# EVALUATING THE ACCURACY OF A NON-DESTRUCTIVE THERMOCOUPLE 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.

| **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 | | | | | |

**Table. Oven recipe used in the study**

Figure 1a. TC attachment on top of the BGA

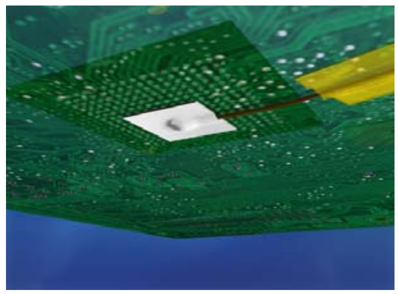

Figure 1b. TC attachment on the bottom of the PCB directly underneath the BGA location

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 Non-Destructive 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.

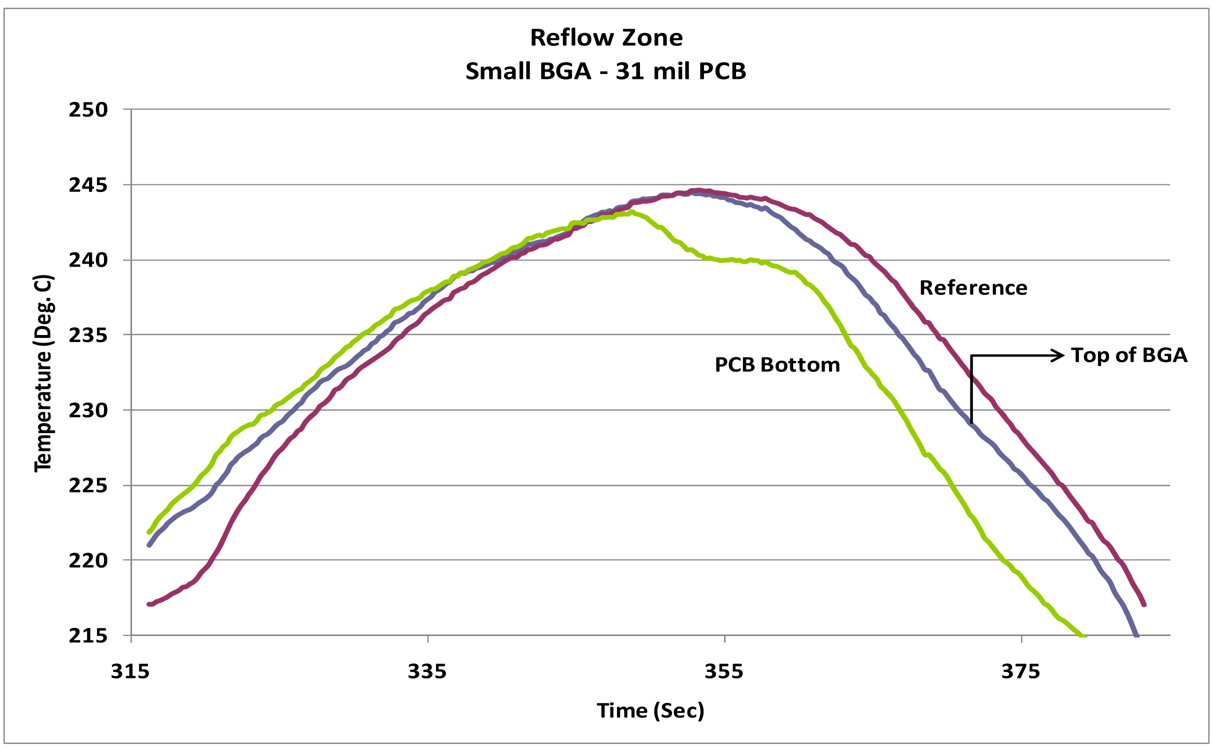


**Figure 3. Profile overlay for reference TC, small BGA and 31 mil PCB**

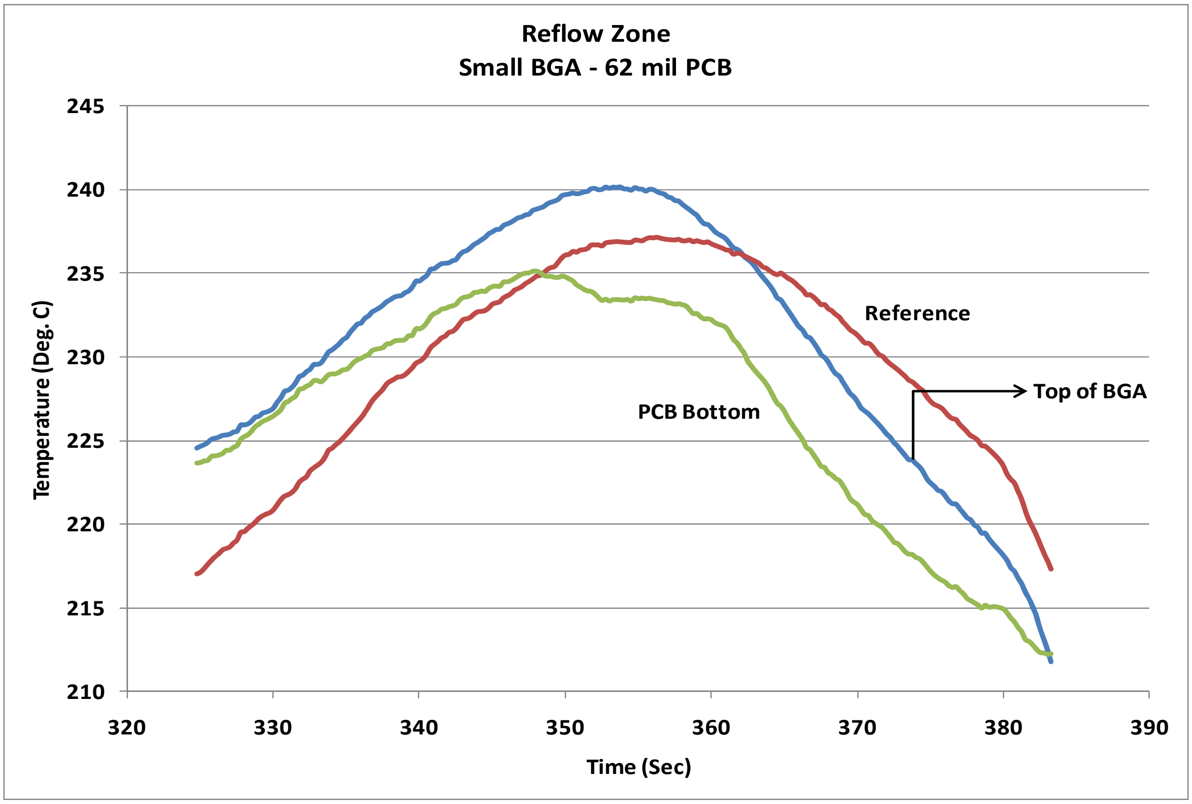


Figure 4. Profile overlay for reference TC, small BGA and 62 mil PCB

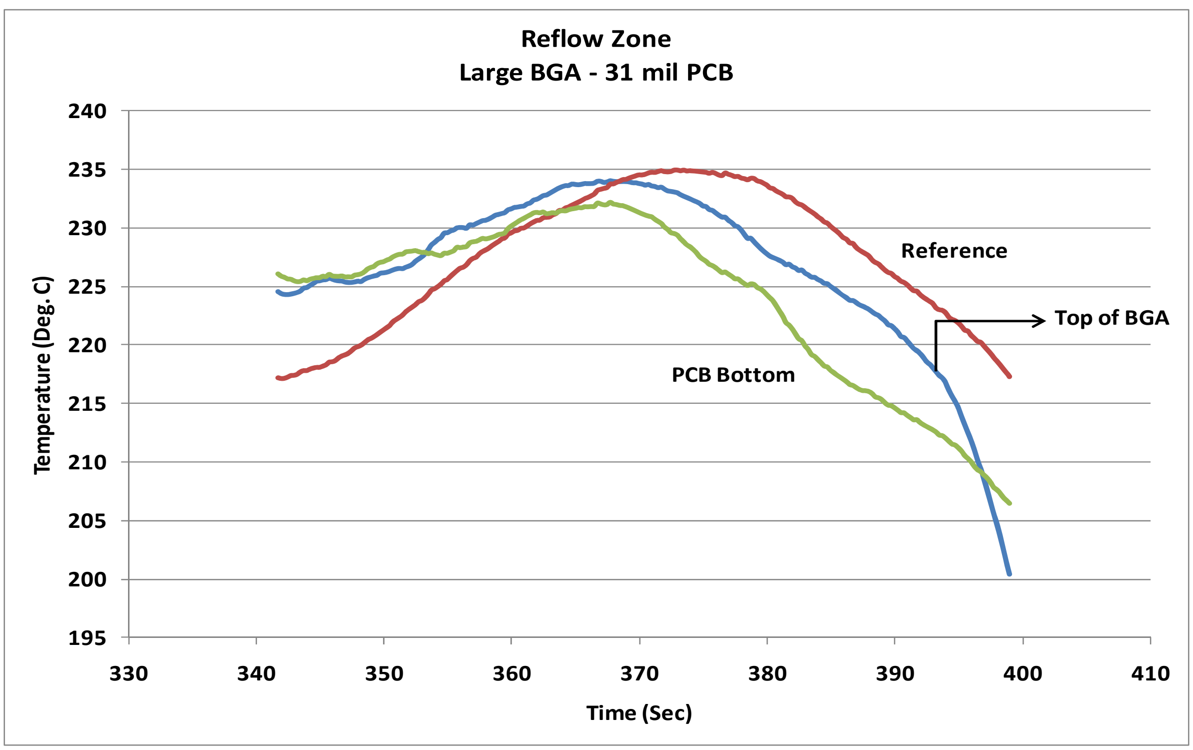


Figure 5. Profile overlay for reference TC, large BGA and 31 mil PCB

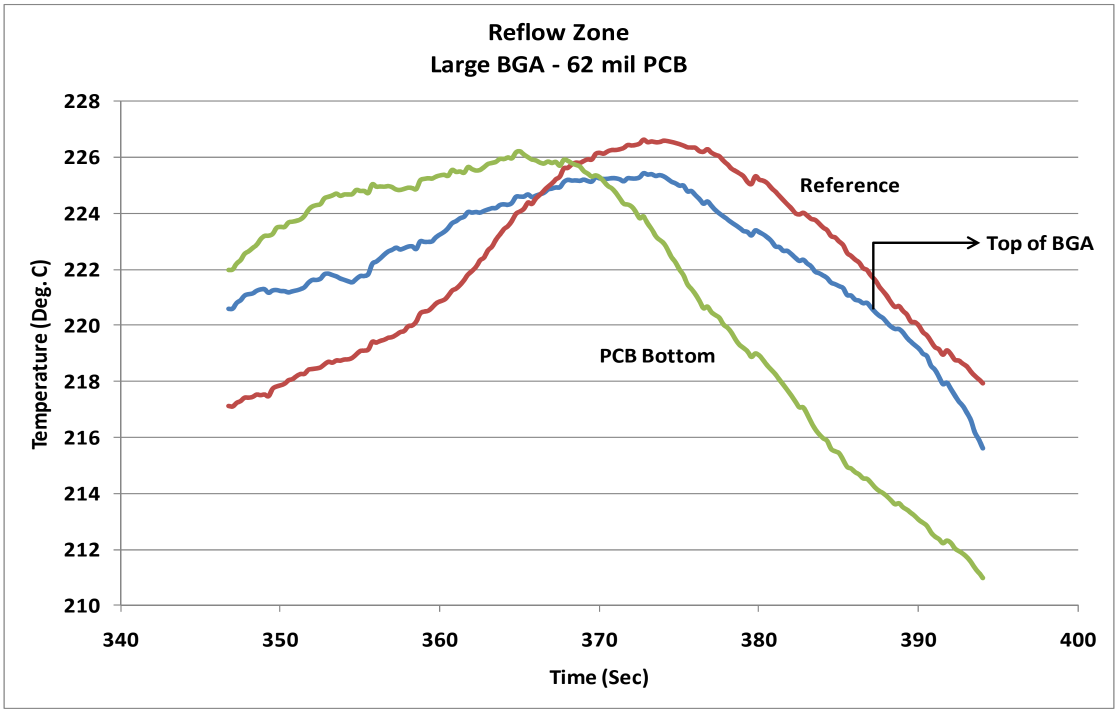


Figure 6. Profile overlay for reference TC, large BGA and 62 mil PCB

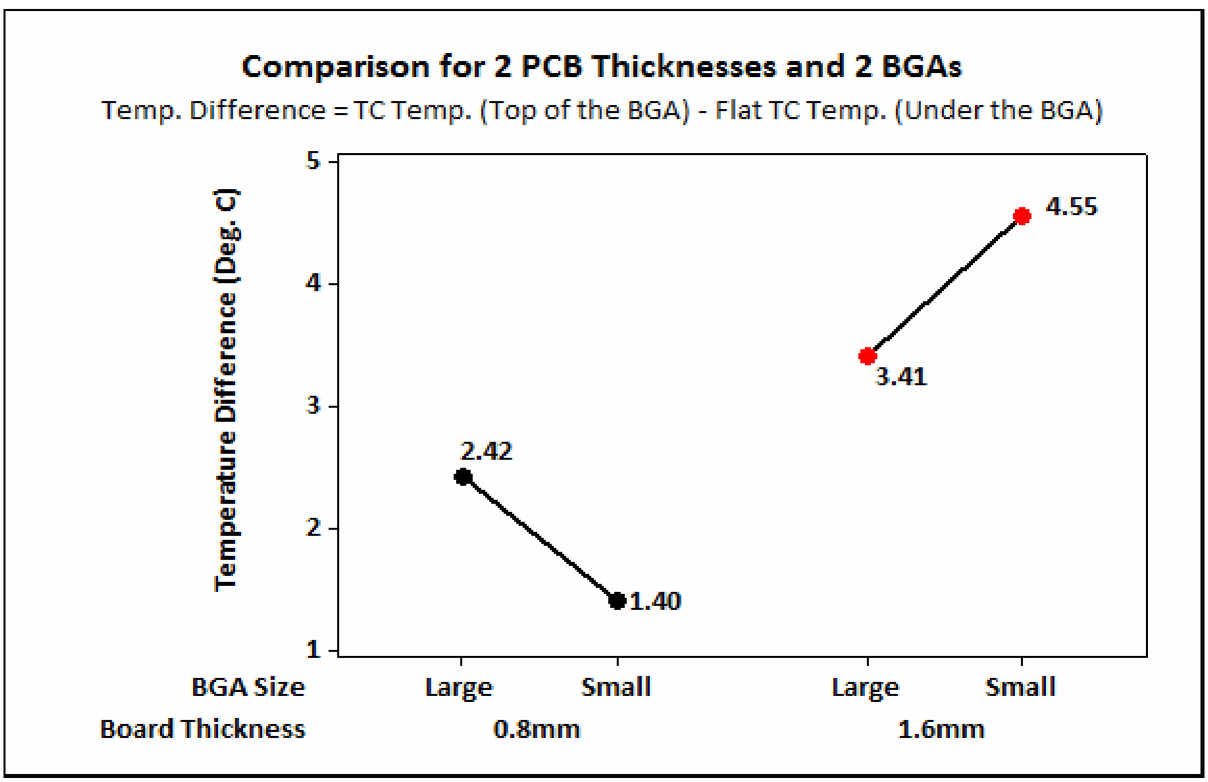


Figure 7. Temperature offset for 2 PCB sizes and two PCB thicknesses

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

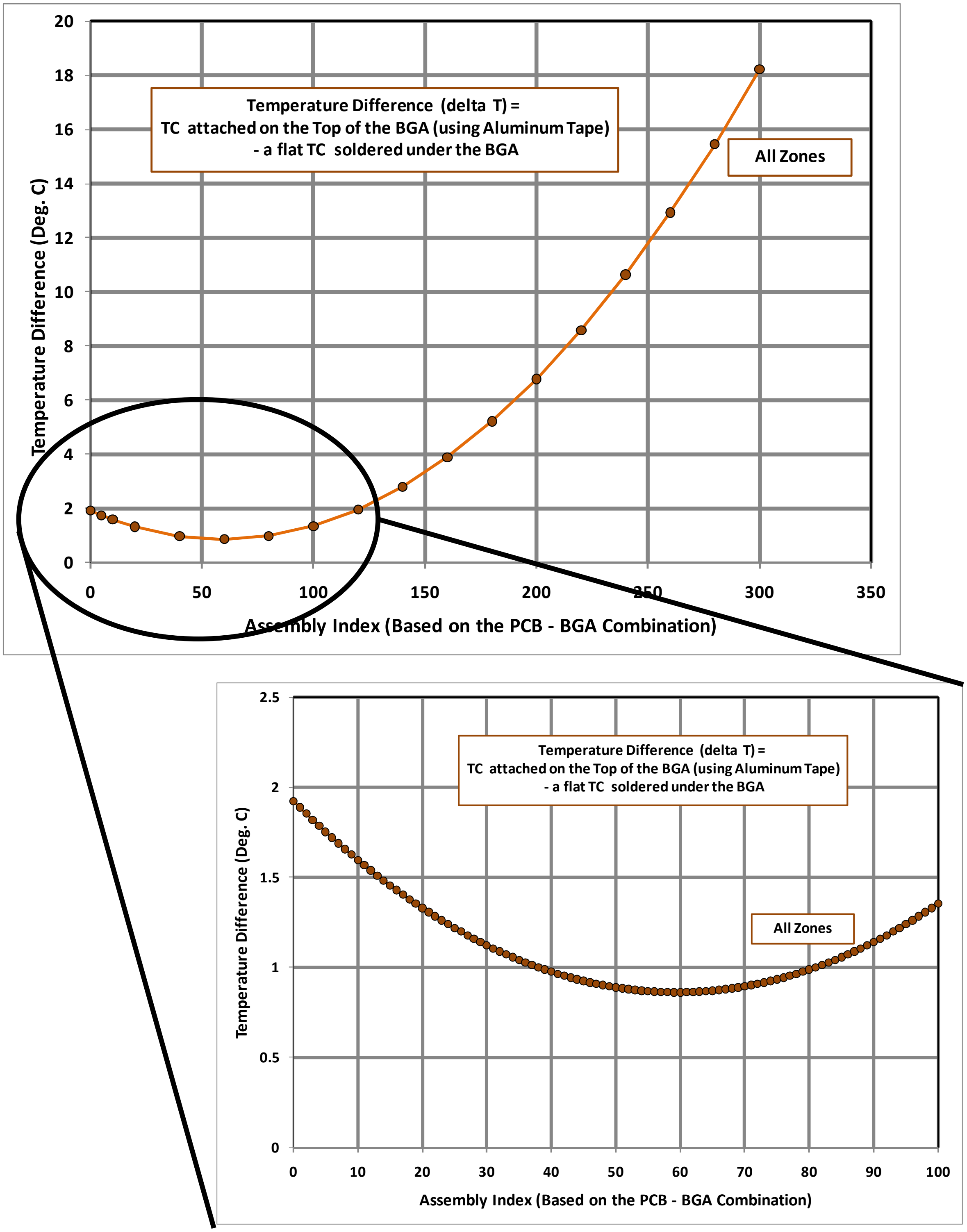


**Figure 8. Graph for temperature offsets All Zones combined based on the AI formula**

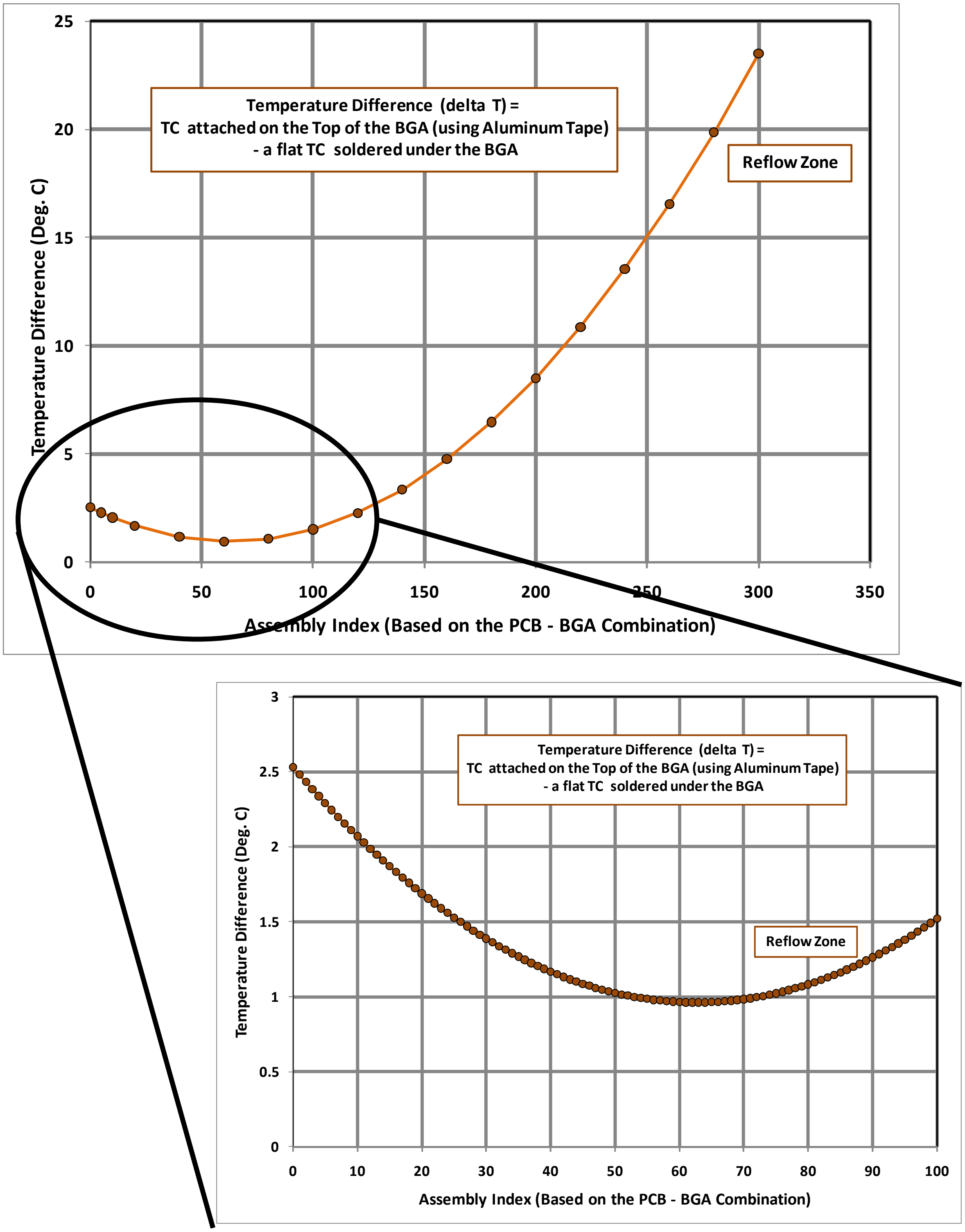


**Figure 9. Graph for temperature offsets for Reflow Zone only based on the AI formula**

## 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.