HELLER INDUSTRIES

Repeatability of the Temperature Profile Under Load Variation

Prepared by: John Poling

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I. Objectives of the Study

For many years, the electronics industry has been utilizing forced convection reflow with excellent results as a method to rapidly and reproducibly process SMT products. Convection eliminates the need for infrared panels and reduces thermal shock to the components from rapid heating or over heating conditions. Forced convection also permits fine-tuning temperature profiles to the specific board or assembly type while providing the benefit of process repeatability. The current oven design utilized by Heller Industries, permits the programming of a multi-zone temperature profile that has been determined to be optimal for the manufacturing process. The temperature conditions in the heated zones can be specifically maintained regardless of the process load ensuring consistent manufacturing yields.

This report examines the functionality and stability of the Heller Industries Reflow Oven products when processing a variety of process load conditions. To demonstrate the repeatability of the process conditions, specific tests were conducted to measure the performance of the Heller Oven under several process loading conditions.

The experiments were designed to permit the evaluation of several operational parameters and are detailed in this report. The report covers:

1. Temperature uniformity across the heated zones of the oven.
2. Temperature delta between large and small components on a circuit board (ΔT).
3. Sensitivity to normal and excessive process load conditions.
4. A measurement of the effect on temperature and power consumption in the reflow zone under heavy load conditions.

II. Oven Used for the Study

A. The Heller 1800 EXL

The oven selected for the studies summarized in this report was the Heller 1800EXL. The 1800EXL is a state of the art Reflow Oven System designed to provide highly flexible temperature profiling for a wide range of SMT process applications.

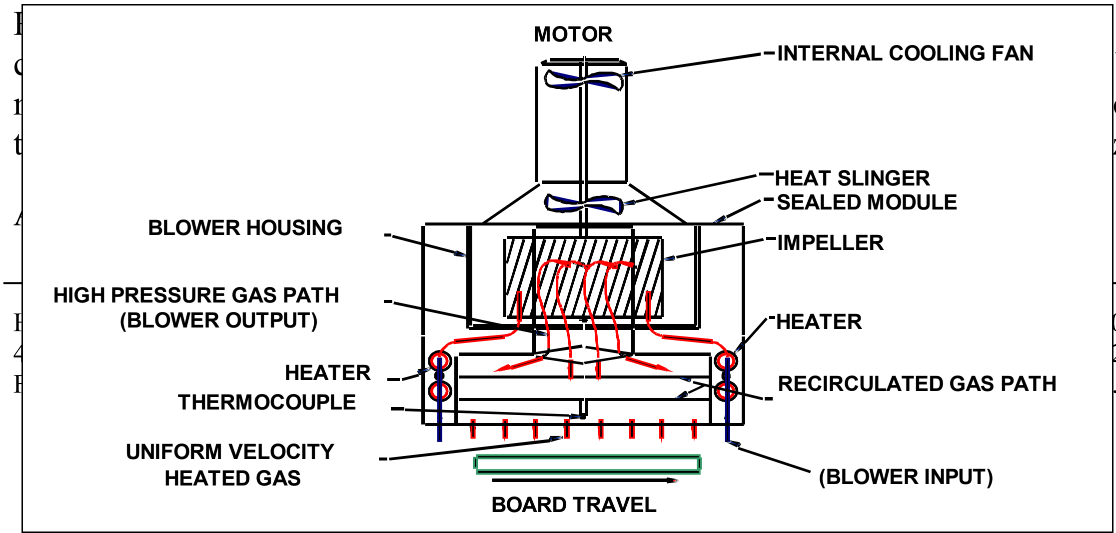
The 1800EXL is an excellent selection for this study as it has been designed to provide a high degree of temperature stability and profile repeatability. In previous studies, the Heller ovens have shown to have the robustness and control required for difficult SMT production applications. The 1800EXL has also been shown to be extremely well suited to accomplish the high throughput requirements of the SMT market.

Two configurations were utilized during the study, an 1800EXL configured for operation with an air atmosphere and an 1800EXL configured with a nitrogen atmosphere. The oxygen level in the nitrogen configuration was tested to be less than 30 PPM as part of the standard manufacturing specification of the 1800EXL. Part of the design criteria in the development of the 1800EXL focused on optimization of the heating efficiencies for complete temperature profile control while being mindful of the consumption rates in the case of the nitrogen configuration.

A photo of the Heller 1800 EXL used to perform these tests is shown in Figure 1.

Figure 1: The Heller 1800 EXL (Configured for air and/or nitrogen operation)

B. Heller Pure Convection Module



I forced
c blower
r control
t zone.

A

Figure 2: Heller Pure Convection Module

Each of the Pure Convection heating modules consist of the following features:

1. Low-mass open coil ni-chrome heaters.
2. High temperature impeller
3. Heavy duty blower motor
4. Blower housing
5. Inner diffusion grill
6. Process control thermocouple located in the process gas stream.

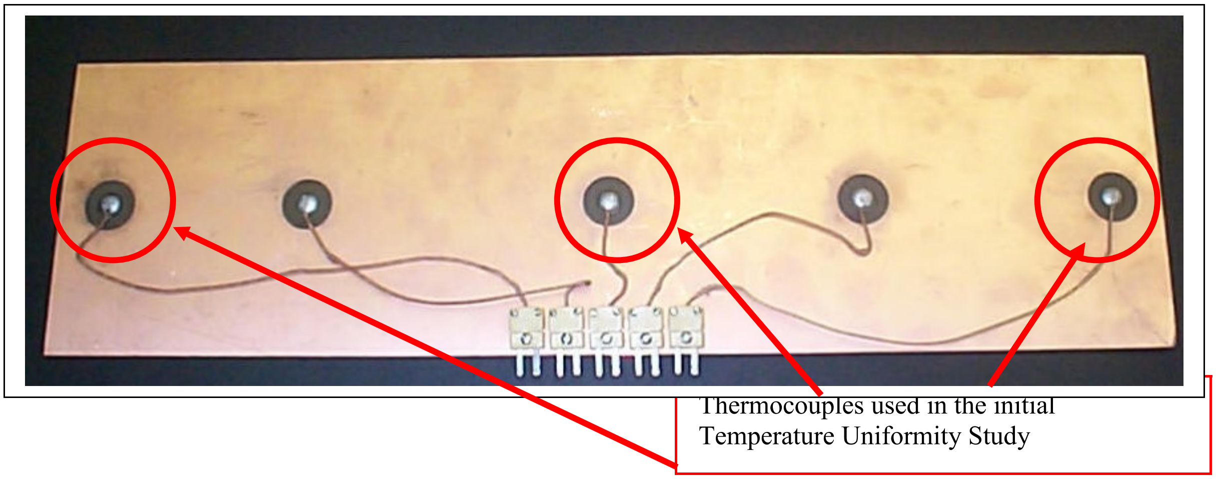
It is important to note that the design of the Heller heating module is the same for both air and Nitrogen processing.

The operational parameters such as the speed and volume of the output of the Convection Heating Module are identical regardless of the oven operation under air or nitrogen.

III. Defining the Baseline Performance of the 1800EXL

A. TEMPERATURE UNIFORMITY ACROSS THE HEATING ZONES

Thermocouples were attached on a 22-inch by 5-inch glass epoxy board laminated with copper as shown in Figure 3.



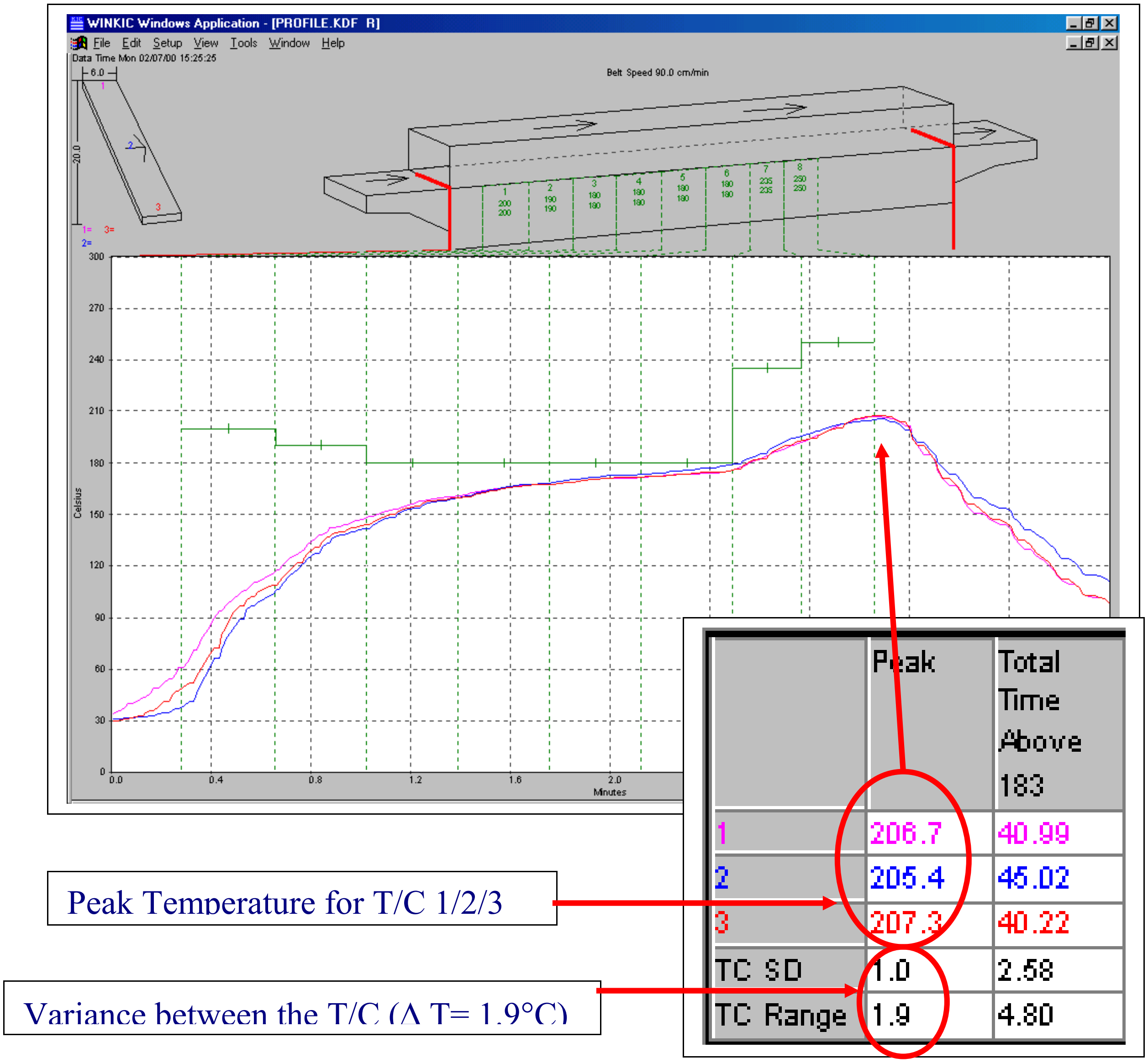
Thermocouples used in the initial Temperature Uniformity Study

Figure 3: The temperature profile board and the placement of the thermocouples on the profile board.

The profile board used for this study was configured with a thermocouple placed at the center of the board and two thermocouples placed one inch from the right and left edges of the board.

The temperature settings of the zones for the Oven Uniformity Test are shown in Figure 4. The Profile board was passed through the oven at 90 cm/min and the temperature measured across the width for each of the heated zones. The actual temperature profiles for each of the T/C readings are graphed and shown in Figure 4.

At the maximum temperature, the range of the temperature between the measurement points (206.7, 205.4, 207.3) shows a differential of less than 2.0° C between the thermocouples.



	Peak	Total Time Above 183
1	206.7	40.99
2	205.4	45.02
3	207.3	40.22
TC SD	1.0	2.58
TC Range	1.9	4.80

Peak Temperature for T/C 1/2/3

Variance between the T/C (Δ T= 1.9°C)

Oven Temperature Settings by Zone

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
200°	190°	190°	180°	180°	180°	235°	250°

Belt Speed = 90 cm/min

Figure 4: The temperature plot of the Profile Board provides a baseline to measure the temperature repeatability across the heated tunnel.

IV. Set up of the Load Test

A. Defining the Test Board and the Location of the Thermocouples

The focus of this test was to evaluate the heating repeatability across and between components on a SMT board.

For the entire load testing summarized throughout this report, an SMT board was selected which was densely populated and had a varied number of components (Figure 5 and 6, a laptop computer mother board).

The thermocouples were attached to the board at specific points to evaluate the consistency of the temperature across an array of components. The selection for the placement of the thermocouples was made to measure the effect of temperature variation across a range of components of different size, shape and mass. By varying the load conditions the study will explore the effect on the component temperatures on the SMT board.

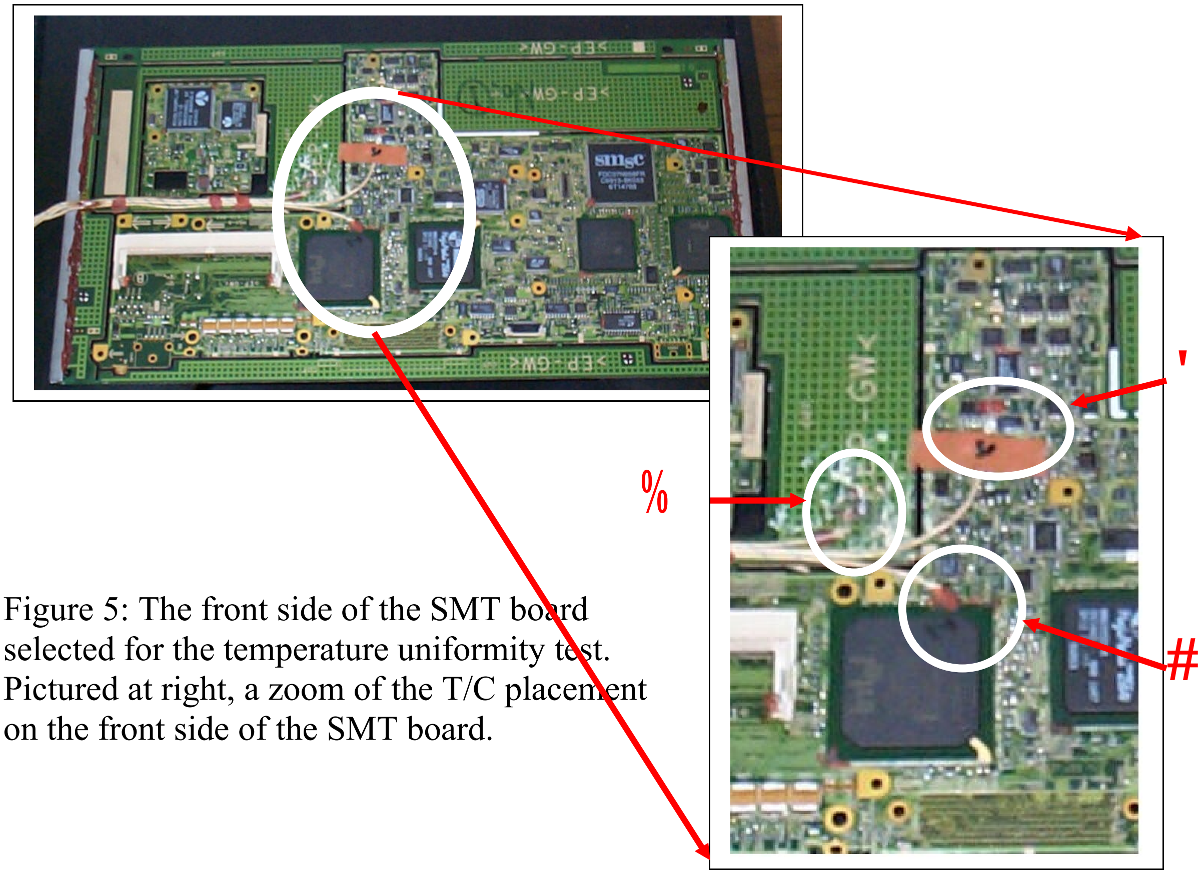


Figure 5: The front side of the SMT board selected for the temperature uniformity test. Pictured at right, a zoom of the T/C placement on the front side of the SMT board.

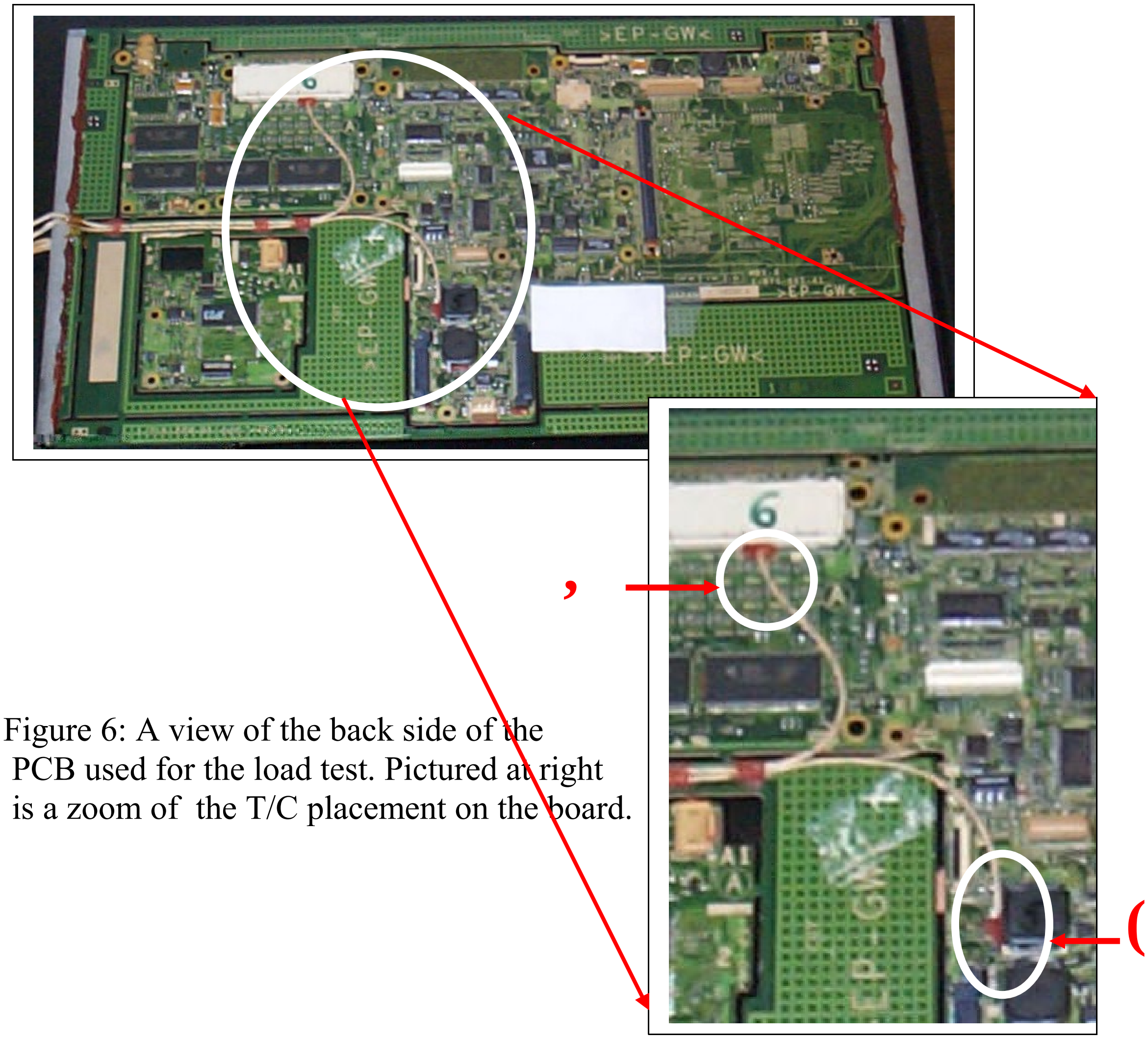


Figure 6: A view of the back side of the PCB used for the load test. Pictured at right is a zoom of the T/C placement on the board.

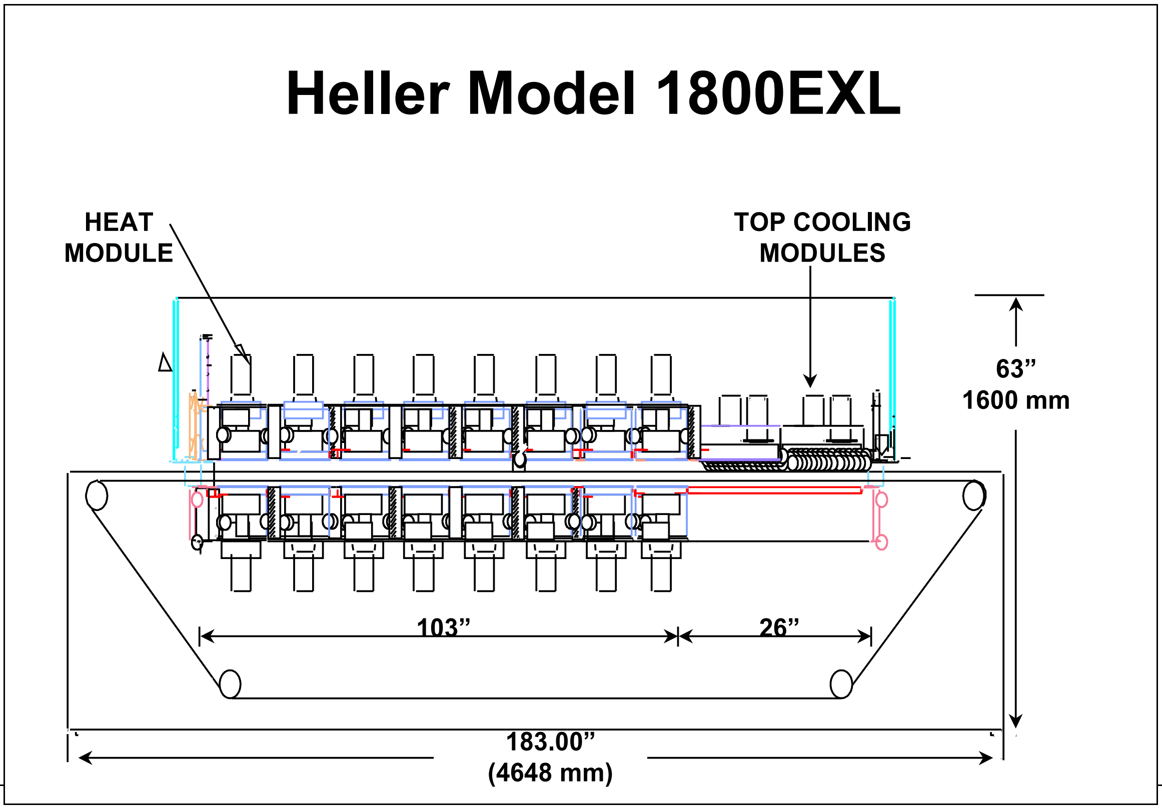
The board shown in Figure 5 and 6, was selected and the thermocouples placed on the board at the following locations:

1. 388 Pin BGA Component	TC1 (Data shown in Pink)
2. Bare Board Attach	TC2 (Data shown in Blue)
3. 28 Pin SOIC	TC3 (Data shown in Red)
4. Black Choke (Underside)	TC4 (Data shown in Black)
5. Test Port Connector (Underside)	TC5 (Data shown in Green)

B. Heller 1800 EXL Operating Conditions for the Load Tests

To establish a basis for comparison and properly validate the measurement conditions used through out the load test experiments, two oven configurations were utilized during the study, an 1800EXL with an air atmosphere and an 1800EXL with a nitrogen atmosphere.

The Heller 1800EXL when configured for air operation consists of 16 independent, rapid response-heating modules oriented vertically into 8-topside and 8-bottom side heating zones. This configuration is illustrated in Figure 7 below. The Heller 1800EXL was set up utilizing the heat profile conditions as shown in Figure 7. All of the load testing done with the air configuration utilized this temperature profile.



Oven Temperature By Zone

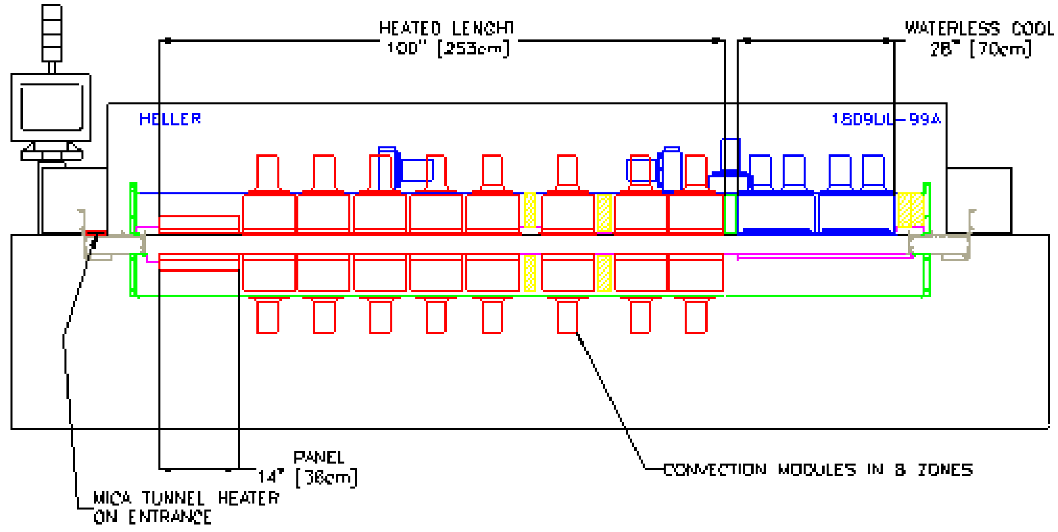
Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
200°	180°	190°	180°	180°	180°	190°	265°

Belt Speed = 75 cm/min

Figure 7: Outline view of the oven temperature settings (by zone) of the 1800 EXL configured with air used for the load studies.

The Heller 1800EXL when configured for operation with a nitrogen environment consists of 18 independent, rapid response-heating modules oriented vertically into 8-topside and 8-bottom side heating zones. The first zone utilizes panel heaters to reduce turbulence at the entrance of the heating zone, followed, by the 16 rapid response forced convection modules. This configuration is illustrated in Figure 8 below. The Heller 1800EXL was set up utilizing the heat profile conditions as shown in Figure 8. All of the load testing done with the nitrogen configuration utilized this temperature profile.

Heller #)**E+L Ni5rogen



Oven Temperature by Zone

Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
200°	180°	190°	180°	180°	180°	190°	265°	240°

Belt Speed = 75 cm/min

Figure 8: Outline view of the oven temperature settings (by zone) of the 1800 EXL configured with nitrogen used for the load studies.

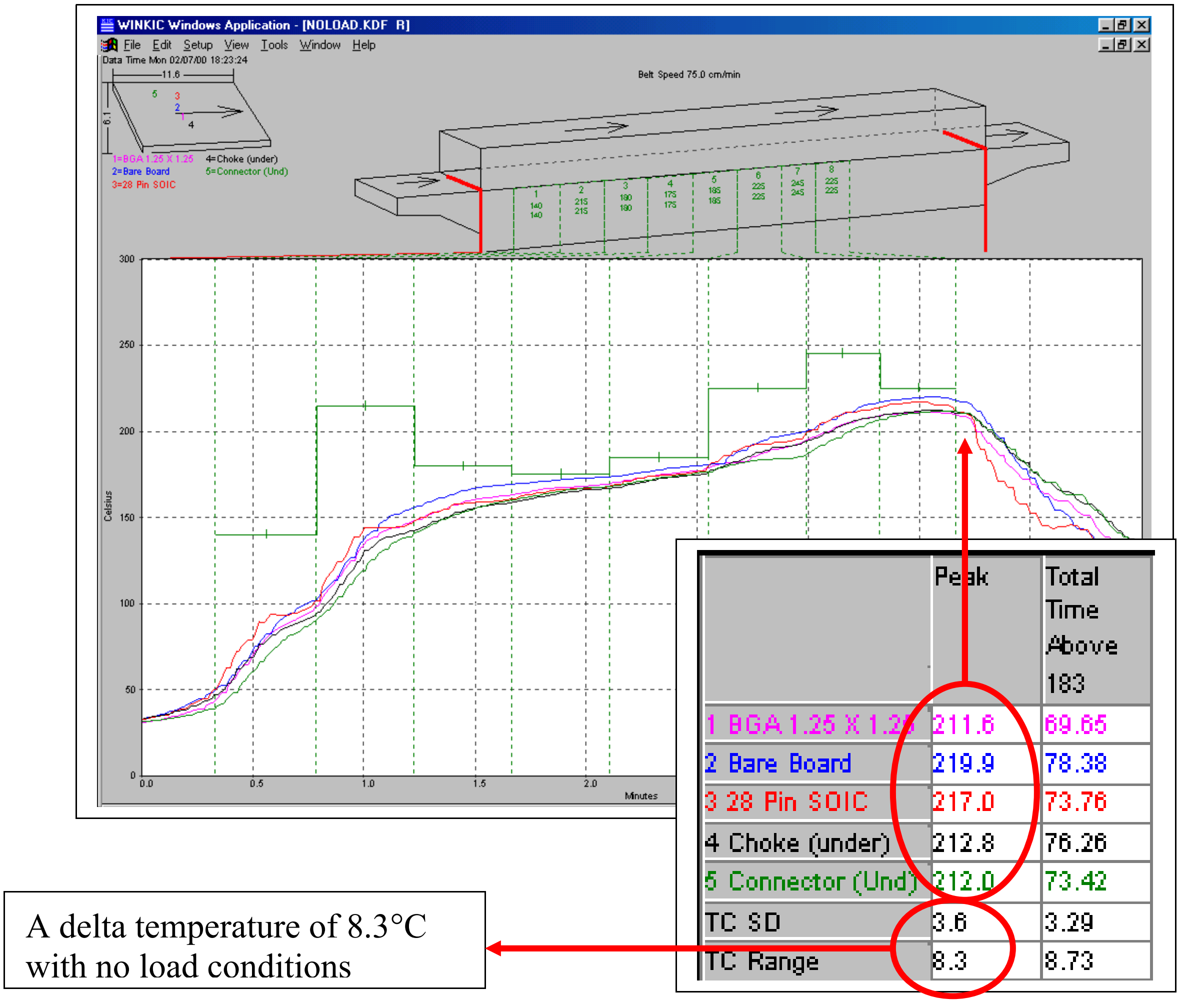
Consideration for the process speed (Belt Speed) and the temperatures selected for the programming of the zones in the Heller 1800 was given so that the profiles and reflow conditions were consistent with the typical expectations of SMT production.

V. Load Test Results with the 1800 EXL

A. Results of the Component Temperature Test (No Load)

This test was designed to measure the component temperatures on the Test Board when processing the board alone or with different amounts of process load. The same board was used for all of the load testing. The test board containing the thermocouples was run on an Edge Hold Conveyor and the resulting temperature profile measured.

The highest temperature was recorded on the bare board T/C 2 (Blue) with a temperature of 219.9°C. The data from the BGA T/C 1 (Pink) shows a peak temperature of 211.6°C was obtained. This represents a difference in temperature of 8.3°C between the components on the test board. In Figure 9, the results of the component temperature are plotted and the peak temperature recorded in the chart on the graph.



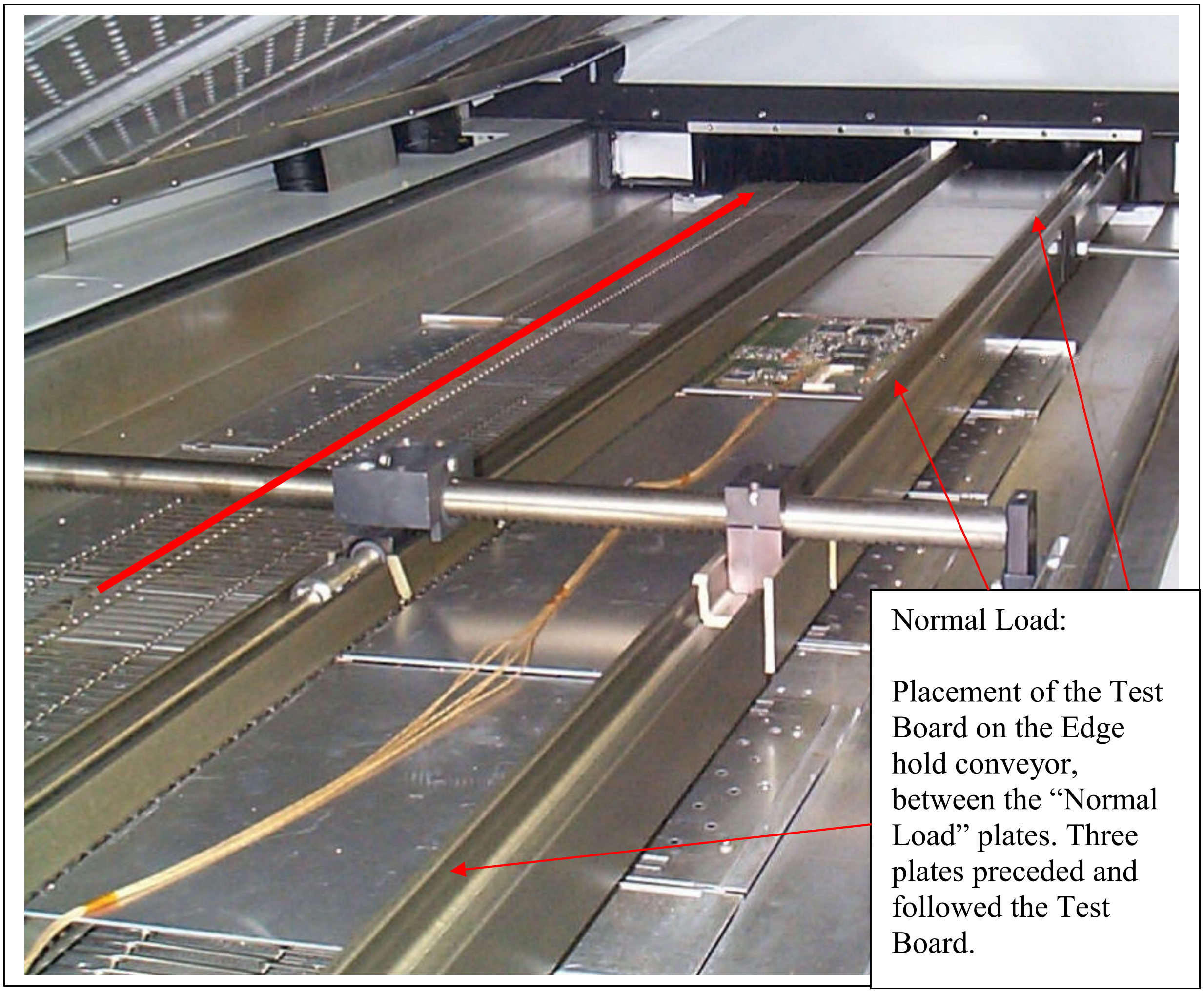
	Peak	Total Time Above 183
1 BGA 1.25 X 1.25	211.6	69.65
2 Bare Board	219.9	78.38
3 28 Pin SOIC	217.0	73.76
4 Choke (under)	212.8	76.26
5 Connector (Und)	212.0	73.42
TC SD	3.6	3.29
TC Range	8.3	8.73

A delta temperature of 8.3°C with no load conditions

Figure 9, the results of the no load test are plotted and the peak temperature shown.

B. COMPONENT TEMPERATURE ACROSS THE BOARD (Normal Process Load)

The test board containing the thermocouples was positioned, as part of a multiple board run. The Test Board was placed in a middle position between several load boards. A photograph is shown in Figure 10 of the board positioning in the oven Tunnel.



Normal Load:

Placement of the Test Board on the Edge hold conveyor, between the “Normal Load” plates. Three plates preceded and followed the Test Board.

Figure 10: The positioning of the SMT board and the load boards for normal load operation.

1. The Normal Load Conditions

To simulate the normal process load, a total of 6 Aluminum “Load Boards” were fabricated to match the dimensions of the test board.

The load boards measured 6.125”(155mm) wide, 11.625”(300mm) length and 0.06”(2mm) thick, with an individual weight of 0.42 lbs. per board were processed with the test board through the Heller 1800EXL.

The “Test Board” was processed following the third “Load Board” and was followed by three additional “Load boards”.

The weight of the load during the process was 2.58 lbs. plus the Test Board, which contributed an additional load of 0.50 lbs.

The combined weight of the test was 3.08 lbs.

	Width	Length	Thick	Weight
“Normal Load”	6.125”(155mm)	11.625”(300mm)	0.06”(2mm)	0.50lbs

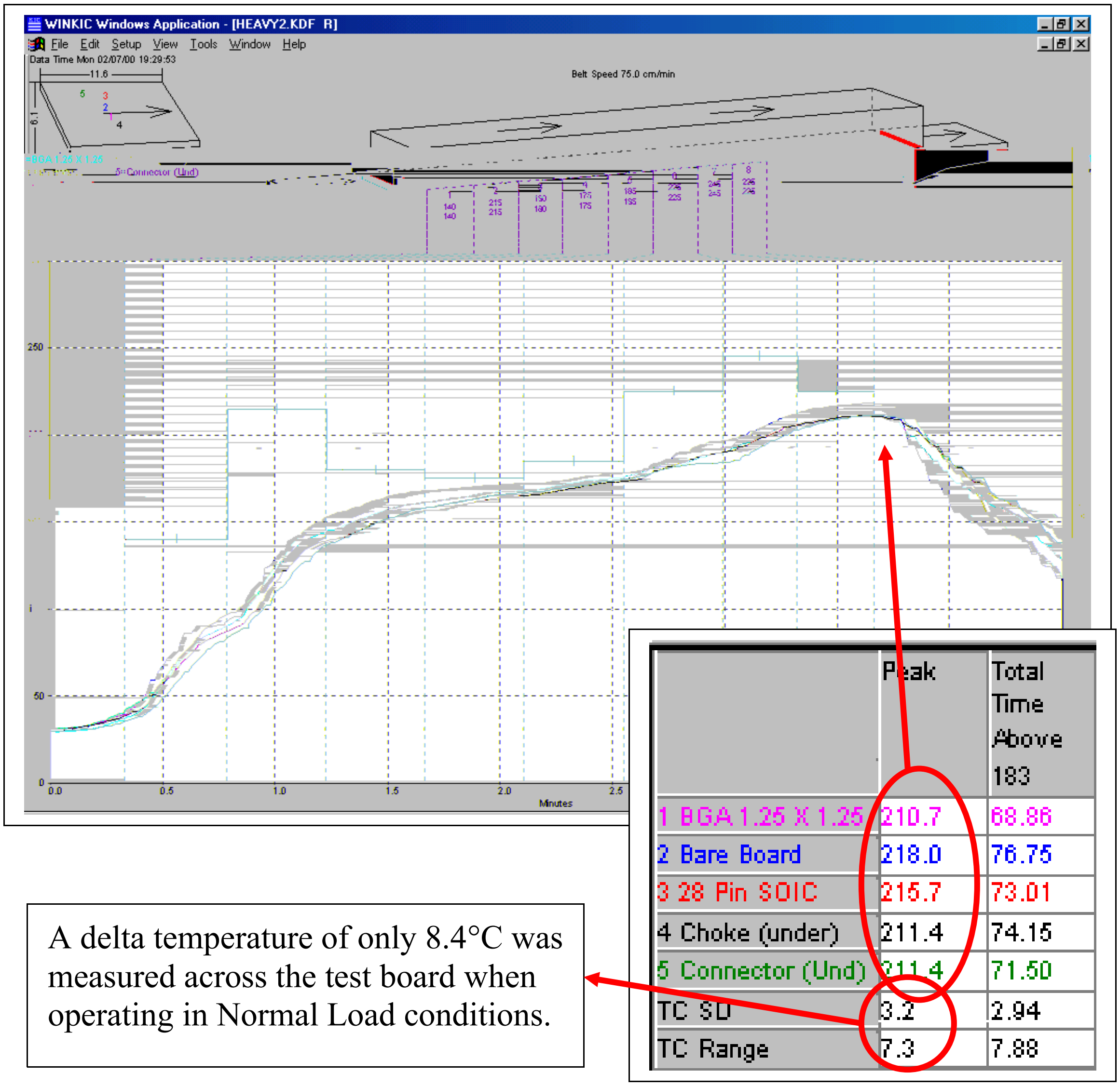
Total Weight of Load = 3.08 lbs

Figure11: Normal Load Summary Chart

2. Component Temperature Test (Normal Load)

The objective of this test was to measure the effect that an increased load might have on the repeatability of the component temperatures, the procedure described in the previous study was repeated with the Normal Load conditions.

The resulting data is summarized in the following graph (Figure 12).



	Peak	Total Time Above 183
1 BGA 1.25 X 1.25	210.7	68.86
2 Bare Board	218.0	76.75
3 28 Pin SOIC	215.7	73.01
4 Choke (under)	211.4	74.15
5 Connector (Und)	211.4	71.50
TC SD	3.2	2.94
TC Range	7.3	7.88

A delta temperature of only 8.4°C was measured across the test board when operating in Normal Load conditions.

In Figure 12, the temperatures of the components are plotted and the peak temperature recorded in the chart on the graph.

The data recorded by T/C 2 placed on the bare board (Blue) was 219.6°C, temperature of the BGA T/C 1 (Pink) shows a temperature of 211.2°C was obtained. A delta temperature between the T/C readings of only 8.4°C was measured.

3. “Normal Load Test” compared to “No Load”

When compared to the data generated under the no load conditions, the conclusion is the addition of a normal load has had no effect on the repeatability of the component temperatures or the repeatability of the temperatures achieved during the processing of the SMT boards.

C. COMPONENT TEMPERATURE ACROSS THE BOARD (Heavy Process Load Conditions)

This test was designed to measure the effect of the load on the component temperatures of the Test Board when processing the board under heavy oven load conditions.

As in the prior studies, the same board as utilized in the No Load and Normal Load Conditions (Figures 9 and 10) was used in the Heavy Load Conditions. A photograph is shown in Figure 13 of the board positioning in the oven tunnel.

Heavy Load:

Placement of the Test Board on the Edge hold conveyor, between the "Heavy Load" plates.

Three plates preceded and followed the Test Board.

Figure 13. The "Test Board" was positioned in the oven following of several large plates of aluminum to act as heat sinks.

Test Board (Fig 6/7)

1. Defining the Heavy Load Conditions

To simulate the heavy process load, a set of 6 Aluminum “Heavy Load Boards” was fabricated to match the dimensions of the test board.

The load boards measured 6.125” (155mm) wide, 11.625” (300mm) in length, and 0.81” (20mm) thick, with an individual weight of 5.42 lbs. per board. The boards were processed with the test board through the Heller 1800EXL.

The “Test Board” was processed following the third “Load Board” and was followed by 3 additional “Load boards”.

The combined weight of the load during the process was 32.66 lbs. plus the Test Board, which contributed an additional load of 0.50 lbs.

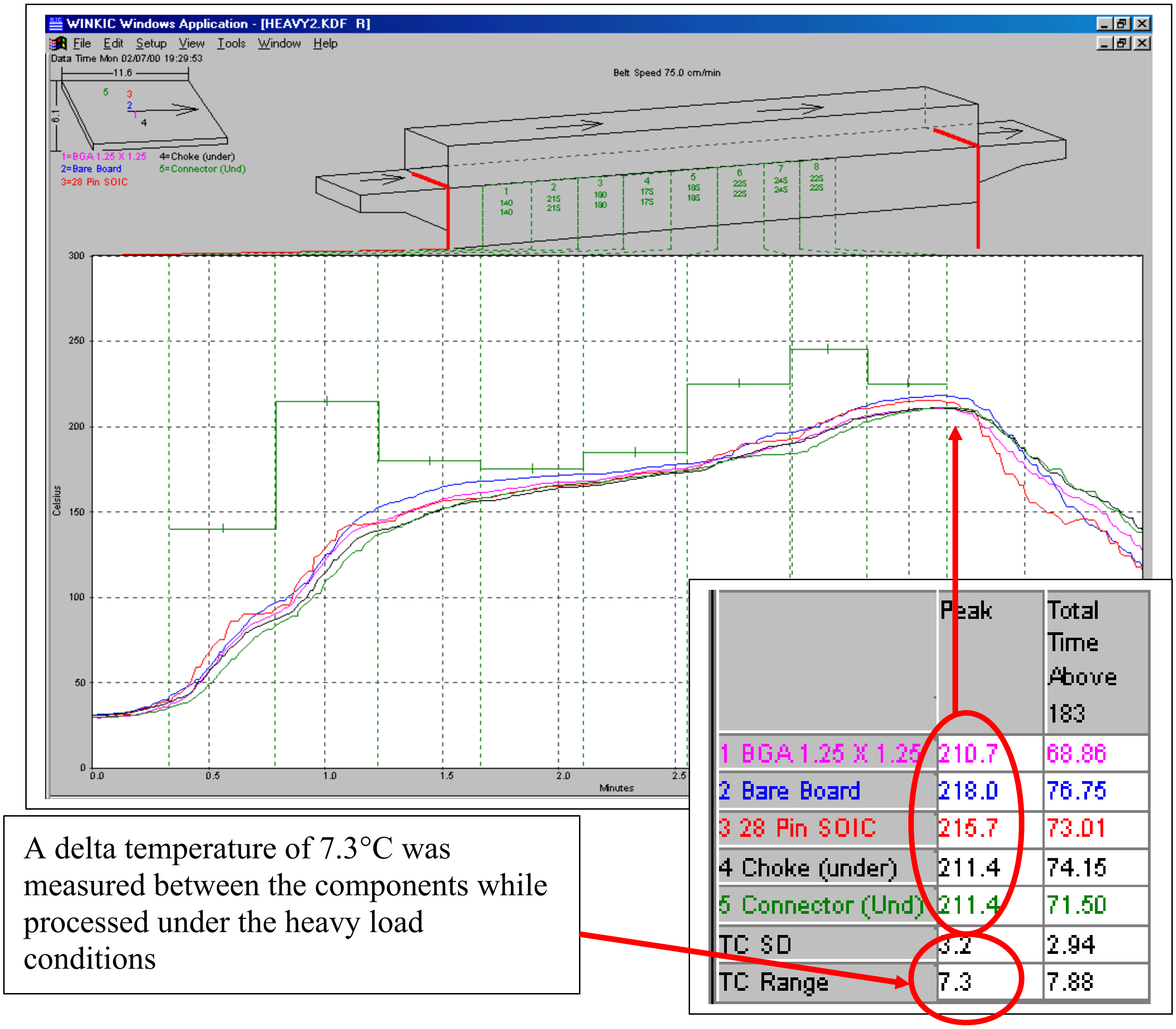
The combined weight of the test was 33.18 lbs.

	Width	Length	Thick	Weight
“Heavy Load”	6.125”(155mm)	11.625”(300mm)	0.81”(20mm)	5.42lbs

Total Weight of Load = 33.18 lbs

Figure 14: Summary Chart for Heavy Load Conditions

2. Component Temperature Test (Heavy Load)



	Peak	Total Time Above 183
1 BGA 1.25 X 1.25	210.7	68.86
2 Bare Board	218.0	76.75
3 28 Pin SOIC	215.7	73.01
4 Choke (under)	211.4	74.15
5 Connector (Und)	211.4	71.50
TC SD	3.2	2.94
TC Range	7.3	7.88

A delta temperature of 7.3°C was measured between the components while processed under the heavy load conditions

Figure 15: The plot of the profile achieved by the test board when run as part of a process under excessive load conditions.

3. Results compared to “No Load” and “Normal Load” Tests

The results of the component temperature are plotted and the peak temperature recorded in the chart. The data recorded by T/C 2 located on the bare board (Blue) was 218.0°C while the BGA Component, T/C 1 (Pink), shows a peak temperature of 210.7°C was obtained. A delta temperature of only 7.3°C was measured between the components when processed under the heavy load conditions.

VI. Load Testing the 1800 EXL under Nitrogen Conditions

A. Parameters of the test

As previously outlined, two configurations were utilized during the study, an 1800EXL configured for operation with an air atmosphere and an 1800EXL configured with a nitrogen atmosphere.

Part of the design criteria in the developing of the 1800EXL focused on optimization of the heating efficiencies for complete temperature profile control while being mindful of the consumption rates in the case of the nitrogen configuration.

Regardless of the working environment (air or nitrogen), each of the forced convection modules consists of low mass open coil heaters, a high temperature blower motor assembly, blower housing, inner diffusion box and a process control thermocouple strategically located to ensure precise process temperature in the zone. See diagram of the Heater Module on Page 6.

As with the testing performed on the oven using the air configuration, the test board containing the thermocouples was positioned, as part of a multiple board run. The Test Board was placed in a middle position between several load boards. A photograph is shown in Figures 10 (Page 14) and Figure 13 (Page 17) indicating the board positioning in the oven tunnel.

The data generated using the three load conditions using the nitrogen-configured oven is quoted below.

1. Results Summary “No Load”

The data from the BGA T/C 1 (Pink) shows a peak temperature of 211.6°C was obtained while the highest temperature was recorded on the bare board T/C 2 (Blue) with a temperature of 219.9°C.

A delta temperature of 8.3°C was measured between the components on the test board.

2. Results of “Normal Load”

The data from the BGA T/C 1 (Pink) shows a temperature of 208.1°C was obtained while the temperature recorded by T/C 2 placed on the bare board (Blue) was 215.9°C.

A delta temperature of only 9.6°C was measured.

3. Results of “Heavy Load”

The data from the BGA Component T/C 1 (Pink) shows a peak temperature of 209.1°C was obtained while the maximum temperature recorded by T/C 2 located on the bare board (Blue) was 214.0°C.

A delta temperature of only 10.1°C was measured between the components when processed under the heavy load conditions.

4. Conclusion of the Study Results with the Nitrogen Configuration

When compared to the data generated under the other load conditions, the conclusion is the addition of excessive load has had no effect on the ability of the oven to produce repeatable component temperatures during the processing of the SMT boards.

The data collected during the heavy load conditions, when compared to the data generated under the no load and normal load conditions, shows the load variation had no effect on the component temperatures. The conclusion is the 1800 EXL is able to control zone temperature regardless of the load and assure the repeatability of the temperatures achieved during the processing of the SMT boards.

VII. EFFECT OF LOAD ON THE POWER OUTPUT FOR TEMPERATURE MAINTENANCE.

In order to maintain the precision of the temperature within the zone, and insure that the processing conditions are precisely maintained, the oven must vary the power and maintain the temperature set point in response to the heat drain that the load presents.

Functionally, the effect of load traveling through the zones acts as a heat sink absorbing the heat and potentially causing a variation in the actual temperature in the zone. Under production conditions, variation in zone temperature during the processing of the PCB could result in product, which is not properly reflowed, leading to higher rejection.

As part of this study, the response of the Heller 1800EXL to the change in load was monitored. To define the performance of the 180EXL to load conditions, several parameters were measured including:

1. The effect of a load on the overall temperature of the reflow zones. The temperature was monitored for each of the load conditions as described in the Normal Load and Heavy Load conditions (See pages 14 and 17).
2. To measure the changes in the power required to accurately maintain the temperature set point and assure the stability of the zone temperature, the power output to the heating system was monitored.
3. By plotting the effect of the temperature in the zone as the load passed through the zone and by measuring the power output, information regarding the impact of the load on the oven temperature and the power control needed to maintain the temperature can be viewed.
4. As with the introduction of load to the heated zone, the exiting of the load from the zone also requires an adjustment to the heater power to maintain the temperature in a lower mass condition. The study includes information regarding the effect on the power consumption in the zone when the load is exiting the heated zone.

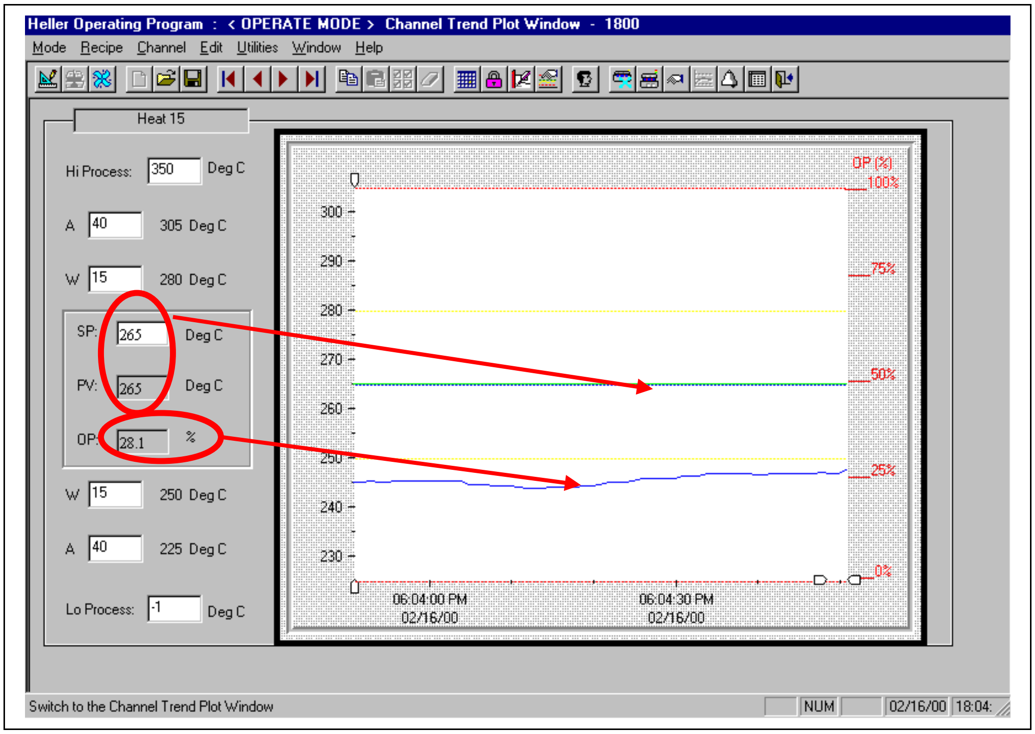
The graph displays the overall temperature set point of the heated zone (blue dotted line) and the actual temperature being maintained in the zone (green solid line).

It is possible to monitor any of the zones during the production run, for the purpose of this study, the highest set point (Zone 15 with a set point of 265°C) is shown and the actual temperature of the zone overlaid. The effect of the load on the power output is measured to demonstrate the response of the oven to the load (Blue).

The Trend Plots displayed in Figures 19 and 20 summarize the data for the tests performed under the normal and heavy load conditions. For all of the studies, the PV or Process Value (actual temperature in the zone) and SP or Set Point temperature are identical at 265°C. The OP or Output Percentage illustrates the overall power output to the heaters in the zones to maintain the temperature.

In both the Normal and Heavy load conditions, when the load boards and control board passed through the reflow zone the process value (actual temperature) and set point temperature deviated by less than 2°C. In these cases the power output to maintain the temperature set point is modulated in the 20% to 40% range.

The resulting data is shown in the following graphs:



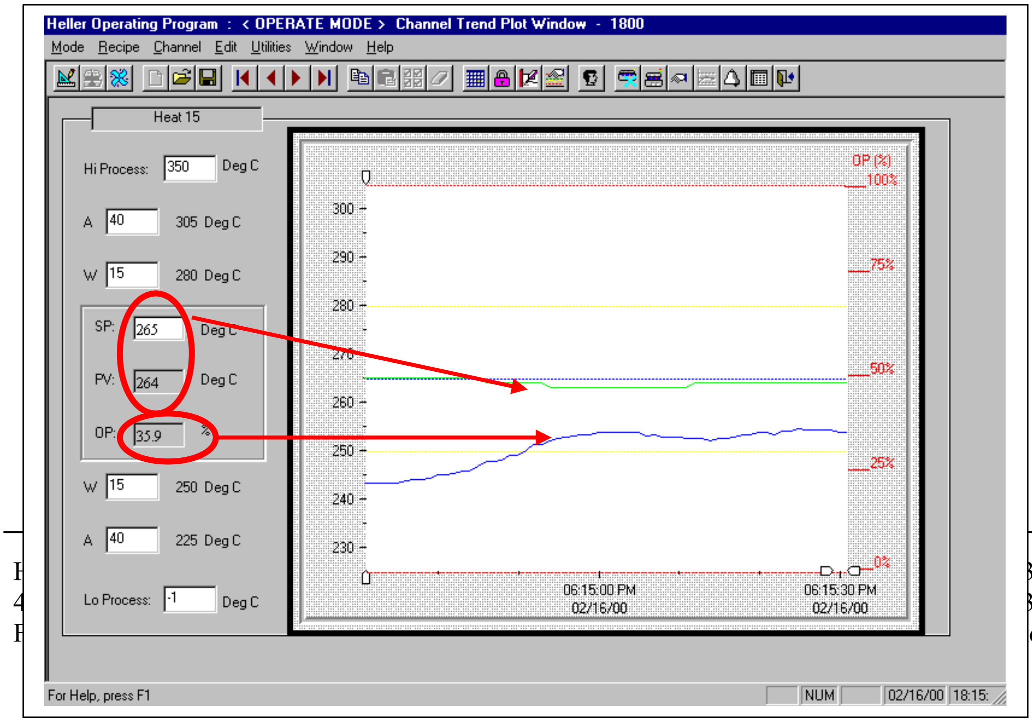
Heller Operating Program : < OPERATE MODE > Channel Trend Plot Window - 1800

Heat 15

Hi Process: 350 Deg C
A 40 305 Deg C
W 15 280 Deg C
SP: 265 Deg C
PV: 265 Deg C
OP: 28.1 %
W 15 250 Deg C
A 40 225 Deg C
Lo Process: -1 Deg C

Switch to the Channel Trend Plot Window

Figure 19, Normal Load.



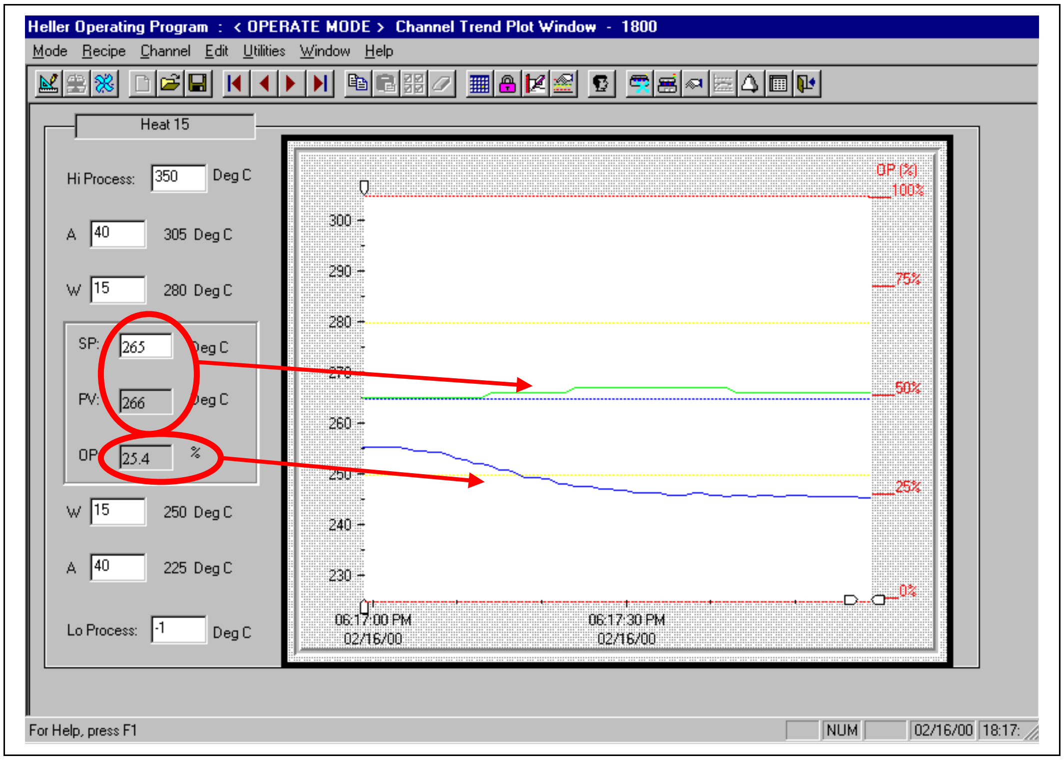
Heller Operating Program : < OPERATE MODE > Channel Trend Plot Window - 1800

Heat 15

Hi Process: 350 Deg C
A 40 305 Deg C
W 15 280 Deg C
SP: 265 Deg C
PV: 264 Deg C
OP: 35.9 %
W 15 250 Deg C
A 40 225 Deg C
Lo Process: -1 Deg C

For Help, press F1

Figure 20, Heavy Load



Hi Process: 350 Deg C
A 40 305 Deg C
W 15 280 Deg C
SP: 265 Deg C
PV: 266 Deg C
OP 25.4 %
W 15 250 Deg C
A 40 225 Deg C
Lo Process: -1 Deg C

For Help, press F1
02/16/00 18:17:

Figure 21, Response of Zone following the exit of the load.

The figures above provide data summarizing the effect of the load on the temperature of the zone. The data provided clearly shows the potential effect that the load has on the temperature of the zone. The data also clearly shows the response of the heating system and the power management required to maintain the temperature and insure the stability of the process conditions.

VIII. Conclusion of the Study

The Heller 1800EXL offers the precision, performance and the high throughput expected by the surface mount industry. The studies summarized in this report set out to demonstrate and document the reliability and control offered through the unique design of the Heller Reflow Oven Products. The data clearly shows the ability of the Heller 1800 to provide the accuracy and repeatability regardless of the throughput demanded.

A. A final summary of the data

A final summary of the data from all three of the studies under the two process conditions (Air and Nitrogen) provides statistical proof of the robustness of the Heller Ovens regardless of the load.

#	TC	No Load	Normal Load	Heavy Load	Ave.	Standard Deviation
	Air Oven					
1	**BGA**	211.60	211.20	210.60	211.13	**0.50**
2	**Bare Board**	219.90	219.60	218.60	219.37	**0.68**
3	**SOIC**	217.00	216.90	215.40	216.43	**0.90**
4	**Choke**	212.80	212.30	211.50	212.20	**0.66**
5	**Connector**	212.00	212.30	211.40	211.90	**0.46**
	TC Delta	**8.30**	**8.40**	**8.00**	**8.23**	**0.21**
	Nitro Oven					
1	**BGA**	208.40	208.00	209.10	208.50	**0.56**
2	**Bare Board**	216.40	215.90	214.30	215.53	**1.10**
3	**SOIC**	214.10	213.60	212.90	213.85	**0.35**
4	**Choke**	209.00	208.90	207.50	208.47	**0.84**

5	**Connector**	206.70	206.30	204.20	205.73	**1.34**
	TC Delta	**9.70**	**9.60**	**10.10**	**9.80**	**0.26**

B. Conclusion of Report

The benefits of the Heller Industries Reflow Oven Products outlined in this report, can be summarized as follows:

1. The ability of the Heller Oven to maintain temperature with very small variations across the width of the oven.
2. Providing throughput without compromising the precision of the manufacturing process requirements while responding to the changes in load of product passing through the oven.
3. The capability of heating massive components without overheating the substrate or the smallest components.

The goal of these tests was to provide definitive proof as to the applicability of the Heller products to meet the stringent demands of the SMT market ensuring reliable and repeatable production at high rates of throughput.

In conclusion, this study provides evidence of the applicability of the Heller products when customers are faced with making an investment in reliable production tools such as a reflow oven. The study supports the conclusion that the Heller Reflow Oven Products provide the instrumental confidence for reflow customers that have as their key criteria…quality, reliability, precision and throughput when selecting a reflow technology.