A Comparison of Methods for Attaching Thermocouples to Printed Circuit Boards for Thermal Profiling

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Finding a Quick and Reliable Method for Attaching Thermocouples

As more PCB assemblers become aware of the value of regular process monitoring, the frequency of thermal profiling is increasing dramatically. High temperature solder is recognized in the SMT industry as the most reliable method of attaching thermocouples for thermal profiling. Unfortunately, high temperature soldering of thermocouples is extremely time consuming and usually damages the board profiled to the point that it must be scrapped. Alternatives to the conventional method of thermocouple attachment, especially those that do not require a sacrificial board, can lessen the "pain" associated with thermal profiling in terms of both labor and material costs. The inspiration for this experiment came from a visit to Solectron's new Everett WA plant. High temperature solder had always been our standard method of attaching thermocouple for thermal profiling, but at Solectron they were using aluminum tape. Solectron told us they had tested this method and determined it was repeatable and gave results similar to soldered TC's. We have been evaluating alternative methods of attaching TC's for several years, and have yet to find an inexpensive method we felt comfortable using or recommending to our customers. After our visit to Solectron, we initiated this experiment to determine if aluminum tape was a reasonable alternative to high temperature solder.

This paper will discuss the results of a thorough comparison of the various methods of attaching thermocouples to a printed circuit board for thermal profiling. The focus will be on non-destructive attachment methods and how well they compare to the standard method of attachment using high temperature solder. Several queries posted on Technet have convinced us that we have included the majority of methods currently being used in the SMT Industry.

The attachment methods compared are high temperature solder, Aluminum Tape, Kapton tape, and Conductive Epoxy. The repeatability of each attachment method will be analyzed, and comparisons will be made between the various attachment methods. Comparison criteria includes the variation of key profile statistics such as peak temperature, maximum rising slope, and time above reflow. Results will be compared to establish which methods offer: high repeatability, ease of use, and most closely replicate the results attained with high temperature solder.

High Temp Solder Attachment: Pro's and Cons

High Temperature Soldering is widely acknowledged as the most reliable method of attaching thermocouples to printed circuit boards. Done correctly, it is a permanent means of attaching TC's, and creates a "Golden Board" that can be used for between five and thirty profiles before the PCB material begins to deteriorate from thermal stress and a new "Golden Board" needs to be made up. High temperature soldering is time consuming, requires a special high temperature soldering iron, and some people find it difficult to get a good thermally conductive solder joint. Soldering and unsoldering the TC joint also has the potential to damage the board, and if the board is used for multiple runs, it will have to eventually be scrapped.

Descriptions of Alternative Methods

The alternative methods to be evaluated in this experiment are: Aluminum Tape, Kapton tape, and Conductive Epoxy.

Aluminum Tape: used in combination with Kapton tape provides a secure connection with good thermal conductivity. The Aluminum tape is cut with scissors to a size of approximately 1\8 X 1\8 inch and is used to secure the thermocouple to the PCB. The Aluminum taped connection is then overlaid with a ¼" piece of Kapton tape to prevent lifting.

Kapton Tape: is an electrical tape with good thermal conductivity. The Kapton tape is cut with scissors to a size of approximately 1/8 X 1/8 inch and is used to secure the thermocouple to the PCB.

Conductive Epoxy: We tested a popular adhesive system for wire tacking on a PCB. The system consists of two parts: instant adhesive and accelerator. The instant adhesive is dropped over the thermocouple junction, then the accelerator is sprayed over the adhesive. Within 5 seconds the wire is fixed in place.

Advantages of Alternative Methods

Aluminum Tape is also a simple method of attaching TC's to PCB's, however the Aluminum tape must be overlaid with Kapton to prevent lifting.

Kapton tape is a simple and inexpensive method of attaching TC's to PCB's.

Conductive Epoxy was the simplest method for attaching TC's. The cure time is only 5 seconds.

Design of Experiment

This experiment was designed to test various methods of thermocouple attachment to PCB's for thermal profiling and compare them against high temperature solder attachment.

Four identical printed circuit boards were used for testing. The boards were populated, material was FR4, and dimensions were 11.25" x 8.25". The first board was instrumented with 12 thermocouples, paired at precise locations on the board, and all connected by high temperature solder. From this board a realistic thermal relationship between each test point was established. The other three test PCB's were instrumented with 6 thermocouples attached using high temperature solder and 6 thermocouples attached using one of the three alternative attachment methods. All boards utilized identical test points, with odd numbered thermal couples being soldered and even numbered thermocouples being alternative methods. (See Figure1) Each test PCB was run through a Research Thermoflow 6 six zone forced convection oven five times, for a total of 20 thermal profiles.

Reliability data on each method was collected as the profiles were run. When the 20 profiles were completed, the statistical data consisting of: Peak temperature, Maximum rising slope, and Total time above 183°C, was extracted and pasted into MS Excel. Using MS Excel, the statistical differences were then calculated, charted, and evaluated.

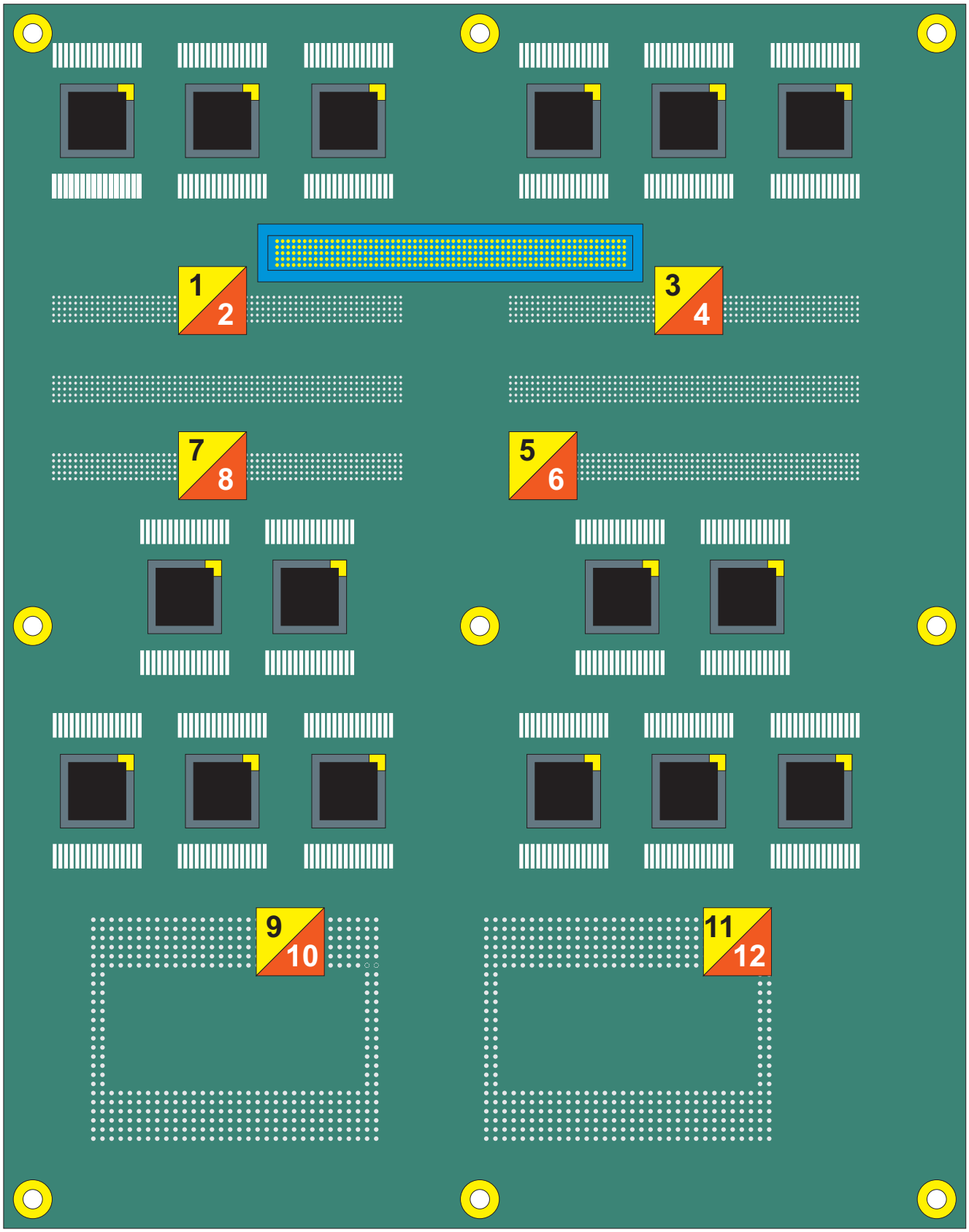
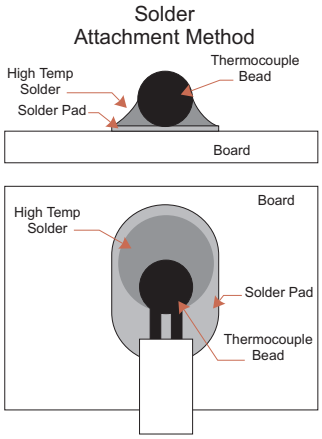


Figure 1 Attachment Points for TC's on Test Boards

Results of the Experiment

PCB #1 (Soldered)



This test board consists of 12 type K thermocouples attached using high temperature solder. The thermocouples are arranged in pairs and each pair is positioned to read the same temperatures. This pairing of thermocouples will measure the repeatability of the temperature measurements from the soldered thermocouples. The three test boards following this one measure how alternative attachment methods compare to high temperature solder.

After the 12 thermocouples have been attached to PCB # 1, the board will then be tested by running 5 thermal profiles. Using data from the 5 thermal profiles the following statistical information will be extracted: Peak temperature, Maximum rising slope, and Total time above 183°C. The statistical data will then be compared.

PCB # 1 (Soldered) Reliability

Profile 1. All thermocouples stayed connected to test board. No repairs necessary.

Profile 2. All thermocouples stayed connected to test board. No repairs necessary.

Profile 3. All thermocouples stayed connected to test board. No repairs necessary.

Profile 4. All thermocouples stayed connected to test board. No repairs necessary.

Profile 5. All thermocouples stayed connected to test board. No repairs necessary.

High Temperature Solder

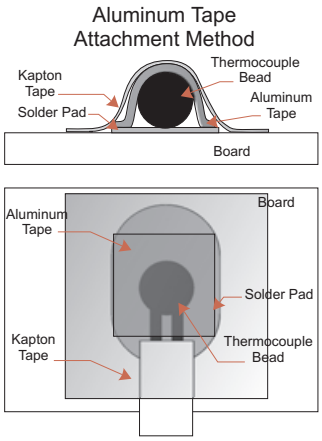
During all 5 profiles, all 12 thermocouples stayed connected to the test board. No repairs were necessary.

Peak temperatures proved to be within an average of 1.8° Celsius, total time above 183° Celsius proved to be within an average of 1.02 seconds of each other, and maximum rising slope within an average of 0.53° Celsius/second.

			Run #1	Run #2	Run #3	Run #4	Run #5		Average	Range	Std Dev
Attached with Solder (compared for control data)	Peak Temperature	Control TC	226.0	226.0	225.7	225.8	225.7		225.84	0.30	0.14
		Soldered TC	227.9	227.7	227.4	227.6	227.6		227.64	0.50	0.16
		Δ	**1.9**	**1.7**	**1.7**	**1.8**	**1.9**	→	**1.80**	**0.20**	**0.09**
	Time Above 183°C	Control TC	123.8	116.1	124.0	116.6	123.2		120.74	7.90	3.60
		Soldered TC	124.7	117.0	125.1	117.5	124.6		121.76	8.11	3.71
		Δ	**0.8**	**0.9**	**1.1**	**0.9**	**1.4**	→	**1.02**	**0.57**	**0.22**
	Slope (°C/sec)	Control TC	2.93	3.01	3.06	2.97	2.63		2.92	0.43	0.15
		Soldered TC	3.50	3.38	3.51	2.56	3.49		3.29	0.95	0.37
		Δ	**0.57**	**0.37**	**0.45**	**0.41**	**0.86**	→	**0.53**	**0.49**	**0.18**

These values will be used as a baseline for comparison of each attachment method. Each attachment method will be compared via statistical value, repeatability, and solidity.

PCB #2 (Soldered vs. AL Tape)



This test board consists of six pairs of type K thermocouples. The first thermocouple of each pair is attached using high temperature solder, and the second is attached using Chomerics T405 Aluminum tape.

The six pairs thermocouples were attached to the PCB in pre-determined locations that should see identical temperatures during the reflow process. After the 12 thermocouples have been attached to PCB # 2, the board will be tested by running 5 thermal profiles. Using data from the 5 thermal profiles the following statistical information will be extracted: Peak temperature, Maximum rising slope, and Total time above 183°C. The statistical data will then be compared.

PCB # 2 (Soldered/AL tape) Reliability

Profile 1. Thermocouple # 10(AL tape), slightly lifted. Necessary repairs made.

Profile 2. Thermocouple # 8(AL tape), slightly lifted. Necessary repairs made.

Profile 3. Thermocouple # 8, & # 10(both AL tape), slightly lifted. Necessary repairs made.

Profile 4. All thermocouples stayed connected to test board. No repairs necessary.

Profile 5. Thermocouple # 10(AL tape), slightly lifted. No repairs necessary.

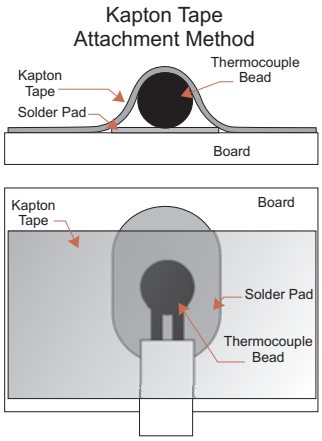
Aluminum Tape

The Aluminum tape is easy to apply and removal is easy as well. The Aluminum tape is non destructive and leaves no scars or residuals.

Peak temperatures proved to be within an average of 3.10° Celsius, total time above 183° Celsius proved to be within an average of 4.38 seconds of each other, and maximum rising slope within an average of 0.40° Celsius/second.

			Run #1	Run #2	Run #3	Run #4	Run #5		Average	Range	Std Dev
Attached with Aluminum Tape	Peak Temperature	Control TC	226.0	226.7	226.7	226.7	228.4		226.90	2.40	0.80
		Alum TC	223.2	223.8	230.1	223.5	231.6		226.44	8.40	3.64
		Δ	**2.8**	**2.9**	**3.4**	**3.2**	**3.2**	→	**3.10**	**0.60**	**0.22**
	Time Above 183°C	Control TC	113.3	109.7	119.1	106.3	118.0		113.29	12.89	4.88
		Alum TC	108.9	113.7	122.9	111.8	122.3		115.90	13.99	5.67
		Δ	**4.4**	**3.9**	**3.7**	**5.5**	**4.3**	→	**4.38**	**1.78**	**0.62**
	Slope (°C/sec)	Control TC	2.50	2.44	2.49	2.53	2.44		2.48	0.09	0.04
		Alum TC	2.82	2.90	2.88	2.97	2.81		2.88	0.16	0.06
		Δ	**0.32**	**0.46**	**0.39**	**0.44**	**0.37**	→	**0.40**	**0.14**	**0.05**

PCB #3 (Soldered vs. Kapton)



This test board consists of six pairs type K thermocouples. The first thermocouple of each pair is attached using high temperature solder, and the second is attached using Kapton tape.

The six pairs thermocouples were attached to the PCB in pre-determined locations that should see identical temperatures during the reflow process. After the 12 thermocouples have been attached to PCB # 2, the board will be tested by running 5 thermal profiles. Using data from the 5 thermal profiles the following statistical information will be extracted: Peak temperature, Maximum rising slope, and Total time above 183°C. The statistical data will then be compared.

PCB # 3 (soldered vs. Kapton) Reliability

Profile 1. All taped thermocouples had slight lift. All taped thermocouples repressed.

Profile 2. All taped thermocouples had slight lift. All taped thermocouples repressed. #12 tape replaced.

Profile 3. All taped thermocouples had slight lift. All taped thermocouples repressed.

Profile 4. All taped thermocouples had slight lift. All taped thermocouples repressed.

Profile 5. All taped thermocouples had slight lift.

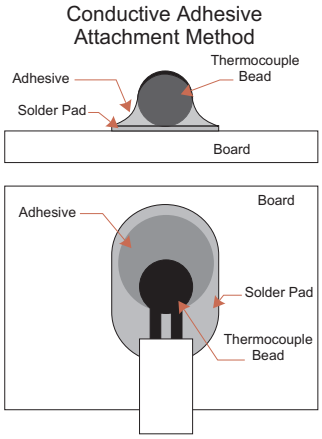
Kapton Tape

The Kapton tape is easy to apply. At lower temperatures Kapton may hold better, however at normal reflow temperatures the tape slightly lifted during each profile.

Peak temperatures proved to be within an average of 4.62° Celsius, total time above 183° Celsius proved to be within an average of 4.47 seconds of each other, and maximum rising slope within an average of 5.66° Celsius/second.

			Run #1	Run #2	Run #3	Run #4	Run #5		Average	Range	Std Dev
Attached with Kapton Tape	Peak Temperature	Control TC	222.1	228.8	228.6	221.7	228.3		225.90	7.10	3.27
		Kapton TC	224.7	231.6	231.2	233.2	231.9		230.52	8.50	2.99
		Δ	**2.6**	**2.8**	**2.6**	**11.5**	**3.6**	→	**4.62**	**8.90**	**3.46**
	Time Above 183°C	Control TC	120.3	117.5	111.4	119.4	119.9		117.69	8.83	3.28
		Kapton TC	124.0	121.4	118.5	123.1	123.8		122.16	5.49	2.05
		Δ	**3.7**	**3.9**	**7.1**	**3.8**	**3.9**	→	**4.47**	**3.34**	**1.30**
	Slope (°C/sec)	Control TC	3.11	3.00	2.57	3.09	2.62		2.88	0.54	0.23
		Kapton TC	3.60	3.48	2.92	3.43	2.88		3.26	0.72	0.30
		Δ	**0.49**	**0.48**	**0.35**	**0.34**	**0.26**	→	**0.38**	**0.23**	**0.09**

PCB #4 (Soldered vs. Conductive Epoxy)



This test board consists of six pairs of type K thermocouples. The first thermocouple of each pair is attached using high temperature solder, and the second is attached using Loctite, Tak Pak 382 Adhesive.

The six pairs thermocouples were attached to the PCB in pre-determined locations that should see identical temperatures during the reflow process. After the 12 thermocouples have been attached to PCB # 2, the board will be tested by running 5 thermal profiles. Using data from the 5 thermal profiles the following statistical information will be extracted: Peak temperature, Maximum rising slope, and Total time above 183°C. The statistical data will then be compared.

PCB # 4(Soldered vs. Conductive Epoxy) Reliability

Profile 1. All thermocouple attached using Loctite adhesive are very brittle. All junctions replaced.

Profile 2. Thermocouples 6, 10, and 12 all had slight lift. Replace junctions for #'s 6,10, and 12.

Profile 3. All thermocouple attached using Loctite adhesive are very brittle. All junctions replaced.

Profile 4. Thermocouples 8, 10, and 12 had slight lift. Each junction replaced.

Profile 5. Thermocouple #10 completely unattached from PCB.

Conductive Epoxy

Conductive Epoxy is very easy to work with. This Adhesive sets in 5 seconds. I noticed that the adhesive became very brittle after only one profile. I had to reattach the thermocouples after each profile. The conductive epoxy removes easily after it has been exposed to the reflow cycle. The manufacturer suggests a specific solvent for removing the Conductive Epoxy, but it was not available for this test.

Peak temperatures proved to be within an average of 4.74° Celsius, total time above 183° Celsius proved to be within an average of 8.04 seconds of each other, and maximum rising slope within an average of 0.91° Celsius/second.

			Run #1	Run #2	Run #3	Run #4	Run #5		Average	Range	Std Dev
Attached with Conductive Epoxy	Peak Temperature	Control TC	229.0	224.7	224.9	229.0	228.7		227.26	4.30	2.01
		Epoxy TC	227.2	229.8	229.2	230.7	239.5		231.28	12.30	4.27
		Δ	**1.8**	**5.1**	**4.3**	**1.7**	**10.8**	→	**4.74**	**9.10**	**3.31**
	Time Above 183°C	Control TC	113.7	113.8	118.9	116.3	114.7		115.47	5.18	1.95
		Epoxy TC	99.5	106.5	124.2	121.1	106.1		111.49	24.70	9.51
		Δ	**14.2**	**7.3**	**5.3**	**4.9**	**8.6**	→	**8.04**	**9.39**	**3.38**
	Slope (°C/sec)	Control TC	2.92	2.83	2.86	3.09	2.73		2.89	0.36	0.12
		Epoxy TC	3.31	4.48	4.01	3.83	3.37		3.80	1.17	0.43
		Δ	**0.39**	**1.65**	**1.15**	**0.74**	**0.64**	→	**0.91**	**1.26**	**0.44**

Reliability of Alternative Methods

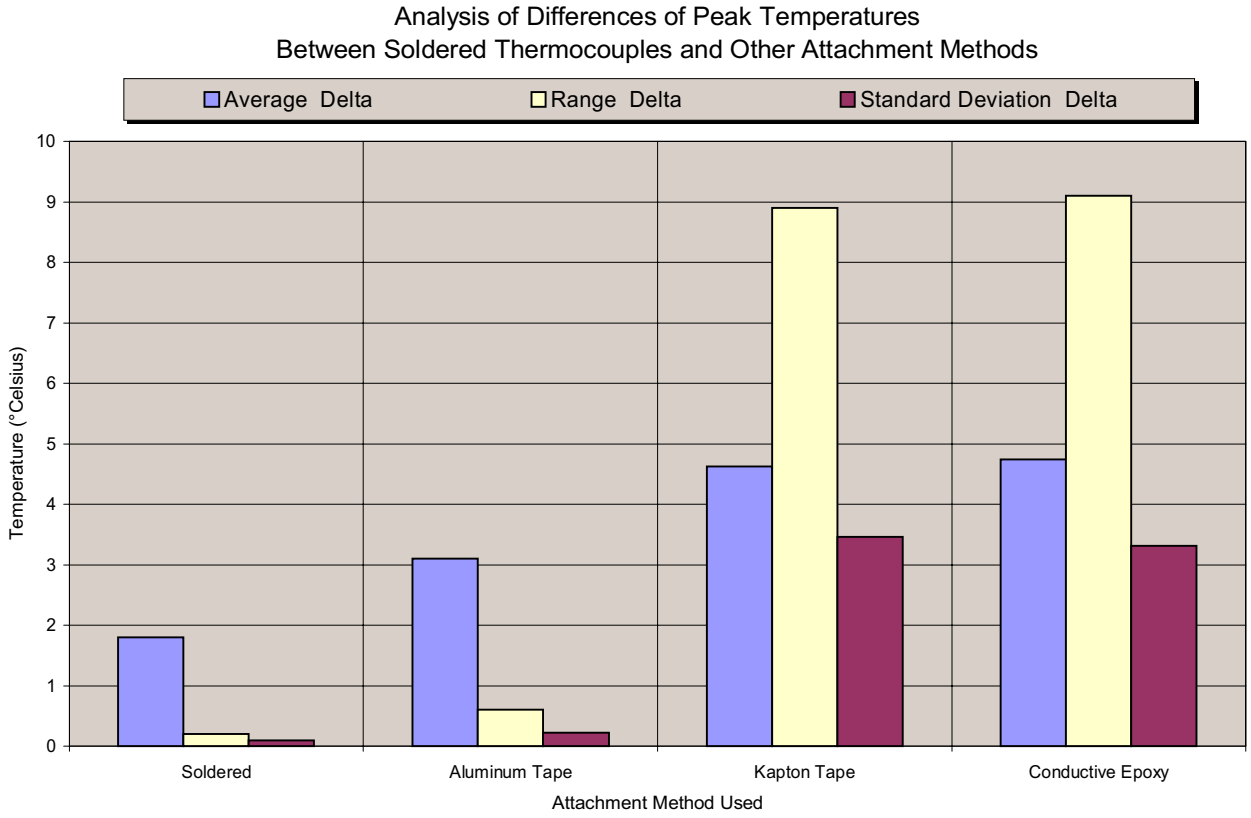
Aluminum Tape, when used with Kapton tape, is simple, effective, and reliable. There was slight lifting of a few TC's during the profile, but the profile results indicate that the effect of this on overall profile accuracy was minor. Aluminum Tape is a completely nondestructive.

Kapton tape is the simplest and least expensive method of attaching TC's to PCB's. It is also the least reliable. The fact that all TC's attached with Kapton tape lifted during profiling indicates that this is not a reliable method of attaching thermocouples.

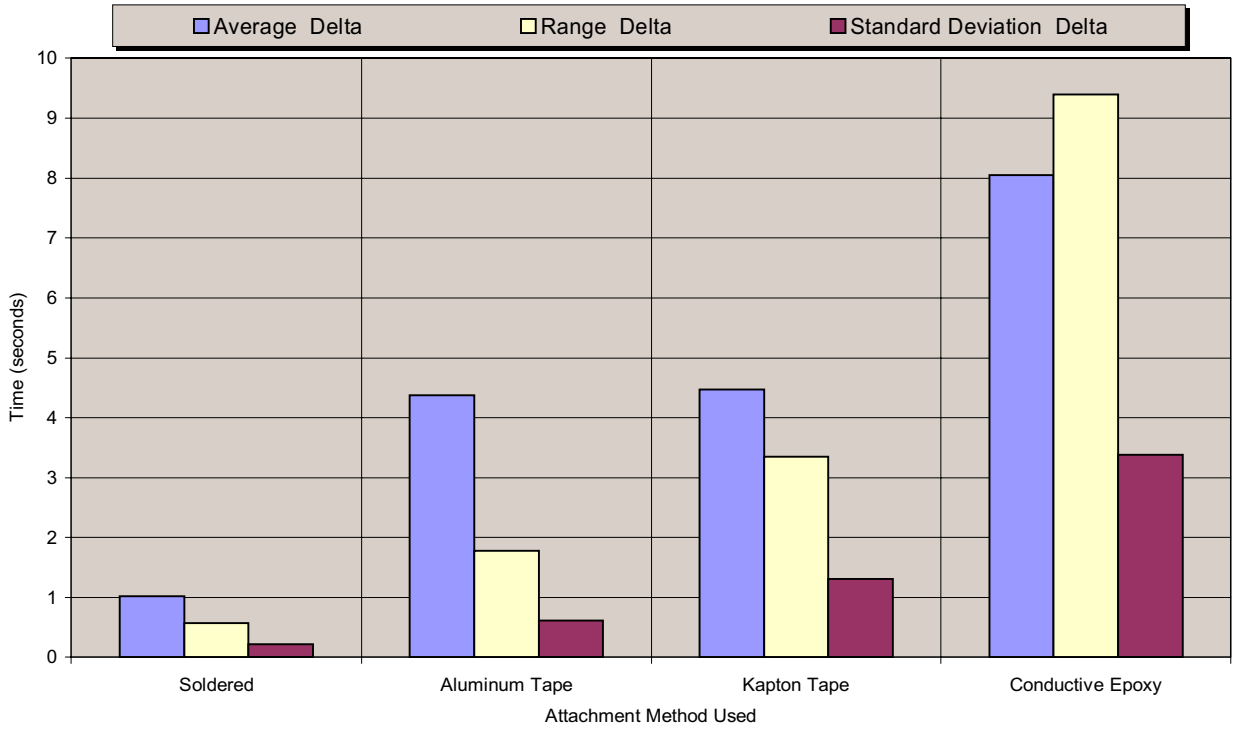
Conductive Epoxy is a quick, simple, and relatively inexpensive way of attaching TC's. It works in tight locations where tape cannot be used, but breaks down after a single profiling run.

Accuracy of Alternative Methods

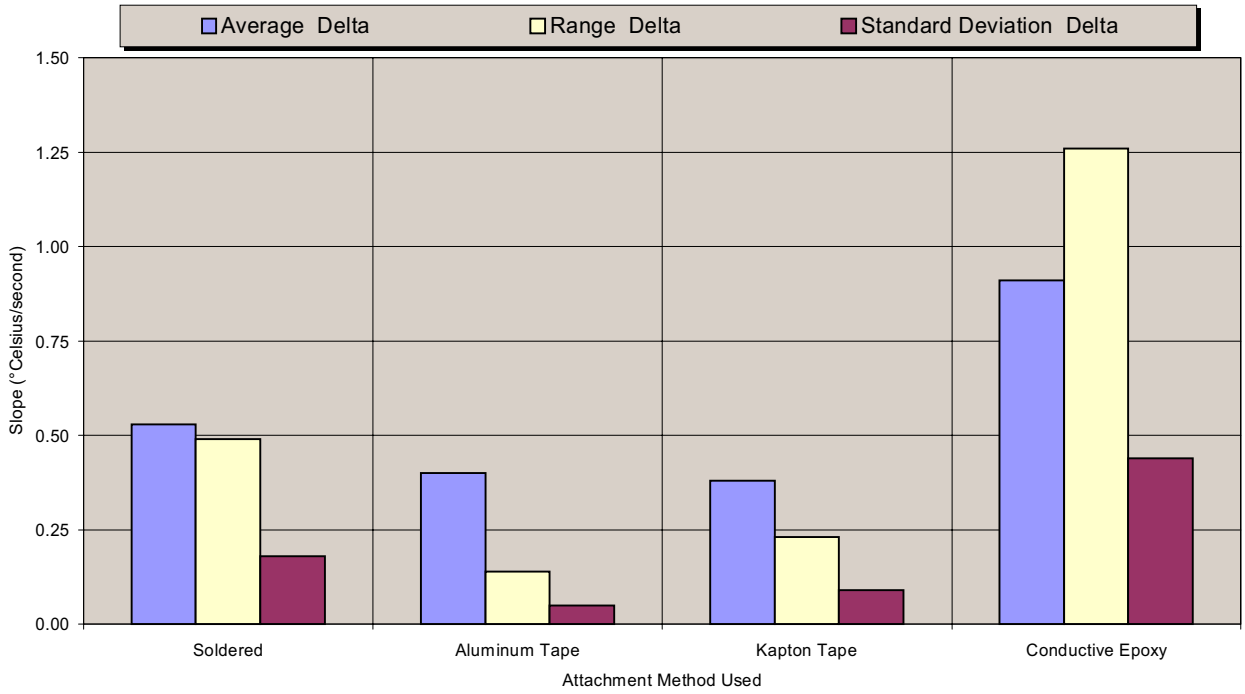
The graphs below represent the statistical results of the experiment and compare the tested methods of attaching thermocouples.



Analysis of Differences at Times Above 183°C
Between Soldered Thermocouples and Other Attachment Methods



Analysis of Differences of Maximum Rising Slopes (°C/sec)
Between Soldered Thermocouples and Other Attachment Methods
(max rising slope = largest temperature change in a 10 second period)



Statistics were compiled from the data files recorded on each of the 20 profiling runs. The data was pasted into an Excel spreadsheet and the resulting Deltas calculated in the Excel spreadsheet. Average, Standard Deviation, and Range Deltas were calculated for each method of attaching thermocouples. The lower the calculated Deltas, the more repeatable the method of thermocouple attachment is.

High temperature solder was found to be the most reliable and repeatable method of attaching thermocouples to PCB's.

Aluminum tape provides a reliable alternative to high temperature solder, though it is slightly less repeatable.

Kapton tape is not reliable or repeatable.

Conductive epoxy is reliable for a single profiling run, but offers poor repeatability Its thermal conductivity is very inconsistent, and the results of these profiles do not seem accurate or reliable.

Conclusion

It was found that of the three alternative methods for attaching thermocouples to PCB's, none are as repeatable as high temperature solder. This was not a surprise.

What was a pleasant surprise was the reliability and repeatability of aluminum tape. Aluminum tapes offers users of pass-through profilers a simple, inexpensive, and nondestructive method of attaching thermocouples to PCBs for thermal profiling. Using Aluminum tape reduces the amount of effort and expense required to obtain a accurate thermal profile, and this is a step forward in terms of both quality control and yield for SMT manufacturers.