

Thermocouple Tactics: A Comparative Study of Attachment Methods

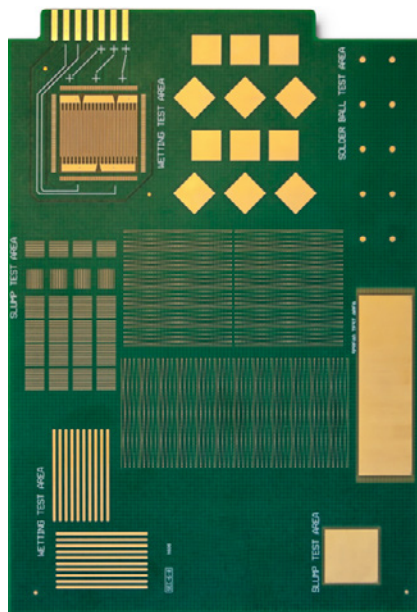
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Abstract

Achieving high-quality Printed Circuit Board (PCB) assemblies requires precise control of the time-temperature profile during reflow soldering. This profile must align with the specifications of the materials and components and remain consistent as the product moves through the oven. Inaccurate control of this profile can result in defects, costly rework and scrap, making reliable, repeatable and accurate temperature monitoring and control critical during the reflow soldering process.

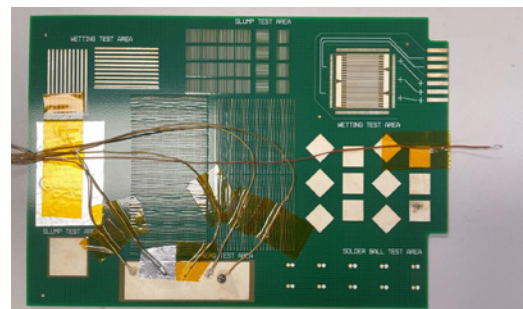
Time-temperature profiling typically involves attaching thermocouples to a sample PCB and passing it through a reflow process to monitor temperatures at key points. However, the reliability, repeatability and accuracy of these measurements depend on the method used to attach the thermocouples.

This article presents findings from experiments conducted at the Rochester Institute of Technology (RIT) to evaluate common methods of attaching thermo-



■ Figure 1. SMT Test Board.

couples to modern High-Density (HDI) circuit boards. The objective was to compare these methods and identify the most

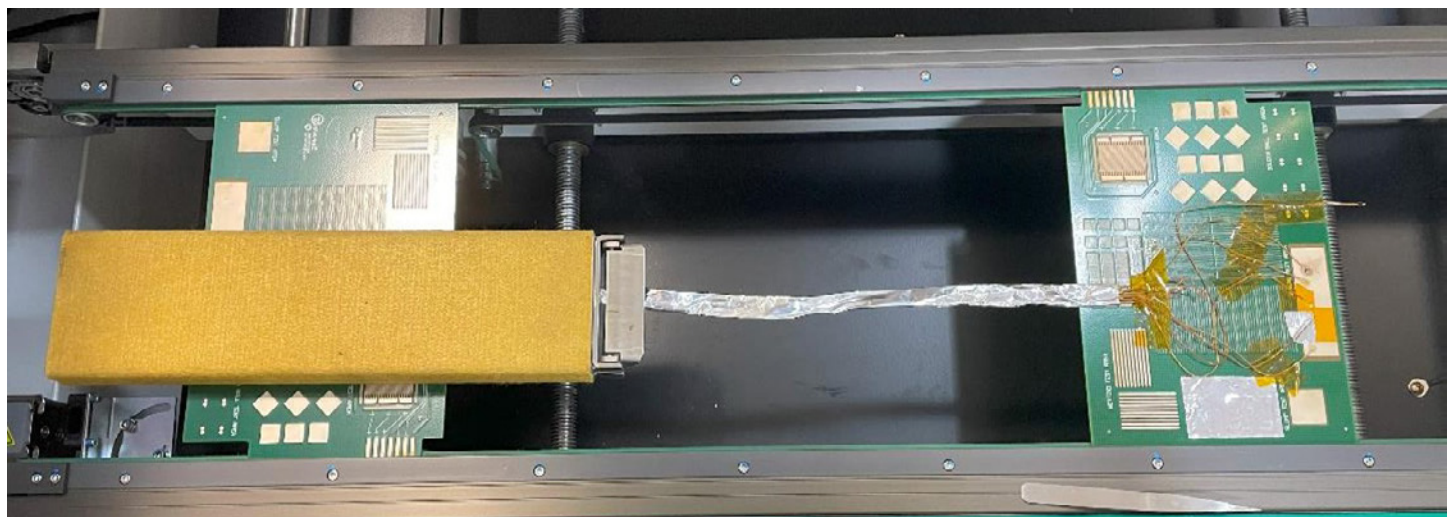


■ Figure 2. Test Pad.

effective techniques for achieving reliable, repeatable and accurate time-temperature measurements. The study explores different attachment methods, including polyimide tape, aluminum tape, high-temperature solder, and two types of thermally conductive adhesive.

THE RIT FINDINGS REVEALED THAT

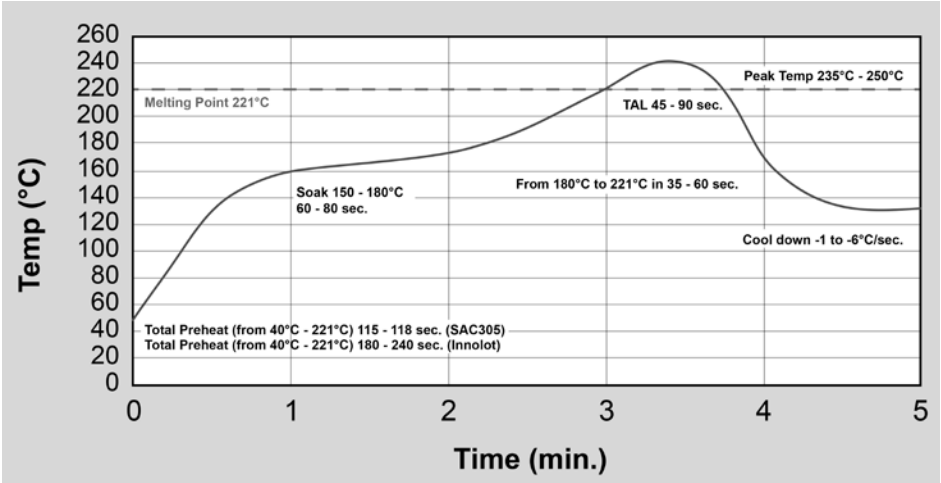
- **Thermally conductive adhesives** can be highly effective, reliable, repeatable and accurate for attaching thermocouples to high-density cir-



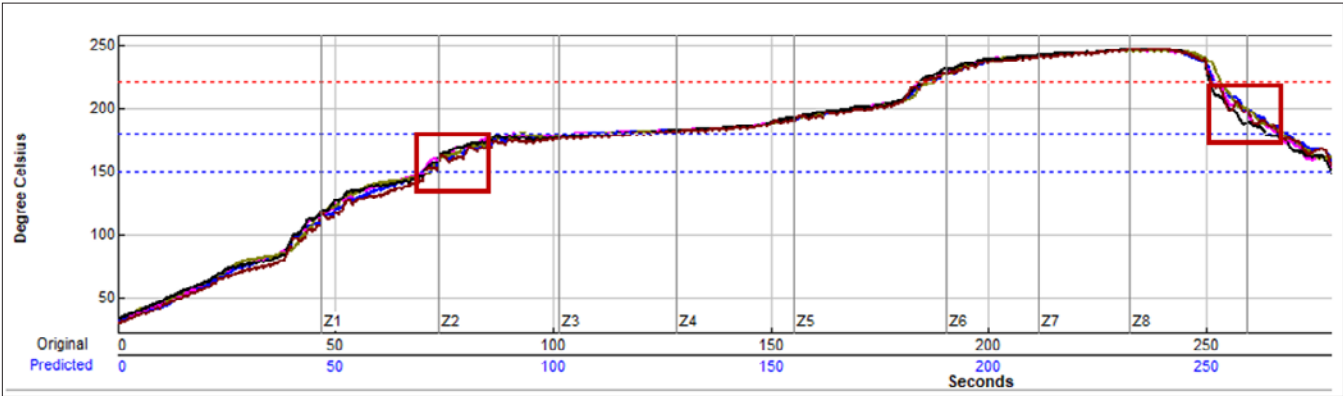
■ Figure 3. Test Board with KIC SPS Smart Thermal Profiler

cuit boards with limited bare space. However, their performance depends on the adhesive's formulation, particularly its thermal conductivity, viscosity and compatibility with solder masks.

- **Aluminum and polyimide tapes** are unsuitable for securing thermocouples to high-density PCBs with components, as both types will lift components off the PCB during the solder liquidus phase of the reflow cycle. The scarcity of open spaces on HDI PCBs makes tape impractical in these situations.
- **Accuracy of solder attachments** is influenced by the volume of solder used. Larger solder volumes increase



■ Figure 4. Pb-Free Reflow Profile Used in Testing



■ Figure 5. Rising and Falling Slopes on Reflow.

the thermal mass at the measurement site, causing it to act as a heat sink during heating and as a heat source during cooling.

PREVIOUS WORK

In 1999, KIC¹ tested various methods of attaching thermocouples to PCBs for thermal profiling. While traditional high-temperature soldering was effective, it was time-consuming, required a skilled technician, and risked PCB damage. KIC evaluated four attachment methods:

- High-temperature solder (Sn10/Pb88/Ag2 high-lead cored solder wire)
- Polyimide tape
- Aluminum tape
- Non-conductive adhesive (LOCTITE Tak-Pak)

These methods were tested on four bare PCBs, each subjected to multiple tin-lead reflow cycles, recording key

temperature metrics like peak temperature, rising slope, and time above liquidus. Using bare PCBs eliminated space constraint issues and allowed precise application of all application methods without component interference. However, this setup, while effective for confirming repeatability, didn't validate accuracy in real-world scenarios where PCBs are populated with components. The study found:

- High-temperature solder (Sn10/Pb88/Ag2) was the most reliable and repeatable method for thermocouple attachment.
- Aluminum tape was an effective alternative, particularly when combined with polyimide tape. It was easy to apply and remove without causing damage to the PCB, although some minor thermocouple lifting occurred during reflow.
- Polyamide tape alone, while simple

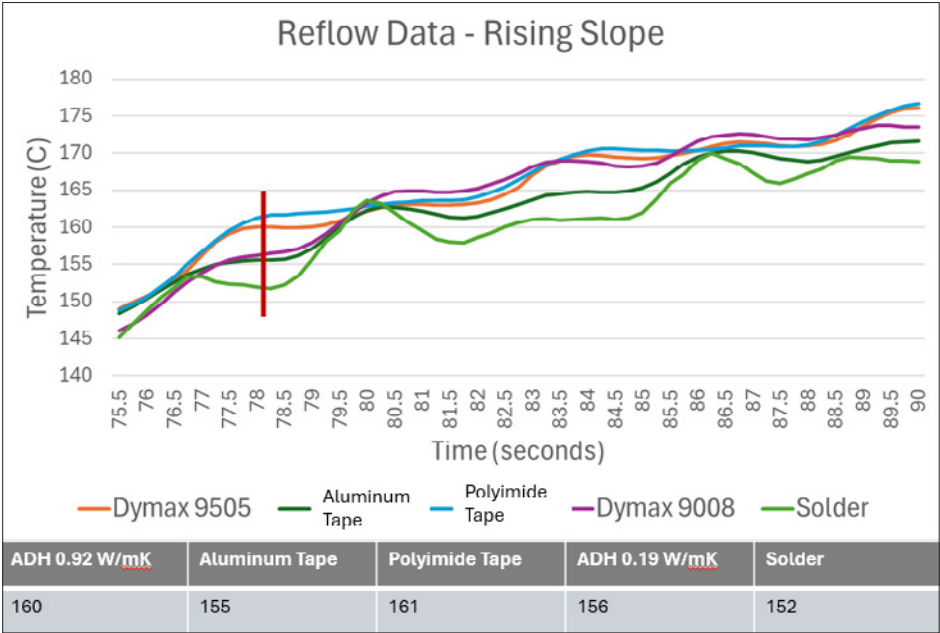
and cost-effective, was less reliable due to the formation of air pockets which led to consistent thermocouple lifting.

- The non-conductive adhesive utilized was unsuitable for reflow temperatures, becoming brittle after 1-2 cycles, proving to be ineffective for thermocouple attachment.

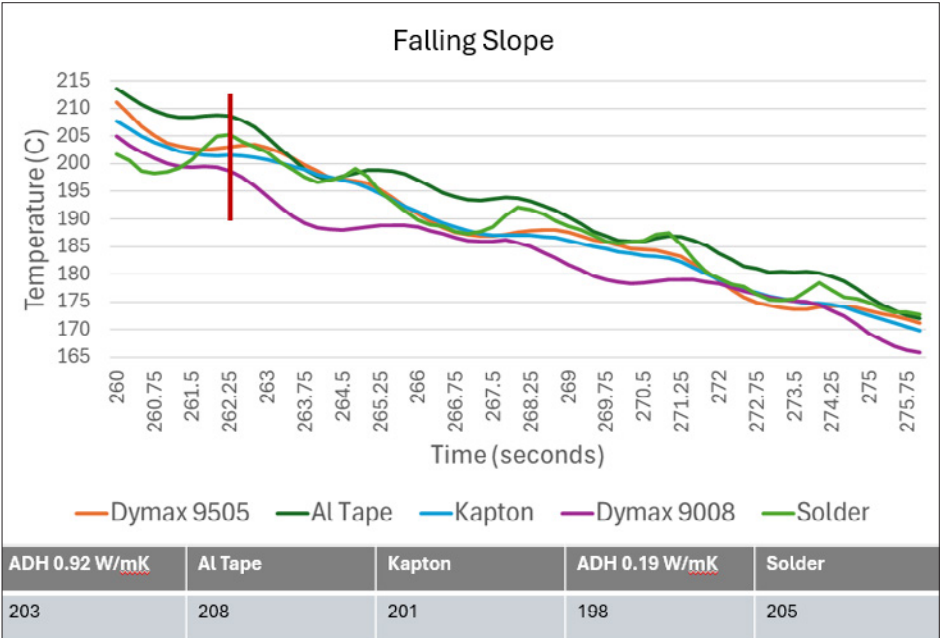
TEST EQUIPMENT AND MATERIALS

The following equipment and materials were used in the experiments:

- Heller 1808 MKIII 10-zone reflow oven (8 heat, 2 cooling)
- Type-K, 30 gauge (0.010" diameter wire) with rated tolerance of $\pm 1^{\circ}\text{C}$
- Standard SMTA test board (8.0" x 5.5" with 0.062" thick 4-layer PCB)
- SMT Components (01005, 0201, 0402, 0603, 1206, Amkor PoP, Amkor 12mm QFNs, and Amkor 13mm BGAs)



■ Figure 6. Rising Slope on Reflow Cycle



■ Figure 7. Falling Slope on Reflow Cycle

- SAC305 no-clean solder paste
- Thermal Profiler for data acquisition

PRELIMINARY EVALUATION OF ACCURACY

The first experiment compared the accuracy of thermocouple attachment methods by securing multiple thermocouples to a large, metallized test pad on a bare test PCB (Figures 1 & 2).

THE METHODS TESTED WERE

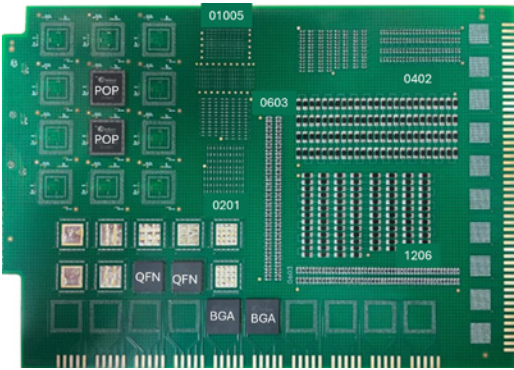
- High-temperature solder (Kester Sn10/Pb88/Ag2 high-lead cored solder wire)
- Polyimide tape,
- Aluminum tape
- Dymax 9505-TC adhesive with 0.92 W/mK thermal conductivity (UV-curable)
- Dymax 9008 adhesive with 0.19

W/mK thermal conductivity (UV-curable)

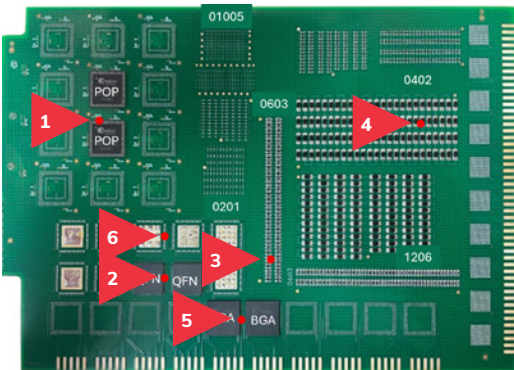
- All thermocouples were affixed to the same PCB pad and connected to a thermal profiler for data collection (Figure 3). The PCB was then processed through a reflow oven using the thermal profile recommended by the solder paste supplier (Figure 4). Running all five thermocouple attachment methods simultaneously on the same pad yielded similar results (Figure 5), with temperature differences of approximately 9°C. Analyzing the plot in the rising and falling temperature zones provided insights into the accuracy of each attachment method.

RISING SLOPE ANALYSIS

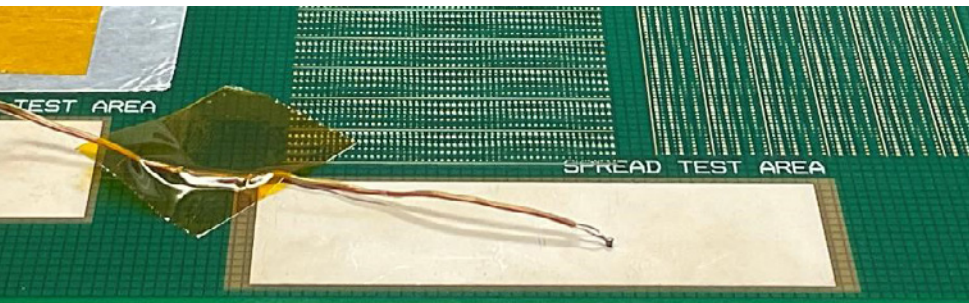
Examining the rising slope (Figure 6) shows that high-lead solder, with the highest thermal mass, recorded the lowest temperature, followed by aluminum tape. This can be attributed to their higher thermal mass, which presumably creates a heat sink effect, causing them to heat more slowly. In contrast, polyimide tape, with the lowest thermal mass, recorded



■ Figure 8. Top Side Test Board.



■ Figure 9. Attachment Locations



■ Figure 10. Thermocouple Stress Relief



■ Figure 11. High Temp Solder

the highest temperature. The two adhesives, with moderate thermal mass, fell in between. The maximum temperature difference between the high-lead solder and polyimide tape was about 9°C, though this varied throughout the reflow cycle.

FALLING SLOPE

Examining the falling slope (Figure 7) reveals that aluminum tape and solder are now recording the highest temperatures, suggesting these materials, which initially behaved as heat sinks, have transitioned to acting as heat sources. This transition implies that materials with greater thermal mass not only heat more slowly but also take longer to cool, potentially compromising the accuracy of time-temperature profiling.

EXPERIMENTAL SETUP FOR REMAINING TESTS

The remaining tests were conducted on standard SMTA test boards populated with various SMT components, including

01005, 0201, 0402, 0603, 1206, Amkor PoP, Amkor 12mm QFNs, and Amkor 13mm BGAs. Thermocouples were attached using:

- High-temperature solder (Kester Sn10/Pb88/Ag2 high-lead cored solder wire)
- Polyimide tape
- Aluminum tape
- Dymax 9505-TC with 0.92 W/mK thermal conductivity (UV-curable)
- Dymax 9008 with 0.19 W/mK thermal conductivity (UV-curable)

Each attachment method was evaluated on identical SMTA test boards (Figure 8) with six thermocouples strategically placed at key locations across the board and spanning a range of component types, from small passives to larger 12mm and 13mm semiconductor components (Figure 9). One thermocouple was dedicated to measuring air temperature.

Each test board and attachment method underwent 20 reflow cycles with cooling intervals between runs. A thermal



■ Figure 12. Polyimide Tape.

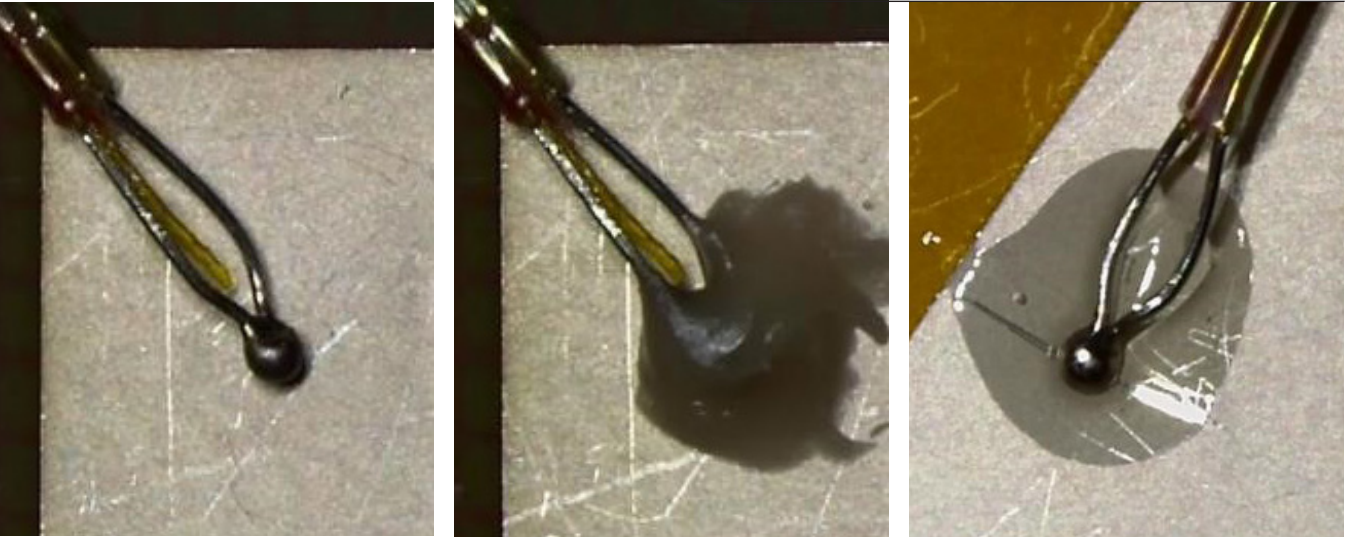


■ Figure 13. Aluminum Tape Supported with Polyimide tape.

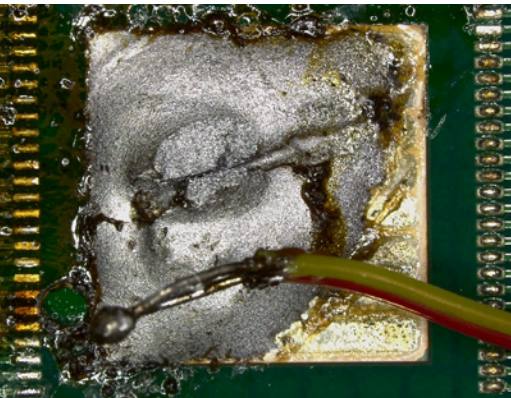
profiler recorded peak reflow temperatures and monitored time above liquidus for each cycle.

THERMOCOUPLE ATTACHMENT DETAILS

All thermocouples were bent down-



■ Figure 14a. Bare Thermocouple; Figure 14b. DYMAX 9505-TC; Figure 14c. DYMAX 9008.



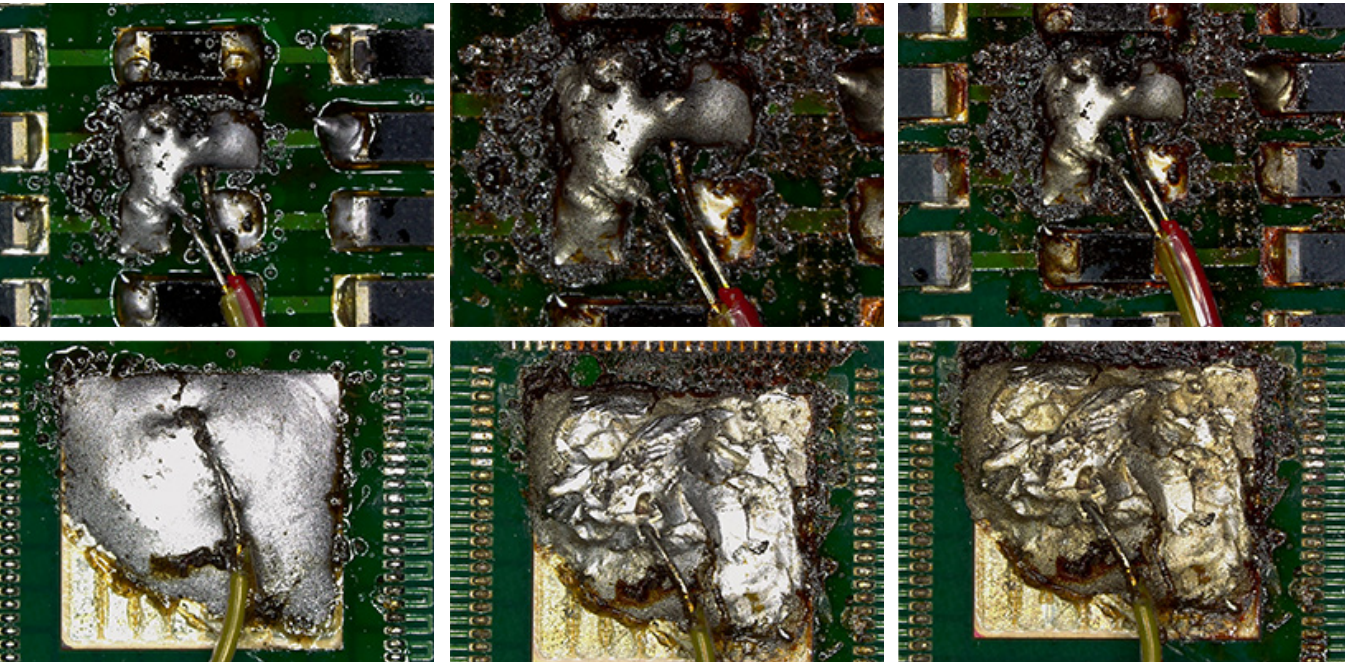
■ Figure 15. High Temp Solder

ward to create spring like tension at the bond location. Wires were secured to the PCB with polyimide tape to provide additional stability (Figure 10).

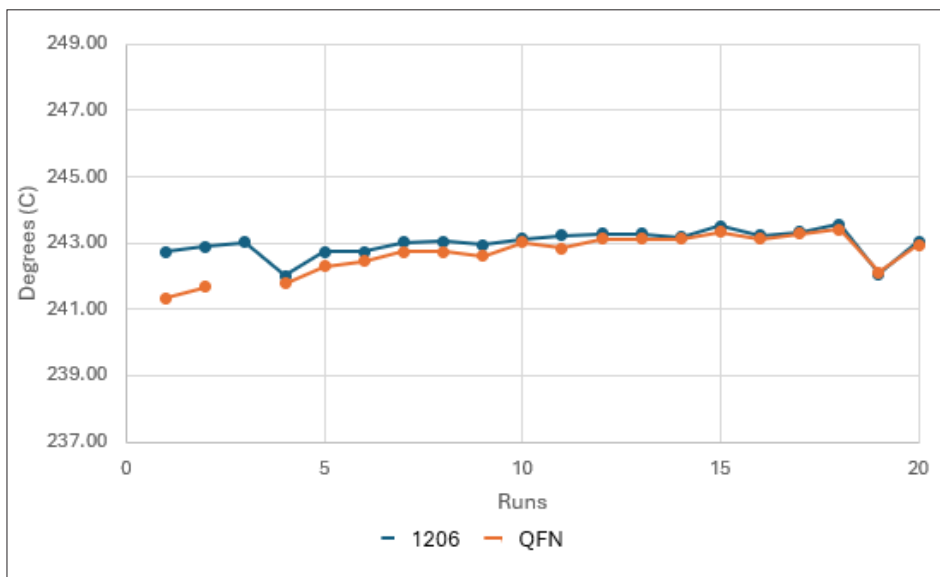
HIGH-TEMPERATURE SOLDER ATTACHMENT DETAILS

Attaching thermocouples to high-density circuit boards using high-temperature, high-lead solder presents several challenges. While this method provides strong thermally conductive bonds, its use is increasingly restricted by environmental regulations, such as EU’s REACH directive, which

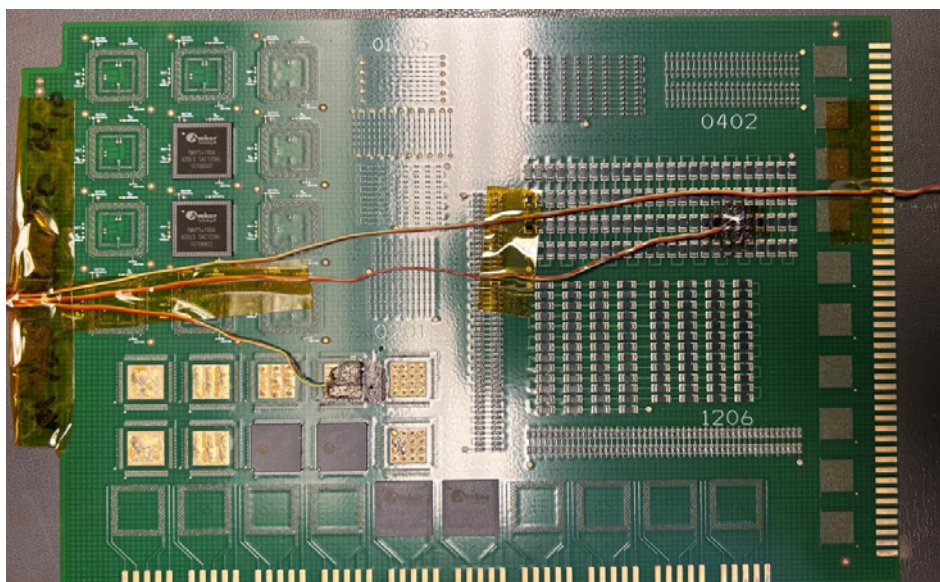
limits the use of lead-based materials. Additionally, soldering often requires the removal of components to access metallized surfaces, requiring a skilled technician proficient in this type of work. Furthermore, the high temperatures required for proper solder flow can impose thermal stress on both the soldering iron and the PCB, increasing the risk of damage to components and the board itself. Preheating the PCB to 95°C before soldering can help mitigate thermal shock (Figure 11), but this approach complicates handling and increases the risk of burns to the technician.



■ Figure 16. High Temp solder Run 0, 11 and 20



■ Figure 17a. Thermocouple Readings for High Temp Solder.



■ Figure 17b. High Temp Solder Attachment

TAPE ATTACHMENT DETAILS

Tape attachment typically involved using either aluminum or polyimide tape. Aluminum tape is often preferred for its higher thermal conductivity, while polyimide is valued for its ability to block airflow interference with the temperature readings. However, to ensure stability, aluminum tape needs to be secured with polyimide tape in a technique known as “framing.”

Regardless of the type of tape used, one critical issue remains: the tape must adhere to the PCB itself, not to components. If attached to components, the tape will lift

them off the board when the solder reaches its liquidus temperature. On high-density PCBs, limited space can prevent direct attachment of tape – whether aluminum or polyimide – to the bare board.

POLYIMIDE TAPE ATTACHMENTS

Polyimide tape was effective for attaching thermocouples to the PCB when applied directly on bare sections of the board in large strips. However, applying tape over components caused them to lift during the liquidus phase. Additionally, air pockets formed under the tape,

requiring significant force to secure it after each run (Figure 12).

Polyimide tape was also used to affix the thermocouple wires to the board's edge, which restricted wire movements and helped minimize stress-related failures.

ALUMINUM TAPE ATTACHMENTS

Aluminum tape alone lacked sufficient strength to stay attached through multiple reflow cycles. However, reinforcing it with polyimide tape on both sides effectively secured the thermocouple to the board (Figure 13).

ADHESIVE ATTACHMENT DETAILS

UV-curable, thermally conductive adhesives with thermal fillers are widely used in electronics to create strong, heat-conductive bonds that withstand high temperatures. They harden upon exposure to light of specific curing wavelengths and intensities and are ideal for densely populated circuit boards where space is limited.

Adhesive viscosity impacts ease of application and thermal performance. High-viscosity adhesives, with a thicker, gel-like consistency, are easier to apply and provide better coverage. While low-viscosity adhesives are thinner, often requiring multiple layers to fully cover the thermocouple bead.

DYMAX 9505-TC ADHESIVE:

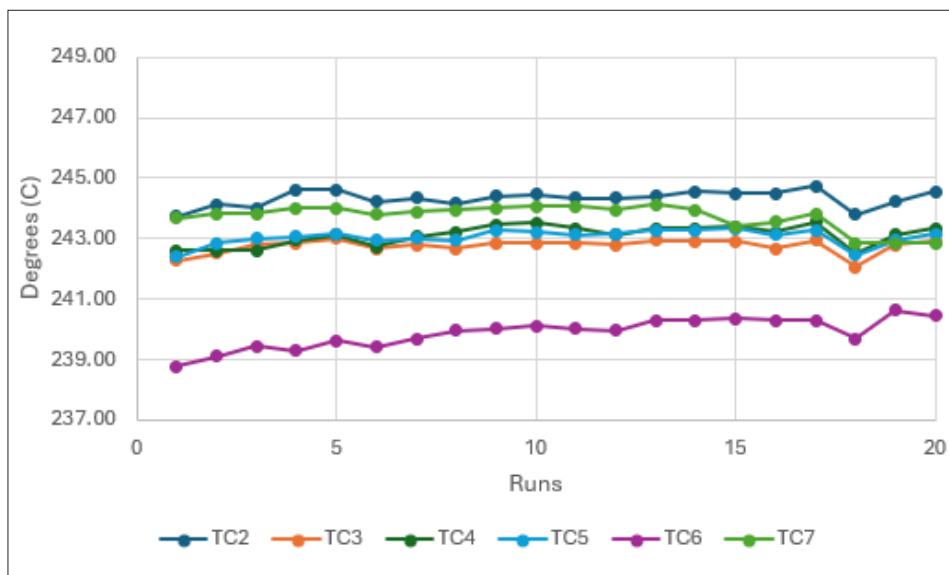
This adhesive has a high viscosity and thermal conductivity of 0.92 W/mK due to its high filler ratio, meaning it contains a large proportion of metallic particles relative to its base material. This high filler ratio enhances thermal conductivity, increases viscosity, reduces fluidity, and makes the application process easier.

DYMAX 9008 ADHESIVE

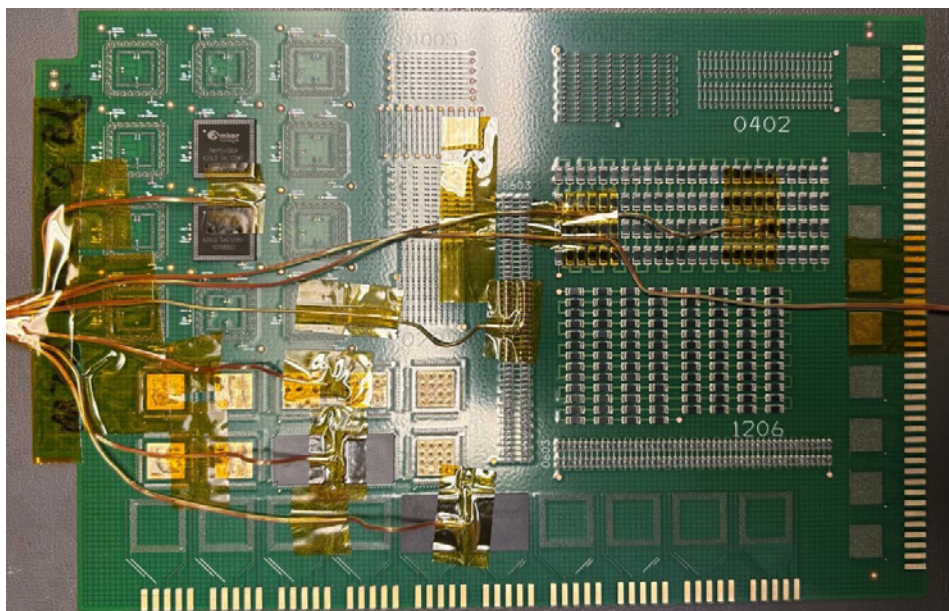
In contrast, 9008, with a lower thermal conductivity of 0.19 W/mK and lower viscosity compared to Dymax 9505-TC, is more challenging to apply, requiring 2-3 applications with a toothpick to ensure adequate coverage. Figures 14a, 14b and 14c show the appearance of the bare thermocouple and both adhesives.

DATA ANALYSIS: HIGH-TEMPERATURE SOLDER

The repeatability of high-temperature solder attachments stayed within the thermocouple's tolerance limit of $\pm 1^\circ\text{C}$.



■ Figure 18a. Thermocouple Readings with Polyimide



■ Figure 18b. Polyimide Attachment

However, some solder joints cracked, dislodging thermocouples after several cycles (Figure 15). Soldered attachments on the 1206 resistor and QFN pad also showed significant board damage and solder joint deterioration, with charring likely due to the no-clean flux experiencing multiple thermal excursions (Figure 16).

Temperature data from the 20 reflow cycles ranged from 241°C to 243°C (Figures 17a & 17b), with a dip at run 19 at the start of day two of testing. During run 3, a thermocouple detached

from its solder joint, causing a loss of data, but was reattached for subsequent runs. Soldering locations were limited to the 1206 resistor and QFN pad due to difficulties achieving consistent solder joint volume and quality.

Variations in thermal mass of the solder joint can impact the accuracy of temperature measurements since larger masses absorb and dissipate heat more slowly, leading to delayed thermal responses and less accurate time-temperature profiles.

DATA ANALYSIS: POLYIMIDE TAPE

Polyimide tape-maintained repeatability within the thermocouple tolerance limits of $\pm 1^\circ\text{C}$, though a dip occurred during run 18 at the start of day two (Figure 18a & 18b). Some tape lifting due to air pockets was observed, indicating that polyimide tape can deliver consistent readings if monitored for lifting between runs.

TC6, located between two BGA components, recorded lower temperatures compared to the other thermocouples on the board, yet maintained consistent readings throughout the test. This lower temperature is likely due to the higher thermal mass of the BGAs absorbing more heat.

Data Analysis: Aluminum Tape

Initial testing with aluminum tape, without polyimide tape framing, led to frequent tape lifting and detachment of thermocouples. Temperature data from thermocouples that detached due to tape lifting was removed from the graph. Once reattached with polyimide tape framing, consistent temperature readings within $\pm 1^\circ\text{C}$ of the tolerance limits were maintained, comparable to that achieved with high-temperature solder and polyimide tape (Figure 19a & 19b).

A major challenge was component lifting when the tape was attached to the top of components, resulting in components getting pulled off the pads during reflow. As solder reached its liquidus temperature, components like 1206 resistors detached, resulting in a complete loss of adhesion to the PCB (Figure 20).

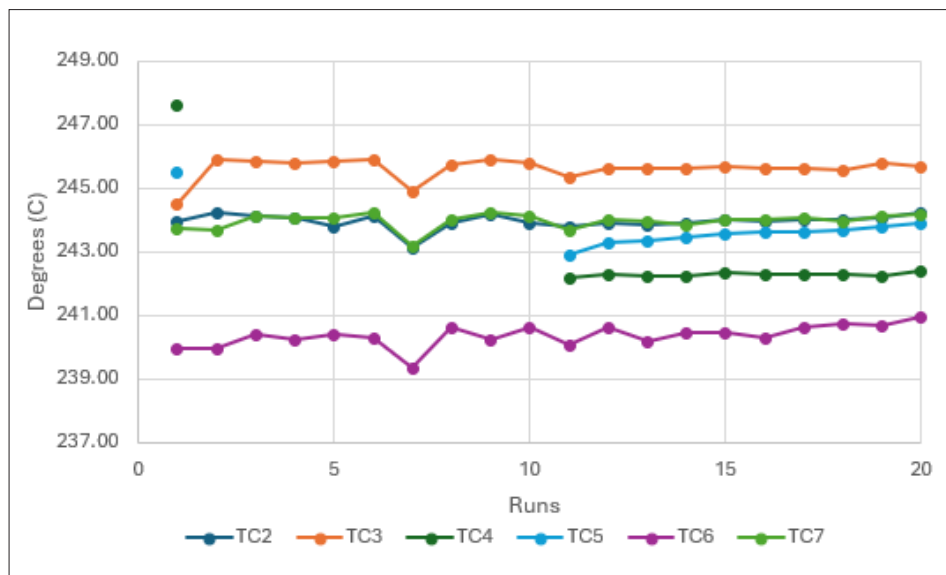
DATA ANALYSIS: THERMALLY CONDUCTIVE ADHESIVES

Prior to attaching thermocouples to board, alcohol wipes were used to clean the surface areas to ensure good adhesion.

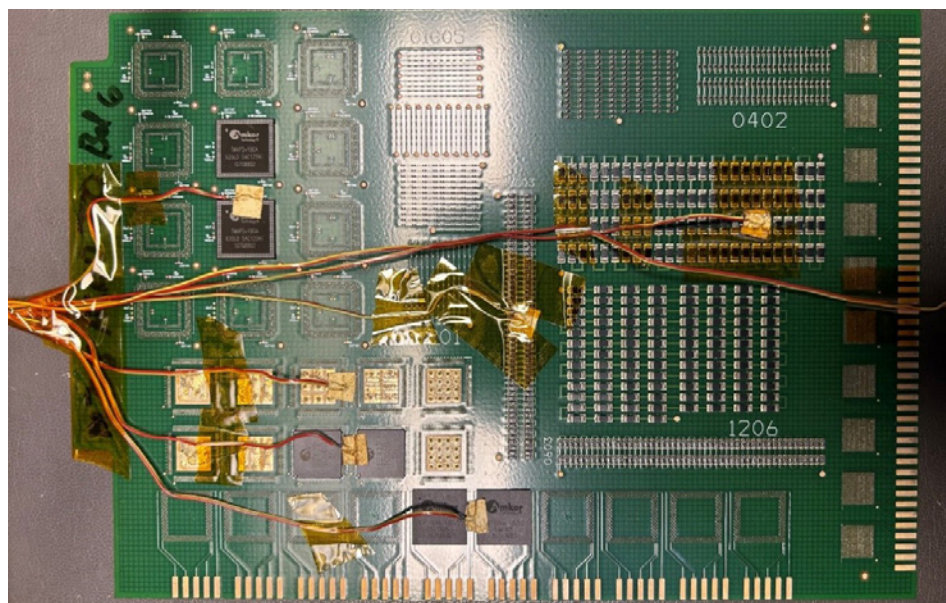
DYMAX 9505-TC UV CONDUCTIVE ADHESIVE (0.92W/MK)

Adhesives may struggle to bond with low surface-energy surfaces like solder masks.

In this test, DYMAX 9505-TC adhered well to metallized QFN and test pads but was incompatible with solder mask areas. When applied over components, similar to tape, it causes them to lift off the board during the liquidus stage of reflow. Figure 21 shows where some 1206 components were pulled off the board due to inadequate adhesion to the solder mask.



■ Figure 19a. Thermocouple Attachment Aluminum



■ Figure 19b. Thermocouple Attachment Aluminum

Therefore, use of this adhesive should be limited to metallized surfaces.

DYMAX 9008 UV CONDUCTIVE ADHESIVE (0.19W/MK)

DYMAX 9008 bonded well with the solder mask, making it well-suited for this application. However, its lower viscosity required additional coatings to ensure proper coverage of the thermocouple, as an inadequate adhesive layer could cause the thermocouple to detach. Early testing confirmed that

inadequate coating led to premature failures, with the thermocouple breaking away from the adhesive. This study showed that the adhesive my failure after one or two passes if the adhesive thickness is inadequate. Figures 22a & 22b show that DYMAX 9008 provided reliable and repeatable results across all 20 runs, with no detachments. Slightly lower temperatures were recorded on the first and 15th run, consistent with being the first run of the day, but overall, the

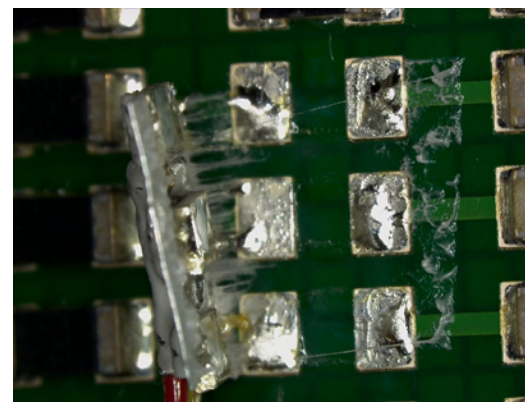
thermocouples attached with DYMAX 9008 remained within the $\pm 1^\circ\text{C}$ tolerance, demonstrating excellent reliability and repeatability.

DISCUSSION

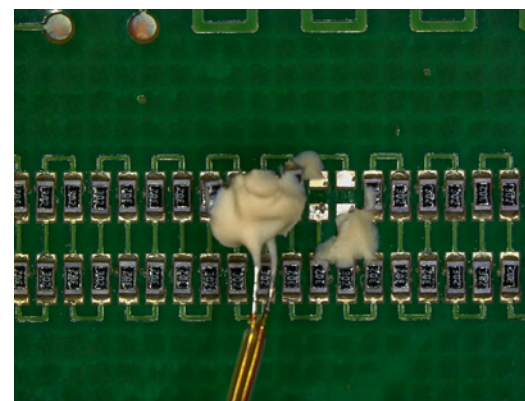
This study, conducted at Rochester Institute of Technology, evaluated five different thermocouple attachment methods under modern PCB assembly processes, including a lead-free reflow and high-density PCBs with SMT components. Key characteristics of each attachment method are summarized in the following table.

CONCLUSIONS

Thermally conductive adhesives can be highly effective, reliable, repeatable and accurate for attaching thermocouples to high-density circuit boards



■ Figure 20. Component Lifting with Tape.



■ Figure 21. Thermocouple Attachment DYMAX 9505-TC

with limited bare space. However, their performance depends on the adhesive's formulation, particularly its thermal

conductivity, viscosity and compatibility with solder masks.

Aluminum and polyimide tapes are unsuitable for securing thermocouples to high-density PCBs with components, as both types will lift components off the PCB during the solder liquidus phase of the reflow cycle. The scarcity of open spaces on HDI PCBs makes tape impractical in these situations.

Accuracy of solder attachments is influenced by the volume of solder used. Larger solder volumes increase the thermal mass at the measurement site, causing it to act as a heat sink during heating and as a heat source during cooling.

REFERENCES

- 1 A Comparison of Methods for Attaching Thermocouples to Printed Circuit Boards for Thermal Profiling. Conference proceedings February 23, 1999 Presented at Nepcon West 1999 By Cameron Sinohui, KIC <https://kicthermal.com/article-paper/261-a-comparison-of-methods-for-attaching-thermocouples-to-printed-circuit-boards-for-thermal-profiling-3/>
- 2 SMTA test board available for purchase at Shea Engineering chrys@sheaengineering.com
- 3 Dymax 9008 UV Adhesive
- 4 Dymax 9505 UV Adhesive

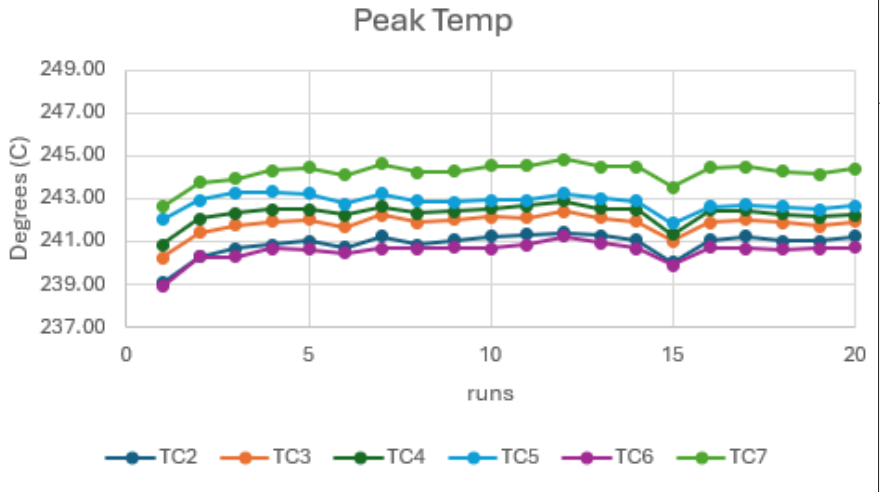


Figure 22a. Thermocouple Attachment Dymax 9008

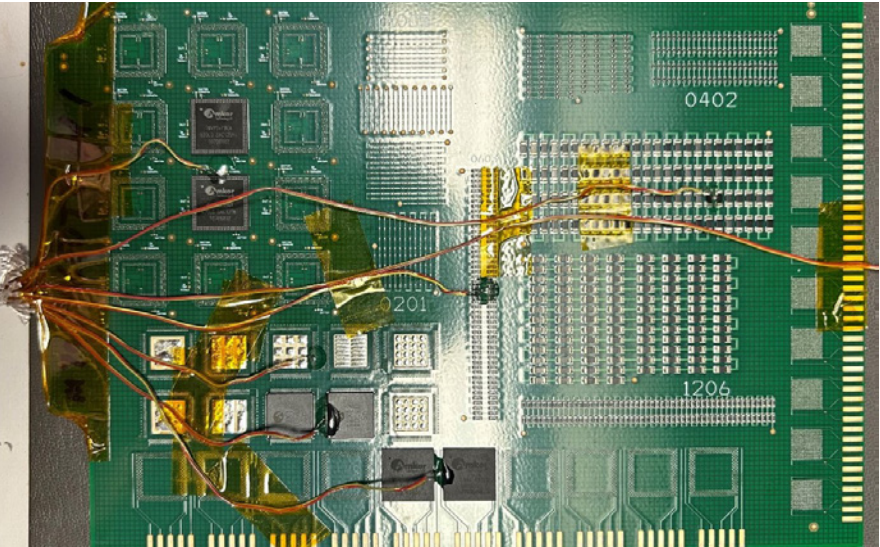


Figure 22b. Thermocouple Attachment Dymax 9008

Attachment Method	Advantages	Limitations
High-temperature, High-Lead Solder (Sn10/Pb88/Ag2)	Good Repeatability Effective on metallized pads without components	Restricted by environmental regulations due to lead content Requires skilled technician to control hand-soldering process; difficult to control solder volume Variations in solder volume affect accuracy; higher thermal mass causes slower heating/cooling Risk of damage to PCB and components; preheating mitigates risk but adds safety concerns Destructive process; difficult to remove without PCB damage
Polyimide tape	Good Repeatability Nondestructive; easy to apply and remove without PCB damage	Prone to air pocket formation; requires inspection Risk of component lifting when applied over components
Aluminum tape	Good Repeatability Nondestructive; easy to apply and remove without PCB damage	Requires polyimide tape framing for secure attachment at high reflow temperatures Risk of component lifting when applied over components
DYMAX 9505-TC UV Adhesive TC (0.92 W/mK)	Suitable for high-density PCBs when applied to metallized pads without components	Incompatible with solder mask Requires UV-curing with specialized equipment
DYMAX 9008 UV Adhesive (0.19 W/mK)	Excellent reliability, repeatability and accuracy Ideal for high-density PCBs with components Compatible with solder mask	Requires additional coatings for proper thermocouple coverage due to low viscosity Requires UV-curing with specialized equipment