

Thermal Profiling of Electronic Assemblies

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ABSTRACT

With the advent of lead-free soldering there is a greater need for thermal profiling of electronic assemblies during soldering, so that the more stringent requirements, of achieving reflow while not exceeding the specified maximum temperature of components, can be met. The requirement for greater precision has required that all aspects of profiling have been investigated and the impact on the measurement certainty assessed.

From these experiments a number of important recommendations are made and constitute an industry Code of Practice. Issues covered include: thermocouple and equipment choice; thermocouple attachment; reflow oven design; thermocouple logger position; initial profiling and setting up.

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Head, Materials Centre

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1 INTRODUCTION

The electronics industry world-wide has begun the move to eliminate lead from its manufacturing processes. Driven by impending European legislation and by consumer preferences for environmentally friendly products, the industry has already made great strides towards finding alternative alloys for solder (SnPb) and for Pb-containing printed circuit boards finishes. However, the increased wave and reflow soldering temperatures associated with these new alloys mean a narrowing of soldering process windows, with many components now being subjected to temperatures close to or in excess of their designed maximum. Because of this situation, process engineers are redefining their requirements for the monitoring and set-up of soldering profiles and the accuracy of measuring solder joint and component temperatures during soldering.

In determining the thermal profile of an assembly during soldering, the electronics process engineer is trying to strike a careful balance between a number of conflicting requirements of the materials in the process. The manufacturer of his solder paste wants a carefully controlled ramp and preheat to prevent solder balling and to activate the flux, but not excessive enough to cause flux activity to be wasted too early. He also wants peak temperature to be as high as possible to aid wetting. The component manufacturer requires the lowest peak temperature possible to prevent component damage but would still like the profile to be hot enough, and for long enough, to get good solder joint formation with aged components. The PCB supplier also wants a slow ramp up, to help prevent multilayer delamination, and low peak temperatures to prevent board damage. All of these factors become more critical with the higher temperatures of lead-free soldering.

With such a tightrope to walk, it is imperative that the engineer is able to measure assembly temperatures accurately during the soldering process. This is increasingly the case, as lead-free soldering is beginning to be introduced in the industry with its accompanying higher melting point solders. Since the maximum soldering temperatures for components are often fixed, and the minimum temperature that the solder joints have to reach has been increased to a few degrees above the new alloy melting point, the target window is reduced in size. Hence the assembly requires more careful profiling.

This report covers an investigation into a number of aspects of measuring the thermal profiles of electronic assemblies. The normal method of measuring solder joint temperatures is to attach thermocouples to solder joints and record the temperatures reached on a data logger that travels through the oven. These data logger systems have thermal protection, normally in the form of a thermal jacket to prevent the solder joints inside the logger from melting. The data are then downloaded to a PC and analysed with specialist software.

The four main suppliers of data logging equipment have supported this project, which covers materials for attaching thermocouples, attachment method, attachment position and guidelines for using data loggers. Systems for checking oven repeatability are also investigated. These areas are dealt with in the following Sections of the report.

2 AMOUNT OF MATERIAL REQUIRED TO ATTACH THERMOCOUPLES RELIABLY

2.1 EXPERIMENTAL PROCEDURE

Prior to investigating different materials for thermocouple attachment, a short investigation was undertaken to determine the amount of attachment material required for the subsequent work.

For this initial evaluation a SOIC test assembly was chosen as shown in Figure 1. This was a simple single-sided assembly incorporating 25 SOIC14 components on a 1.6mm thick single-sided PCB. The assembly measured approximately 76 x 78mm. Trials were conducted to ascertain four parts of the assembly that reached similar temperatures during a typical lead-free soldering profile. These four positions are as shown in Figure 1.

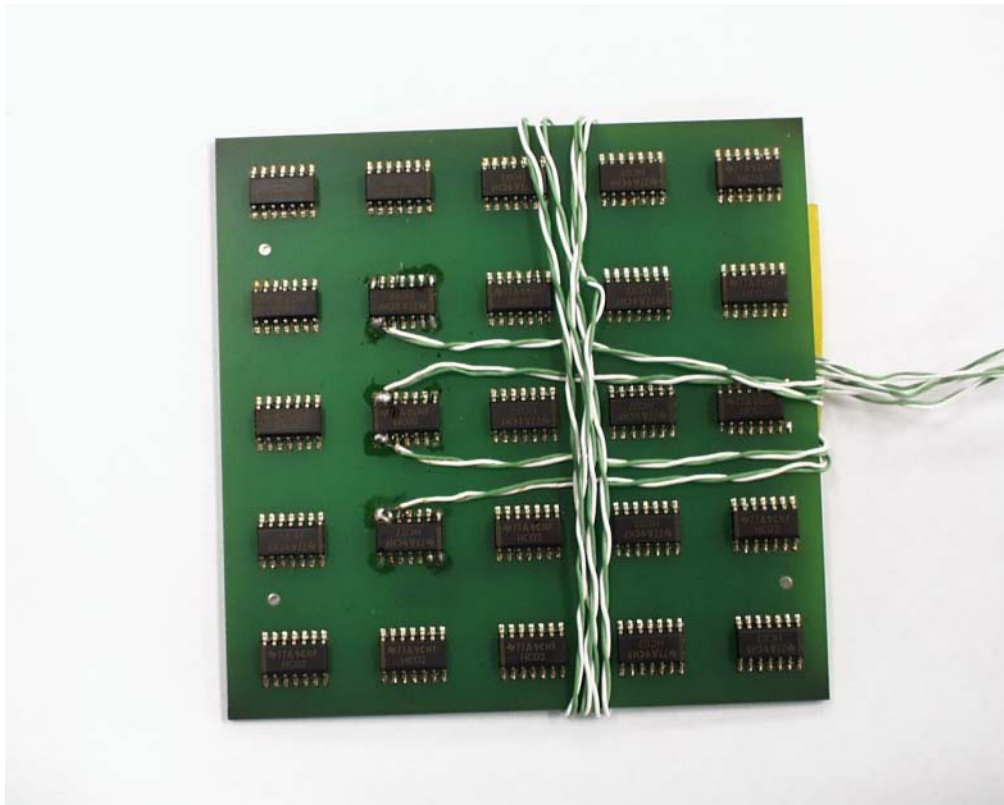


Figure 1: Test assembly showing thermocouple attachment positions.

The assembly, with thermocouples attached using high temperature solder, was connected to a travelling data logger, and was profiled three times through a typical lead-free reflow process, to check profile stability and position temperatures. Similar assemblies using aluminium tape, polyimide tape, wave soldering adhesive, and thermally conductive adhesive were also profiled twice each. Different sizes of attachment adhesive and tapes were used to determine if this had an effect on the temperatures obtained or the durability of the attachment method.

2.2 RESULTS

Results for the profiling runs are given in Table 1.

Table 1: Measured temperatures using different methods of thermocouple attachment

Thermocouple Position	Run	TC 1	TC 2	TC 3	TC 4	Average
High Temp. Solder	1	242.5	242	243	244	242.9
	2	244	243.5	244	244.5	244
	3	243.5	243	244	243	243.4
Bead size		2mm	4mm	6mm	8mm	Average
Thermal Adhesive	1	242.5	237	236	239.5	238.8
	2	242	237	236	240	238.8
Bead size		1.5mm	2.5mm	4mm	6mm	Average
Wave Adhesive	1	243.5	241.5	241.5	243.5	242.5
	2	242.5	241.5	241.5	243.5	242.3
Tape size		10x10mm	5x5mm	5x10 parallel to package	5x10 perpen. to package	Average
Polyimide Tape	1	244	292.5	244	246.5	256.8
	2	243.5	270.5	241	245	250
Aluminium Tape	1	249.5	247	248	249.5	248.5
	2	249	247.5	248.5	250.5	248.9

2.3 DISCUSSION

Figure 2 shows the results from the 3 runs using high temperature solder to attach the thermocouples. During set-up trials, problems were encountered with the melting point of the high temperature solder being lowered by contamination with the tin/lead solder. This resulted in thermocouples becoming detached during the profiling run. To overcome this problem, as much as possible of the tin/lead solder was removed before thermocouple attachment and a 296°C melting point alloy (93.5% lead, 5% tin, 1.5% silver) was used.

From Figure 2 it can be seen that attachment with high temperature solder gave repeatable results over the 3 runs with good agreement in temperature between the four thermocouple positions.

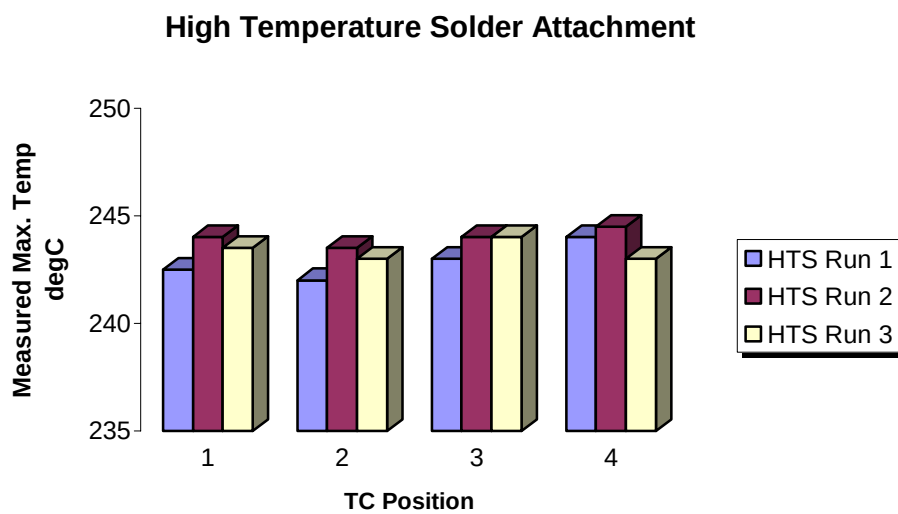


Figure 2: Measured maximum temperatures for high temp. solder attachment

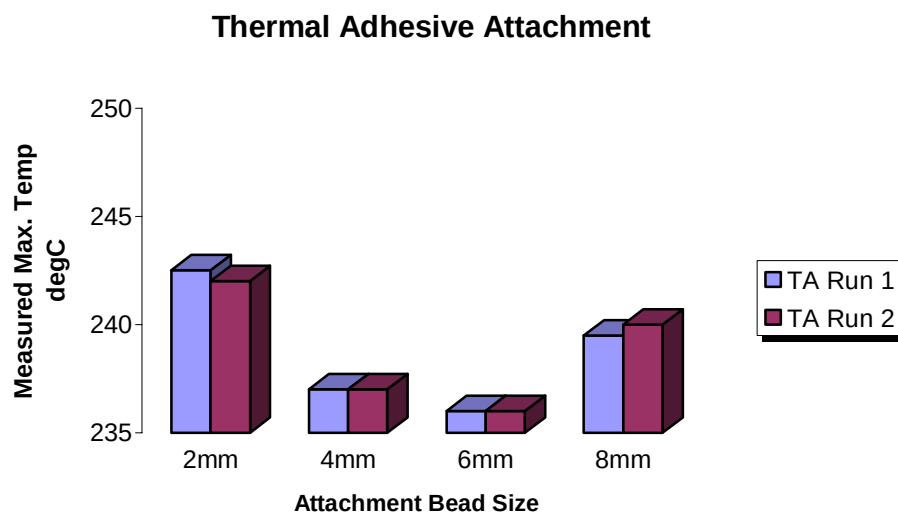


Figure 3: Measured maximum temperatures for thermal adhesive attachment

Figure 3 shows the results for the different bead sizes of thermal adhesive. The temperatures measured were generally lower than for high temperature solder, with the 2mm and 8mm beads giving higher measured temperatures than the 4 and 6 mm beads. All bead sizes showed good run-to-run repeatability. A 2mm bead was felt not to be sufficiently robust so a 4mm bead size was chosen for subsequent work.

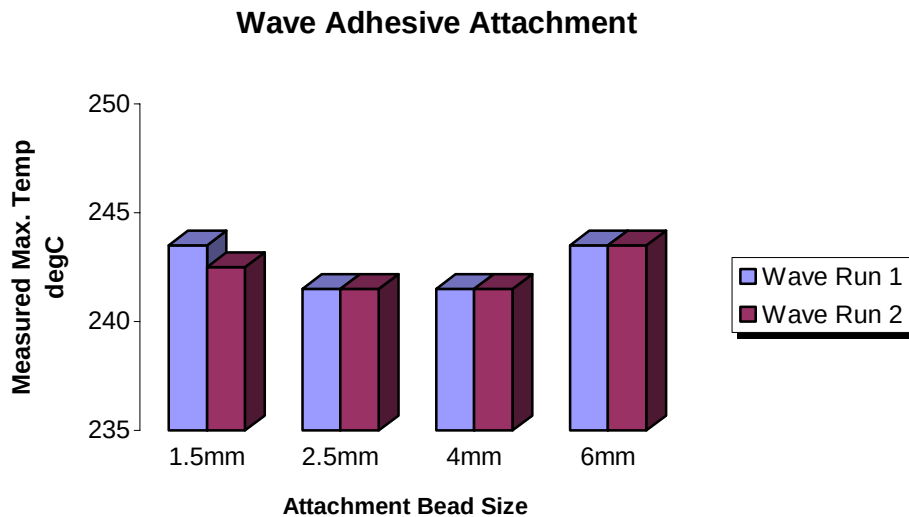


Figure 4 : Measured maximum temperatures for wave adhesive attachment

Figure 4 presents the results for the different bead sizes of wave soldering adhesive. This attachment method showed good run-to-run repeatability with little difference noticeable between the bead sizes. Again a 1.5mm bead was felt to be too weak so a 2.5 mm bead was chosen for subsequent work.

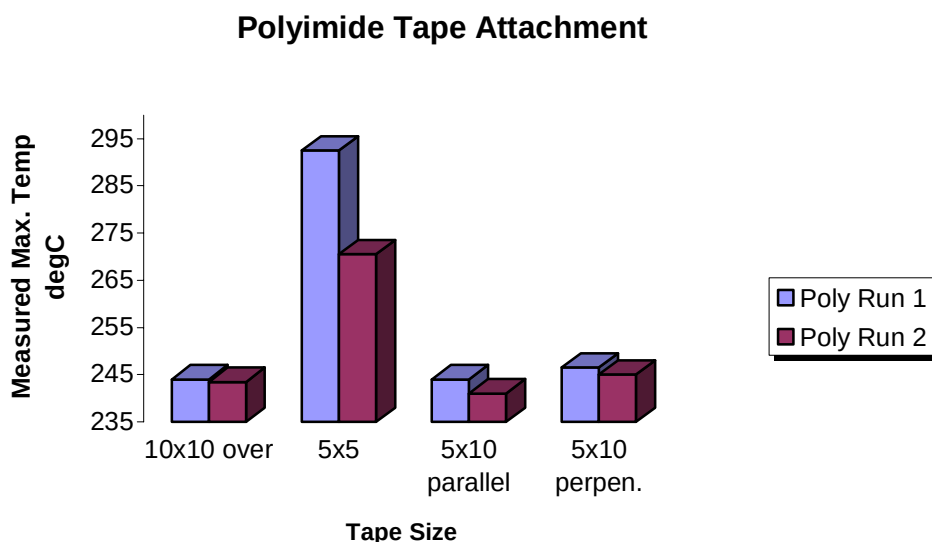


Figure 5 : Measured maximum temperatures for polyimide tape attachment

The results for the different sizes of polyimide tape are presented in Figure 5. The 5x10 mm tape was aligned on two axes, parallel and perpendicular to the body of the component. The high temperatures measured by the 5 x 5 mm tape sample were due to the thermocouple becoming detached and measuring air temperatures rather than joint temperatures. The other tape sizes showed little differences and a 10 x 10 mm tape size was chosen for subsequent work to give maximum area for tape adhesion.

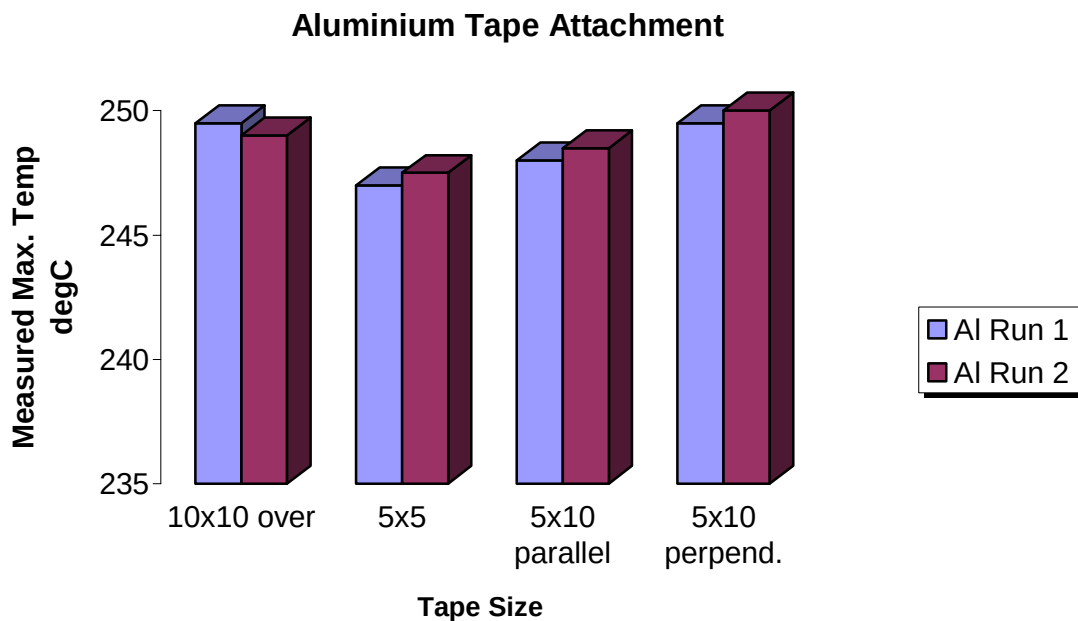


Figure 6: Measured maximum temperatures for aluminium tape attachment

Figure 6 shows the results for the different sizes of aluminium tape. The temperatures recorded were generally higher than for high temperature solder, with the larger tape sizes perhaps showing slightly higher temperatures. For ease of attachment and comparison with polyimide tape, a 10 x 10 mm tape size was chosen for subsequent work.

3 COMPARISON OF THERMOCOUPLE ATTACHMENT METHODS

This Section describes the work undertaken to investigate if different thermocouple attachment methods affect the temperatures measured, and the ability of the attachment methods to withstand multiple passes through a reflow oven.

3.1 EXPERIMENTAL PROCEDURE

The Roke Manor test assembly is shown in Figure 7 with the thermocouple attachment positions marked. This assembly was approximately 100 x 50 mm and the PCB was approximately 1.6mm thick. Its application is as a digital tuner. The assembly contained a range of surface mount devices, 0603 passives and IC packages including a 176 I/O 0.5mm pitch QFP.

Thermocouples were attached to six identical assemblies using five different attachment methods. These six assemblies were designated by the attachment method:

HTS A : High temperature solder (93.5% lead, 5% tin, 1.5% silver melting at 296°C)

HTS B : High temperature solder (93.5% lead, 5% tin, 1.5% silver melting at 296°C)

WAVE : Wave soldering adhesive (2.5mm bead)

THERMAL : Thermal adhesive (4mm bead of 2-part adhesive)

ALUMINIUM : Aluminium tape (10 x 10 mm tape size)

POLYIMIDE : Polyimide tape (10mm x 10mm tape size)

The thermocouples were connected to a data recorder that travelled through the oven behind the assembly, which measured the temperature excursion experienced by each thermocouple used in the comparison. The thermocouple positions are shown in Figure 7 and detailed in Table 2.

Table 2 : Thermocouple positions

Thermocouple	Position
1	Data logger case (to ensure that instrument did not overheat)
2	Tantalum component
3	SOT223
4	Quad flat pack
5	0603 capacitor
6	Small outline IC

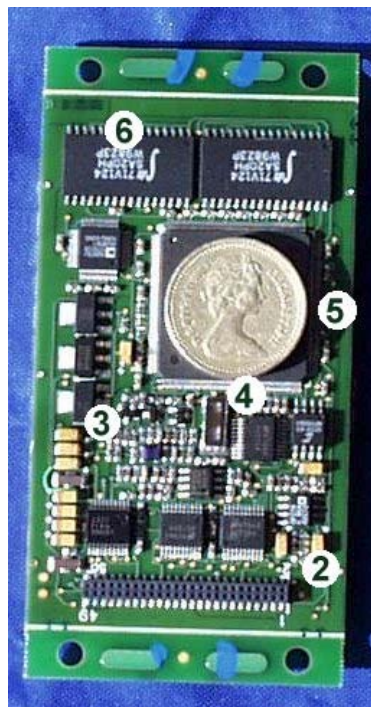


Figure 7: Test assembly with thermocouple positions marked

The oven used was a BTU Paragon 5 zone convection reflow system. Figure 8 shows the profile used with peak reflow temperatures of around 235 to 240°C, depending on the component type. Each assembly was profiled five times through the same profile.

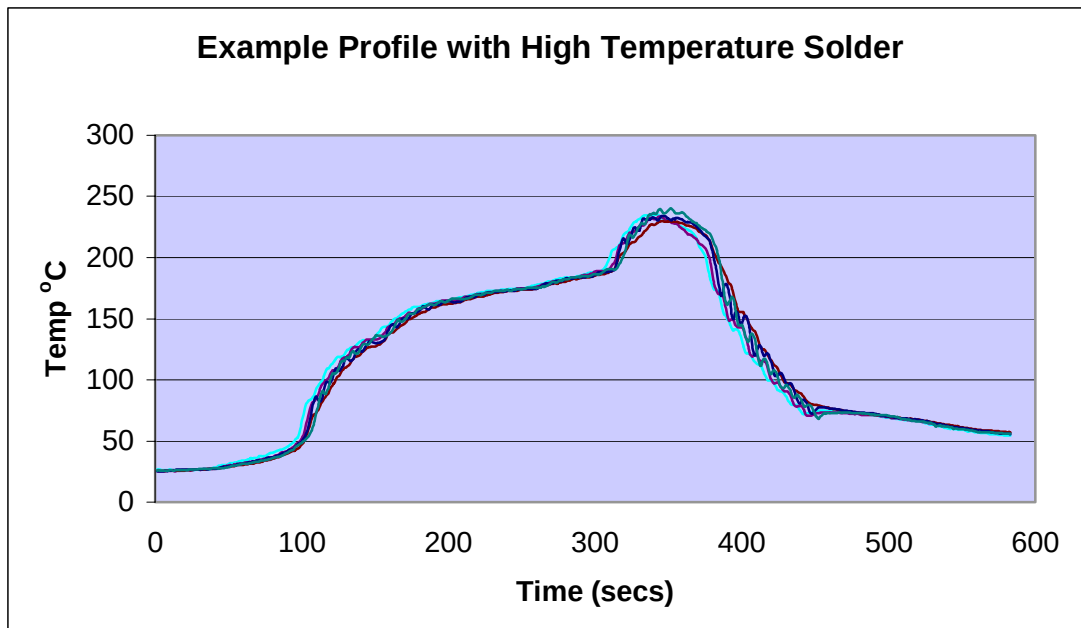


Figure 8: Reflow profile used (measured with thermocouples attached with high temperature solder)

3.2 RESULTS

The results are given in Table 3 for thermocouple positions 2 to 6.

Table 3 : Results from attachment method test runs with averages and standard deviations for each thermocouple position

T/C 2	HTS A	HTS B	Wave	Thermal	Aluminium	Polyimide
Run 1	236.5	(1)	(1)	(1)	(1)	(1)
Run 2	237.8	(2)	242.2	(2)	238.5	243
Run 3	243.5	235	241.5	235.5	239.5	244.5
Run 4		235	242.5	236.5	240	244
Run 5		236	242.5	235.5	239.5	244.5
Average	239.3	235.3	242.2	235.8	239.4	244.0
Std. Dev.	3.7	0.6	0.5	0.6	0.6	0.7

T/C 3	HTS A	HTS B	Wave	Thermal	Aluminium	Polyimide
Run 1	230	236	232.5	231	235.5	260.5
Run 2	229.5	(2)	232.2	(2)	232.5	252.5
Run 3	236	233.5	233	231.5	231.5	258.5
Run 4		233.5	232	232.5	233	261
Run 5		234	235	232.5	233.5	256
Average	231.8	234.3	232.9	231.9	233.2	257.7
Std. Dev.	3.6	1.2	1.2	0.8	1.5	3.5

T/C 4	HTS A	HTS B	Wave	Thermal	Aluminium	Polyimide
Run 1	232.5	229.5	239.5	232	233.5	232
Run 2	232.2	(2)	237.8	(2)	231.5	231.5
Run 3	237	230	240	232.5	231.5	233.5
Run 4		229	238.5	232.5	233.5	234
Run 5		229.5	240.5	232	233	234.5
Average	233.9	229.5	239.3	232.3	232.6	233.1
Std. Dev.	2.7	0.4	1.1	0.3	1.0	1.3

T/C 5	HTS A	HTS B	Wave	Thermal	Aluminium	Polyimide
Run 1	229	234.5	235.5	233	237.5	249
Run 2	230.6	(2)	234.5	(2)	234	244.5
Run 3	231	234	234.5	232	234	250
Run 4		233.5	235	232.5	233	255
Run 5		235.5	236.5	233	234	248
Average	230.2	234.4	235.2	232.6	234.5	249.3
Std. Dev.	1.1	0.9	0.8	0.5	1.7	3.8

T/C 6	HTS A	HTS B	Wave	Thermal	Aluminium	Polyimide
Run 1	233.5	238.5	236	233.5	238.5	(1)
Run 2	232.2	(2)	235	(2)	239	238.5
Run 3	235.5	240	237	233.5	238	238
Run 4		238.5	235.5	234.5	238.5	241.5
Run 5		240	236	234	239	240.5
Average	233.7	239.3	235.9	233.9	238.6	239.6
Std. Dev.	1.7	0.9	0.7	0.5	0.4	1.7

(1) Detached thermocouple (2) Data download failure

3.3 DISCUSSION

Summaries of the maximum temperatures measured during the profiling runs for the thermocouples attached to the QFP and SOT223 are shown graphically in Figures 9 & 10. Each column represents an individual profile run and thus it can be seen that all the attachment methods, with the exception of the polyimide tape on the SOT223, showed good run-to-run repeatability. With the quad flat pack (QFP), the wave-soldering adhesive did show slightly higher temperatures than the other methods but this was not noted in the SOT223 position.

QFP Joint Temperatures

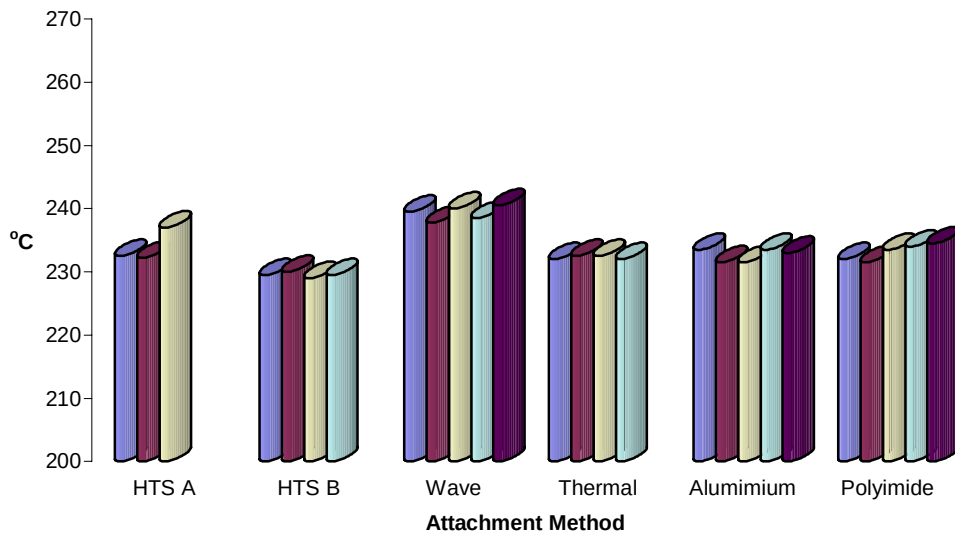


Figure 9 : Summary of maximum QFP joint temperatures

SOT223 Joint Temperatures

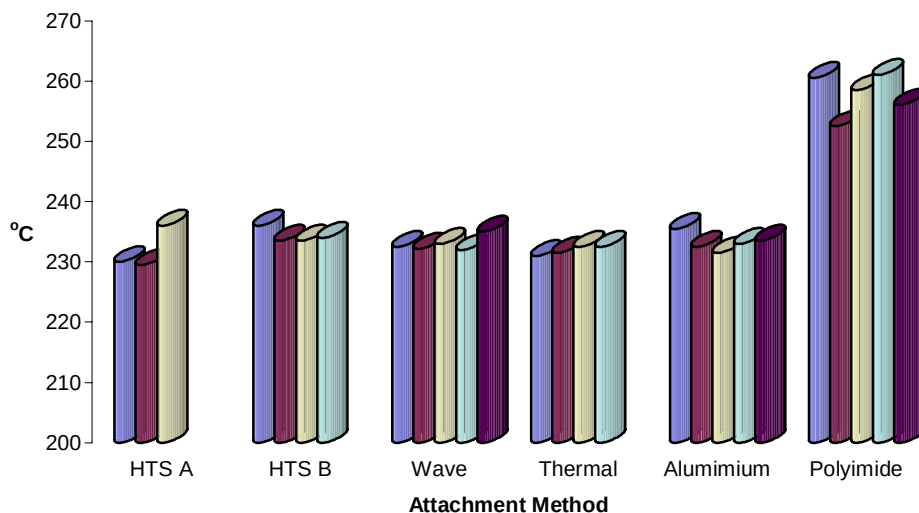


Figure 10 : Summary of maximum SOT223 joint temperatures

The polyimide tape measurements were significantly higher than for the other attachment methods for the SOT223 thermocouple. This was because the adhesion of the tape to the component was poor for the SOT223 component (as can be seen in Figure 11) and the thermocouple became detached from the joint during profiling. Consequently the higher temperatures measured reflect air temperatures not joint temperatures. After every run the thermocouple had to be reattached by pushing the tape down into contact with the component. This problem did not occur with the QFP thermocouple because the contact area of the tape was much greater as can be seen in Figure 12.

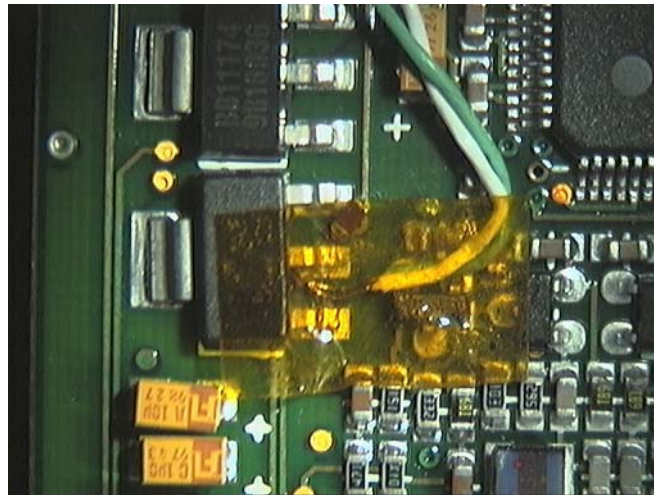


Figure 11 : Attachment of thermocouple to SOT223 with polyimide tape

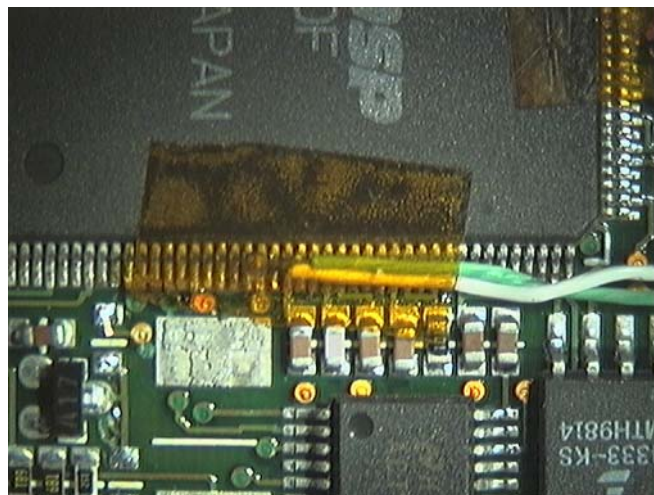


Figure 12 : Attachment of thermocouple to QFP with polyimide tape

The run-to-run variability is shown in Figure 13 for the QFP thermocouple temperatures for each attachment method. There was no apparent trend as the five profiles were conducted. ***It can therefore be concluded that all materials were suitable for multiple profiling.*** Polyimide tape (indicated as Kapton in the Figure) does require sufficient contact area to work efficiently.

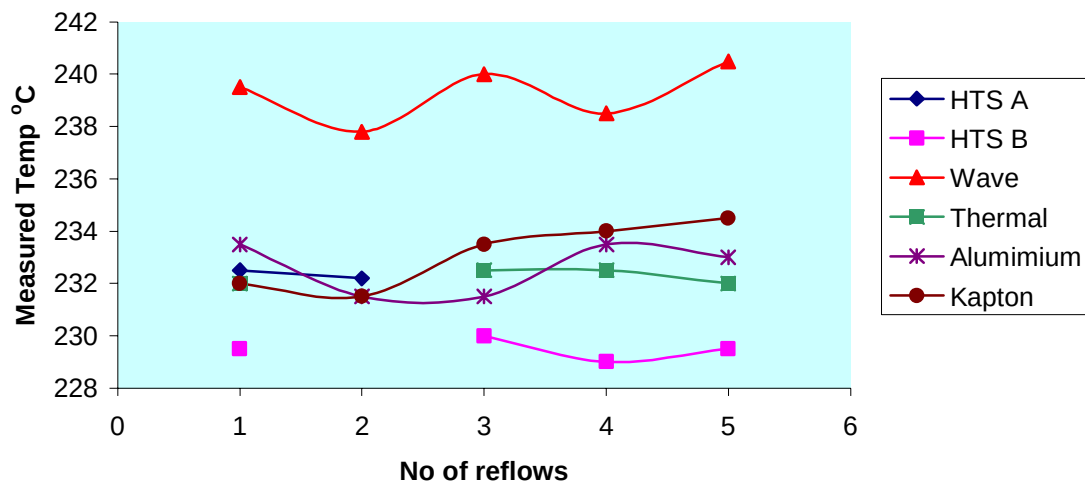
Effect of No. of Reflows on Measured Temperature**Figure 13 : Trends during multiple profiling**

Table 4 and Figure 14 show a comparison of the mean maximum recorded temperatures. Each column in Figure 14 represents the difference between the average maximum temperature for that position and the average maximum temperature for the HTS B assembly. It can be noted from these data that the maximum mean temperatures recorded for both the thermal adhesive and the aluminium tape were within 5°C of the high temperature solder control assembly. This would suggest that either method would be suitable as a replacement for high temperature solder. Both methods are easier to apply than solder, with the aluminium tape clearly the optimum temporary attachment method.

Table 4 : Comparison of mean maximum temperatures recorded for each assembly

	HTSB	HTSA	Wave	Thermal	Aluminium	Kapton
Tantalum	235.3	239.3	242.1	235.8	239.4	244.0
SOT223	234.3	231.8	232.9	231.9	233.2	257.7
QFP	229.5	233.9	239.3	232.3	232.6	233.1
C0603	234.4	230.2	235.2	232.6	234.5	249.3
SOIC	239.3	233.7	235.9	233.9	238.6	239.6
deltaT	9.8	9.1	9.2	4.0	6.8	24.6

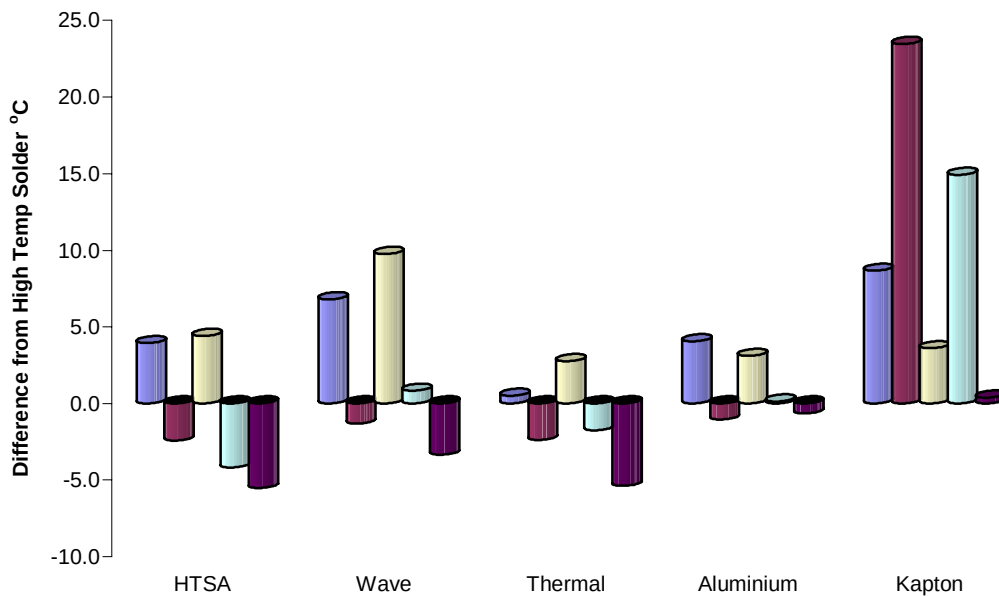


Figure 14 : Comparison of mean max. temperatures recorded for all assemblies

The comparative results for the wave adhesive showed a greater difference from the solder control. Here differences are in the $\pm 10^{\circ}\text{C}$ temperature range. The difference is even greater for the polyimide (Kapton) adhesive with maximum measured temperatures up to 23°C greater than the solder control.

The differences in the measured maximum temperatures between the two high temperature soldered assemblies should also be noted. This is in the order of $\pm 5^{\circ}\text{C}$, similar to the results for thermal adhesive and aluminium tape. This somewhat surprising result was investigated further by determining the typical differences between similar assemblies during profiling. Section 4 details work to establish this repeatability.

4 MEASUREMENTS ON ASSEMBLIES WITH THERMOCOUPLES ATTACHED BY SAME METHOD

This Section describes the work undertaken to investigate the extent of differences in maximum measured temperatures on assemblies with thermocouples attached in a similar manner.

4.1 EXPERIMENTAL PROCEDURE

For this work, high temperature solder and thermal adhesive were chosen as attachment methods. Five identical assemblies were manufactured for each of these two methods. HTSA, HTSB, HTSC, HTSD and HTSE for assemblies manufactured with high temperature solder and TAA, TAB, TAC, TAD and TAE for assemblies using thermal adhesive. Each of these ten assemblies was passed through the same oven profile three times. The Roke Manor test

vehicle used was the same as for Section 3, with the thermocouples attached in the same positions.

4.2 RESULTS

The results for the average, maximum and minimum recorded temperatures are given in Table 5.

Table 5 : Maximum recorded temperatures on profiled assemblies on high temperature solder assemblies (A) and thermal adhesive assemblies (B)

(A)						
Position	Assembly	HTS A	HTS B	HTSC	HTS D	HTS E
Tantalum	Highest	243.5	236.0	234.0	(Note 1)	237.5
	Lowest	236.5	233.5	231.5		237.0
	Average	239.3	234.9	233.1		237.2
SOT223	Highest	236.0	236.0	230.5	232.5	231.0
	Lowest	229.5	233.5	228.9	225.6	227.0
	Average	231.8	233.8	229.8	229.9	228.4
QFP	Highest	239.3	236.0	233.1	232.5	237.2
	Lowest	229.5	233.5	228.9	225.6	227.0
	Average	234.2	234.4	230.6	229.3	230.9
R0603	Highest	239.3	236.0	233.1	229.9	237.2
	Lowest	229.5	233.5	228.9	229.9	227.0
	Average	233.7	234.6	230.6	229.9	230.9
SOIC	Highest	239.3	236.0	233.1	229.9	237.2
	Lowest	229.5	233.5	228.9	229.3	227.0
	Average	234.2	234.7	230.8	229.7	231.5

Note 1 : No results were obtained for the tantalum thermocouple on HTS D as the component and pad became detached during manufacture and thus it was not possible to reattach the thermocouple.

(B)						
Position	Assembly	TA A	TA B	TA C	TA D	TA E
Tantalum	Highest	236.5	234.5	233.5	231.7	229.0
	Lowest	235.5	229.5	228.9	230.5	227.5
	Average	235.8	231.3	231.0	231.1	228.3
SOT223	Highest	232.5	234.0	231.0	229.5	234.0
	Lowest	231.0	231.5	229.5	227.5	233.4
	Average	231.9	232.4	230.2	228.5	233.6
QFP	Highest	232.5	227.5	227.0	228.0	235.0
	Lowest	232.0	222.8	222.2	226.7	233.5
	Average	232.3	224.8	224.4	227.2	234.3
R0603	Highest	233.0	230.0	230.0	227.5	227.5
	Lowest	232.0	225.0	227.2	225.5	224.5
	Average	232.6	227.7	228.2	226.2	226.3
SOIC	Highest	234.5	229.5	235.0	230.5	231.5
	Lowest	233.5	223.5	230.6	228.4	226.7
	Average	233.9	227.1	232.7	229.3	229.1

4.3 DISCUSSION

The differences between the average values for the maximum temperatures recorded for the three runs and the average for all recorded temperatures in each position are shown in Figures 15 and 16.

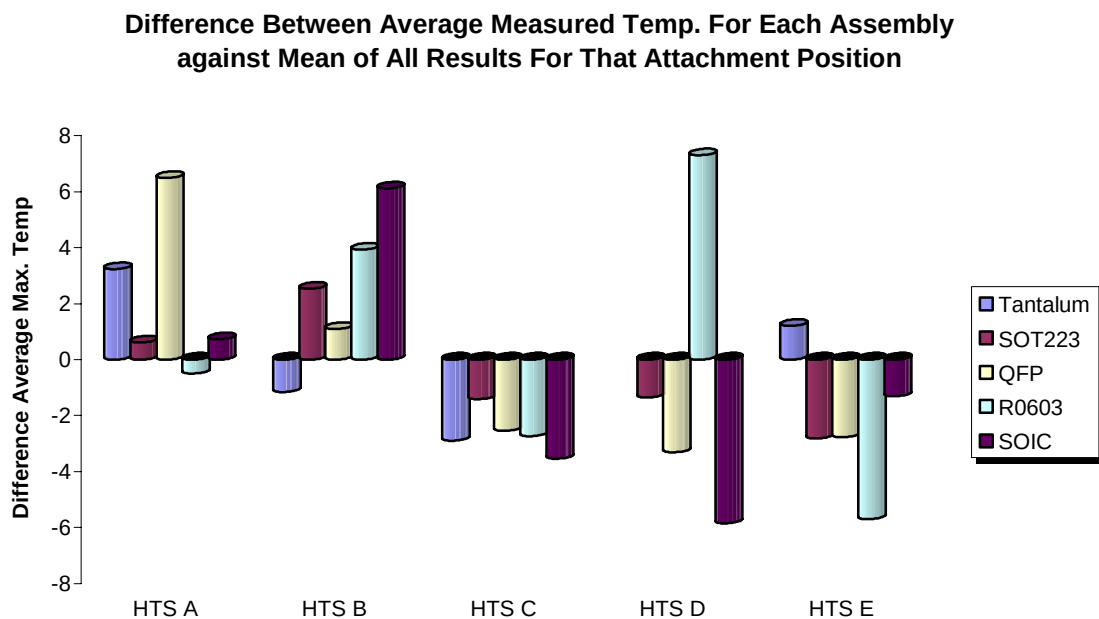


Figure 15: Comparison of results for assemblies using high temperature solder

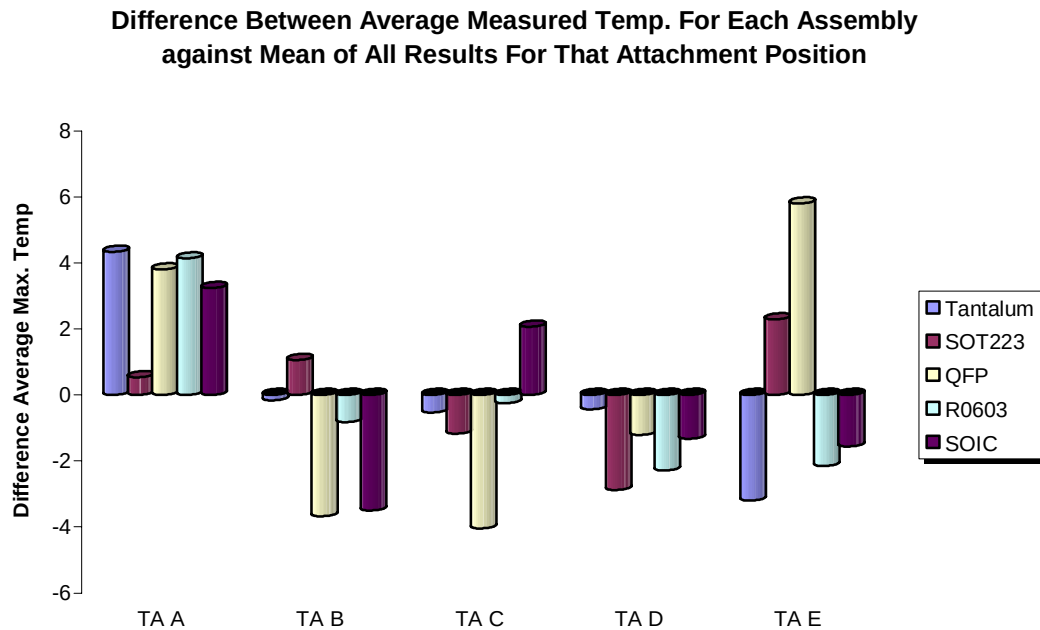


Figure 16: Comparison of results for assemblies using thermally conductive adhesive

Figure 15 shows the comparison between the five assemblies using high temperature solder to attach the thermocouples. It can be seen that individual positions on assemblies vary by as much 8°C from the average for that position. Broadly speaking, individual assemblies are either hotter or cooler than the average.

Figure 16 shows the comparison between the five assemblies using thermally conductive adhesive to attach the thermocouples. Again, individual assemblies are generally either hotter or cooler than the average for all assemblies, but the maximum difference for an individual position for its average are slightly less for the thermally conductive adhesive at 6°C.

An alternative representation of the comparison between the attachment methods for each attachment position is presented in Figure 17. Again it can be concluded that the variation between assemblies using thermally conductive adhesive is slightly less than that for high temperature solder. In both cases, the average temperatures are broadly similar.

4.4 CONCLUSIONS

Thermal adhesive provides an attractive method of attaching thermocouples to electronic assemblies during soldering. It is easy to attach the thermocouples with attachment being independent of thermocouple bead wetting. Results indicate that the repeatability of measurement using this method is at least as good as that for high temperature solder if not better. The material is also lead-free. However, attachment is not instantaneous, requiring a cure period of several minutes, and is more expensive than solder.

High temperature solder is the normal method of attachment in the industry. The process is instantaneous but with thermocouples, particularly K-type, the bead can be difficult to wet,

and this may be the cause of their slightly more inconsistent repeatability, compared to

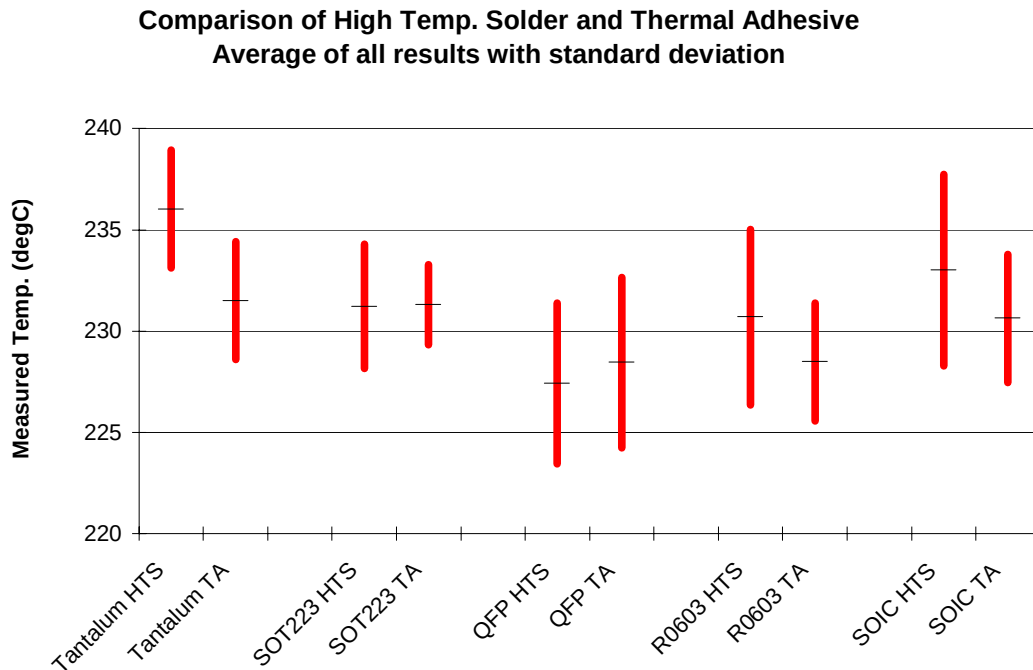


Figure 17: Comparison of high temperature solder and thermal adhesive

thermally conductive adhesive. The only alloys available that will withstand the higher temperatures typical of lead-free soldering are alloys that contain lead. The use of such alloys may be complicated by the introduction of the European legislation on Waste of Electrical and Electronic Equipment (WEEE) and the Restriction on the use of Hazardous Substances (ROHS), which in the draft format ban the use of lead with electronics soldering.

5 MEASUREMENTS ON THERMOCOUPLES ATTACHED AT DIFFERENT ANGLES

5.1 EXPERIMENTAL PROCEDURE

To determine the effect of using different routes of taking the thermocouple away from the solder joint, the SOIC test assembly as shown in Figure 18 and detailed in Section 2.0 was used. The test assembly and attachment positions were the same as those described in Section 2.0, i.e. the position shown to reach the same maximum temperature during the test run. In addition, a second assembly was manufactured with the position of each thermocouple placement style randomised, to check for any PCB systematic effects, as shown in Table 6. The thermocouple orientations are described in Figure 19. Both assemblies were also profiled in reverse, i.e. using the rear of the assembly as the leading edge.

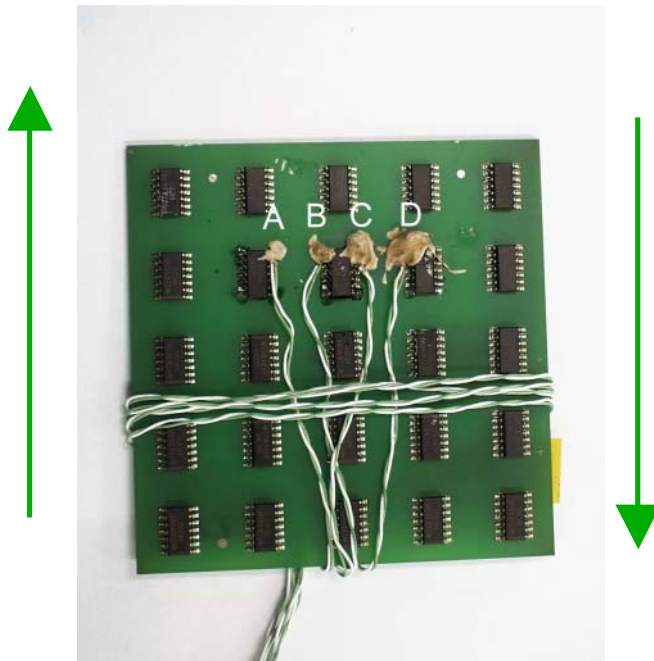


Figure 18: SOIC test assembly

Table 6: Thermocouple Positioning On Test Assemblies

Attachment Method	TC1	TC2	TC3	TC4
Assembly 1 (H1)	Vertical	Horizontal Perpendicular	Horizontal Parallel	Angled
Assembly 2 (H2)	Horizontal Parallel	Angled	Vertical	Horizontal Perpendicular

The thermocouples were attached using thermally conductive adhesive in four different ways as shown in Figure 19. With the horizontal perpendicular method, the thermocouple is brought away from the solder joint directly out from the component, along the surface of the PCB as close as possible but without touching the component. The horizontal parallel method is similar but the thermocouple is led along the side of the component, touching the component leads. With both the remaining methods, the thermocouple is led away through the air around the component. With the vertical method, this is straight upwards above the solder joint and with the angled method, the thermocouple is led sideways directly away from the joint at an angle of 45° to the horizontal.

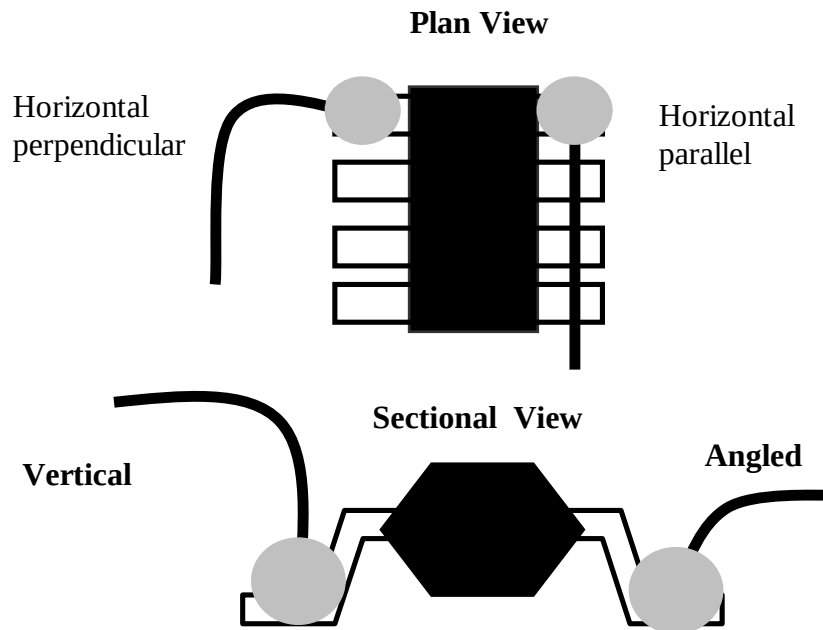


Figure 19: Thermocouple attachment angles

5.2 EXPERIMENTAL RESULTS

The results from the profiling runs are shown in Tables 7 & 8.

Table 7 : Results for different thermocouple angles experiment

	H1 Run	H1 Run	H1 Run	H2 Run	H2 Run	H2 Run
<i>Maximum Temps. Reached</i>	1	2	3*	1	2	3*
Horizontal perpendicular	241	241	244	243	242.5	243
Horizontal parallel	242.5	242.5	244	244.5	243.5	245.5
Angled	246.5	244.5	246	245	244	247
Vertical	246.5	246	251	247.5	246.5	247

* reversed run

Table 8 : Average maximum temperatures reached for different thermocouple angles experiment

	Average of all runs
Horizontal perpendicular	242.4
Horizontal parallel	243.8
Angled	245.5
Vertical	247.4

5.3 DISCUSSION

The results are represented graphically in Figure 20 with the averages shown in Figure 21.

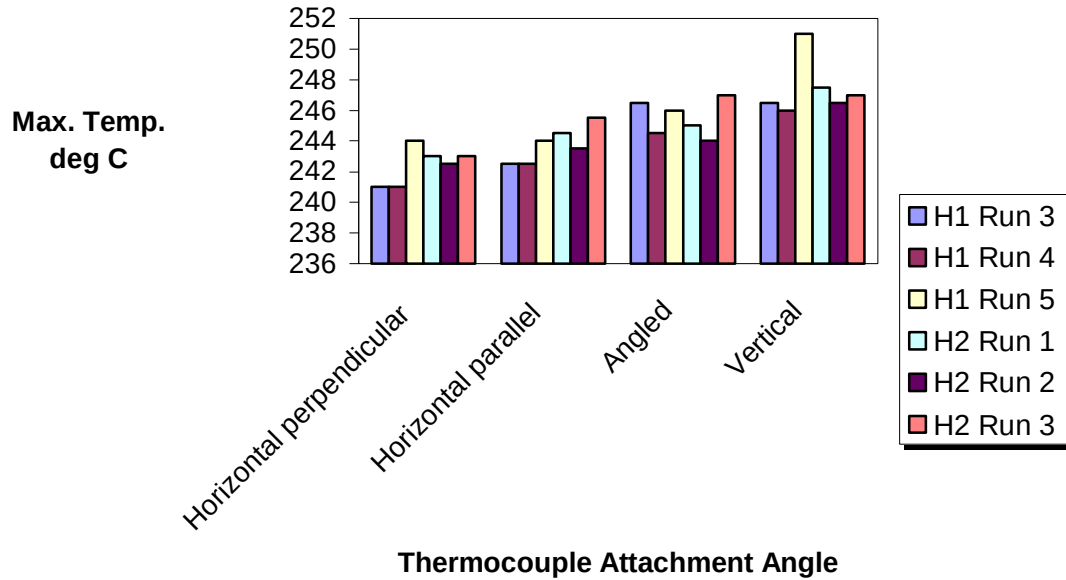


Figure 20: Results for thermocouple attachment angles

Both these Figures clearly show that the maximum temperatures recorded in each position are consistently higher for the vertical and angled attachment methods. The vertical method gives the higher temperatures of these latter two. This is probably due to airflow around the thermocouples causing a warming of the thermocouple and subsequent conduction of heat to the solder joint. It is considered that the lower temperatures measured are likely to be the more accurate as there are many mechanisms by which the joint temperature can be raised but few, if any, by which it can be lowered. Of the two methods where the thermocouple is tracked away from the joint along the surface of the PCB, the method in which the thermocouple is taken along the side of the component gave higher maximum temperatures than when the thermocouple is led directly away from the joint. This may be due to the proximity of the component body and resultant additional conduction of heat from the component along the thermocouple to the joint.

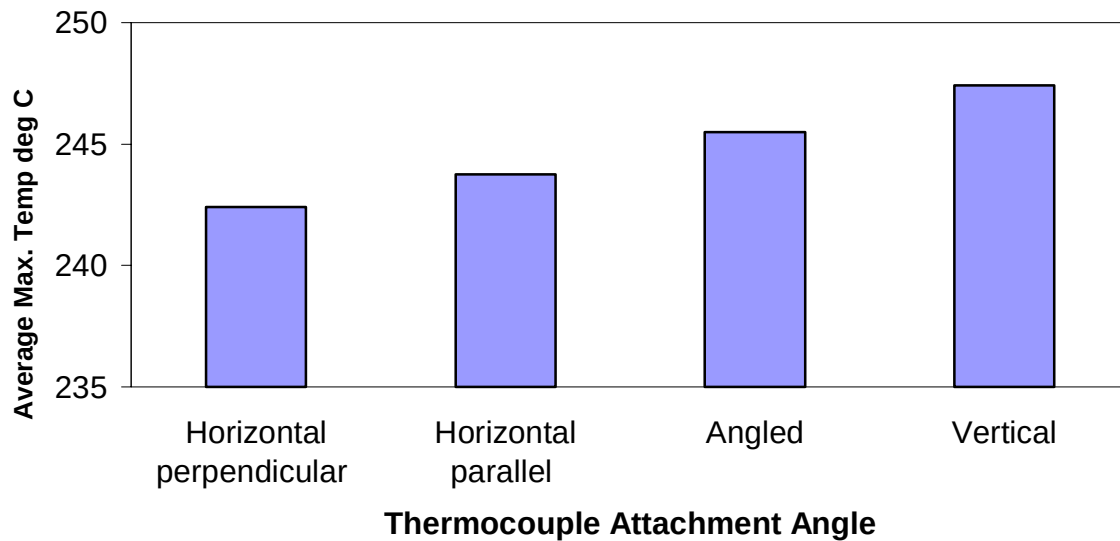


Figure 21: Averages for each attachment method over all positions

5.4 CONCLUSIONS

It has be shown that the best method for bringing the thermocouple away from the joint is to do so by routing it directly away from the solder joint at right angle to the component body and along the surface of the PCB.

6 MEASUREMENTS ON THERMOCOUPLES OF DIFFERENT DIAMETERS

6.1 EXPERIMENTAL PROCEDURE

To assess the effects of different diameter thermocouples the SOIC test assembly (detailed in Section 2.0) was again utilised for this experiment. In each of the four positions that reached similar maximum temperatures, a thermocouple of a different gauge was attached. Two assemblies were again manufactured with the thermocouples juxtapositioned on the second assembly. The thermocouples were attached using thermally conductive adhesive with the thermocouples being led directly away from the joints, perpendicular to the component body. Several profiling runs were conducted including reverse runs where the back of the assembly was used as the leading edge. Details are provided in Table 9.

Table 9 : Types and positions of thermocouples used

Attachment Method	TC1	TC2	TC3	TC4
Assembly G1	0.2mm dia. PTFE covered	0.3mm dia Glass covered	0.13mm dia. PTFE covered	0.25mm dia. PTFE covered
Assembly G2	0.13mm dia. PTFE covered	0.25mm dia. PTFE covered	0.2mm dia. PTFE covered	0.3mm dia Glass covered

6.2 RESULTS

The results from the two assemblies are given in Table 10.

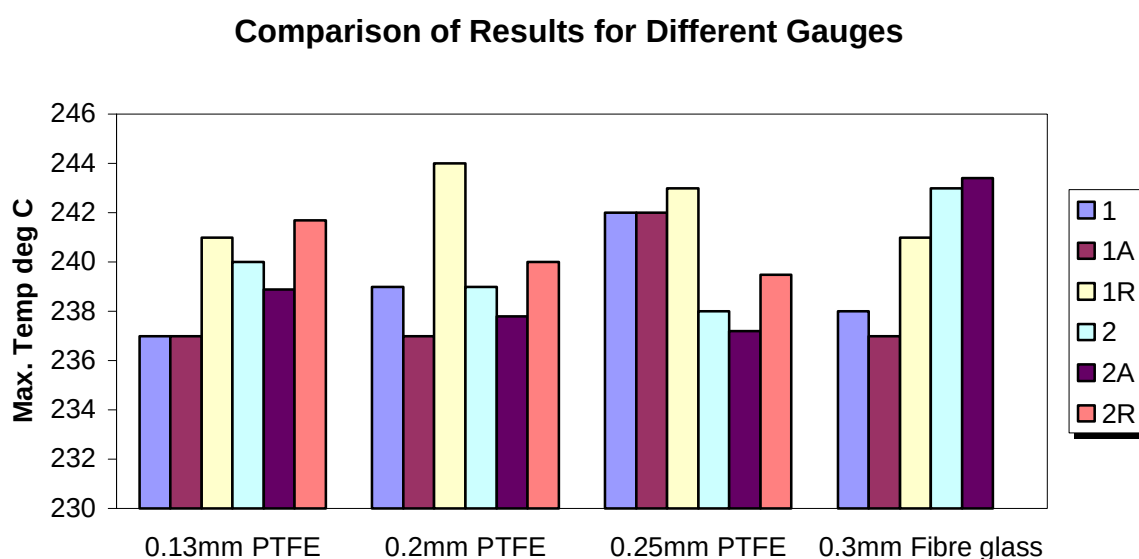
Table 10 : Results for different thermocouple gauges

	Assembly G1			Assembly G2		
<i>Maximum Temps. Reached</i>	Run 1	Run 1A	Run 1R*	Run 2	Run 2A	Run 2R*
0.13mm PTFE	237	237	241	240	239	242
0.2mm PTFE	239	237	244	239	238	240
0.25mm PTFE	242	242	243	238	237	240
0.3mm Fibre glass	238	237	241	243	243	(1)

*assembly reversed
(1) thermocouple disconnected

6.3 DISCUSSION

A comparison of the results is shown in Figure 22.

**Figure 22: Comparison of results for different gauges of thermocouples**

No noticeable trends can be concluded from these data. However, the largest gauge thermocouples (0.3mm fibre glass coated) were very stiff and one thermocouple did become detached during measurement.

6.4 CONCLUSIONS

Finer flexible thermocouples are preferred as, although there is no difference in the maximum temperatures measured, these are easier to attach and due to their flexibility, are easier keep attached during profiling. Some users have reported that the very finest grade thermocouples are prone to fracture during use but no problems were experienced in these trials.

7 TRENDS IN ATTACHMENT POSITIONS OF THERMOCOUPLES ON TYPICAL ASSEMBLIES

7.1 EXPERIMENTAL PROCEDURE

To determine trends in maximum temperatures reached by solder joints and the time spent by the joints above the melting point of the solder, a series of test assemblies were monitored through soldering profiles in two different ovens. The first oven was a smaller 5 zone convection reflow system with an overall heated length of around 2 metres manufactured by Reddish Electronics. The second was a larger 10 zone system with an overall heated length of around 4 metres manufactured by BTU. Thermocouples were attached to each assembly in positions considered to represent the likeliest hottest and coldest parts of the assemblies. The thermocouples were attached using thermally conductive adhesive and all thermocouples were led away directly away from their corresponding solder joint along the surface of the PCB.

Both systems were set up with lead-free profiles i.e to obtain a maximum temperature reached of around 225°C for a minimum of 20 seconds for the coolest part of each assembly. The hottest part of each assembly was restricted to a time above 217 °C of 60 seconds maximum where possible. In total six different assemblies were used as detailed below. Results are presented as an average of three runs through each oven.

On each photograph of the test assemblies (see Figures 23, 26, 29 and 32) a UK one pound coin has been placed, these are 22.5mm in diameter.

7.2 ALSTOM TEST ASSEMBLY.

The Alstom test assembly is shown in Figure 23 with the thermocouple attachment positions marked. This assembly was approximately 305 x 220 mm and the PCB was approximately 2mm thick. Its application is in industrial controls. The assembly contained a range of surface mount devices, mostly IC packages including a 160 I/O 0.65mm pitch QFP. The joints to which the thermocouples were attached are depicted in Figure 23.



SOIC Edge (1)
SOIC Centre (2)
PLCC (3)
QFP (4)
SOT23 (5)
Large Relay (6)

Figure 23: Alstom test assembly with £ coin scaler

7.3 ALSTOM TEST ASSEMBLY RESULTS

The results for the Alstom assembly for the 5-zone and 10-zone ovens are given in Tables 10 & 11.

Table 11 : Results for average maximum temperatures reached for Alstom test assembly

Deg C	5-ZONE OVEN	10-ZONE OVEN
SOIC Edge (1)	267	235
SOT23 (5)	262	240
QFP (4)	244	227
Large Relay (6)	238	230
SOIC Centre (2)	230	227
PLCC (3)	225	224
Delta T (deg C)	42	16

Table 12 : Results for average time above 217°C reached for Alstom test assembly

<i>Seconds</i>	5-ZONE OVEN	10-ZONE OVEN
SOIC Edge (1)	106	45
SOT23 (5)	99	49
QFP (4)	75	35
Large Relay (6)	64	40
SOIC Centre (2)	46	36
PLCC (3)	30	29

7.4 DISCUSSION OF RESULTS FOR ALSTOM TEST ASSEMBLY

A comparison of the maximum temperatures reached and the time above melting point with both the 5-zone and 10-zone ovens is given in Figures 24 & 25.

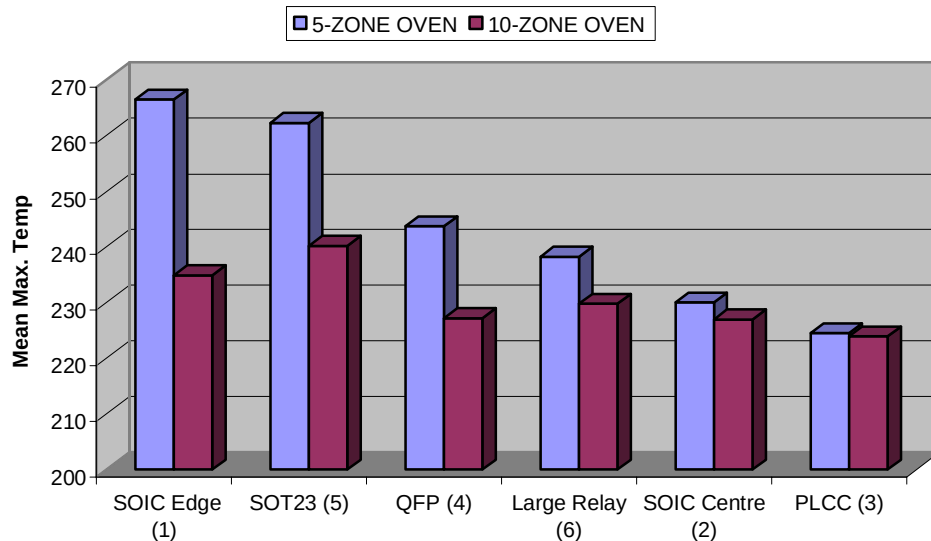


Figure 24: Comparison of maximum temperatures reached for both ovens with the Alstom test assembly

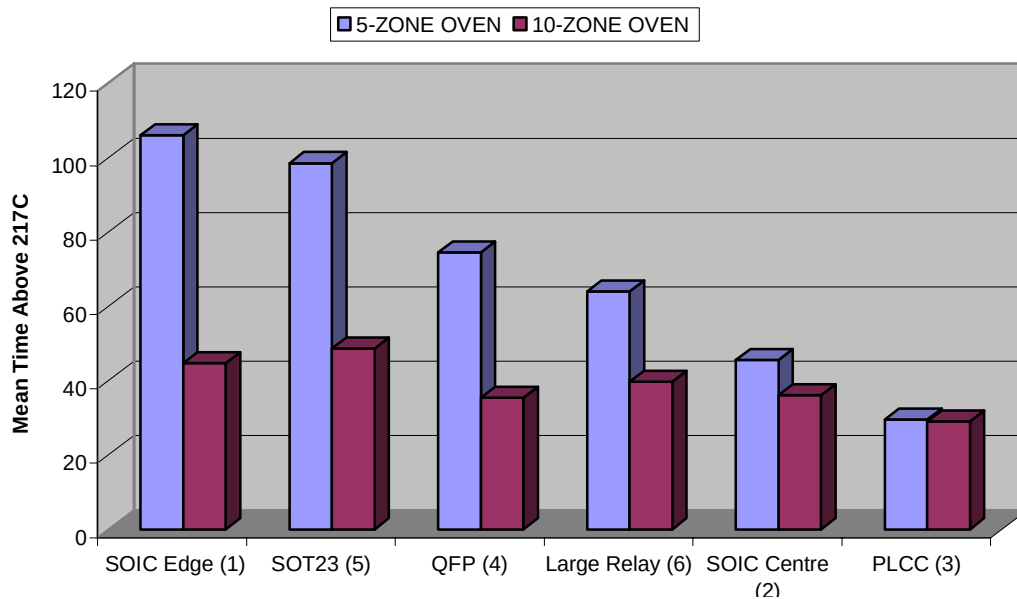


Figure 25: Comparison of time above solder melting point for both ovens with the Alstom test assembly

The profiles on both ovens were set to give similar conditions for the coolest part of the assembly (i.e. approximately 10°C above melting point for a minimum of 20 secs), in this case the PLCC (3). However it can be seen that the resulting profiles are very different at other parts of the assembly. The relative order of maximum temperatures reached and times above solder melting point are similar for both ovens. But the delta T (difference between the hottest and coldest parts of the assembly) and the maximum temperatures reached are much greater for the 5-zone oven. The delta T is 42°C compared to 16°C for the 10-zone oven. The times above the melting point of solder are also much longer for the smaller oven (106 secs compared to 45 seconds). Component manufacturers are still formulating their lead-free profile recommendations but few currently recommend times above 217°C in excess of 60 seconds.

Other points worth noting include the fact that the SOIC joint near the edge of the assembly (position 1) gets significantly warmer for longer in both ovens than its identical partner in the centre of the assembly (position 2). The PLCC joint (position 3) towards the centre of the assembly is the coolest part measured despite the QFP in position 4 being a larger device. This latter device is closer to the edge of the assembly

7.5 FUJITSU TEST ASSEMBLY

The Fujitsu test assembly is shown in Figure 26 with the thermocouple attachment positions marked. This assembly was approximately 215 x 210 mm and the PCB was approximately 1.8mm thick. Its application is in telecommunications. The assembly contained a range of surface mount devices, mostly tantalum capacitors and IC packages including several 176 I/O 0.5mm pitch QFPs. The joints to which the thermocouples were attached are depicted in Figure 26.

QFP Front (1)
R0603 Rear (2)
Tant Rear (3)
Tant Centre (4)
Socket (5)
Large Rectifier (6)

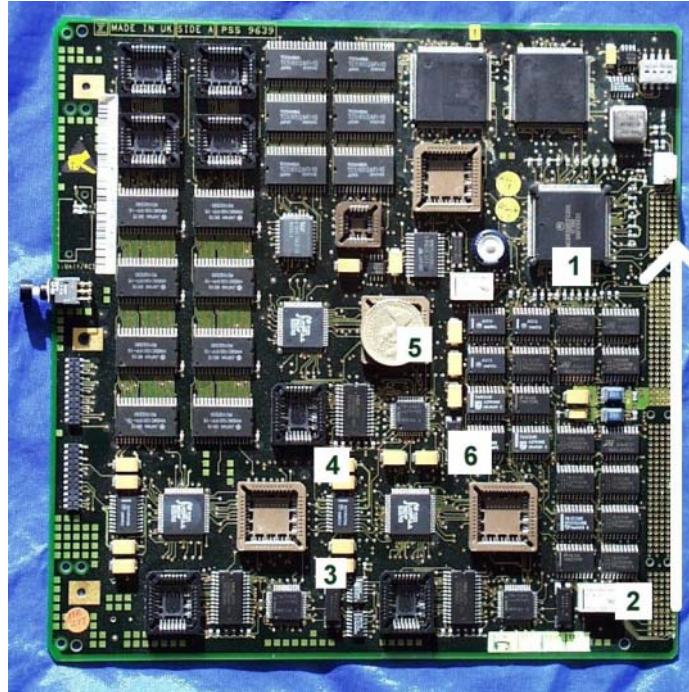


Figure 26: Fujitsu test assembly with £ coin scaler

7.6 FUJITSU TEST ASSEMBLY RESULTS

The results for the Fujitsu assembly for the 5-zone and 10-zone ovens are given in Tables 12 & 13.

Table 12 : Results for average maximum temperatures reached for Fujitsu test assembly

<i>Deg C</i>	5-ZONE OVEN	10-ZONE OVEN
R0603 Rear (2)	265	229.5
QFP Front (1)	242	221.5
Tant. Rear (3)	230	222
Large Rectifier (6)	228	221.5
Tant. Centre (4)	224	220.5
Socket (5)	223	221.5
Delta T (Deg C)	42	9

Table 13 : Results for average time above 217°C reached for Fujitsu test assembly

<i>Seconds</i>	5-ZONE OVEN	10-ZONE OVEN
R0603 Rear (2)	101	42
QFP Front (1)	75	21
Tant Rear (3)	37	32
Large Rectifier (6)	37	28
Socket (5)	31	26
Tant Centre (4)	27	27

7.7 DISCUSSION OF RESULTS FOR FUJITSU TEST ASSEMBLY

A comparison of the maximum temperatures reached and the time above melting point with both the smaller and larger ovens is given in Figures 27 & 28.

The profiles on both ovens were set to give similar conditions for the coolest part of the assembly, in this case the socket at position 5. However, again it can be seen that the resulting profiles are very different at other parts of the assembly. Broadly, the relative order of maximum temperatures reached and times above solder melting point are the same for both ovens. But, the delta T (difference between the hottest and coldest parts of the assembly) is much greater for the 5-zone oven (42°C compared to 9°C). The maximum temperatures reached are also much higher for the 5-zone oven. Similarly the times above solder melting point are longer (101 secs compared to 42 seconds).

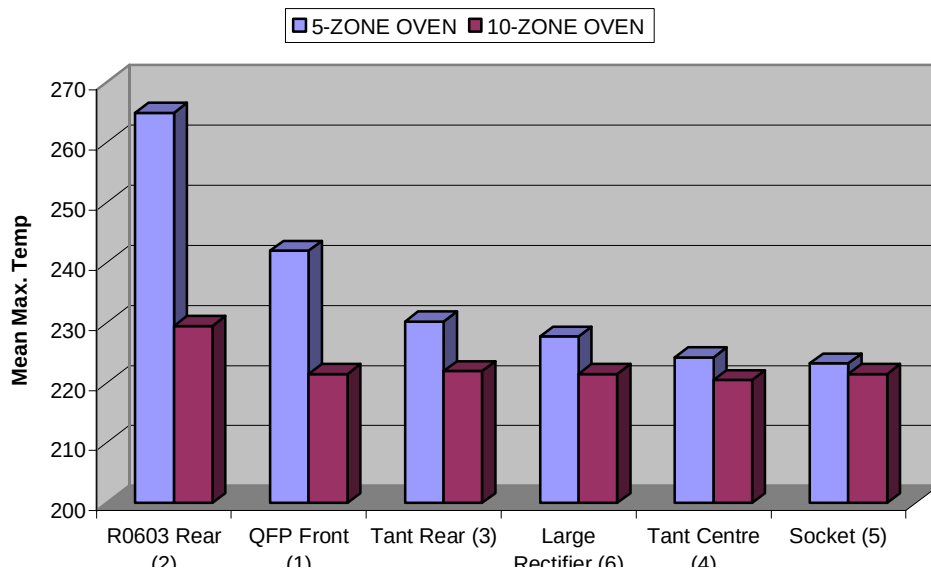


Figure 27: Comparison of maximum temperatures reached for both ovens with the Fujitsu test assembly

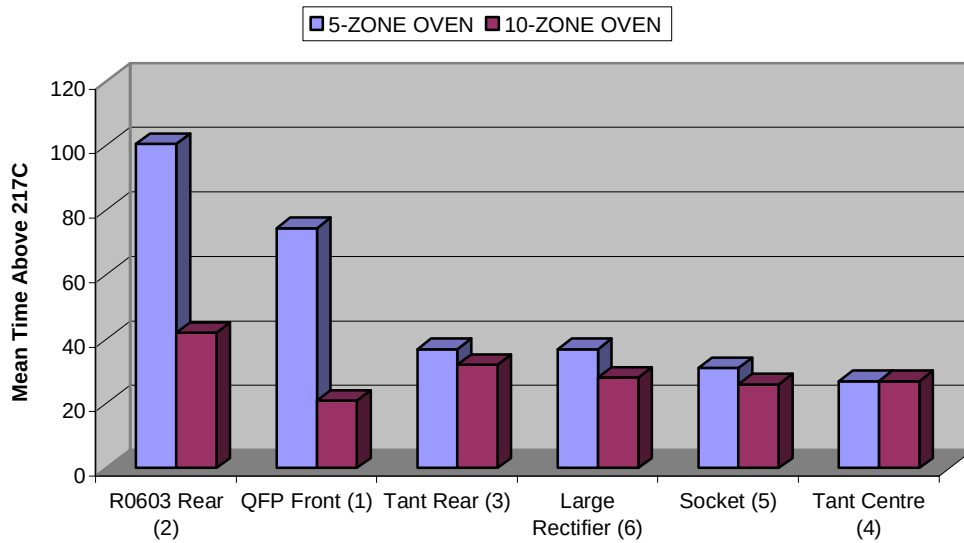


Figure 28: Comparison of time above solder melting point for both ovens with the Fujitsu test assembly

Other points worth noting include the fact that the R0603 (position 2) got the hottest for longest with both ovens. This is a very low thermal mass component situated close to the rear edge of the assembly. The tantalum rear (position 3) was hotter than a similar component tantalum centre (position 4). Position 3 is closer to an edge of the assembly than position 4. The coolest part of the assembly was either the PLCC socket (position 5) or the tantalum centre (position 4). Both components were near the centre of the assembly.

7.8 ROKE MANOR TEST ASSEMBLY

The Roke Manor test assembly as shown in Figure 29 and detailed in Section 3.1 was again utilised here.

- 2 Tantalum
- 3 SOT223
- 4 QFP
- 5 C0603
- 6 SOIC

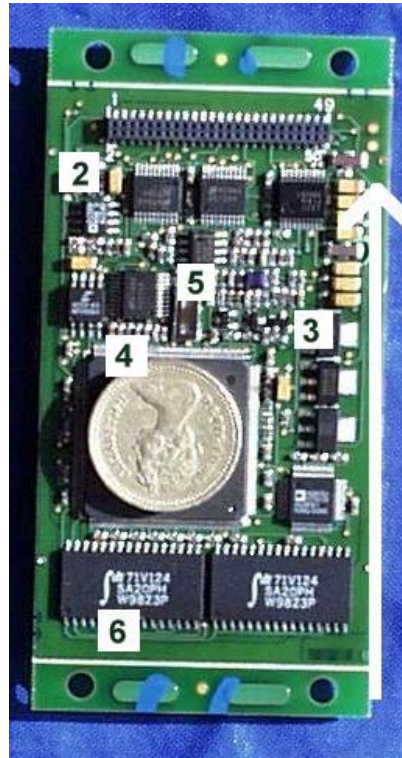


Figure 28: Roke Manor test assembly with £ coin scaler

7.9 ROKE MANOR TEST ASSEMBLY RESULTS

The results for the Roke Manor assembly for the 5-zone and 10-zone ovens are given in Tables 14 & 15.

Table 14 : Results for average maximum temps. reached for Roke Manor test assembly

<i>Deg C</i>	5-ZONE OVEN	10-ZONE OVEN
SOIC (6)	236	234
Tantalum (2)	235	232
C0603 (5)	235	229
SOT223 (3)	234	231
QFP (4)	231	226
Delta T	5	8

Table 15 : Results for time above 217°C reached for Roke Manor test assembly

<i>Seconds</i>	5-ZONE OVEN	10-ZONE OVEN
Tantalum (2)	67.5	85
SOIC (6)	65.5	83
C0603 (5)	64	84
SOT223 (3)	62	69
QFP (4)	58.5	70

7.10 DISCUSSION OF RESULTS FOR ROKE MANOR TEST ASSEMBLY

A comparison of the maximum temperatures reached and the time above melting point with both the 5-zone and 10-zone ovens is given in Figures 30 & 31.

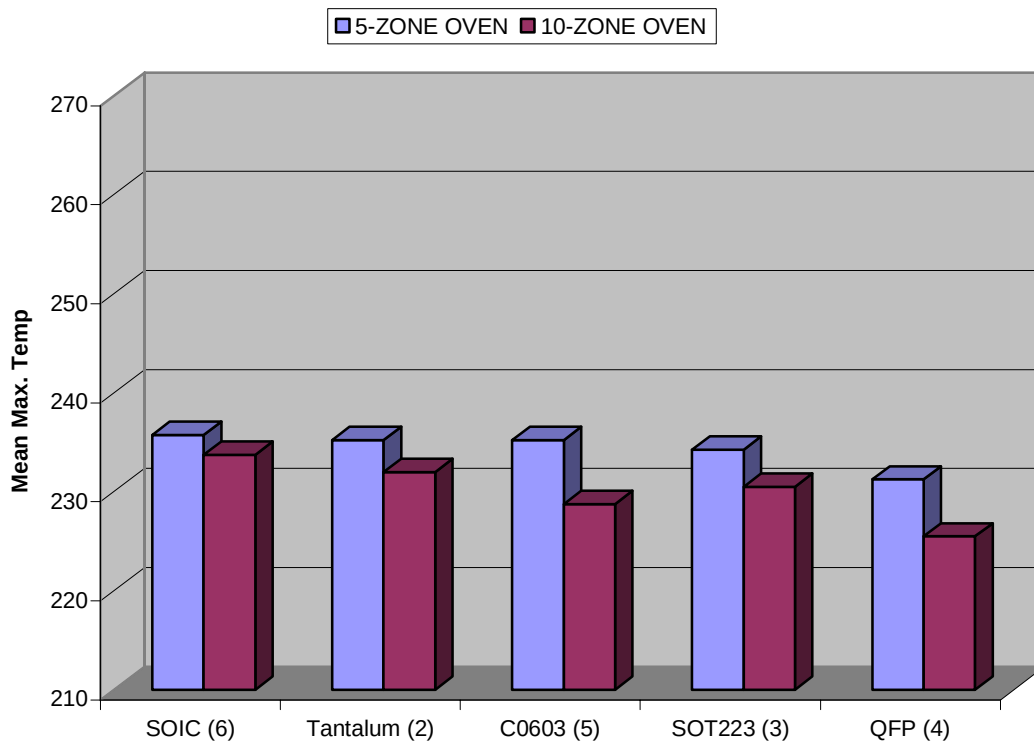


Figure 29: Comparison of maximum temperatures reached for both ovens with the Roke Manor test assembly

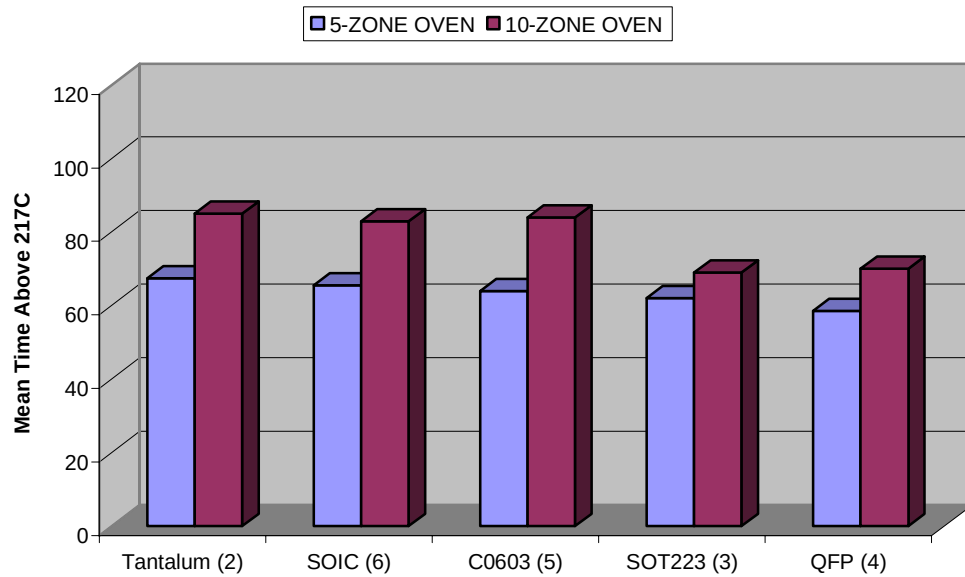


Figure 30: Comparison of time above solder melting point for both ovens with the Roke Manor test assembly

With this lower thermal mass assembly, the profiles on both ovens are similar. Broadly, the relative order of maximum temperatures reached and times above solder melting point was the same for both ovens. The delta T was also similar (5°C compared to 8°C). The maximum temperatures reached were higher for the 5-zone oven but perhaps these could have been lowered with an improved profile.

Other points worth noting include the fact that the QFP is the coolest joint for both ovens, which is not surprising as this component has by far the greatest thermal mass.

7.11 MOBILE PHONE TEST ASSEMBLY

The mobile phone test assembly is shown in Figure 32 with the thermocouple attachment positions marked. This assembly was approximately 130 x 50 mm and the PCB was approximately 1.0mm thick. The assembly contained a range of surface mount devices, including 0402 passives and a 144 I/O 0.5mm pitch QFP. The joints to which the thermocouples were attached are depicted in Figure 32.

- C0805 alone (1)
- C0805 near QFP (2)
- QFP front (3)
- SOT23 Alone (4)
- QFP side (5)
- C0805 (6)

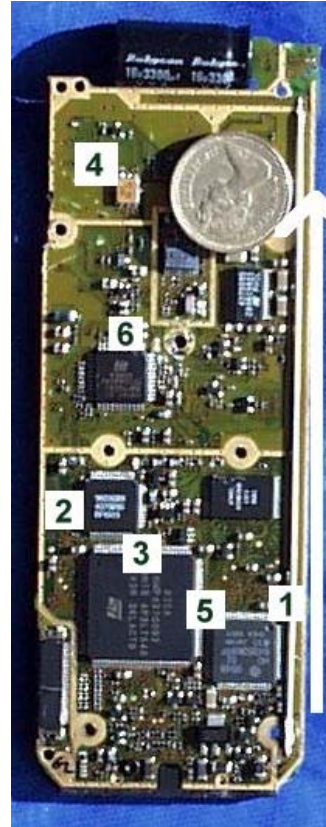


Figure 31: Mobile phone test assembly with £ coin scaler

7.12 MOBILE PHONE TEST ASSEMBLY RESULTS

The results for the mobile phone assembly for the 5-zone and 10-zone ovens are given in Tables 16 & 17.

Table 16 : Results for average maximum temps. reached for mobile phone test assembly

<i>Deg C</i>	5-ZONE OVEN	10-ZONE OVEN
SOT23 Alone (4)	245	234.5
C0805 alone (1)	243	232.5
C0805 (6)	241	236
C0805 near QFP (2)	237	231.5
QFP side (5)	233	230
QFP front (3)	232	229
Delta T	14	7

Table 17 : Results for average time above 217°C reached for mobile phone test assembly

<i>Seconds</i>	5-ZONE OVEN	10-ZONE OVEN
C0805 (6)	71	52
C0805 alone (1)	70.5	47
SOT23 Alone (4)	69.5	48
C0805 near QFP (2)	63.5	44
QFP side (5)	57.5	44
QFP front (3)	53	40

7.13 DISCUSSION OF RESULTS FOR MOBILE PHONE TEST ASSEMBLY

A comparison of the maximum temperatures reached and the time above melting point with both the 5-zone and 10-zone ovens is given in Figures 33 & 34.

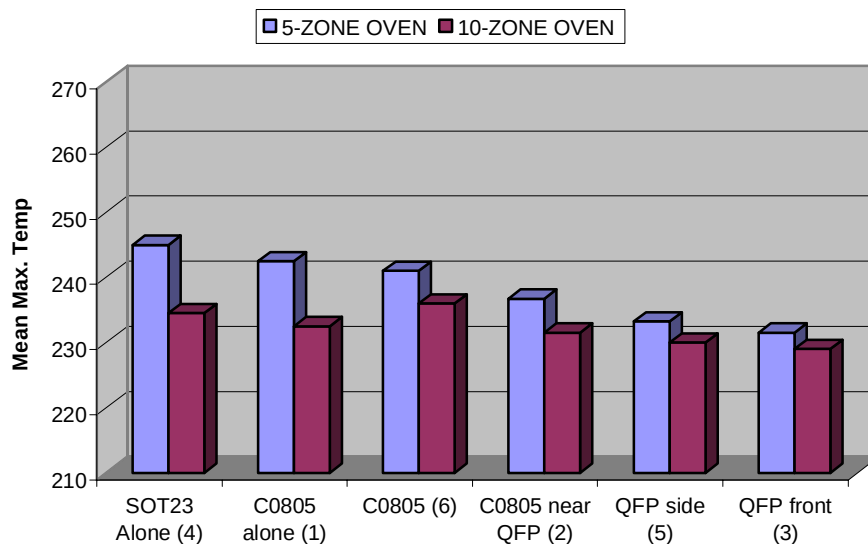


Figure 32: Comparison of maximum temperatures reached for both ovens with the mobile phone test assembly

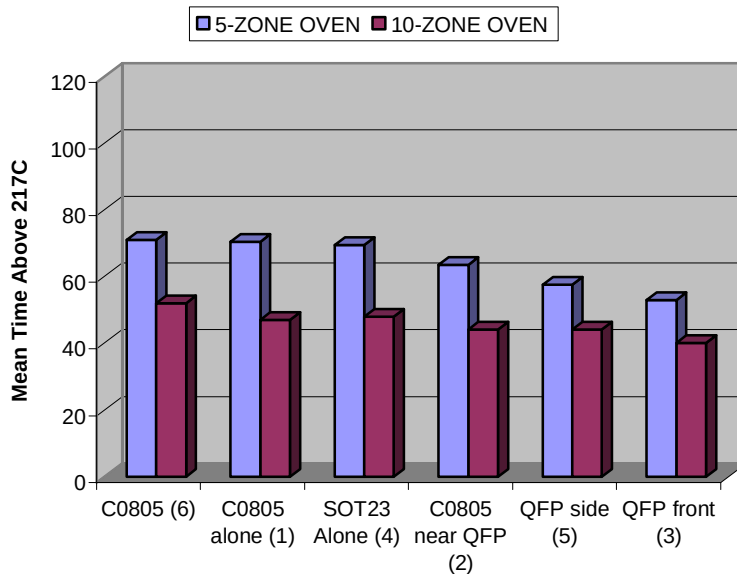


Figure 33: Comparison of time above solder melting point for both ovens with the mobile phone test assembly

The profiles on both ovens were set to give similar conditions for the coolest part of the assembly. However, again it can be seen that the resulting profiles are different at other parts of the assembly. Broadly, the relative order of maximum temperatures reached and times above solder melting point were the same for both ovens. But, the delta T (difference between the hottest and coldest parts of the assembly) for the smaller 5-zone oven was twice that of the 10-zone oven (14°C compared to 7°C). The times above solder melting point reached were also much longer for the smaller 5-zone oven (73 secs compared to 52 seconds).

Other points worth noting include the fact that the C0805 (positions 1 & 6) and SOT23 (position 4) got the hottest for longest with both ovens. These are very low thermal mass components situated in parts of the assembly with low packing density. A similar C0805 close to the QFP was 4 to 6 °C cooler than the other C0805's. This reduction in maximum temperature reached is due to the proximity of this device to the large QFP which is acting as a heat sink. The QFP itself is clearly the coolest part of the assembly due to its large thermal mass, but there is no difference between the two sides of the QFP monitored.

7.14 PC GRAPHICS CARD TEST ASSEMBLY

The graphics card test assembly is shown in Figure 35 with the thermocouple attachment positions marked. This assembly was approximately 270 x 190 mm and the PCB was approximately 1.6mm thick. The assembly contained a range of surface mount devices, including a large BGA. The joints to which the thermocouples were attached are depicted in Figure 35.

- QFP Outer (1)
- QFP Inner (2)
- Res alone (3)
- Res near QFP (4)
- PLCC (5)
- BGA (6)



Figure 34: Graphics card test assembly with £ coin scaler

7.15 PC GRAPHICS CARD TEST ASSEMBLY RESULTS

The results for the PC Graphics Card assembly for the 5-zone and 10-zone ovens are given in Tables 18 & 19.

<i>Deg C</i>	5-ZONE OVEN	10-ZONE OVEN
Res alone (3)	251	239
QFP Outer (1)	240	234
Res near QFP (4)	230	233
PLCC (5)	228	233
QFP Inner (2)	227	233
BGA (6)	225	231
Delta T	26	8

Table 18 : Results for maximum temperatures reached for PC graphics card test assembly

Table 19 : Results for time above 217°C reached for PC graphics card test assembly

<i>Seconds</i>	5-ZONE OVEN	10-ZONE OVEN
Res alone (3)	74	51
QFP Outer (1)	64	43
Res near QFP (4)	44	43
QFP Inner (2)	38	44
PLCC (5)	35	42
BGA (6)	35	38

7.16 DISCUSSION OF RESULTS FOR PC GRAPHICS CARD TEST ASSEMBLY

A comparison of the maximum temperatures reached and the time above melting point with both the 5-zone and 10-zone ovens is given in Figures 36 & 37.

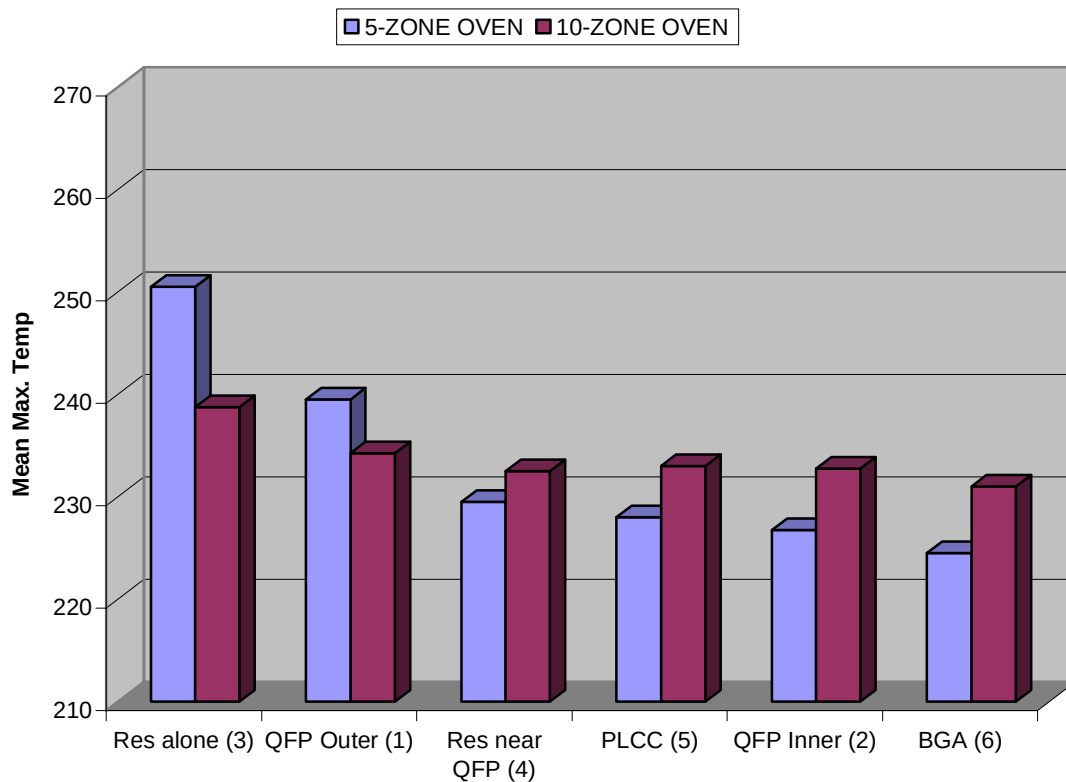


Figure 35: Comparison of maximum temperatures reached for both ovens with the PC graphics card test assembly

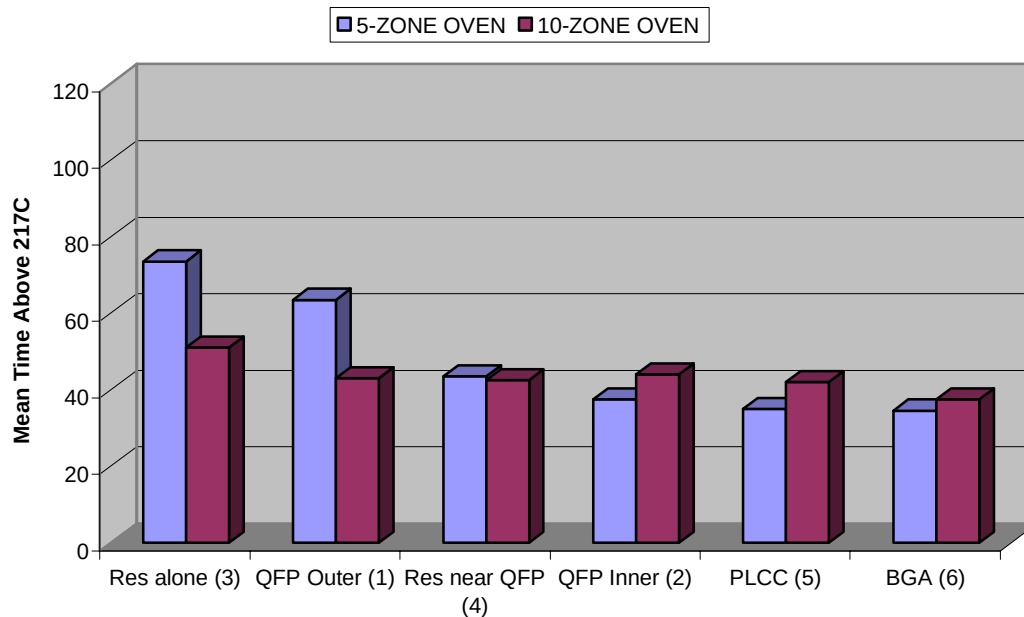


Figure 36: Comparison of time above solder melting point for both ovens with the PC graphics card test assembly

The profiles on both ovens were set to give similar conditions for the coolest part of the assembly. However it can be seen that the resulting profiles are significantly different at other parts of the assembly. Broadly, the relative order of maximum temperatures reached and times above solder melting point were the same for both ovens. But, the delta T was much greater for the smaller 5-zone oven (26°C compared to 8°C). The maximum temperatures reached were also much higher for this oven (for example 251 instead of 234.5). Similarly the times above the melting point of the solder were longer (74 seconds compared to 51 seconds).

Other points worth noting include the fact that the resistor (position 3) was the hottest part of the assembly with both ovens. It was significantly hotter than a similar resistor (position 4). This resistor was cooler because it was further away from the edge of the assembly and adjacent to a large thermal mass component. The BGA was the coolest component in both oven profiles, being the largest thermal mass component. One of the QFPs on the assembly was monitored in two places, close to the edge of the assembly (position 1) and the opposite side, closer to the centre of the assembly (position 2). In the 5-zone oven, the side of the QFP closest to the edge got significantly warmer (240°C compared to 227°C) for longer (64 seconds compared to 38 seconds) than the other side of the QFP. No differences were seen with the larger 10-zone oven profile.

7.17 PANEL TEST ASSEMBLY.

The panel test assembly is shown in Figure 38 with the thermocouple attachment positions marked. This assembly was approximately 180 x 200 mm and the panel was approximately 1.6mm thick. The panel consists of 15 circuits in 5 x 3 array. Their application is lighting control. The assembly contained a range of surface mount passives and small actives. The

joints to which the thermocouples were attached to the same component on the panels as depicted in Figure 38.

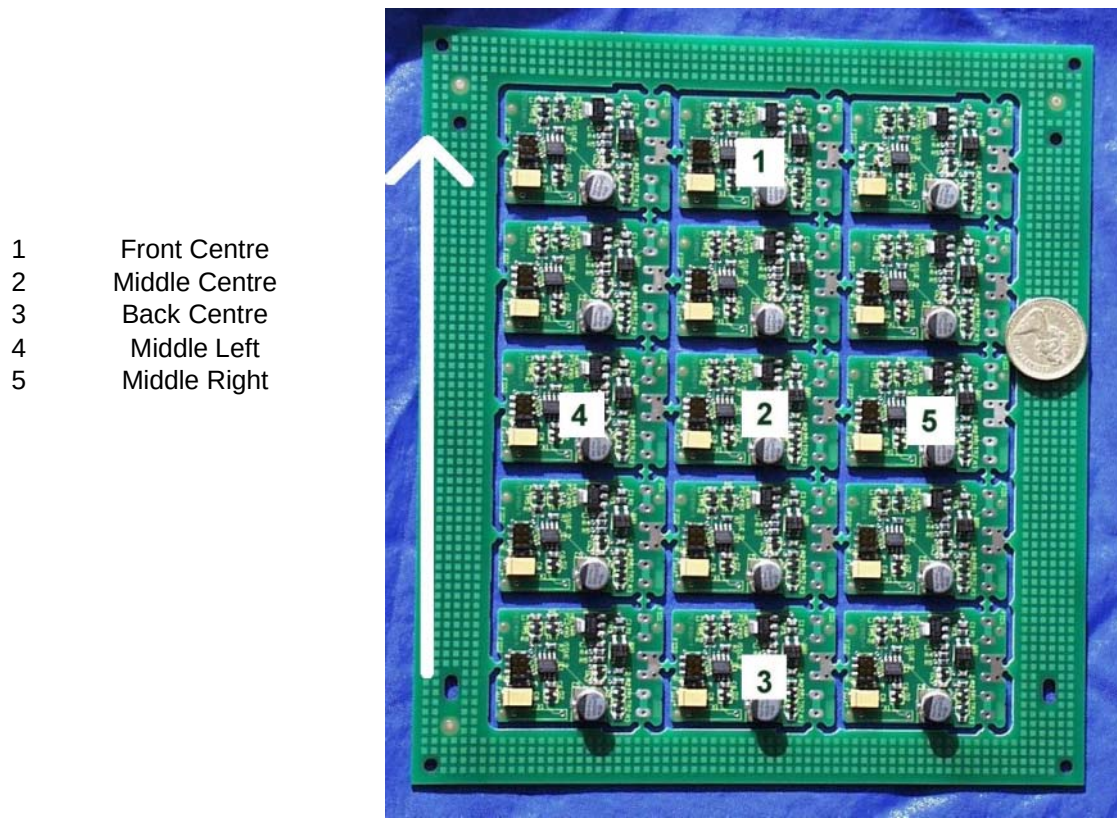


Figure 37: Panel test assembly

The panel was profiled in the forward, reverse and 90 degree orientation. The panel was also profiled with the gaps between the circuits taped up with self-adhesive aluminium tape to prevent airflow as indicated in Figure 39. All trials with this assembly were undertaken in the smaller five zone reflow oven.

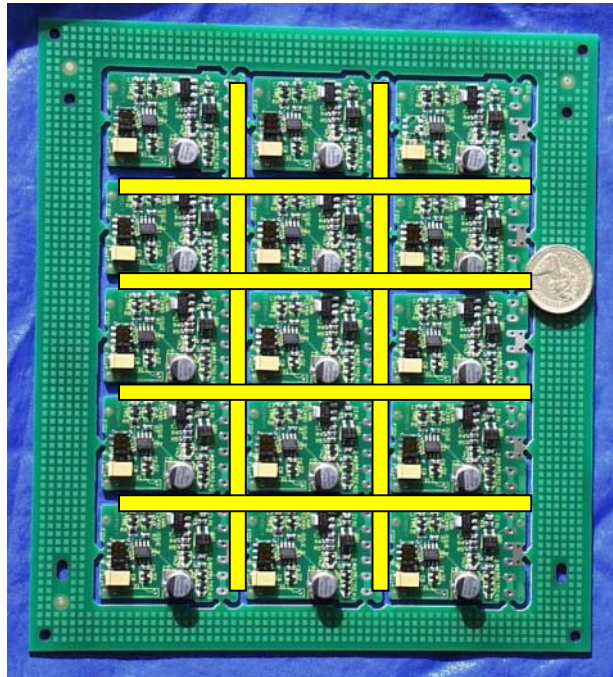


Figure 38: Panel test assembly showing taped areas

7.18 PANEL TEST ASSEMBLY RESULTS

The results for the panel test assembly are given in Tables 20 & 21.

Table 20 : Results for maximum temperatures reached for panel test assembly

Max. Temp degC	Run 1	Run 2	180 deg	90 deg	Taped
Front Centre	246	245.5	245.5	248	235
Middle Centre	248	249.5	249.5	250.5	230.5
Back Centre	248.5	248.5	248	255.5	240.5
Middle Left	247	246	245.5	252.5	246
Middle Right	252	253	252.5	256	243

Table 21 : Results for time above 217°C reached for panel test assembly

Time above 217°C	Run 1	Run 2	180 deg	90 deg	Taped
Front Centre	65	66	68	71	55
Middle Centre	68	69	71	73	42
Back Centre	67	68	69	76	60
Middle Left	69	71	70	73	73
Middle Right	70	71	79	91	66

7.19 Discussion of Results for Panel Test Assembly

A comparison of the maximum temperatures reached and the time above melting point is given in Figures 41 & 42

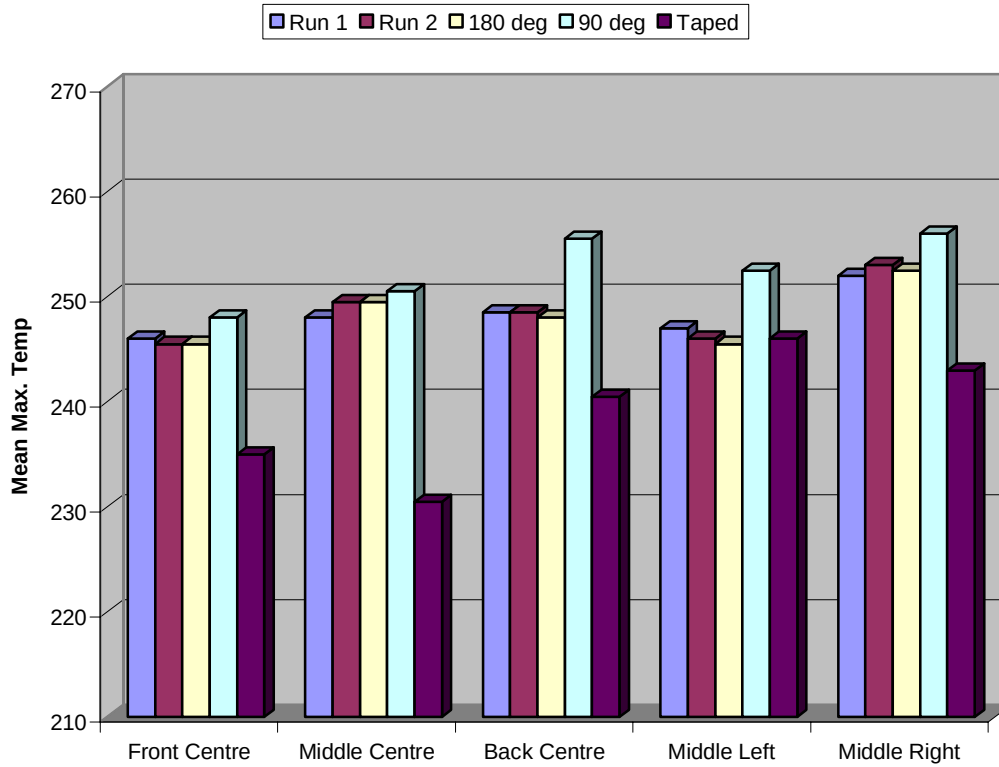


Figure 39: Comparison of maximum temperatures reached with the panel test assembly

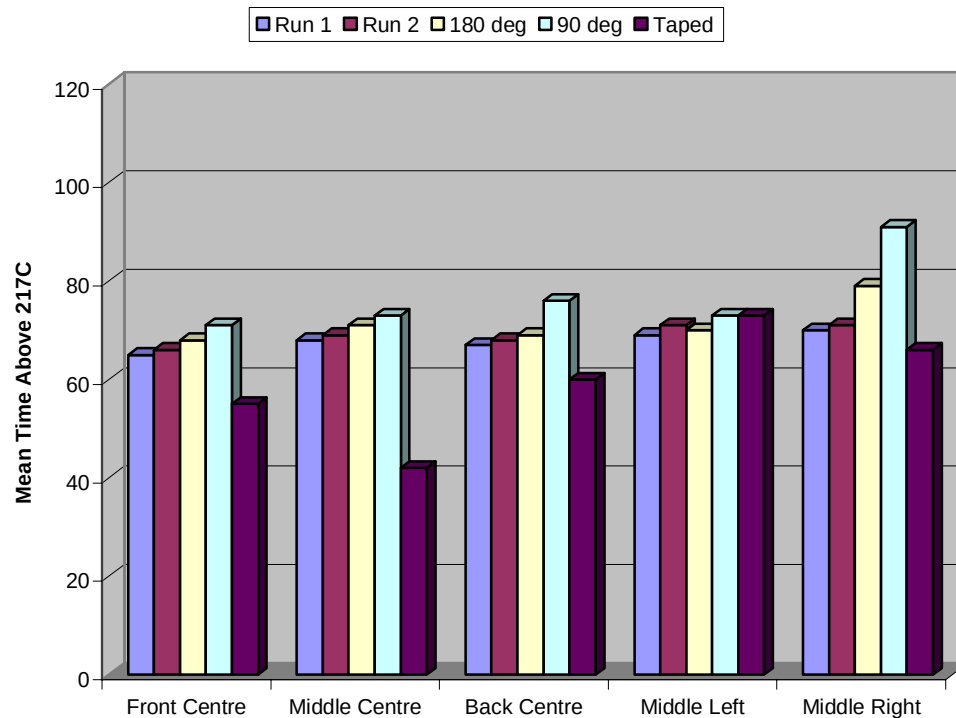


Figure 40: Comparison of time above solder melting point for the panel test assembly

There is little difference between the individual circuit temperatures within the panel no matter which orientation the assembly is profiled. The middle right position is generally slightly warmer for longer than the other positions and this is probably a function of the oven. The even temperature distribution is because the circuits are small and largely independent of each other due to the limited number of connection lugs.

When the routing slots between the individual circuits are taped up and airflow is restricted to the edges of the outermost assemblies, the panel performs much more like a single PCB. The middle left and middle right maximum temperatures and times above the solder melting point were very similar. The middle centre circuit was much cooler with a shorter time above the solder melting point indicating that the edges of the assembly play a significant part in the heat transfer process. The front and back, in the direction of profiling, of the assembly fell in between these two extremes.

7.20 THERMOCOUPLE POSITION CONCLUSIONS

A number of conclusions can be drawn from this section of the work about the likely positions of the maximum and minimum temperatures on an assembly. The temperature that a solder joint reaches has been shown to be effected by at least three factors.

- The first of these factors is thermal mass of the component. A larger thermal mass component results in a lower maximum temperature reached and a shorter time above the solder melting point than for a smaller thermal mass component.

- The proximity of a component to components of high thermal mass is also important. The maximum temperature of smaller components can be suppressed if they are close to a large thermal mass component. Similarly their time above the melting point of the solder will be reduced.
- The final aspect identified here is the proximity of the solder joint to the edge of the assembly. A joint closer to the assembly edge will reach a higher maximum temperature and be above the melting point of the solder for longer than an identical solder joint further away from the edge.
- Where a circuit is part of a panel, provided that each circuit is thermally isolated from its neighbours within the panel by minimal use of connecting lugs, each circuit may be considered to be identical to its partners and profiled accordingly.
- Other factors not explored in this work which may affect the temperatures which solder joints reach, include the extent of any copper planes directly connected to a solder joint, i.e. those planes which would increase the thermal mass of a component.

7.21 REFLOW OVEN CONCLUSIONS

This work clearly shows that oven design can play a significant part in reflow profiling. With most of the assemblies tested here, the larger of the two ovens used gave a better profile. Indeed in many cases, the profile set up on the smaller oven may have caused component damage and certainly exceeded the recommended profiles of many component manufacturers. Ovens with a greater the number of heating zones and/or increasing the length of the heated zones, will give lower delta Ts and lower maximum temperatures.

8 VEHICLES FOR INITIAL PROFILING OF AN ASSEMBLY

When a new assembly is initially profiled, it is often the case that a fully populated assembly cannot be spared for thermocouple attachment, due either to limited availability of components or PCBs, or because the manufacturer does not want the expense of scrapping an entire assembly. This section of the project looks at the suitability of other vehicles for initial profiling.

8.1 EXPERIMENTAL PROCEDURE

To assess the requirements for a vehicle suitable for obtaining an accurate profile of a populated assembly, three different types of vehicle representing two different circuit designs were used. The designs utilised were the Roke Manor test assembly as detailed in Section 7.8 above and a Fujitsu II test assembly. This latter assembly was approximately 215 x 212 mm and the PCB was approximately 1.8mm thick. Its application is in telecommunications. The assembly contained a range of surface mount devices; including a 176 I/O 0.5mm pitch QFP. The two board configurations are shown in Figures 42 & 43.

Tantalum (1)
R0603 (2)
PLCC (3)
QFP1 (4)
QFP2 (5)

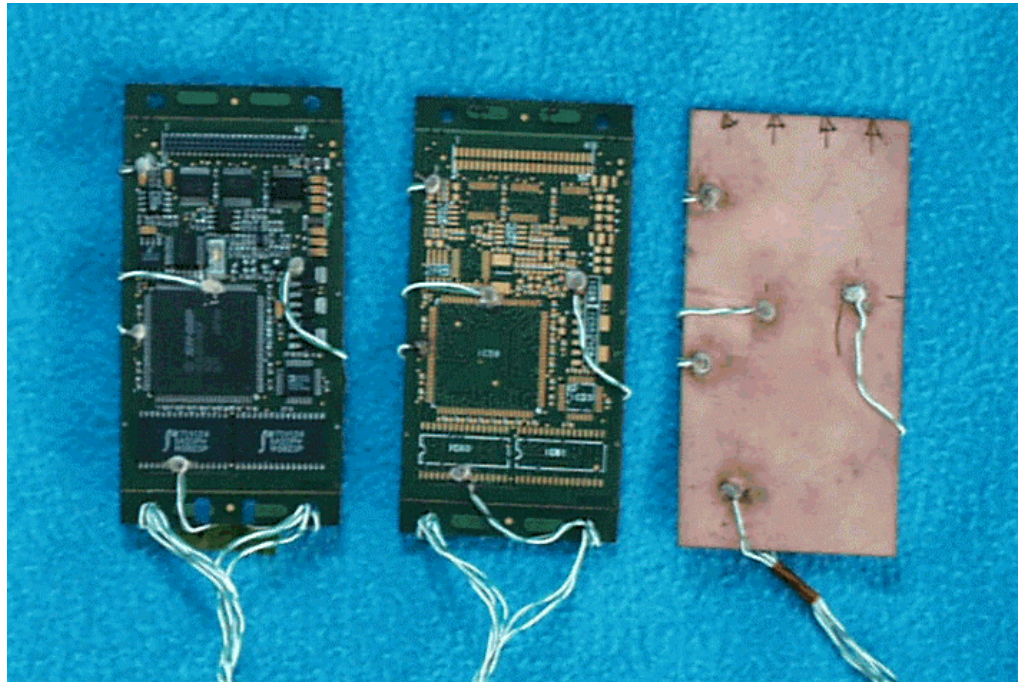


Figure 41: Roke Manor test vehicles (from left to right : populated assembly, bare board and unprocessed laminate)

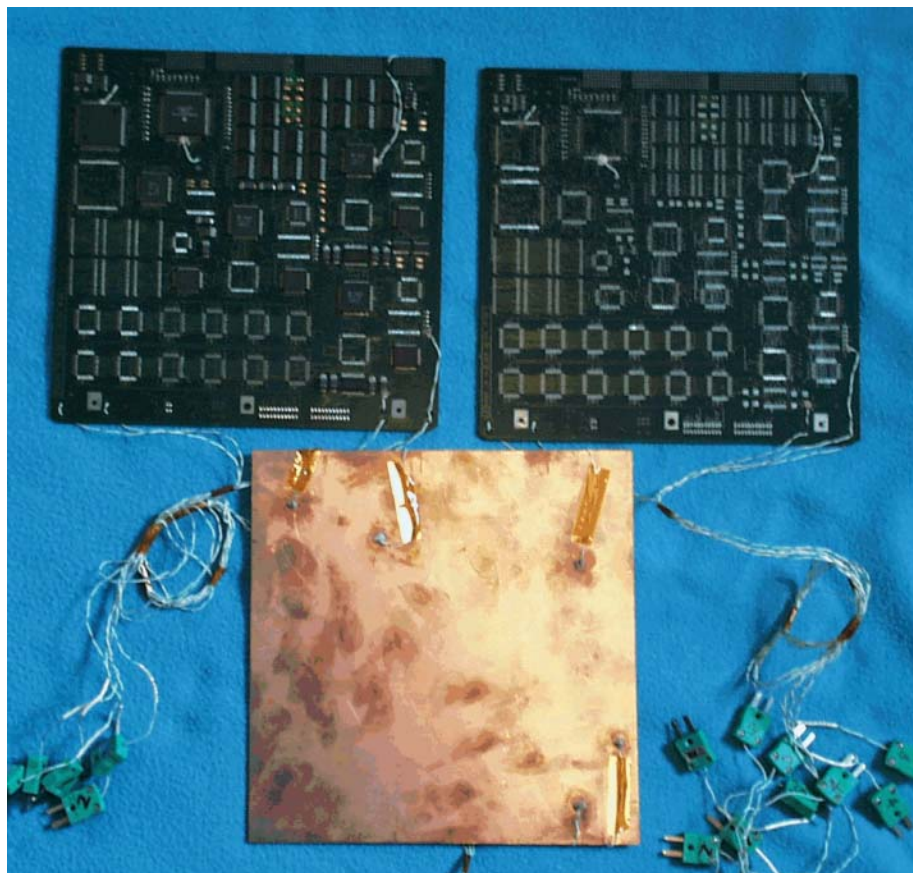


Figure 42: Fujitsu II test vehicles (clockwise from top left : populated assembly, bare board and unprocessed laminate)

Three different representations of these two assemblies were utilised. In addition to a populated assembly, thermocouples were also attached in the same positions to a bare board and to sheets of unprocessed copper clad laminate the same size and shape as the assembly. The three vehicles are shown in Figures 42 and 43. All the vehicles were profiled through the smaller five-zone reflow system with an overall heated length of around 2 metres.

8.2 RESULTS

The results from the two test vehicles are given in Tables 22 to 25.

Table 22: Results for the average maximum temperature in the profile for the Roke Manor test vehicles

Deg C	Laminate Avg.	Bare board Avg.	Assembly Avg.
Tantalum	261	251	237
SOT223	256	249	234
QFP	251	245	231
C0603	257	254	237
SO32W	255	256	238

Table 23: Results for the average time above 217°C for the Roke Manor test vehicles

Seconds	Laminate Avg.	Bare board Avg.	Assembly Avg.
Tantalum	77	69	60
SOT223	73	68	53
QFP	67	63	48
C0603	71	70	58
SO32W	72	72	60

Table 24: Results for the average maximum temperature in the profile for the Fujitsu II test vehicles

Deg C	Laminate Avg.	Bare board Avg.	Assembly Avg.
Tantalum	265	263	255
R0603	271	263	273
PLCC	265	253	244
QFP1	245	239	226
QFP2	266	259	240

Table 25: Results for the average time above 217°C for the Fujitsu II test vehicles

Seconds	Laminate Avg.	Bare board Avg.	Assembly Avg.
Tantalum	94	82	81
R0603	109	95	102
PLCC	86	72	72
QFP1	60	54	31
QFP2	91	84	66

8.3 DISCUSSION

A comparison of the results of maximum temperatures reached for the Roke Manor test vehicles is given in Figure 44. This clearly shows that both the unprocessed laminate and the unpopulated bare board get much hotter than the populated assembly, by at least 12°C. Figure 45 shows the maximum temperature differences.

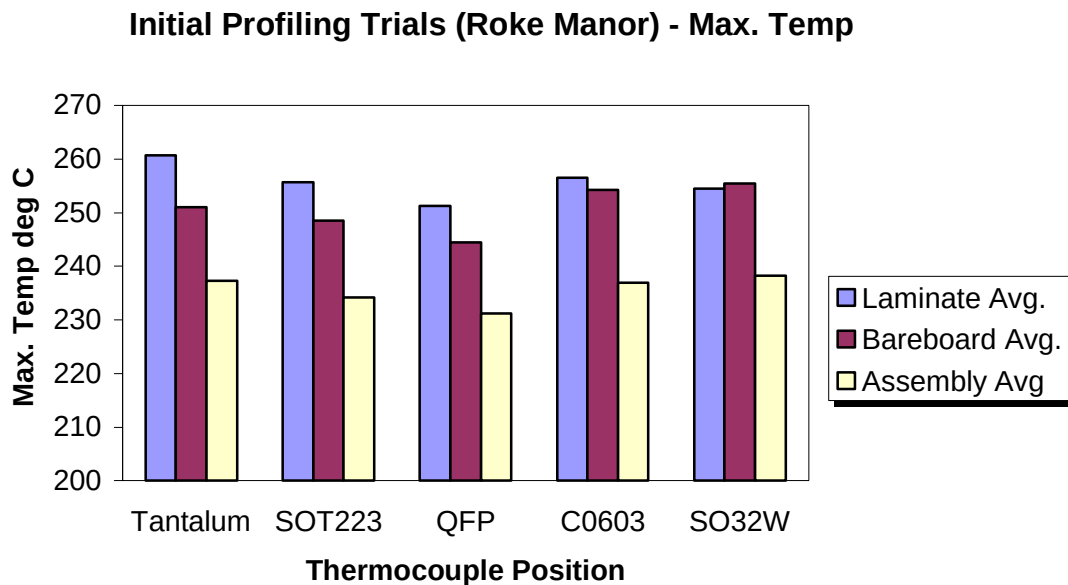


Figure 43: Comparison of maximum temperatures reached for Roke Manor test assemblies

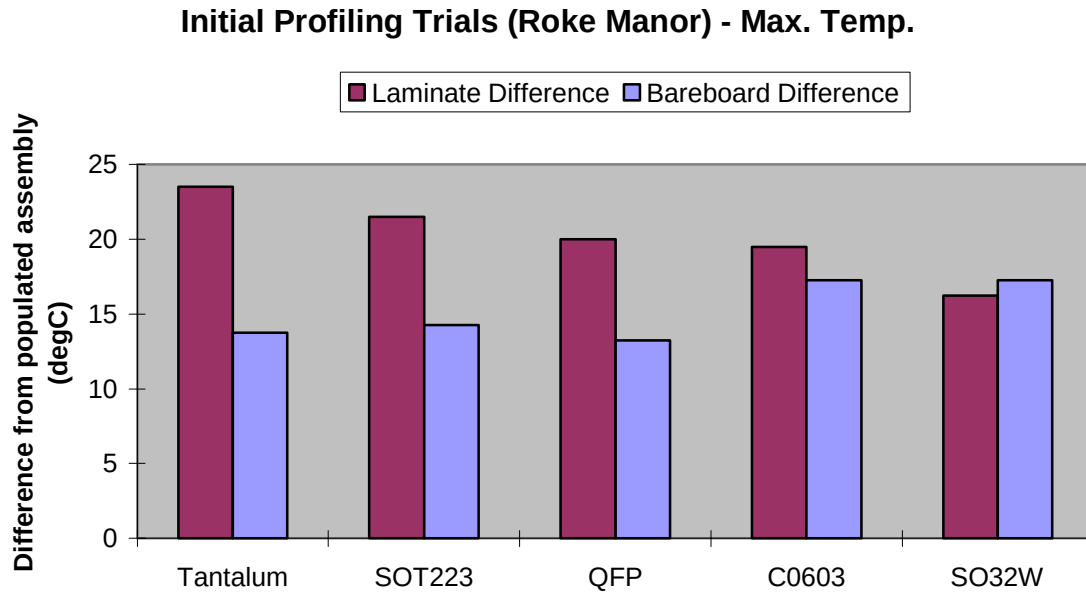


Figure 44: Differences in maximum temperatures reached between unprocessed laminate and unpopulated bare board when compared with the populated assembly for the Roke Manor test vehicles

A comparison of the results of times above 217 °C for the Roke Manor test vehicles is given in Figure 46. This clearly shows that both the unprocessed laminate and the unpopulated bare board get above 217 °C for much longer than the populated assembly, by at least 15 seconds. Figure 47 shows the maximum temperature differences.

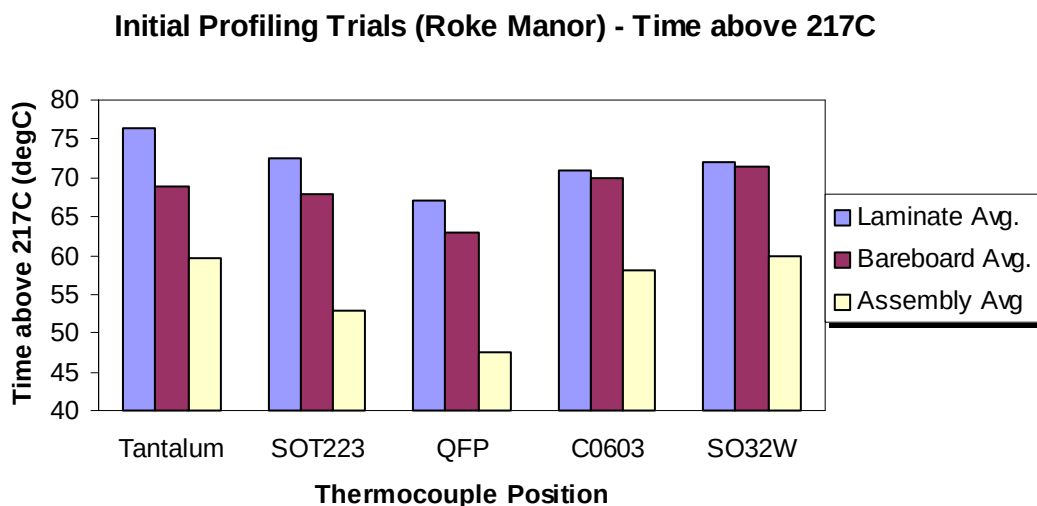


Figure 45: Comparison of times above solder melting point for Roke Manor test assemblies

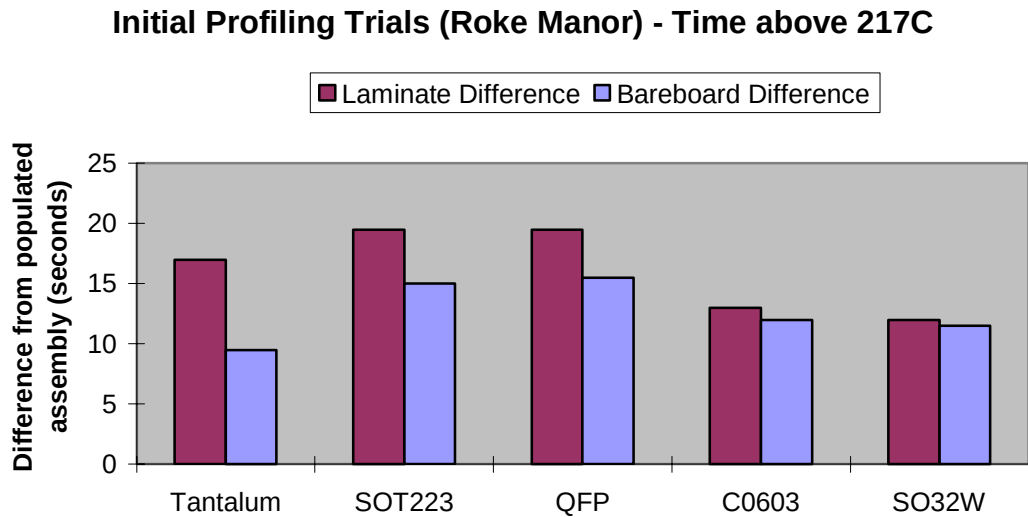


Figure 46: Differences in times above solder melting point between unprocessed laminate and unpopulated bare board when compared with the populated assembly for the Roke Manor test vehicles

A comparison of the results of maximum temperatures reached for the Fujitsu II test vehicles is given in Figure 48. This clearly shows that both the unprocessed laminate and the unpopulated bare board get hotter than the populated assembly, by at least 10 °C. The exception is the R0603 position, which reaches a similar temperature on all three vehicles. This is because this component has a very low thermal mass and is in an isolated position on the vehicles. Figure 49 shows the maximum temperature differences.

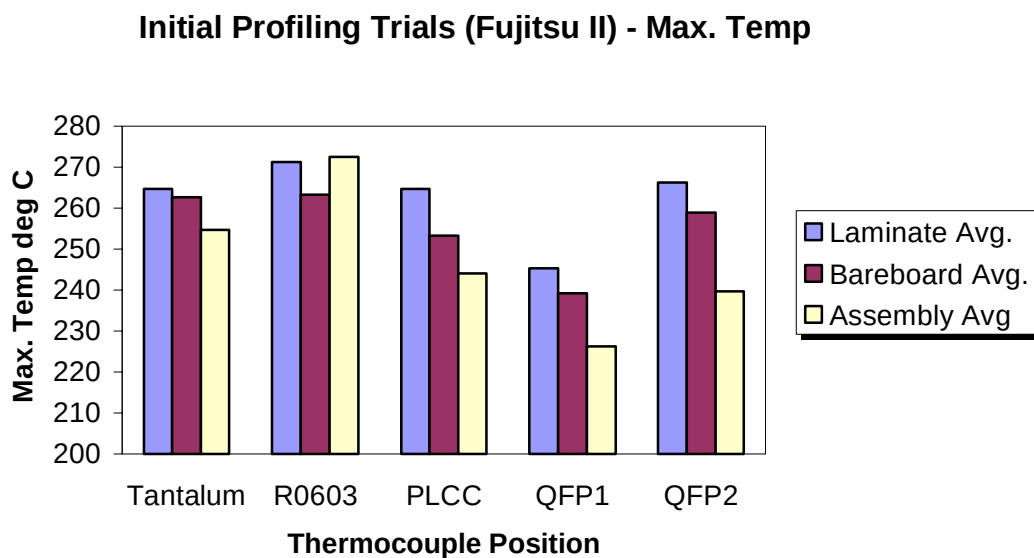


Figure 47: Comparison of maximum temperatures reached for Fujitsu II test assemblies

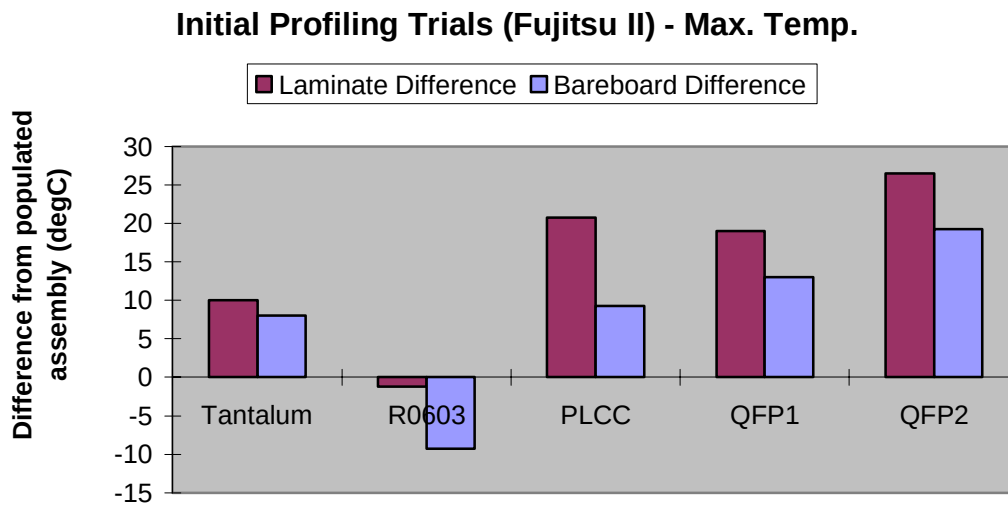


Figure 48: Differences in maximum temperatures reached between unprocessed laminate and unpopulated bare board when compared with the populated assembly for the Roke Manor test vehicles

A comparison of the results of times above 217 °C for the Fujitsu II test vehicles is given in Figure 50. This shows that generally both the unprocessed laminate and the unpopulated bare board get above 217 °C for longer than the populated assembly. The exceptions are the R0603 position, which has a similar time above melting point for the same reasons given earlier. The PLCC and tantalum positions on the bare board show similar times above the solder melting point as the populated assembly. Both positions are close to the edge of the vehicles and therefore will heat quickly to saturation temperature and remain there throughout the profile. The Figure 51 shows the maximum temperature differences.

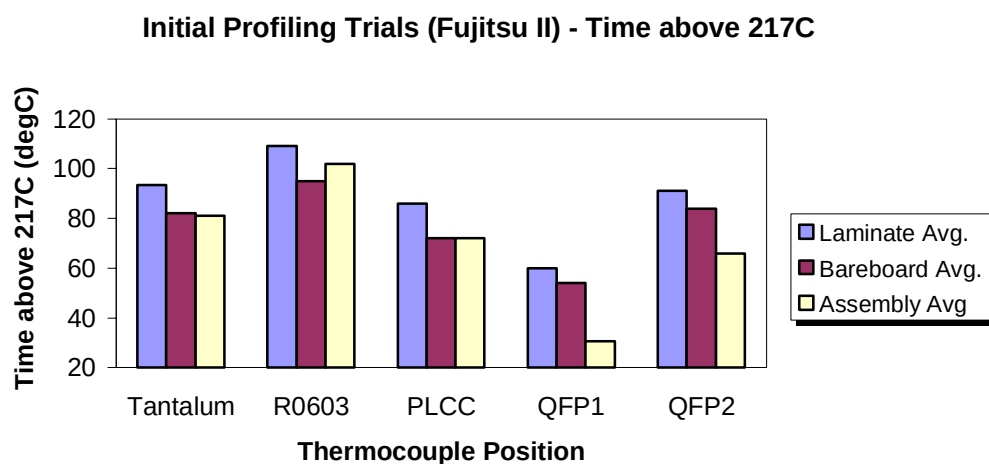


Figure 49: Comparison of times above solder melting point for Fujitsu II test assemblies

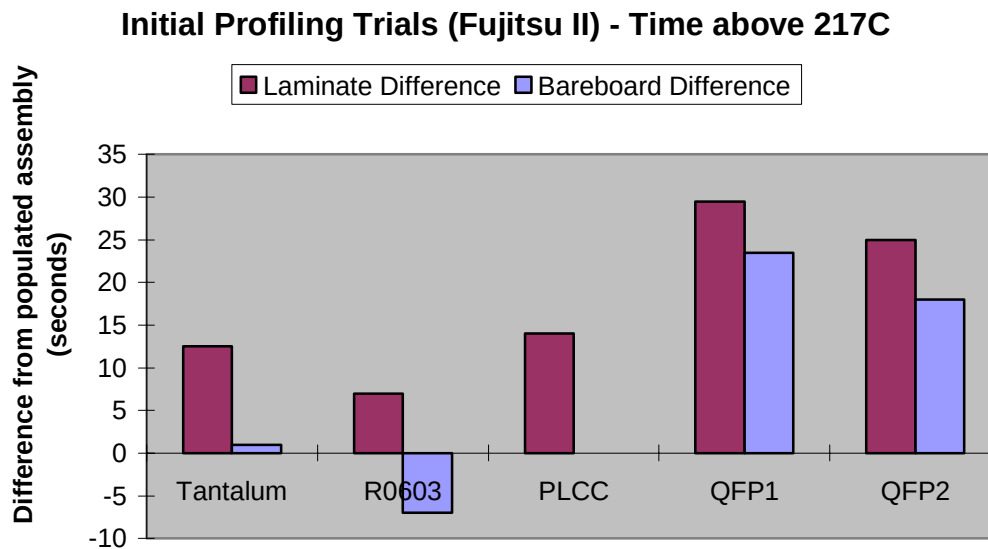


Figure 50: Differences in times above solder melting point between unprocessed laminate and unpopulated bare board when compared with the populated assembly for the Fujitsu II test vehicles

8.4 CONCLUSIONS

Both the unprocessed bare laminate vehicle and the unpopulated bare board vehicle proved unacceptable as vehicles for initial profiling of assemblies. With these vehicles the maximum temperatures reached were generally higher than the populated assembly, with the exception of small thermal mass components in isolated positions.

The times above the melting point of the solder for the alternative vehicles were significantly longer than for the populated assembly except for components in positions close to the edges of the vehicles.

It must therefore be concluded that fully populated assemblies are required to get accurate profiling and that representative temperatures cannot be obtained by using unpopulated bare boards or unprocessed laminate vehicles.

9 USING PROFILERS

9.1 EFFECT OF INITIAL VEHICLE TEMPERATURE ON PROFILE

During initial set up of a profile, it is generally the case that multiple profiling runs are undertaken with little time elapsed between each run. In this section of the work, the effect of

not allowing the initial set-up vehicle to return to room temperature before running the profile is investigated.

9.2 EXPERIMENTAL PROCEDURE

The PC graphics card and the Alstom test assembly as detailed as Sections 7.11 & 7.2 respectively were utilised for this work. The assemblies were sent through the oven in the normal way with a room temperature starting temperature. The assemblies were also sent through the same profile after being soaked for 30 minutes in an air circulation oven at 50°C. The assemblies were profiled through the smaller 5-zone convection reflow system with an overall heated length of around 2 metres.

9.3 EXPERIMENTAL RESULTS

The results for the PC Graphics Card assembly are given in Tables 26 & 27.

Table 26: Results for average maximum temperatures reached for initial vehicle temperature PC graphics card test vehicle

<i>Deg C</i>	Room Temp	50C start
Res alone	253	255
QFP Outer	242	242
Res near QFP	230	235
PLCC	229	232
QFP Inner	229	231
BGA	226	229
Delta T	27	26

Table 27: Results for average time above 217°C for initial vehicle temperature PC graphics card test vehicle

<i>Seconds</i>	Room Temp	50C start
Res alone	76	79
QFP Outer	67	73
Res near QFP	47	58
QFP Inner	43	52
PLCC	40	54
BGA	39	47

The results for the Alstom test assembly are given in Tables 28 & 29.

Table 28: Results for average maximum temperatures reached for initial vehicle temperature Alstom test vehicle

<i>Deg C</i>	No preheat	50 deg preheat
SOIC Edge (1)	259	263
SOT23 (5)	257	261
QFP (4)	239	243
Large Relay (6)	238	241
SOIC Centre (2)	223	228
PLCC (3)	217	223
Delta T	42	40

Table 29: Results for average time above 217°C for initial vehicle temperature Alstom test vehicle

<i>Seconds</i>	No preheat	50 deg preheat
SOIC Edge (1)	92	96
SOT23 (5)	88	92
QFP (4)	63	70
Large Relay (6)	63	67
SOIC Centre (2)	24	38
PLCC (3)	3	23

9.4 DISCUSSION

A comparison of the results of average maximum temperatures reached and the average times above the solder melting point for the initial vehicle temperature test vehicles is given in Figures 52 to 55 below.

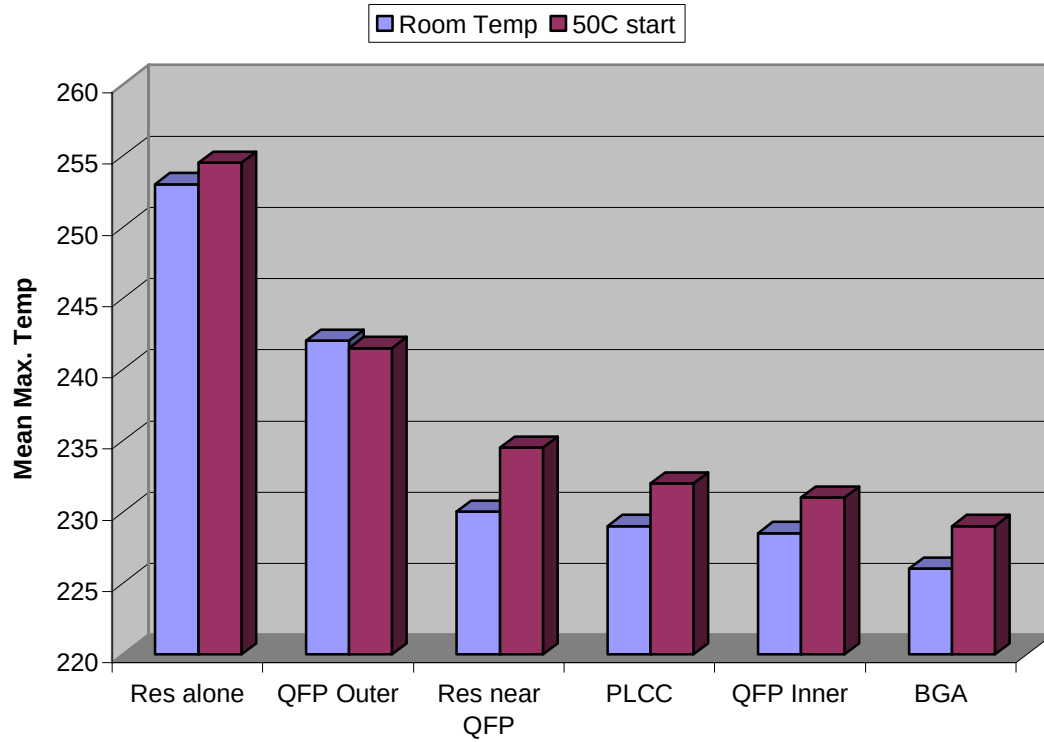


Figure 51: Comparison of maximum temperatures reached for initial vehicle temperature PC graphics card test assembly

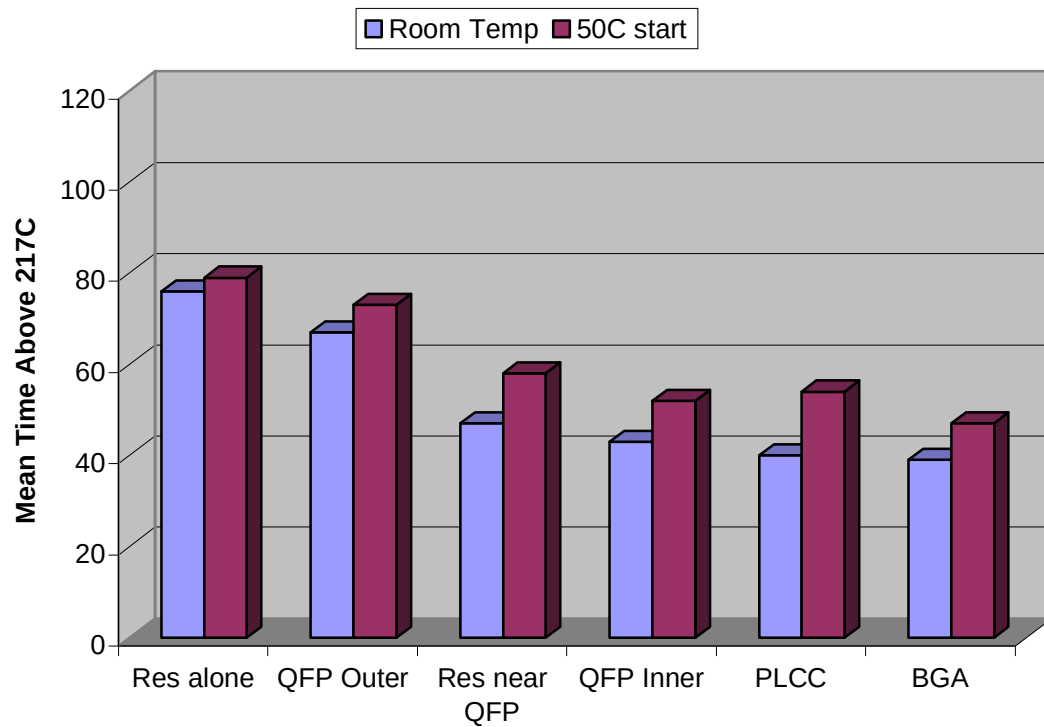


Figure 52: Comparison of times above solder melting point for initial vehicle temperature PC graphics card test assembly

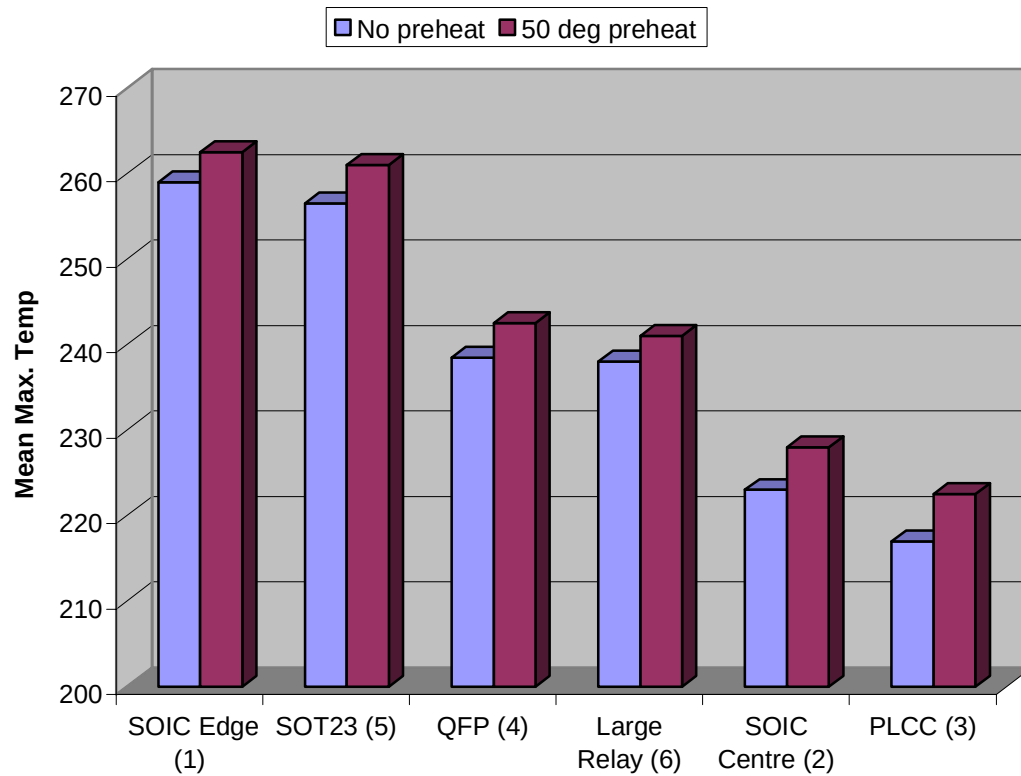


Figure 53: Comparison of maximum temperatures reached for initial vehicle temperature Alstom test assembly

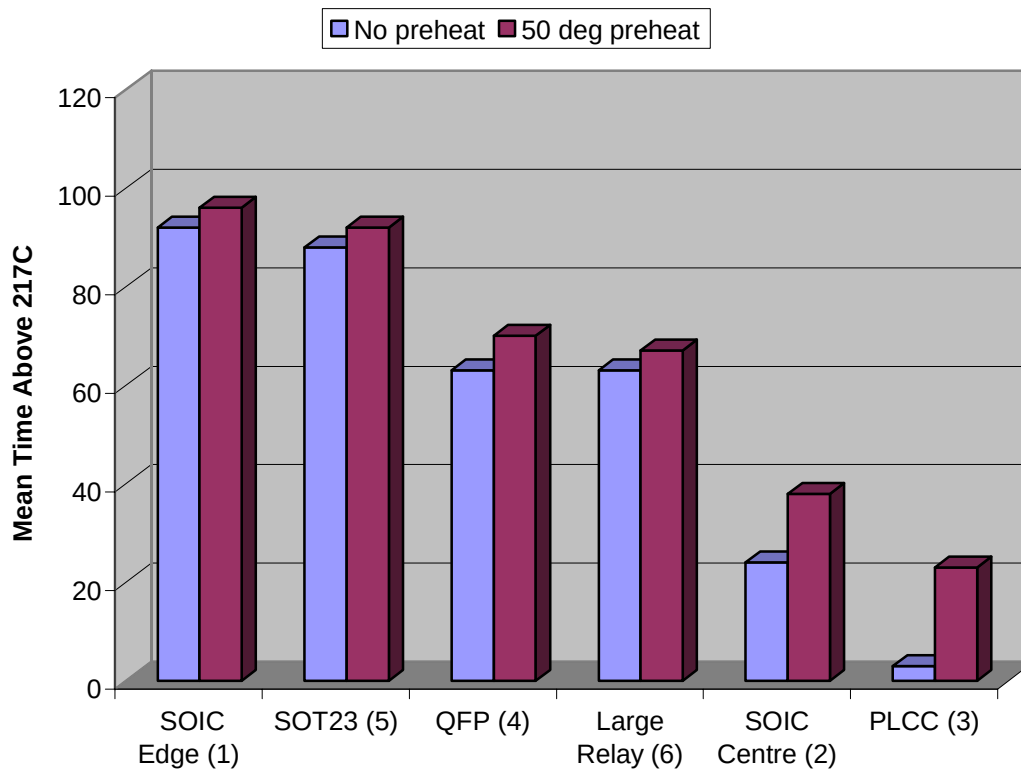


Figure 54: Comparison of times above solder melting point for initial vehicle temperature Alstom test assembly

These results show that although there is little difference in the average maximum temperatures reached by the lower thermal mass PC graphics card assembly, the higher thermal mass Alstom assembly did reach maximum temperatures of around 4 to 6 °C higher after the 50°C preheat. With both test assemblies, it can be seen that the times above the melting point of the solder alloy were increased for the solder joints measured when the 50°C preheat was used. This increase in time was up to 14 seconds or 35% in the case of the PLCC solder joint measured on the PC graphics card assembly, and as much as 20 seconds (670%) on a similar joint on the Alstom assembly.

It should therefore be considered necessary to allow test vehicles to return to room temperature prior to profiling if an accurate set of measurements is to be recorded.

9.5 POSITIONING OF DATA RECORDER

The positioning of the travelling data recorder was investigated to determine if a position in front of, or behind, the assembly being profiled was best. Two test vehicles were used. The Roke Manor test assembly and the Alstom test assembly as detailed in Sections 7.8 and 7.2 above. Both assemblies were profiled with the data recorder behind and in front of the test assembly. The assemblies were profiled through the smaller 5-zone convection reflow system with an overall heated length of around 2 metres.

9.6 EXPERIMENTAL RESULTS

The results for the Roke Manor assembly are given in Tables 30 & 31.

Table 30 : Results for maximum temperatures reached for the Roke Manor test vehicle

<i>Deg C</i>	Profiler behind	Profiler in front
SOIC (6)	236	235
Tantalum (2)	235	232
C0603 (5)	235	233
SOT223 (3)	234	234
QFP (4)	231	229
Delta T	5	7

Table 31: Results for average time above 217°C for the Roke Manor test vehicle

<i>Seconds</i>	Profiler behind	Profiler in front
Tantalum (2)	68	61
QFP (4)	66	64
SOT223 (3)	64	59
SOIC (6)	62	62
C0603 (5)	59	48

The results for the Alstom test assembly are given in Tables 32 & 33.

Table 32 : Results for average maximum temperatures reached for initial vehicle temperature Alstom test vehicle

<i>Deg C</i>	Profiler behind	Profiler in front
SOIC Edge (1)	259	260
SOT23 (5)	257	256
QFP (4)	239	238
Large Relay (6)	238	233
SOIC Centre (2)	223	221
PLCC (3)	217	214
Delta T	42	46

Table 33 : Results for average time above 217°C for initial vehicle temperature Alstom test vehicle

<i>Seconds</i>	Profiler behind	Profiler in front
SOIC Edge (1)	92	89
SOT23 (5)	88	84
QFP (4)	63	59
Large Relay (6)	63	38
SOIC Centre (2)	24	18
PLCC (3)	3	0

9.7 DISCUSSION

A comparison of the results of average maximum temperatures reached and the average times above the solder melting point for the test vehicles is given in Figures 56 to 59 below.

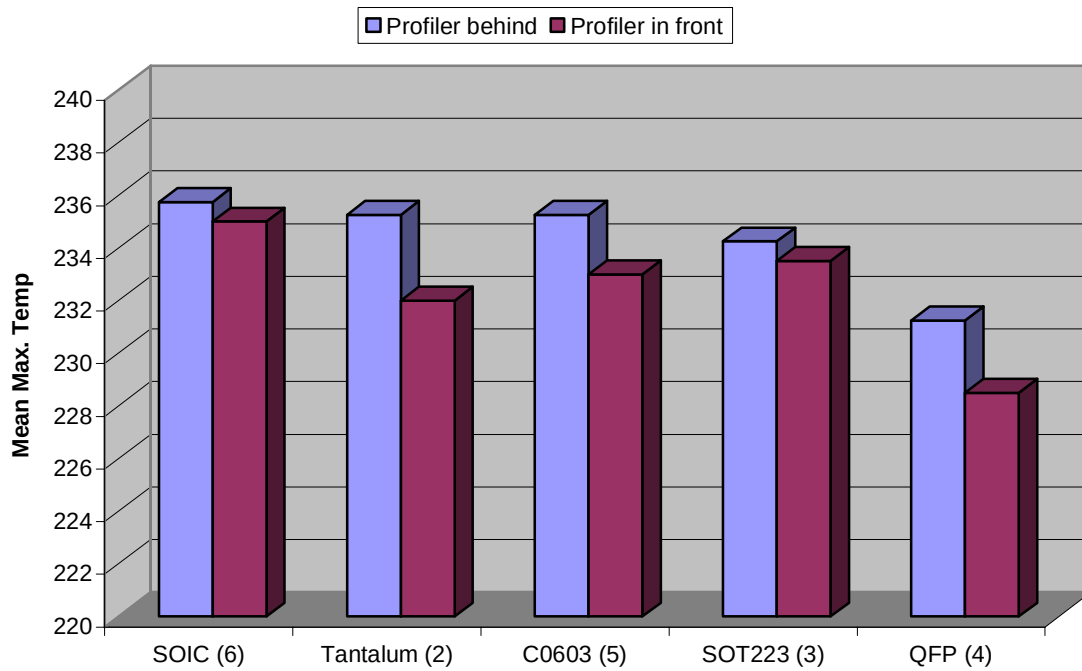


Figure 55: Comparison of maximum temperatures reached for the Roke Manor test assembly

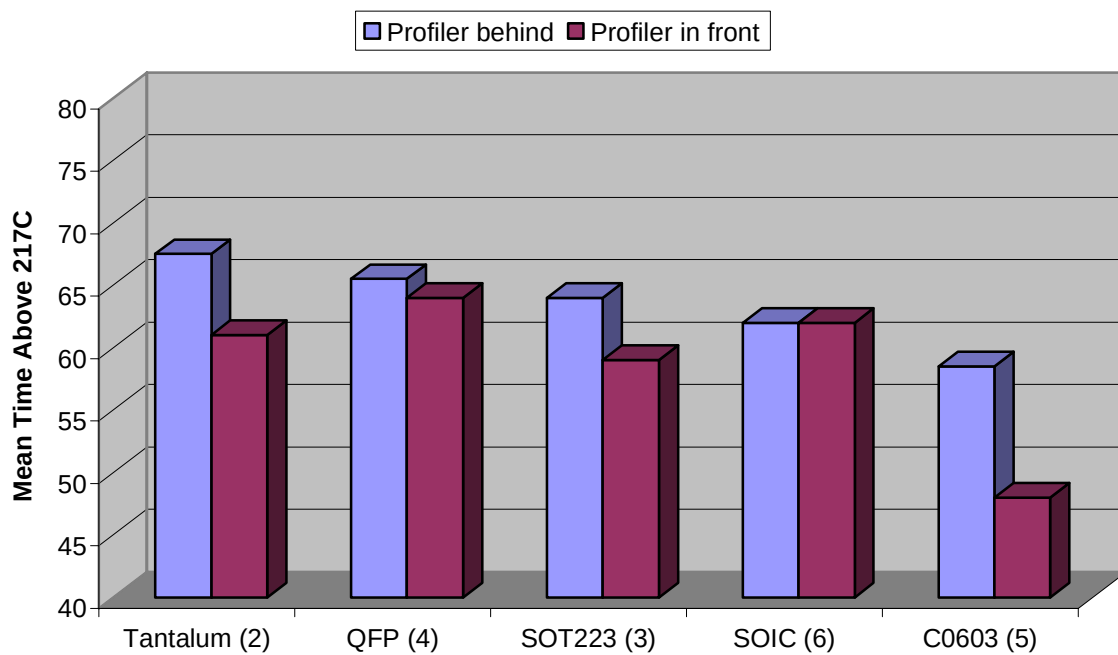


Figure 56: Comparison of times above solder melting point for Roke Manor test assembly

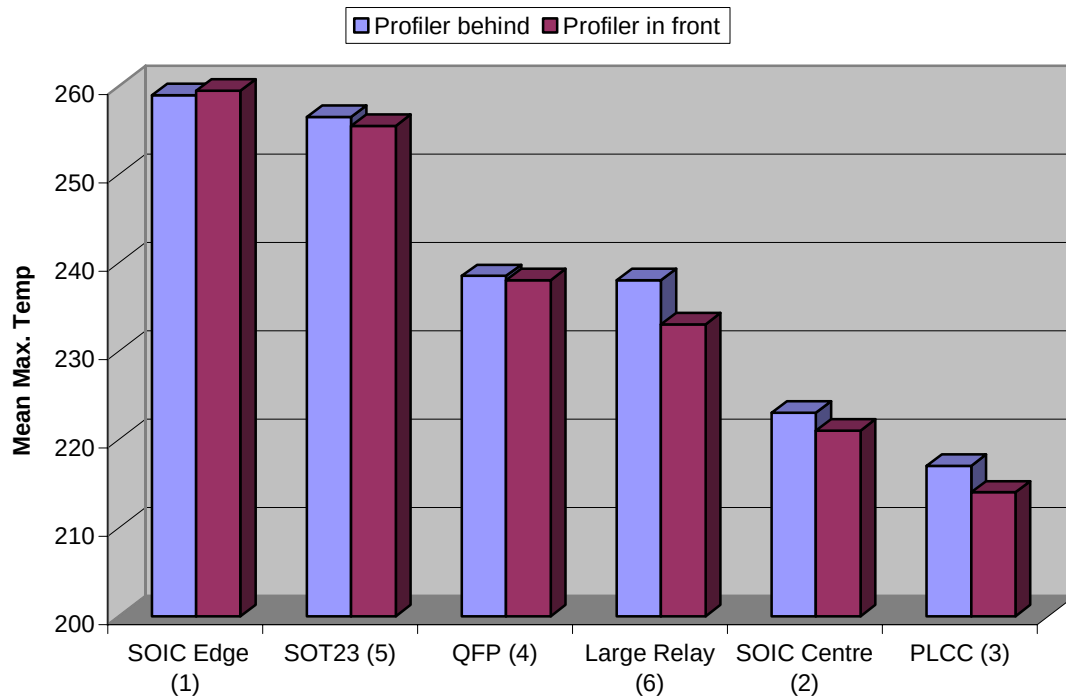


Figure 57: Comparison of maximum temperatures reached for initial vehicle temperature Alstom test assembly

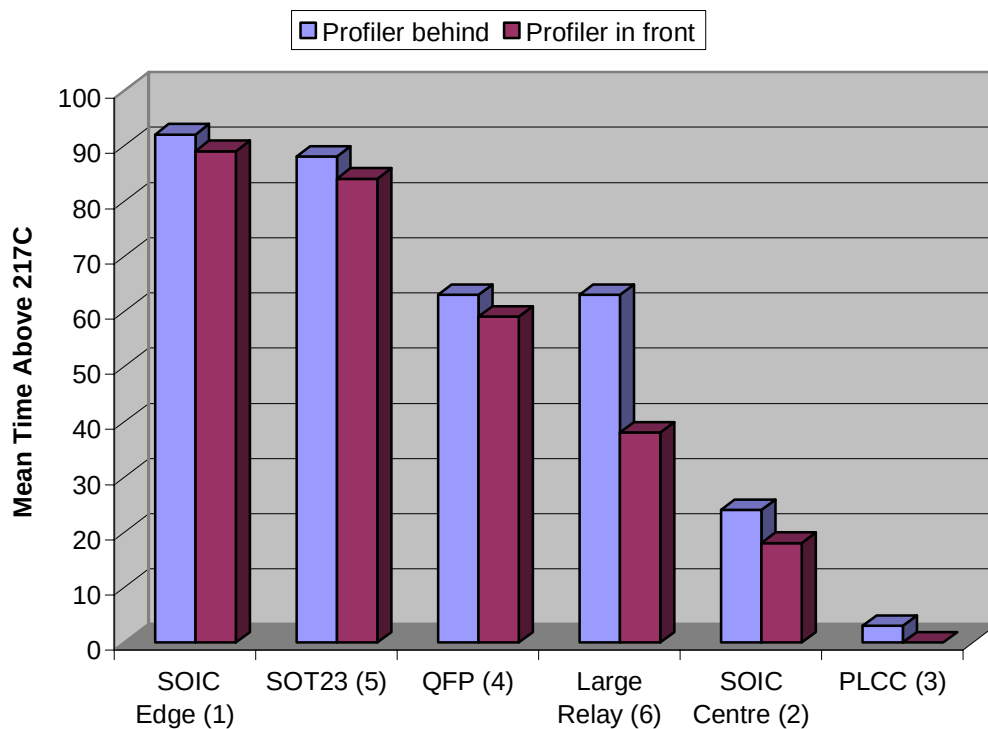


Figure 58: Comparison of times above solder melting point for initial vehicle temperature Alstom test assembly

These results show that by placing the profiler in front of the assembly being measured, the maximum temperatures are generally reduced. The only exception is the SOIC at the edge of the Alstom test assembly. This position is the hottest part of this assembly and has probably saturated in terms of heat input. The remaining positions all decrease in temperature by between 1 and 5°C. In the case of the coolest part of the Alstom assembly, the effect of the profiler is to suppress the temperature of the solder joint below the melting point of the alloy.

Similarly, the time above the melting point of the solder is reduced when the profiler is in front of the test assembly, in some examples quite significantly. The biggest change is in the molten solder time for the large relay, which is reduced by 40% when the profiler is in front of the assembly.

In the case of both these assemblies the profiler, when placed in front of the assembly, is draining heat from the system and the heaters do not have sufficient output to raise the zone temperature back to the required temperature before the assembly passes through it.

It is therefore recommended that the profiler should follow the assembly to be measured to prevent inaccurate readings being logged.

10 REGULAR PROFILERS

10.1 INTRODUCTION

Once the initial profile has been set up, profiling should be regularly undertaken to ensure that the reflow oven is operating according to its set parameters. It is possible to do this with the initial set-up assembly but this will age with every profile run and may not be robust enough to withstand storage and repeated handling. Several suppliers offer bespoke solutions and three such systems have been evaluated here.

10.2 EXPERIMENTAL PROCEDURE

All systems were passed through 3 different profiles to determine if a change in profile was detectable. The standard profile had a final reflow zone temperature of 260°C and a belt speed of 685mm/min. The second profile was similar to the first but the final zone temperature was reduced to 250°C (250C profile). The remaining profile was again similar to the first but the belt speed was increased to 760mm/min (760 profile).

Five systems were profiled in total. The Alstom test assembly as detailed in Section 7.2 was again utilised. Also a panel of unprocessed laminate material (150mm x 150mm) was used which had five thermocouples attached at equal distances down the centre of the panel from front to back.

Three commercial systems were also evaluated. Two of these systems were based on vehicles that are connected to a data-logger and pass through the oven to check the profile. System A monitored the performance of six thermocouples attached to a stainless steel carrier measuring air temperatures.

System B, in addition to monitoring three air temperatures across the belt width, also monitored the temperature of three thermal loads (cylinders of metals approximately 2.5cm in diameter and 1 cm thick) across the belt width. In conjunction with a magnetic sensor, which detects markers at the start of each oven zone, these allow a change in temperature across the zone to be calculated. In subsequent Tables and Figures the monitoring of air temperature is referred to as “ambient”, and the monitoring of the metal cylinders is referred to as “process”.

The third commercial system (System C) was based on a set of stainless-steel clad thermocouple probes that were permanently fixed inside the oven and constantly monitored the oven performance. All three of the commercial systems were accompanied by analysis software to aid the engineer in interpreting collected data, but it is not the remit of this work to compare such packages. Therefore, this work concentrated on comparing the data recorded by the systems hardware.

10.3 RESULTS

The results for the five systems are given in Tables 34 to 42 below.

Table 34: Results for average maximum temperatures reached for Alstom test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
1	235	230	232
2	227	224	224
3	224	220	221
4	227	224	224
5	240	235	237
6	230	226	227

Table 35: Results for average time above molten solder temperature for Alstom test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
1	45	42	37
2	36	32	28
3	29	22	18
4	35	29	27
5	49	46	41
6	39	36	31

Table 36: Results for average maximum temperatures reached for laminate test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
1	241	237	240
2	239	235	237
3	240	235	235
4	238	235	236
5	241	237	238

Table 37: Results for average time above molten solder temperature for laminate test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
1	49	48	43
2	47	46	40
3	49	47	40
4	47	45	41
5	49	47	42

Table 38: Results for average maximum temperatures reached for system A test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
1	229	226	227
2	226	223	223
3	228	224	224
4	226	222	223
5	230	226	227
6	229	225	226

Table 39: Results for average time above molten solder temperature for system A test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
1	31	31	28
2	31	28	24
3	33	29	26
4	29	25	21
5	35	34	28
6	33	30	25

Table 40: Results for average maximum temperatures reached for system B test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
Ambient (A)	244	241	243
Ambient (B)	245	242	243
Ambient (C)	245	244	243
Process (A)	193	191	188
Process (B)	193	190	187
Process (C)	194	192	189

- The monitoring of air temperature is referred to as “ambient”, and the monitoring of the metal cylinders is referred to as “process”. See the experimental Section for details.

Table 41: Results for average time above molten solder temperature (Ambient) and above 170°C (Process) for system B test vehicle

Thermocouple position	Standard profile	250C profile	760mm/min profile
Ambient (A)	47	45	41
Ambient (B)	50	49	45
Ambient (C)	49	48	45
Process (A)	70	68	55
Process (B)	70	68	53
Process (C)	72	71	57

Table 42: Results for average maximum temperatures reached for system C test vehicle (zone 10)

Thermocouple position	Standard profile	250C profile	760mm/min profile
Zone 10	260	256	260

10.4 DISCUSSION

The results for the maximum temperatures recorded for the Alstom test vehicle are shown in Figure 60. Both the subsequent profiles show reduced mean maximum temperatures as compared with the standard profile. This would be expected as the 250°C profile is cooler and the 760mm/min profile is faster, allowing less heating in the final zone and hence lower maximum temps. Figure 61 shows these changes as a percentage of the standard mean maximum temperatures. Although these changes are measured at less than 2.5%, they are significant.

Similar results are shown in Figures 62 and 63 for the mean time above 217°C for the Alstom test vehicle. With the 250°C profile, the % change is in the range of 5 to 25%, with the change for the 760mm/min profile being greater at 15 to 40%. With such a large test assembly, the times above the melting point do show large changes for relatively small changes in profile. This is because parts of the large assembly have not reached maximum temperature during the

profile and therefore adding or removing heat will have a significant effect. Smaller test assemblies would show less change.

However, these results indicate that monitoring time above solder melting point on a populated assembly would be an effective means of determining any necessary changes in belt speed. Either monitoring mean maximum temperatures or time above solder melting point would provide valuable assistance with determining any necessary heating zone changes. Such a system may be expensive depending on the complexity of the assembly, may deteriorate with regular use, and would not be as robust as the regular profiling systems.

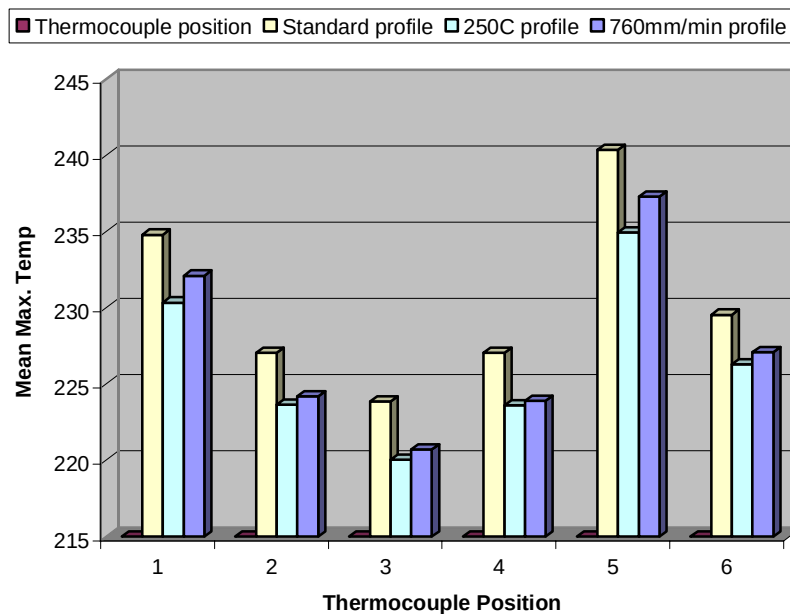


Figure 59: Comparison of mean maximum temperatures recorded on Alstom test vehicle

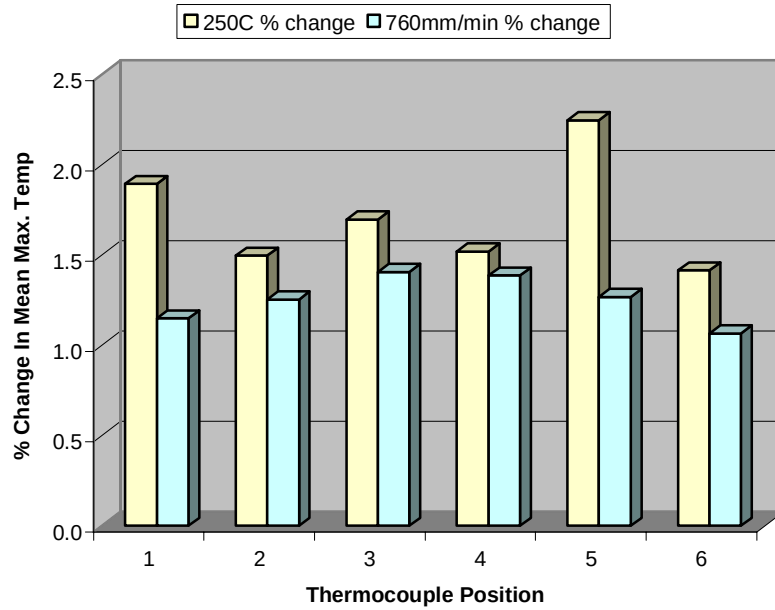


Figure 60: Comparison of % change in mean maximum temperatures recorded on Alstom test vehicle

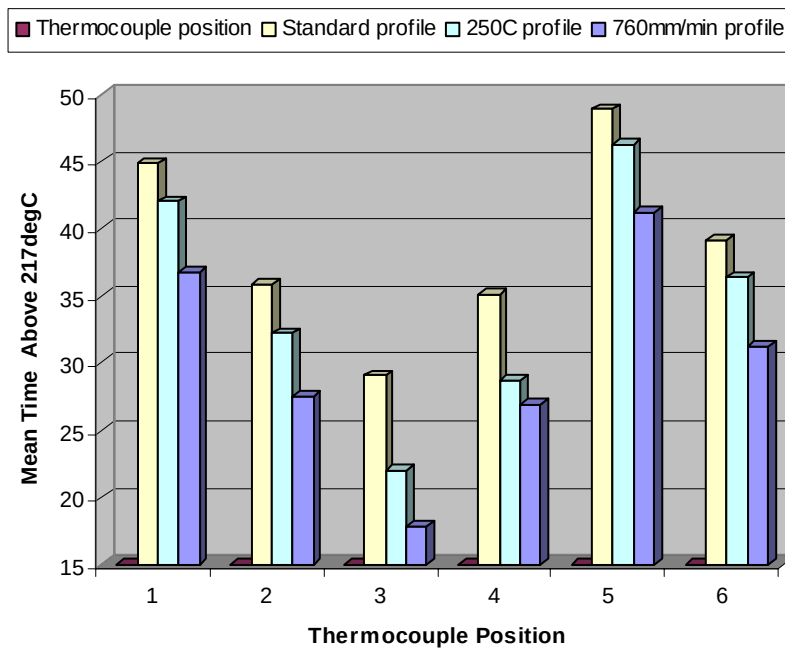


Figure 61: Comparison of mean time above solder melting point recorded on Alstom test vehicle

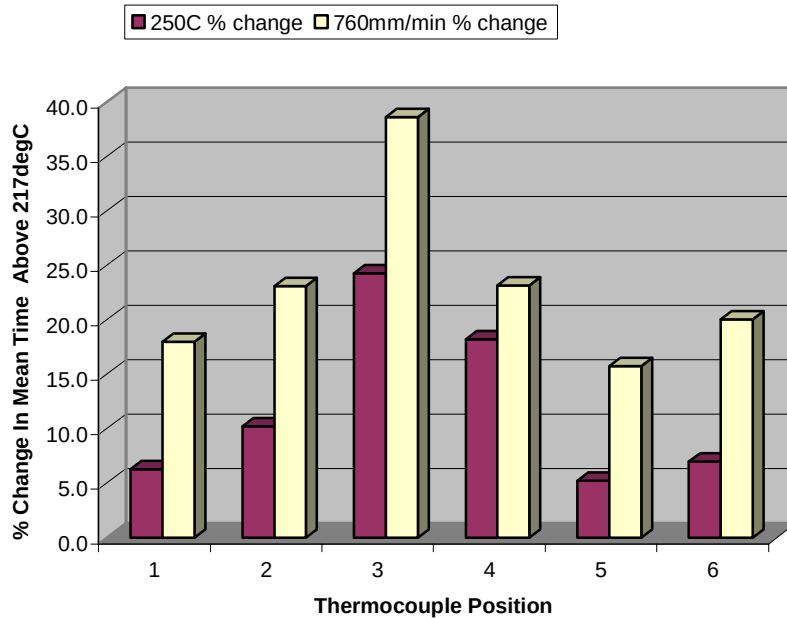


Figure 62: Comparison of % change in mean time above solder melting point recorded on Alstom test vehicle

The results for the maximum temperatures achieved for the laminate test vehicle are shown in Figure 64. Both the subsequent profiles show reduced mean maximum temperatures as compared with the standard profile. This would be expected as the 250°C profile is cooler and the 760mm/min profile is faster, allowing less heating in the final zone and hence lower maximum temps. Figure 65 shows these changes as a percentage of the standard mean maximum temperatures. Although these changes are measured at less than 2%, they are significant.

Similar results are shown in Figures 66 and 67 for the mean time above 217°C for the laminate test vehicle. With the 250°C profile, the % change is of the same order as the mean maximum temperatures (2-4%), but the change that can be seen with the 760mm/min profile is significantly greater at 12 to 17%. These results indicate that monitoring time above solder melting point would be an effective means of determining any necessary changes in belt speed. Either monitoring mean maximum temperatures or time above solder melting point would provide valuable assistance with determining heating zone changes.

Such a system would not be any more robust than a bare board or populated test assembly but would cost considerably less to replace.

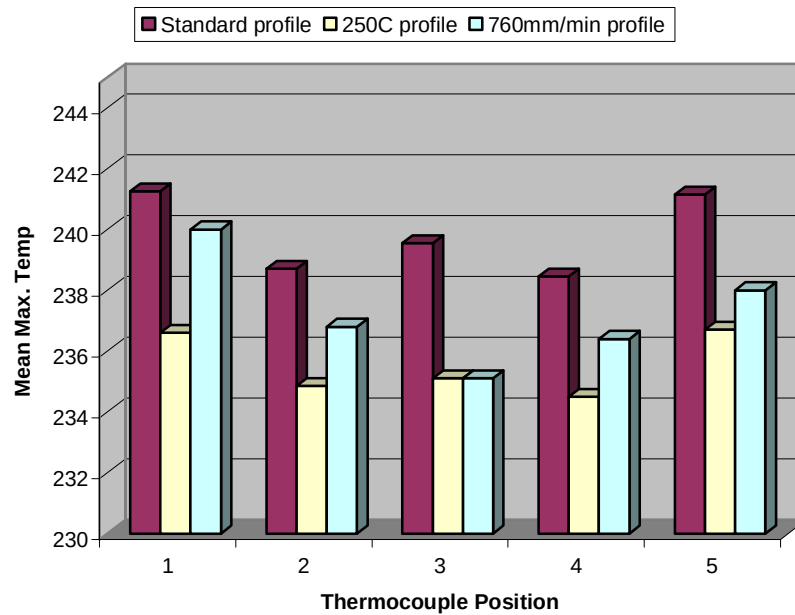


Figure 63: Comparison of mean maximum temperatures recorded on laminate test vehicle

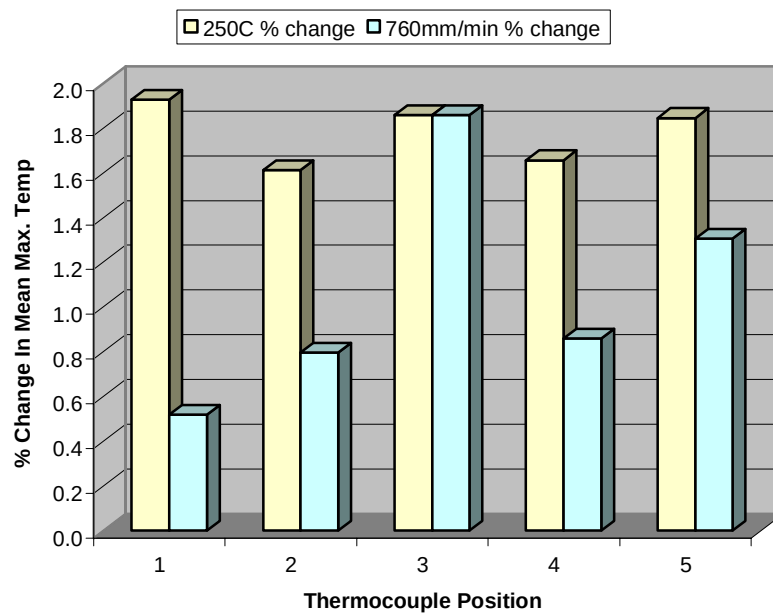


Figure 64: Comparison of % change in mean maximum temperatures recorded on laminate test vehicle

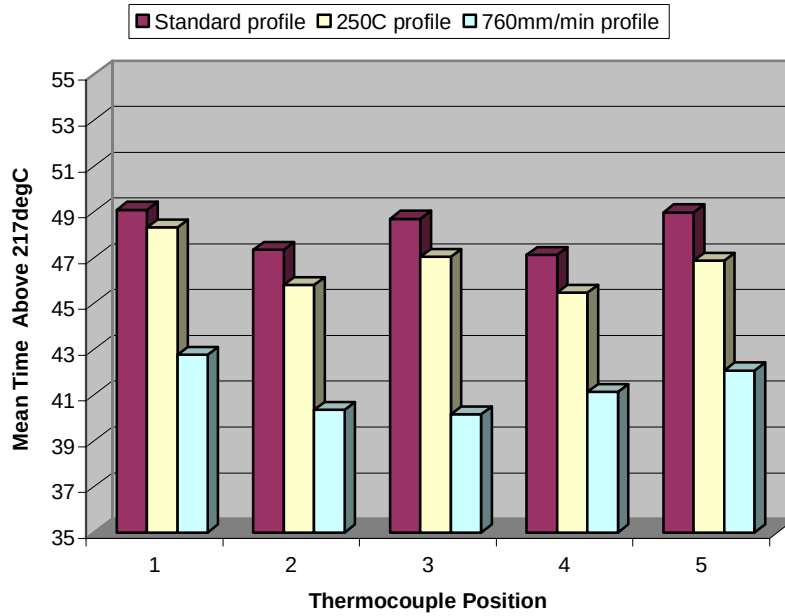


Figure 65: Comparison of mean time above solder melting point recorded on laminate test vehicle

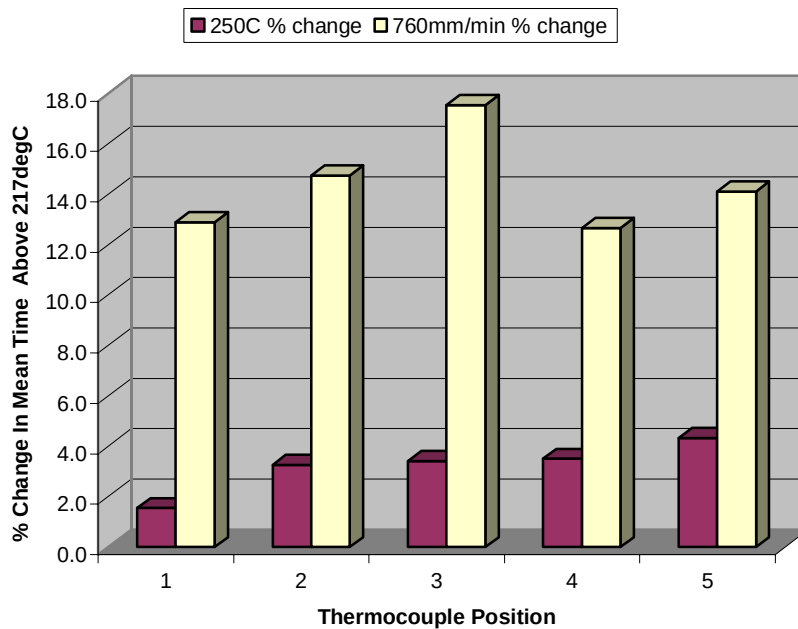


Figure 66: Comparison of % change in mean time above solder melting point recorded on laminate test vehicle

The results for regular profiling system A are shown in Figures 68 to 71. Results for this system are similar to that of the laminate test vehicle. Reduced mean maximum temperatures were monitored for both alternative profiles with changes in the range of 1 to 2 %. However, the system did generally record greater percentage changes in the mean times above solder melting point. These were around 5 to 10% for the 250°C profile (exception being thermocouple position 1) and 10 to 25 % for the 760mm/min profile. Such a system clearly has an advantage over a laminate system in terms of the degree of change measured. In addition, the increased robustness of system, and the advantage of ease of process change recognition (provided by an integrated software system), make the system attractive. However, such a system (thermocouple carrier and software) does cost around £1500 excluding the cost of the data logger.

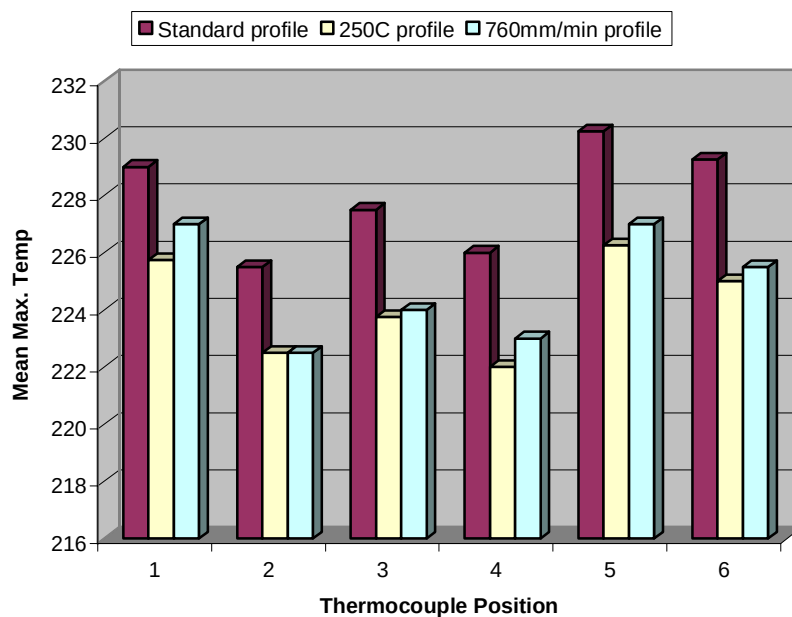


Figure 67: Comparison of mean maximum temperatures recorded on system A test vehicle

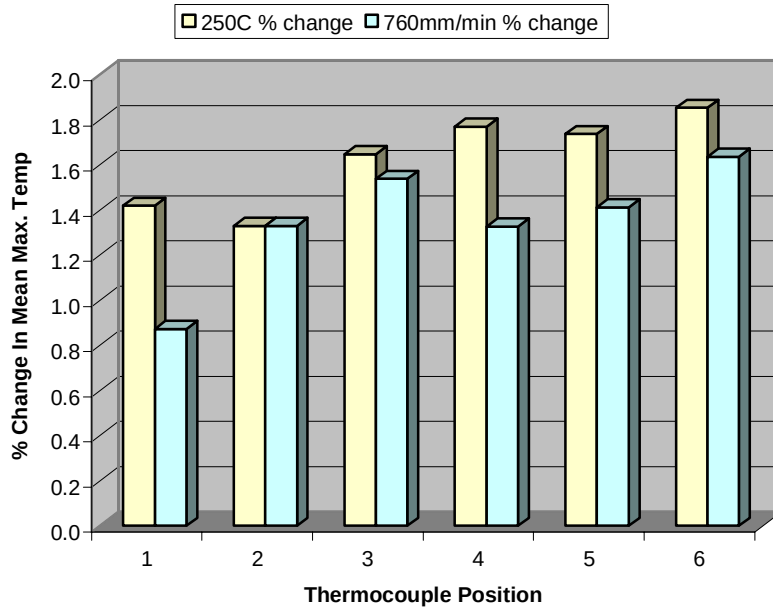


Figure 68: Comparison of % change in mean maximum temperatures recorded on system A test vehicle

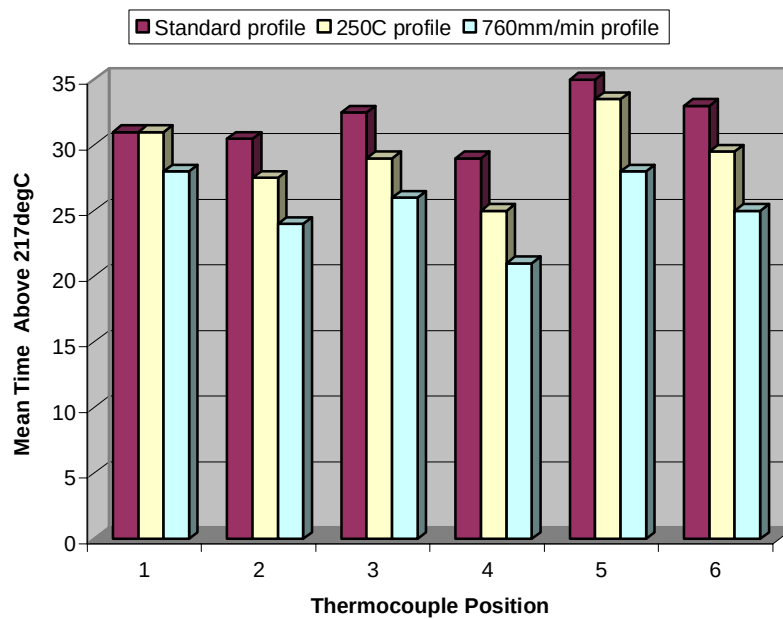


Figure 69: Comparison of mean time above solder melting point recorded on system A test vehicle

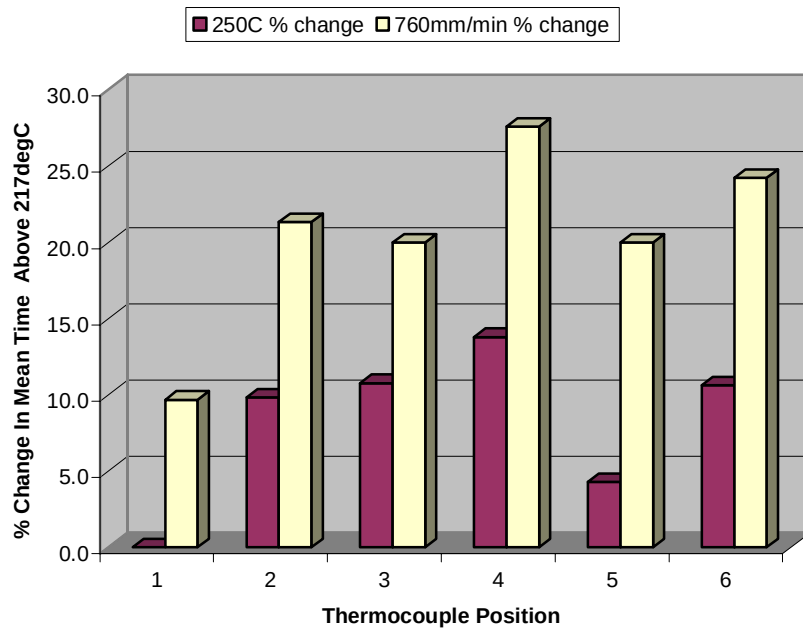


Figure 70: Comparison of % change in mean time above solder melting point recorded on system A test vehicle

The results for regular profiling system B are shown in Figures 72 to 75. Results for this system are similar to the previous two test vehicles. Reduced mean maximum temperatures were monitored for both alternative profiles with changes in the range of 0.5 to 3 %. However, the system did generally record greater percentage changes in the mean times above solder melting point. These were around 2 to 4% for the 250°C profile and 7 to 24 % for the 760mm/min profile. Such a system clearly has an advantage over a laminate system in terms of the degree of change measured. As with system A, the increased robustness of system and the advantages in the ease of process change recognition provided by an integrated software system, make such a system attractive. However, such a system does costs more than £2,000 on top of the cost of the data logger.

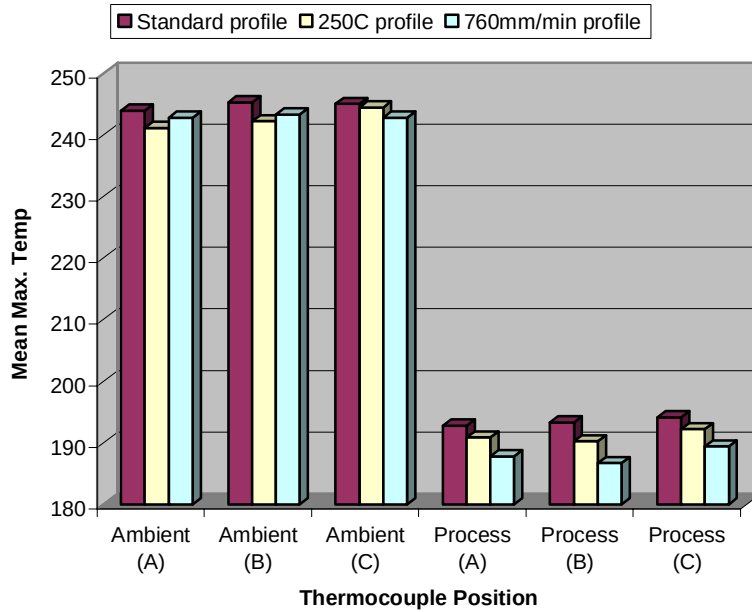


Figure 71: Comparison of mean maximum temperatures recorded on system B test vehicle

(The monitoring of air temperature is referred to as “ambient”, and the monitoring of the metal cylinders is referred to as “process”. See the experimental section for details.)

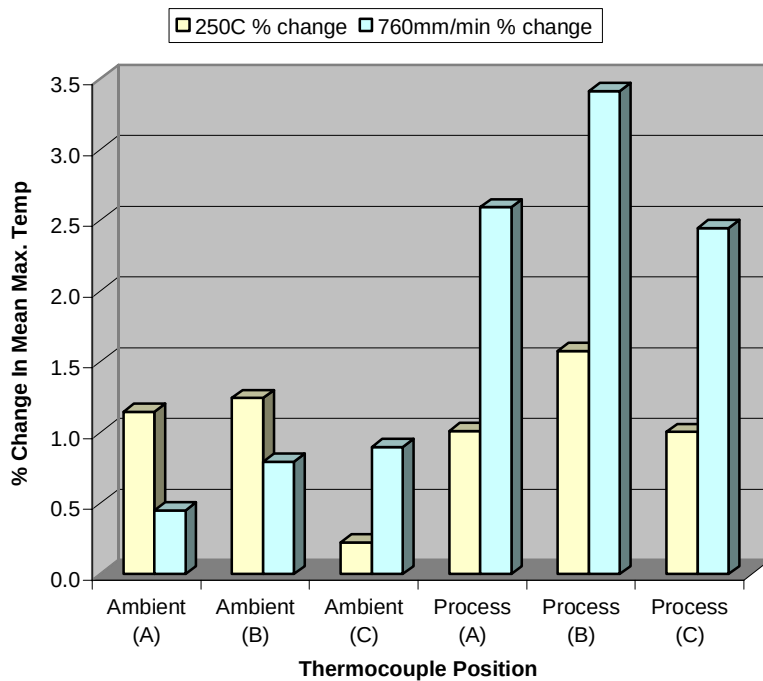


Figure 72: Comparison of % change in mean maximum temperatures recorded on system B test vehicle

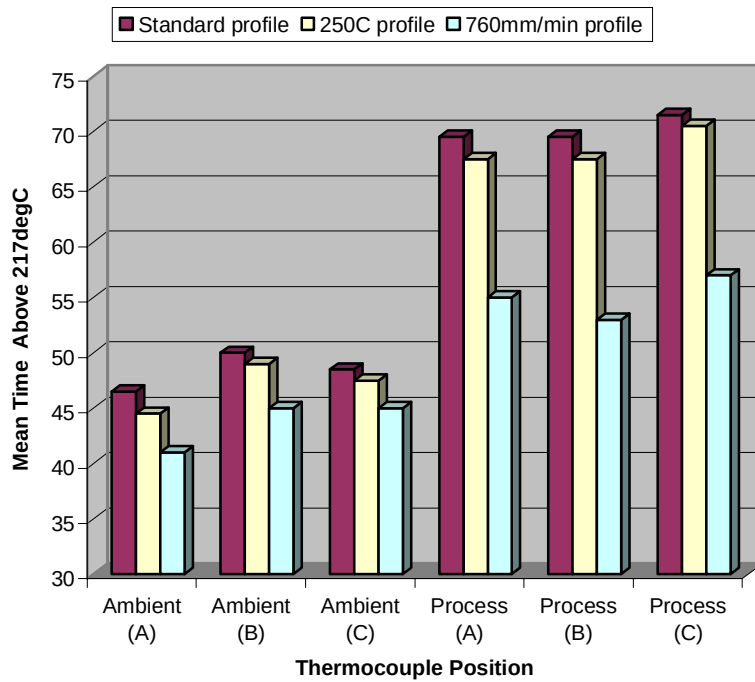


Figure 73: Comparison of mean time above 217°C (ambient) or 170°C (process) recorded on system B test vehicle

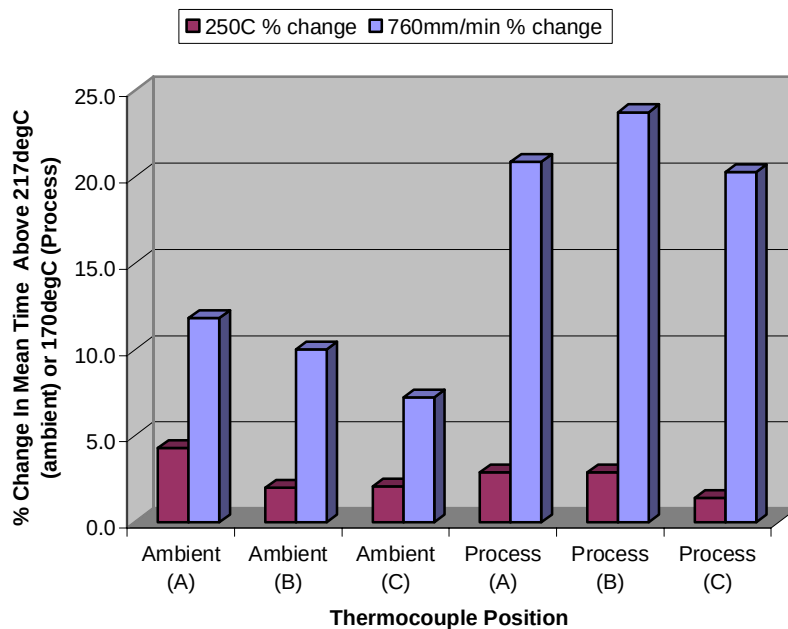


Figure 74: Comparison of % change in mean time above 217°C (ambient) or 170°C (process) recorded on system B test vehicle

The results for regular profiling system C are shown in Figures 76 to 77. As this system uses static thermocouples, there are no results for times above melting point of solder. Results for % change in mean maximum temperatures for this system are similar to those for the previous three test vehicles for the 250°C profile. Reduced mean maximum temperatures were monitored for both alternative profiles with changes in the range of 0.5 to 3 %. However, the system did generally record greater percentage changes in the mean times above solder melting point. Changes of around 2% were recorded. As would be expected, there was no significant change with the 760mm/min profile as the static thermocouple system would not register a belt speed change.

System C returned comparable results to the other systems for the change to the 250°C profile. Such a system, designed for continual use in a reflow oven, would be more robust than the laminate system and would have the added advantage of ease of process change recognition provided by an integrated software system. The software package that is provided with the thermocouple system allows continual logging of the thermocouple temperatures so that the user is provided with a complete history of the oven performance, and alarm limits can be incorporated to highlight when the oven profile changes. However, such a system does have a significant purchase price.

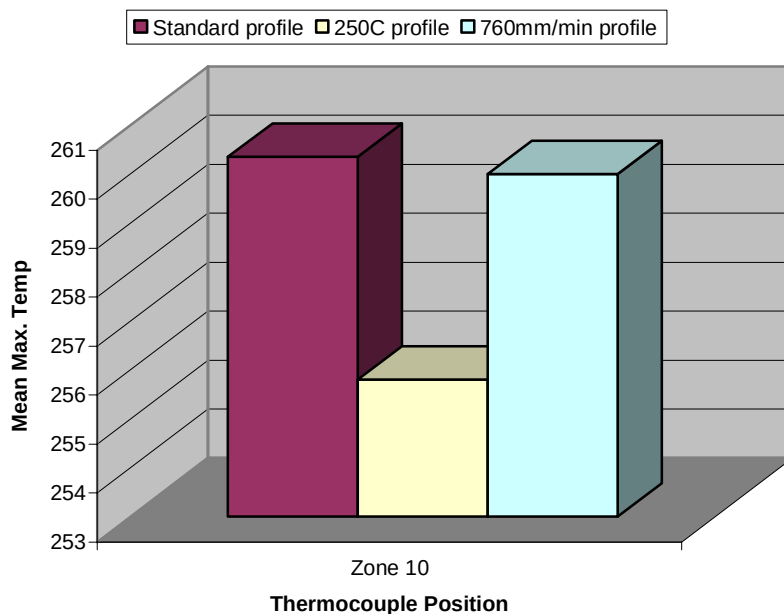


Figure 75: Comparison of mean maximum temperatures recorded on zone 10 thermocouple of System C

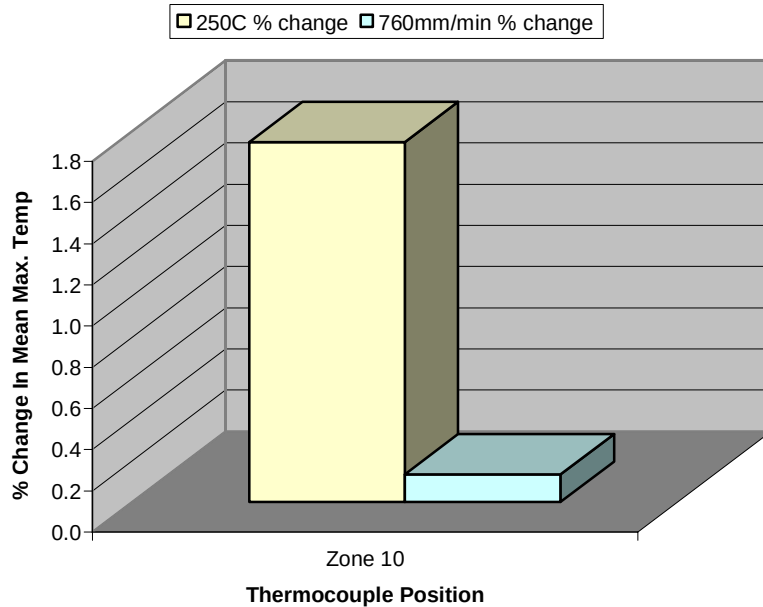


Figure 76: Comparison of % change in mean maximum temperatures recorded on zone 10 thermocouple of System C

10.5 CONCLUSIONS

A comparison of the % changes recorded by the five systems can be seen in Figure 78. For the 250°C and 760mm/min profiles, all the systems showed similar changes for peak temperatures. When looking at the changes in the times above 217°C for the Alstom, laminate and system A or times above 170°C for system B, these systems showed increased changes for both alternative profiles.

This work indicates that monitoring time above melting point of solder may be a more sensitive method of detecting change than measuring peak temperatures.

All the systems showed similar responses to the changes in profile and all proved capable of detecting those changes. Whilst the commercial systems are generally more expensive than the other options, the end user may find benefits in their robustness and ease of use.

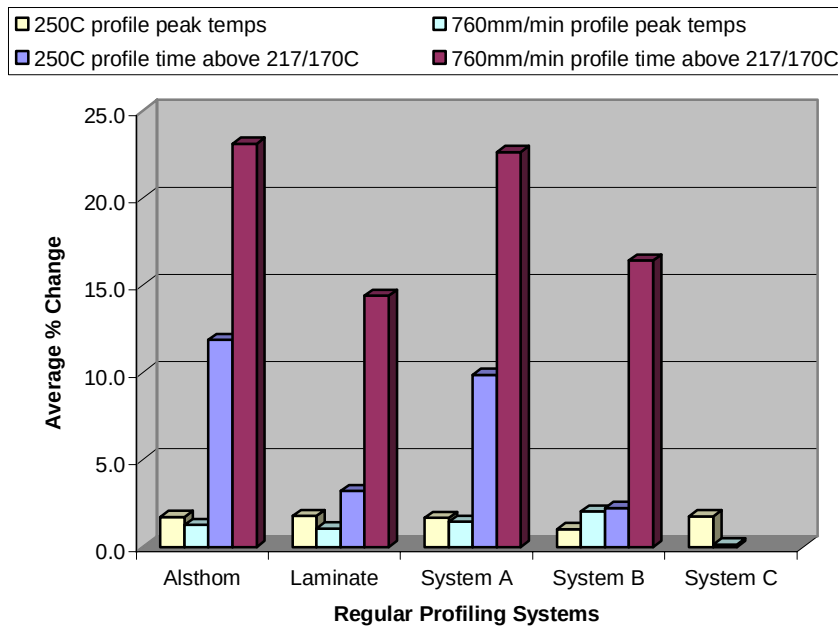


Figure 77: Comparison of % changes measured by the five regular profiling systems

11 CONCLUSIONS AND RECOMMENDATIONS

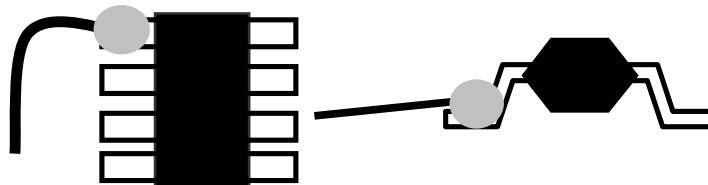
Based on the work undertaken in this project, a number of recommendations can be made to assist process engineers in achieving accurate thermal profiling of electronic assemblies.

11.1 THERMOCOUPLES AND EQUIPMENT FOR THERMAL PROFILING OF SOLDERING PROCESSES

- The majority of data loggers use K type thermocouples and these can be considered an industry standard. T-type thermocouples are also used by some profiling systems, and have certain advantages such as faster responses and wetting solder wetting.
- Flexible PTFE insulated thermocouples of approximately 0.2mm diameter wire are preferred. These are robust enough for repetitive use and widely available. Thicker and ceramic insulated thermocouples are stiffer, and so transfer mechanical force to the attachment position. They are therefore more difficult to “tie” to the assembly and can become more easily detached during profiling and storage.
- Thermocouple length should be kept to a minimum provided that other requirements such as data logger position are considered.
- Data loggers, which travel through the oven behind the test assembly, are preferred. They enable the use of shorter thermocouples, which are less prone to damage and detachment from the test assembly.

11.2 THERMOCOUPLE ATTACHMENT

- Thermally conductive adhesive is preferred as a permanent attachment method, since this provides a strong bond with good thermal properties. Attachment using a bead size of approximately 4mm diameter is easy although not instantaneous and the technique has good repeatability.
- High temperature solder is also acceptable although K-type thermocouples are difficult to wet and the soldering operation can damage the test assembly.
- T-type thermocouples are easier to wet with solder. The high melting point of the attachment solder can be depressed by the solder already on the test assembly, and hence, detachment of thermocouples during profiling can occur. Wave solder adhesive may also be used but the results may not be as repeatable as for the above two methods.
- Aluminium tape is recommended as a temporary attachment method, and is superior to polyimide tape. The latter does not have sufficient adhesion for lead-free soldering temperatures and thermocouple bead attachment.
- To achieve accurate measurement, the thermocouple should be led directly away from the solder joint being measured, at right angles to the component body, and along the surface of the assembly.



- In addition to attachment of the thermocouple bead, thermocouples should be provided with as much additional mechanical support as possible to prevent their detachment. Such assistance can include:
 - Use of mounting holes in PCB to "tie" thermocouples (be careful not to break thermocouples by over tightening)
 - Use polyimide tape or adhesive to tack the thermocouple on its path to edge of PCB
 - Thermocouples should be led well away from the attachment positions (bead) of other thermocouples so that measurement at these other positions is not affected
- The temperature solder joints reach, and the time above melting point of the solder, are a combination of three factors:
 - Thermal mass of component
Larger thermal mass = lower maximum temp. = less time above melting point
 - Proximity of component to components of high thermal mass

Nearer to high thermal mass component = lower maximum temp. = less time above melting point

- o Proximity to edge of assembly

Nearer to edge = higher maximum temp. = more time above melting point

Therefore the coolest solder joints will usually be on large components, close to other large components towards the centre of the assembly. Hottest solder joints will usually be smaller components, in less densely populated regions of the assembly, closer to the edges of the assembly.

- Thermocouples should be attached to solder joints that will show both the hottest and coldest parts of the assembly, to ensure that all joints reach a temperature in excess of the melting point of the chosen solder and that no part of the assembly is getting so hot that irreparable damage can occur. If the hottest and coldest parts of the assembly have not previously been identified, it is recommended that measurements should be taken from at least six positions on the test assembly.
- Two factors can be controlled to reduce the temperature difference between the hottest and coldest parts of the assembly (ΔT). Assemblies can be designed to spread component thermal mass evenly over the PCB, moving larger components towards the hotter edges of the assembly and smaller components towards the cooler centre of the assembly.

11.3 OVEN DESIGN

- Oven design can also be helpful. Profile control can be significantly improved by increasing the number of heating zones and/or length of the heating zones. For larger assemblies, it may not prove possible to set a suitable profile if the oven has insufficient length or number of zones. These factors will be of greater importance with the introduction of lead-free soldering.

11.4 LOGGER POSITION AND SET-UP FOR MEASUREMENT

- If a travelling data logger is used, the instrument should follow the test assembly by a distance at least an oven zone, down the tunnel, otherwise the thermal demand of the data logger will cause unrepresentative measurements of the test assembly by depressing its peak temperatures and reducing the time above solder melting point.
- Care should be taken to ensure that the test assembly is at normal ambient temperature prior to a profiling run. If the assembly temperature is higher than ambient, as can occur during multiple profiling runs on a single test assembly with insufficient time between runs, resultant measured peak temperatures and molten solder times may be increased. Data loggers and associated thermal protection should also be allowed to return to ambient temperature prior to profiling runs to prevent over-heating and damage to the equipment.

11.5 INITIAL PROFILING VEHICLES

- Fully populated assemblies are required for accurate profiling. Both bare laminate and unpopulated PCBs exhibit higher maximum temperatures and longer times above solder melting point, and therefore will not give results comparable with those of a populated assembly.

11.6 REGULAR PROFILING SYSTEMS

- Populated, laminate and commercial systems have all proved capable of detecting changes in zone temperatures and belt speeds. Whilst the commercial systems are generally more expensive than the other options, the end user may find benefits in their robustness and ease of use.

12 ACKNOWLEDGEMENTS

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