- When considering all zones, there was a 2 to 3 degree temperature differential between the bottom of the PCB and the flat TC soldered under the BGA
- When considering Zone 6 there was a 4 to 5 degree temperature differential between the bottom of the PCB and the flat TC soldered under the BGA

Combining All PCB Thicknesses and BGA Sizes

$$AI = \frac{PT \times PW \times PA \times CP}{IOC \times CA \times CW \times CT}$$

- Where…
  - – AI is the Assembly Index

- PT is PCB Thickness (mm)
- PW is PCB Weight (grams)
- PA is Full PCB Area (sq. mm)
- CP is Component Pitch
- IOC is I/O Count
- CA is Component Area (sq. mm)
- CW is Component Weight
- CT is Component Thickness (including solder balls)


Temperature Difference vs. PCB - BGA Combination
Temperature Difference represents the delta T between the TC attached on the Top of the BGA or on the PCB Bottom using Aluminum Tape, and a flat TC soldered Under the BGA
Zone 6 (Reflow Zone)
All Zones
Temperature Difference (Deg. C)
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
300
350
Assembly Index (Based on the PCB - BGA Combination)

Acknowledgements

- Jeff Lonneville - Lab Manager of RIT CEMA Lab
- Timothy Grove – RIT Alum, Initial Researcher
- Bjorn Dahle – President of KIC

Thank You

Are There Any Questions?