# Thermal Profile Variation and PCB Reliability

Jigar Patel and Umut Tosun, ZESTRON Americas

**ABSTRACT**

When designing PCBs, solder paste selection is critical. Once a specific paste type and supplier are identified, the manufacturing process is developed and refined. Critical to the quality of the solder joint is an effective thermal profile.

All solder paste suppliers recommend an appropriate thermal profile for specific paste in accordance with J-STD-004/005 (IPC TM-650). At a minimum, solder paste suppliers confirm that the recommended thermal profile produced have passing results for corrosion, SIR and electrochemical migration tests. However, these tests are performed on bare boards.

As PCB surface density and component mass increases, is the recommended thermal profile sufficient to produce quality solder bonds and fully volatilize flux residues? Flux residues remaining on a PCB surface and/or component may be benign. However, if the residues are ionic in nature, they can lead to failure mechanisms including leakage current, electrochemical migration and dendritic growth.

For high reliable applications that include No Clean or RMA solder paste, it is likely the PCBs are cleaned. If water soluble (OA) solder paste is selected, the PCB is certainly cleaned. An optimized cleaning process cannot address poor solder bonding, but it can remove ionic flux residues minimizing possible failure mechanisms.

This study was conducted to assess the effect of thermal profile variations on flux residue formation. It was limited to No Clean solder pastes as this paste may or may not be cleaned. Six (6) different pastes were considered. The IPC-B-52 test vehicle was used for this study.

For each reflow profile variation, two identical test vehicles were processed; one was cleaned and one was not. Each was subjected to SIR analysis. Test vehicles that were cleaned were processed using a spray-in-air inline cleaner with an aqueous based cleaning agent.

**KEY WORDS**

Reflow profile, SIR, Cleanliness Assessment

**INTRODUCTION**

It has been recognized within the electronics manufacturing industry that the advances made with PCB design, materials and components have posed significant challenges with the reflow process. As stated by a solder materials supplier company in the industry, “The combination of higher lead-free process temperatures, smaller print deposits, and temperature restraints on electrical components has created difficult challenges in optimizing the reflow process. Not only are the electronic components and the PWB at risk, but the ability to achieve a robust solder joint becomes difficult, especially if the PCB is thermally massive” [1].

Temperature restraints on electrical components can certainly narrow the reflow process window. There are numerous component types that can be affected. Temperature sensitive device families acknowledged by the electronics industry include aluminum and polymer capacitors, film capacitors, molded tantalum capacitors (polymer and fused –excluding standard $MnO_2$ type non-fused), fuses, inductors and transformers with wire coils, non-solid state relays and LEDs. Within the SMT process, the common process sensitivities encountered today are limitations with respect to pre-heat time and temperature, time above liquidus (217°C), peak reflow temperature, time within 5°C of peak temperature and number of reflow passes [2].

Thus, the authors recognized that PCB surface temperature variation can exist and result from the challenges of reflow optimization. Given component temperature restraints, this could possibly compromise the integrity of the soldering process. Notwithstanding soldering defects such as voiding, balling and tombstoning, the authors were concerned with the effect of exposed flux activators on assembly reliability following reflow.

If the assembly process included OA or RMA solder pastes, any exposed activators will be cleaned following reflow thereby eliminating possible negative impact. However, in the case of No Clean solder paste when boards are not cleaned, the environment that the assembly may be used within can impact the assembly reliability. In particular, climatic stress can cause cracking of the resin layer thereby exposing hygroscopic polar activators to the atmosphere. These exposed flux activators can cause contamination induced leakage current, electrochemical migration and dendritic growth. However, cleaning No Clean solder paste residues following reflow can remove the exposed activators thereby ensuring assembly reliability.

Recognizing that reflow optimization is increasingly challenging as component density and thermal mass variation increases on the electronic assembly, surface temperature variation on the PCB is inevitable. Representative reflow profile examples of two different PCB assemblies are detailed in Figures 1 and 2.

Each figure represents a thermal profile from a highly dense and varied thermal mass component assembly. The max peak temperature was 250°C, yet temperature variation at the board surface varied up to 18°C (Figure 1) and 15°C (Figure 2). Each board was reflowed with a lead-free No Clean solder paste.

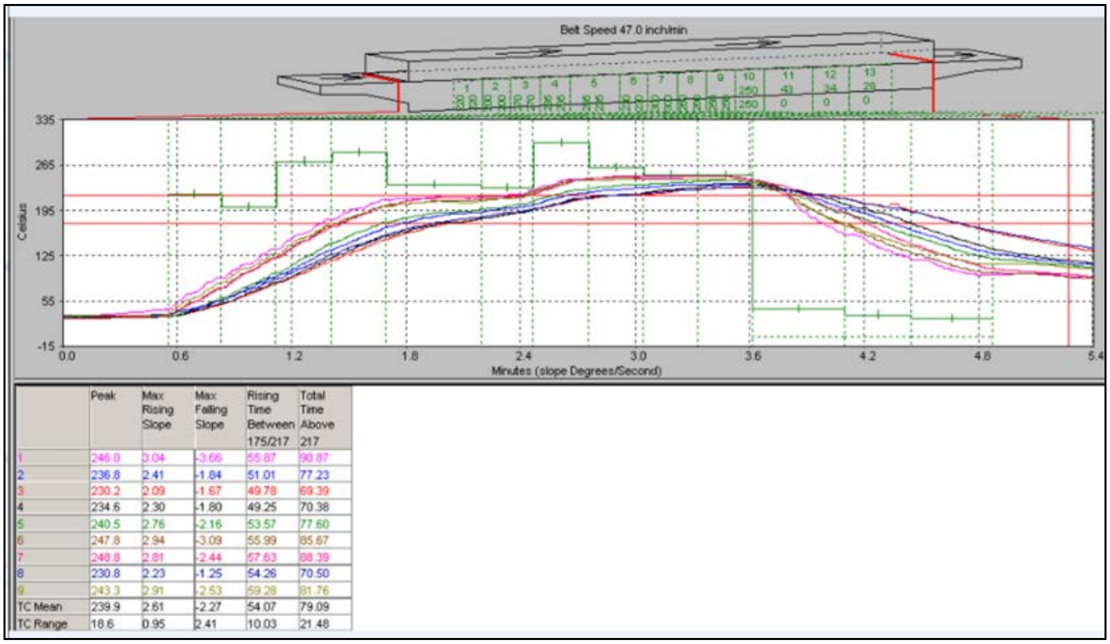



Figure 1.

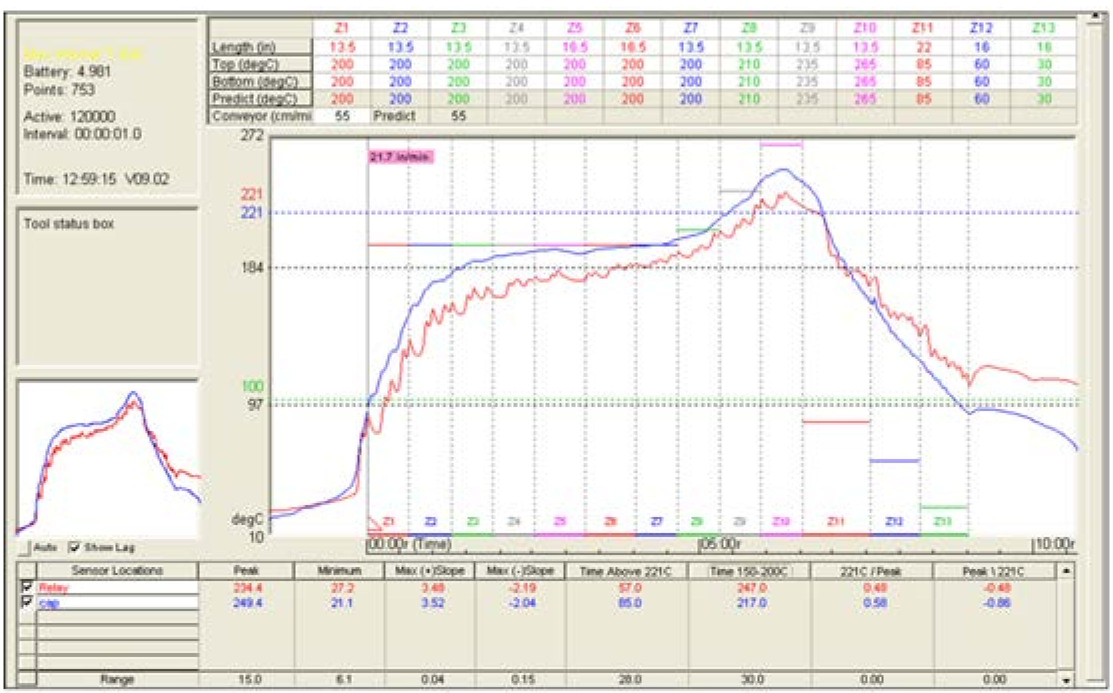



Figure 2.

Given that PCB surface temperature variation can result during reflow, the authors designed a technical study to evaluate the possible effect of this variation on assembly reliability focusing on No Clean solder pastes.

Specifically, they sought to investigate if ionic flux activators could be present on the board surface following a reflow process whereby the peak temperature was not realized. Furthermore, if flux activators are found to be present, would they have a negative impact on the reliability assessment methodology such as SIR analysis? Within this scenario, if a substrate fails SIR, could a post-reflow cleaning process impact the results of the SIR analysis?

For this study, densely populated PCBs with variable mass components were not used as the test vehicle. Rather, the authors chose to employ an unpopulated IPC-B-52 test vehicle as this facilitated SIR analysis. Reference Figure 3.

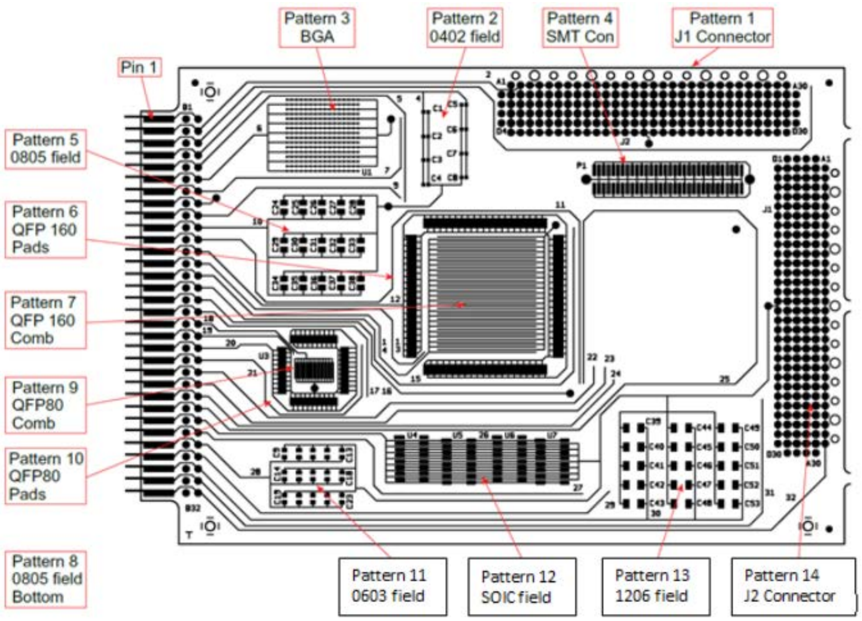



Figure 3.IPC-B-52 Test Vehicle

The IPC-B-52 will not be representative of densely populated production boards nor will it include components with varying mass densities that can result in the temperature variations detailed in Figures 1 and 2. Thus, in order to simulate board surface temperature variation, the authors chose to reduce the recommended peak leaded and lead-free temperature by 10°C and 15°C each and evaluate its effect on surface temperature and subsequent SIR test.

**METHODOLOGY**

For this study, six (6)No-Clean solder pastes were used, three (3) leaded and three (3)lead-free. Reference Table 1.

Table 1.No Clean Solder Paste Types

| **No Clean Solder PasteTypes** | |
|---|---|
| Lead-free | Paste A |
| | Paste B |
| | Paste C |
| Leaded | Paste D |
| | Paste E |
| | Paste F |

Three IPC-B-52 test vehicles were prepared for each solder paste type enabling each paste type to be reflowedat the manufacturer’s recommended profile as well as two additional reflow profiles targeting 10°C and 15°C lower peak temperatures. Realizing that many component types are temperature sensitive, targeting above peak temperatures as a means to offset PCB board surface temperature variation was not considered.

In total, thirty (30) test vehicles were employed. For each solder paste, five (5) process conditions were evaluated. Reference Table 2.

Table 2.Process Conditions

| Process Conditions | | |
|---|---|---|
| 1 | Recommended ramp reflow profile | Not Cleaned |
| 2 | Ramp reflow profile variation (-10°C peak) | Not Cleaned |
| 3 | Ramp reflow profile variation (-10°C peak) | Cleaned |
| 4 | Ramp reflow profile variation (-15°C peak) | Not Cleaned |
| 5 | Ramp reflow profile variation (-15°C peak) | Cleaned |

The recommended leaded and lead-free reflow profiles used are detailed in Tables 3 and 4.

Table 3. Recommended Leaded Reflow Oven Settings

| Recommended Leaded Reflow Oven Settings (°C) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Zone 1** | **Zone 2** | **Zone 3** | **Zone 4** | **Zone 5** | **Zone 6** | **Zone 7** | **Zone 8** | **Zone 9** | **Zone 10** | **Cooling** |
| **Top** | 90 | 100 | 130 | 150 | 160 | 170 | 180 | 190 | 210 | 235 | 3 Zones |
| **Bottom** | 90 | 100 | 130 | 150 | 160 | 170 | 180 | 190 | 210 | 235 | 3 Zones |
| | Fan Speed at 50% | | | | | | | Fan Speed at 60% | | | |

Table 4.Recommended Lead-free Reflow Oven Settings

| Recommended Lead-free Reflow Oven Settings (°C) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Zone 1** | **Zone 2** | **Zone 3** | **Zone 4** | **Zone 5** | **Zone 6** | **Zone 7** | **Zone 8** | **Zone 9** | **Zone 10** | **Cooling** |
| **Top** | 100 | 120 | 150 | 180 | 190 | 200 | 210 | 230 | 245 | 255 | 3 Zones |
| **Bottom** | 100 | 120 | 150 | 180 | 190 | 200 | 210 | 230 | 245 | 255 | 3 Zones |
| | Fan Speed at 50% | | | | | | | Fan Speed at 60% | | | |

For all paste types, cleaning trials were conducted employing a spray-in-air inline cleaner with an aqueous based cleaning agent. Cleaning equipment operating parameters are detailed in Table 5.

Table 5. Cleaning Operating Parameters

| Cleaning Equipment Operating Parameters | |
|---|---|
| Equipment type | Spray-in-Air Inline |
| Cleaning Agent | Aqueous based cleaning agent |
| Concentration | 15% |
| Conveyor Belt Speed | 1 ft/min |
| Pre-wash Pressure (Top/Bottom) | 50 PSI / 40 PSI |
| Wash Pressure (Top/Bottom) | 80 PSI / 70 PSI |
| Wash Hurricane Pressure (Top/Bottom) | 40 PSI / 40 PSI |
| Cleaning Temperature | 150°F |
| **Rinse** | |
| Rinsing Agent | DI-water |
| Rinse Pressure (Top/Bottom) | 80 PSI / 70 PSI |
| Rinse Hurricane Pressure (Top/Bottom) | 40 PSI / 40 PSI |
| Rinsing Temperature | 150°F |
| Final Rinse Pressure (Top/Bottom) | 30 PSI / 20 PSI |
| Final Rinse Temperature | Room Temperature |
| **Drying** | |
| Drying Method | Hot Circulated Air |
| Drying Temperature | 160°F-190°F |

**RESULTS**

Reflow profile variations:

The reflow profile variations, including maximum temperature achieved and TAL (Time Above Liquidus) are detailed in Table 6.

Table 6. Reflow Profile Variations

| **Reflow Profile Variations** | | | |
|---|---|---|---|
| | **Max Temp(°C)** | **ΔT for Max Temp (°C)** | **TAL (sec)** |
| **Lead-free Solder Paste** | | | |
| Recommended ramp reflow profile | 239.8 | - | 64.7 |
| Ramp reflow profile variation (-10°C peak) | 228.6 | -11.2 | 17 |
| Ramp reflow profile variation (-15°C peak) | 224.6 | -15.2 | 13.3 |
| **Leaded Solder Paste** | | | |
| Recommended ramp reflow profile | 217.3 | - | 65.3 |
| Ramp reflow profile variation (-10°C peak) | 206.2 | -11.1 | 25.7 |
| Ramp reflow profile variation (-15°C peak) | 202.4 | -14.9 | 19 |

It is important to note that the liquidus temperature is 217°C and 183°C for the lead-free and leaded pastes respectively.

Reflow profile graphs for the recommended-10°C and -15°C variations are included in the appendix.

We were able to simulate reflow profiles that averaged -11°C and -15°C below peak temperature. Five (5) test vehicles were prepared for each paste type. Of these, three (3) were not cleaned, those exposed to the manufacturers' recommended ramp profile and the -10°C and -15°C ramp profile variations. The remaining two (2), those exposed to the -10°C and -15°C ramp profile variations, were cleaned. In total, thirty (30) test vehicles were reflowed and subjected to SIR analysis. Results summary is detailed in Table 7.

Table 7. SIR Test Results

| **Solder Paste Type** | | **Reflow Profile** | **Cleaned** | **SIR Test Result** |
|---|---|---|---|---|
| Lead-free | Paste A | LF Ramp | No | Pass |
| | | LF Ramp (-10°C) | No | Pass |
| | | LF Ramp (-10°C) | Yes | Pass |
| | | LF Ramp (-15°C) | No | Pass |
| | | LF Ramp (-15°C) | Yes | Pass |
| | Paste B | LF Ramp | No | Pass |
| | | LF Ramp (-10°C) | No | Fail (4,6) |
| | | LF Ramp (-10°C) | Yes | Pass |
| | | LF Ramp (-15°C) | No | Fail (4) |
| | | LF Ramp (-15°C) | Yes | Pass |
| | Paste C | LF Ramp | No | Pass |
| | | LF Ramp (-10°C) | No | Pass |
| | | LF Ramp (-10°C) | Yes | Pass |
| | | LF Ramp (-15°C) | No | Pass |
| | | LF Ramp (-15°C) | Yes | Pass |
| Leaded | Paste D | L Ramp | No | Pass |
| | | L Ramp (-10°C) | No | Fail (4,6,10) |
| | | L Ramp (-10°C) | Yes | Pass |
| | | L Ramp (-15°C) | No | Fail (1,4,6) |
| | | L Ramp (-15°C) | Yes | Pass |
| | Paste E | L Ramp | No | Pass |
| | | L Ramp (-10°C) | No | Pass |
| | | L Ramp (-10°C) | Yes | Pass |
| | | L Ramp (-15°C) | No | Pass |
| | | L Ramp (-15°C) | Yes | Pass |
| | Paste F | L Ramp | No | Pass |
| | | L Ramp (-10°C) | No | Pass |
| | | L Ramp (-10°C) | Yes | Pass |
| | | L Ramp (-15°C) | No | Fail (14) |
| | | L Ramp (-15°C) | Yes | Pass |

As indicated in Table 7, mixed results were achieved depending upon the paste type and reflow variation considered. It is interesting to note that all test vehicles yielded passing SIR results for all paste types reflowed at the recommended thermal profile as well as those reflowed at the -10°C and -15°Creflow variation provided that the test vehicle was cleaned.

Results: Lead-free Pastes
All pastes reflowed at the manufacturers' recommended profile had passing SIR results. The ramp reflow profile variation had no effect on the SIR results with Paste A and C. However, the ramp reflow variations at -10°C and -15°Cwith Paste B resulted in failed SIR results for the test vehicles that were not cleaned.

Results: Leaded Pastes
All pastes reflowed at the manufacturers' recommended profile had passing SIR results. The ramp reflow profile variation had no effect on the SIR results for Paste E. However, the ramp reflow variations at -10°C and -15°C with Paste D resulted in failed SIR results for the test vehicles that were not cleaned. Paste F only had failing SIR results for the -15°C ramp reflow variation in which the test vehicle was not cleaned.

## CONCLUSIONS

There is certainly industry agreement that maximum board temperature and TAL are each critical to the formation of proper solder joints and inert resin layer. It is also clear that reflow optimization can be challenging given board density and component temperature sensitivity resulting in uneven PCB surface temperature. In the case of No Clean solder pastes, exposed flux activators may be present as a result.

In this study, all solder pastes passed SIR when reflowed with the recommended profile. Lead-free Pastes A, C and Leaded Paste E had passing SIR results when soldered with reflow profiles that were 10°C and 15°C below the recommended peak temperatures. However, lead-free Paste B and leaded Paste D failed SIR tests when reflowed below the recommended peak temperature and not cleaned although each paste passed SIR if cleaned post reflow and prior to the SIR tests.

Leaded Paste F has passing SIR results at 10°C below the recommended peak temperature whether it was cleaned or not. However, this paste failed SIR at 15°C below peak temperature when it was not cleaned but had passing SIR results when cleaned.

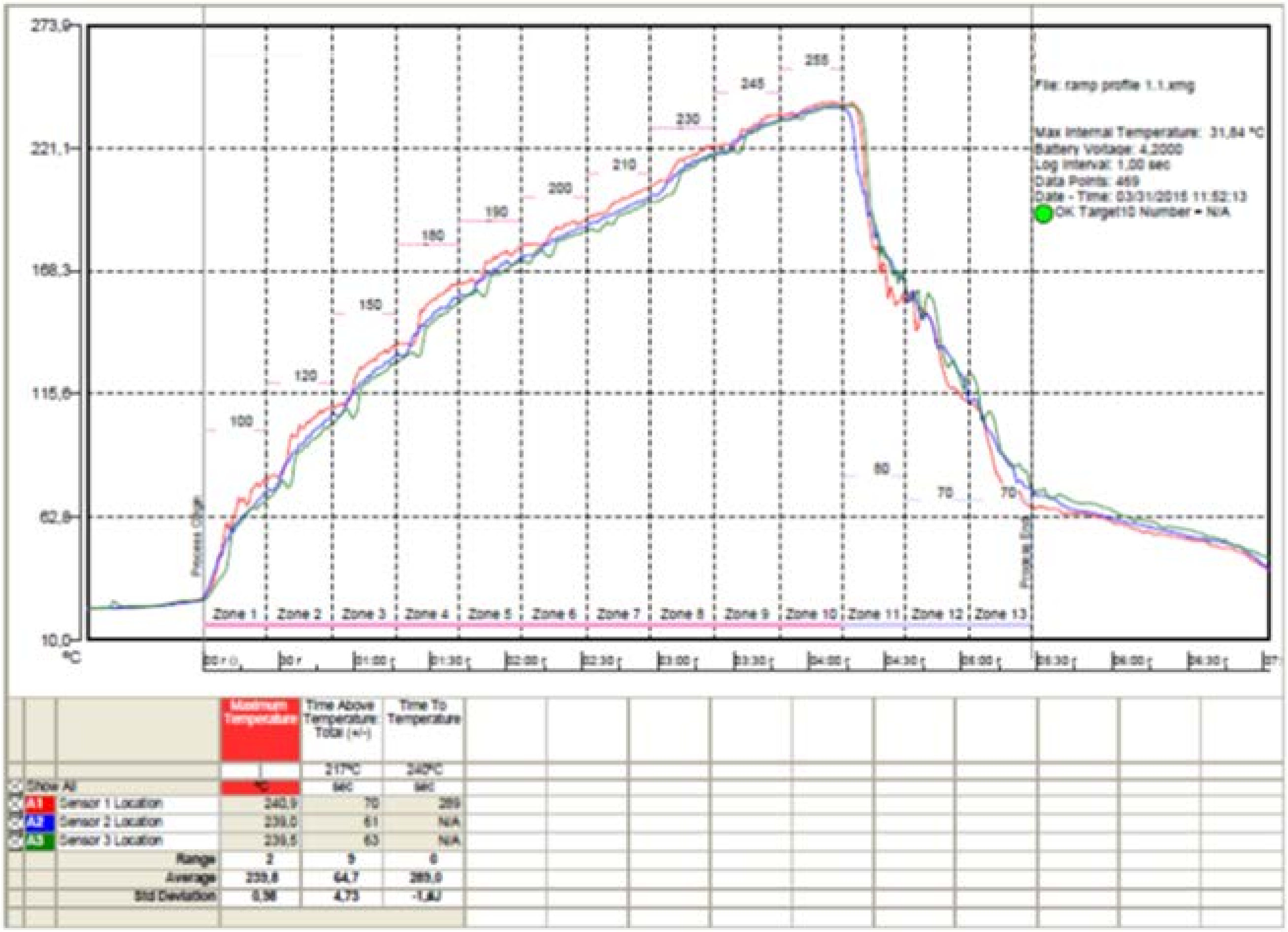
For the solder pastes considered within this study, assemblies exposed to the manufacturers' recommended reflow profile resulted in passing SIR results as one would expect. However, this study confirmed that particular solder pastes exposed to lower than recommended peak reflow temperatures could result in failed SIR analysis. Thus, effective post reflow assembly cleaning can ensure a passing SIR result and resulting product reliability.

## REFERENCES

[1] Best Practices Reflow Profiling for Lead-free SMT Assembly; Ed Briggs and Ronald C. Lasky, Ph.D., PE.
[2] Managing Temperature Sensitive Components in Pb-free Power Assemblies; IBM Power Systems, RTP, NC 2011

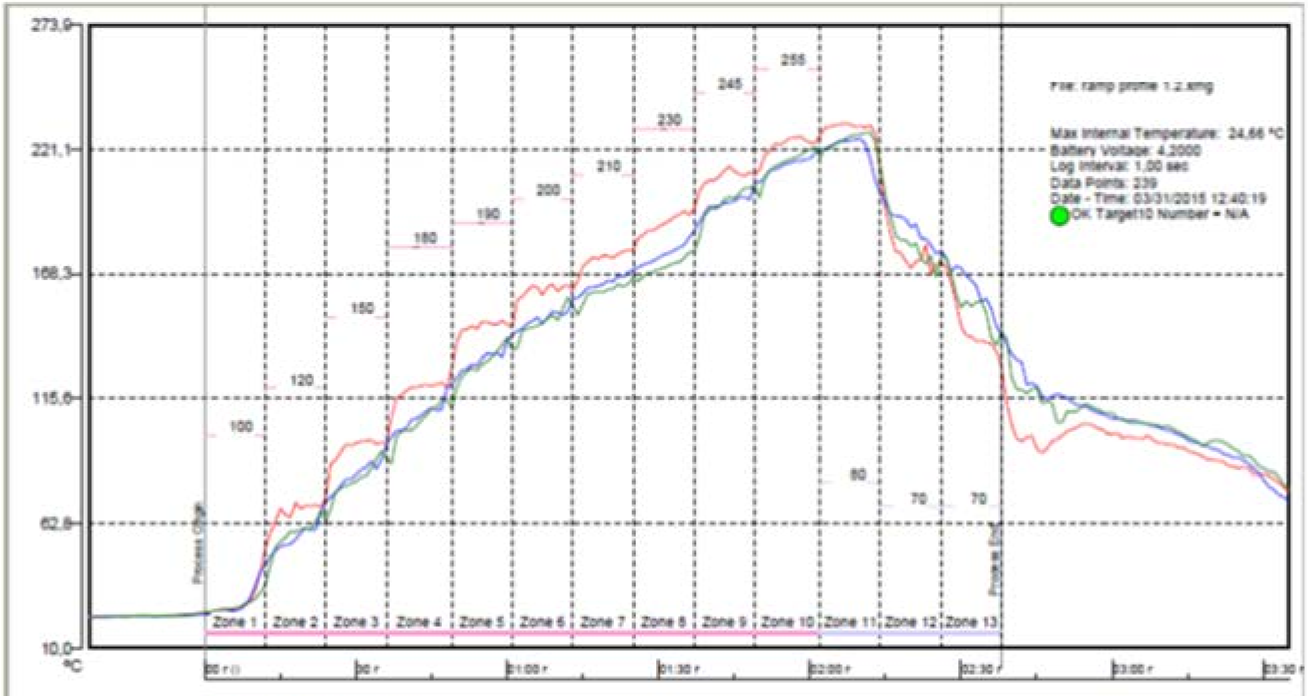
## APPENDIX

Lead-free Ramp Profiles:



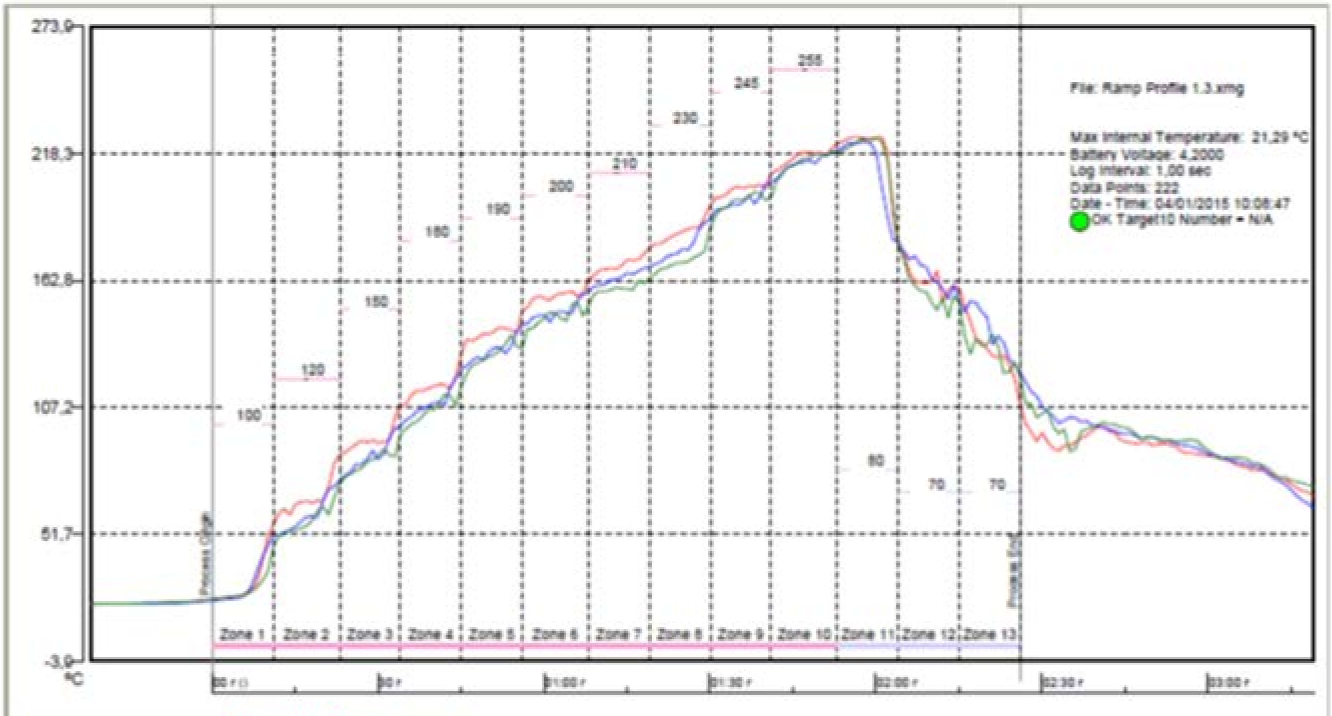

| | Maximum Temperature | Time Above Temperature Total (+/-) | Time To Temperature |
|---|---|---|---|
| | | 217°C | 240°C |
| Show All | °C | sec | sec |
| A1 Sensor 1 Location | 240,9 | 70 | 269 |
| A2 Sensor 2 Location | 239,0 | 61 | N/A |
| A3 Sensor 3 Location | 239,5 | 63 | N/A |
| Range | 2 | 9 | 0 |
| Average | 239,8 | 64,7 | 269,0 |
| Std Deviation | 0,98 | 4,73 | -1,#J |

Recommended reflow profile




| | | Maximum Temperature | Time Above Temperature Total (+/-) | Time To Temperature |
|---|---|---|---|---|
| | | | 217°C | 220°C |
| | Show All | °C | sec | sec |
| A1 | Sensor 1 Location | 232,2 | 23 | 146 |
| A2 | Sensor 2 Location | 225,6 | 11 | N/A |
| A3 | Sensor 3 Location | 225,1 | 17 | N/A |
| | Range | 7 | 12 | 0 |
| | Average | 228,6 | 17,0 | 146,0 |
| | Std Deviation | 3,33 | 6,00 | -1,#J |

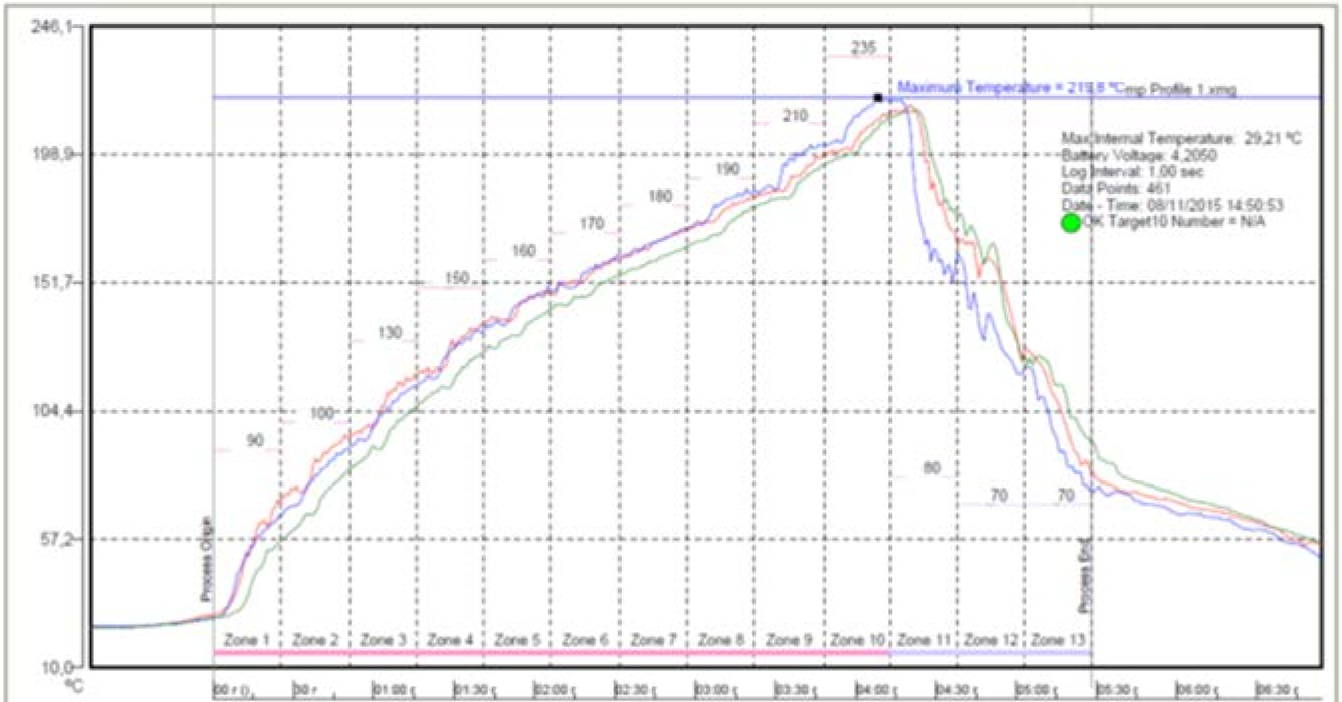
Ramp reflow profile variation (-10°C target)




| | Maximum Temperature | Time Above Temperature TOOX (+/-) | Time To Temperature |
|---|---|---|---|
| | | 217°C | 225°C |
| Show All | °C | sec | sec |
| A1 Sensor 1 Location | 225,5 | 17 | 137 |
| A2 Sensor 2 Location | 223,3 | 10 | N/A |
| A3 Sensor 3 Location | 225,1 | 13 | 142 |
| Range | 2 | 7 | 5 |
| Average | 224,6 | 13,3 | 139,5 |
| Std Deviation | 1,17 | 3,51 | 3,54 |

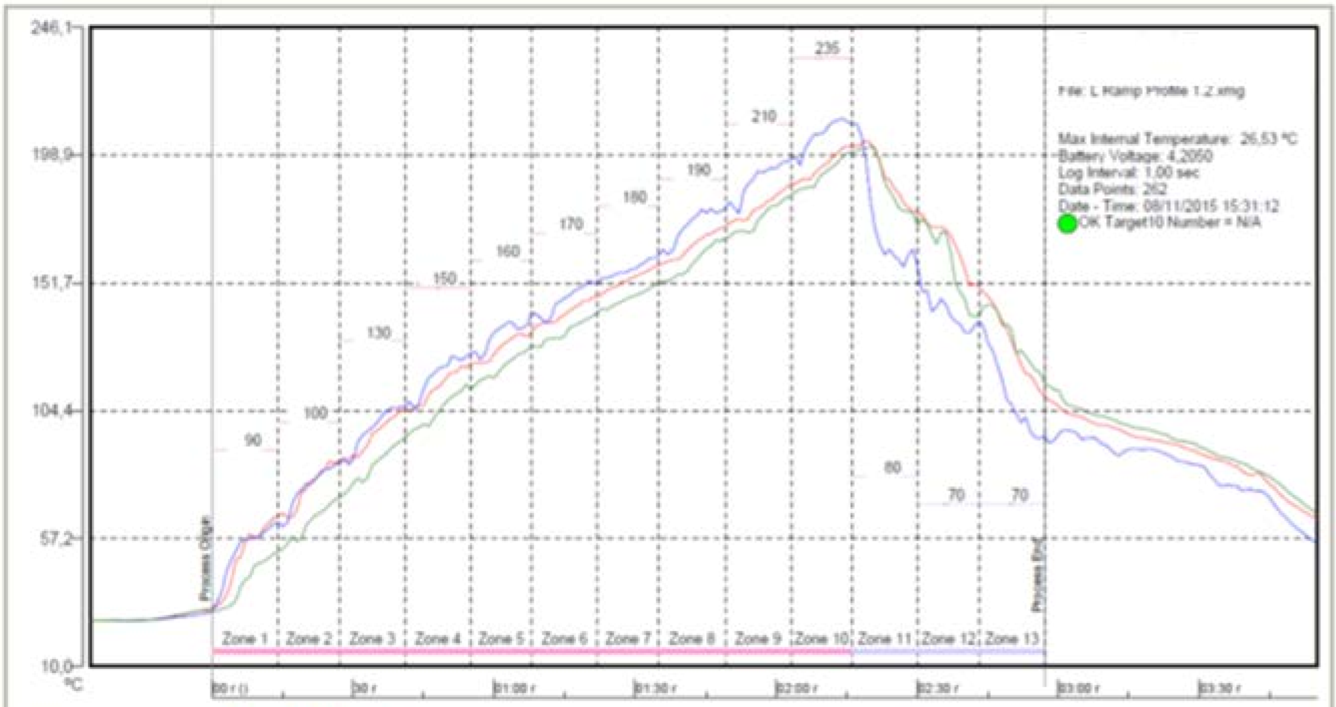
Ramp reflow profile variation (-15°C target)

Leaded Ramp Profiles:



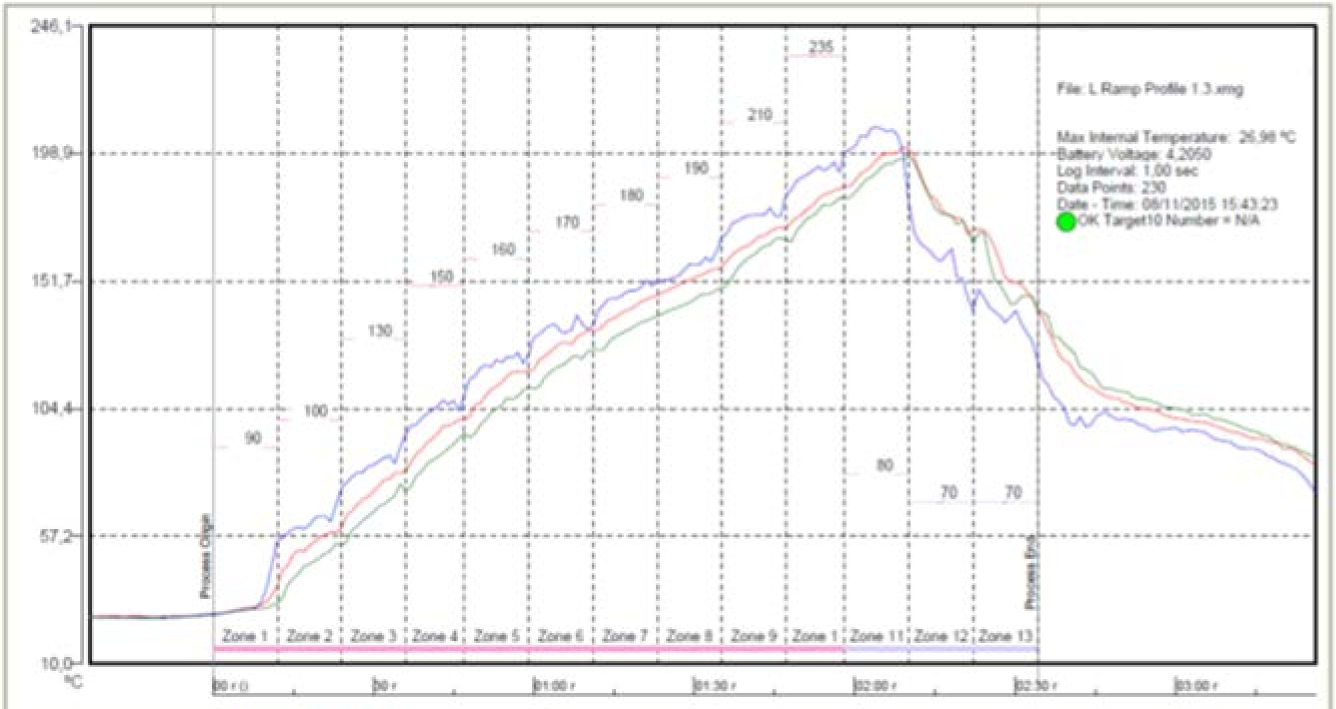

| | Maximum Temperature | Time Above Temperature Total (+/-) | Time To Temperature |
|---|---|---|---|
| | | 183°C | 217°C |
| Show All | °C | sec | sec |
| A1 Sensor 1 Location | 217,1 | 70 | 306 |
| A2 Sensor 2 Location | 219,8 | 69 | 293 |
| A3 Sensor 3 Location | 215,1 | 57 | N/A |
| Range | 5 | 13 | 13 |
| Average | 217,3 | 65,3 | 299,5 |
| Std Deviation | 2,36 | 7,23 | 9,19 |

Recommended ramp reflow profile




| | Maximum Temperature | Time Above Temperature Total (+/-) | Time To Temperature |
|---|---|---|---|
| | | 183°C | 206°C |
| Show All | °C | sec | sec |
| A1 Sensor 1 Location | 204,2 | 27 | N/A |
| A2 Sensor 2 Location | 212,4 | 27 | 154 |
| A3 Sensor 3 Location | 201,9 | 23 | N/A |
| Range | 11 | 4 | 0 |
| Average | 206,2 | 25,7 | 154,0 |
| Std Deviation | 5,52 | 2,31 | -1,#J |

Ramp reflow profile variation (-10°C target)




| | Maximum Temperature | Time Above Temperature: Total (+/-) | Time To Temperature |
|---|---|---|---|
| | | 183°C | 202°C |
| Show All | °C | sec | sec |
| A1 Sensor 1 Location | 201,1 | 20 | N/A |
| A2 Sensor 2 Location | 208,7 | 23 | 144 |
| A3 Sensor 3 Location | 197,4 | 14 | N/A |
| Range | 11 | 9 | 0 |
| Average | 202,4 | 19,0 | 144,0 |
| Std Deviation | 5,76 | 4,58 | -1,#J |

Ramp reflow profile variation (-15°C target)

# Thermal Profile Variation and PCB Reliability

Jigar Patel
ZESTRON Americas

# Thermal Profile Variation and PCB Reliability

- **Introduction**
- Methodology
- Results
- Conclusion

# Introduction

- When designing PCBs, solder paste selection is critical
  - After paste type and supplier are identified, the manufacturing process is developed
  - Correct thermal profile results in good solder joint quality
- In accordance with J-STD-004/005 (IPC TM-650)
  - At a minimum, recommended thermal profile should produce passing corrosion, SIR and electrochemical migration results

# Introduction

- As PCB surface density and component mass increases, is the recommended thermal profile sufficient to produce quality solder bonds and fully volatilize flux residues?
- Residues that are ionic in nature, they can lead to failure mechanisms
  - Leakage current
  - Electrochemical migration
  - Dendritic growth

# Introduction

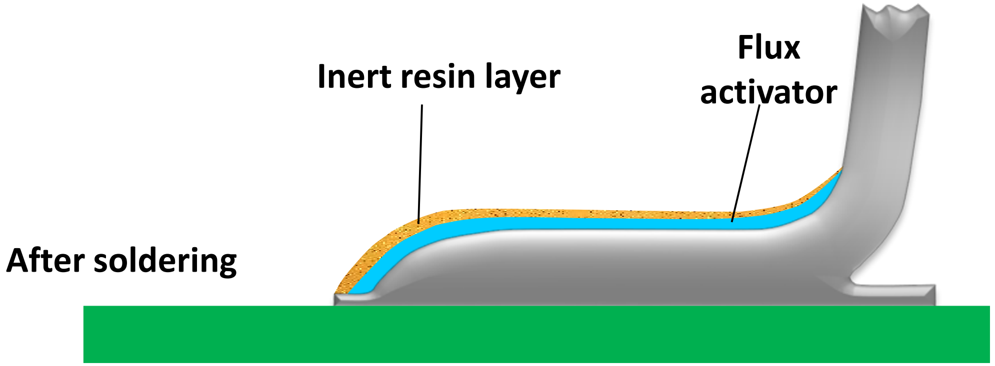
- Reflow optimization challenges due to:
  - High lead-free temperatures
  - Smaller print deposits
  - Board size and density (thermally massive)
  - Temperature sensitive components (Al and polymer capacitors, inductors, LEDs, transformers, fuses etc.)

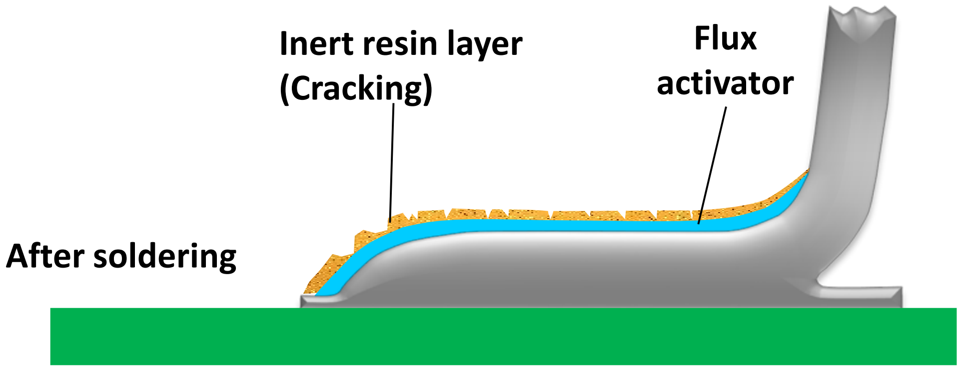
# Introduction

- With OA or RMA solder pastes, activators will be cleaned following reflow eliminating negative impact
- With No-Clean solder paste when boards are not cleaned, reliability can be impacted

# Introduction

- Climatic stress can cause cracking of the resin layer exposing flux activators
  - This can cause contamination induced leakage current, electrochemical migration and dendritic growth
- Cleaning No-Clean solder paste residues following reflow can ensure assembly reliability



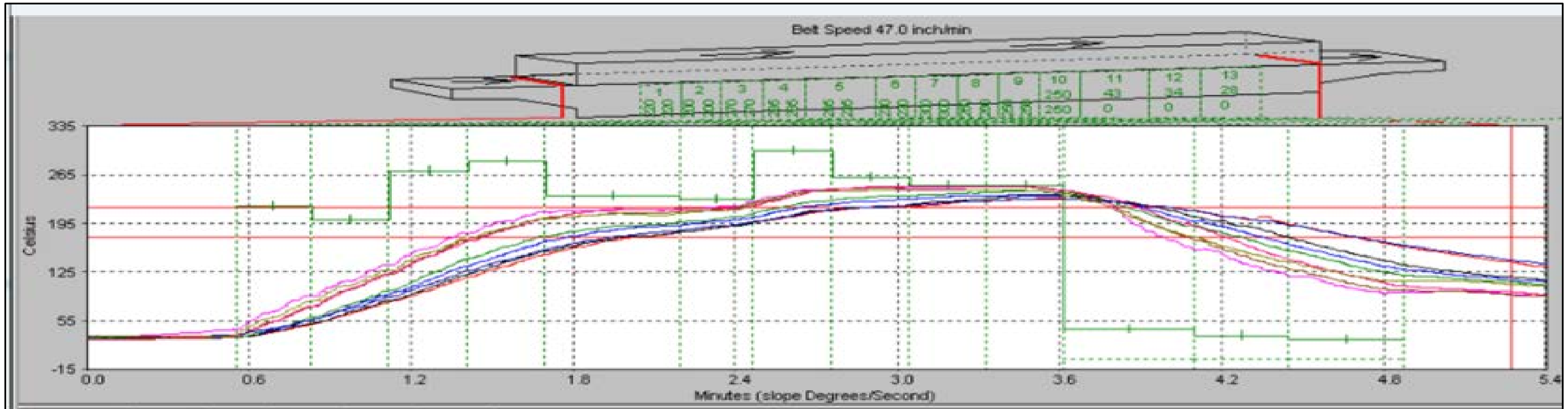



# Introduction

- Surface temperature variation on the PCB is inevitable due to:
  - – Component density increase
  - – Thermal mass variation increase

# Introduction

Example thermal profile of a highly dense assembly:



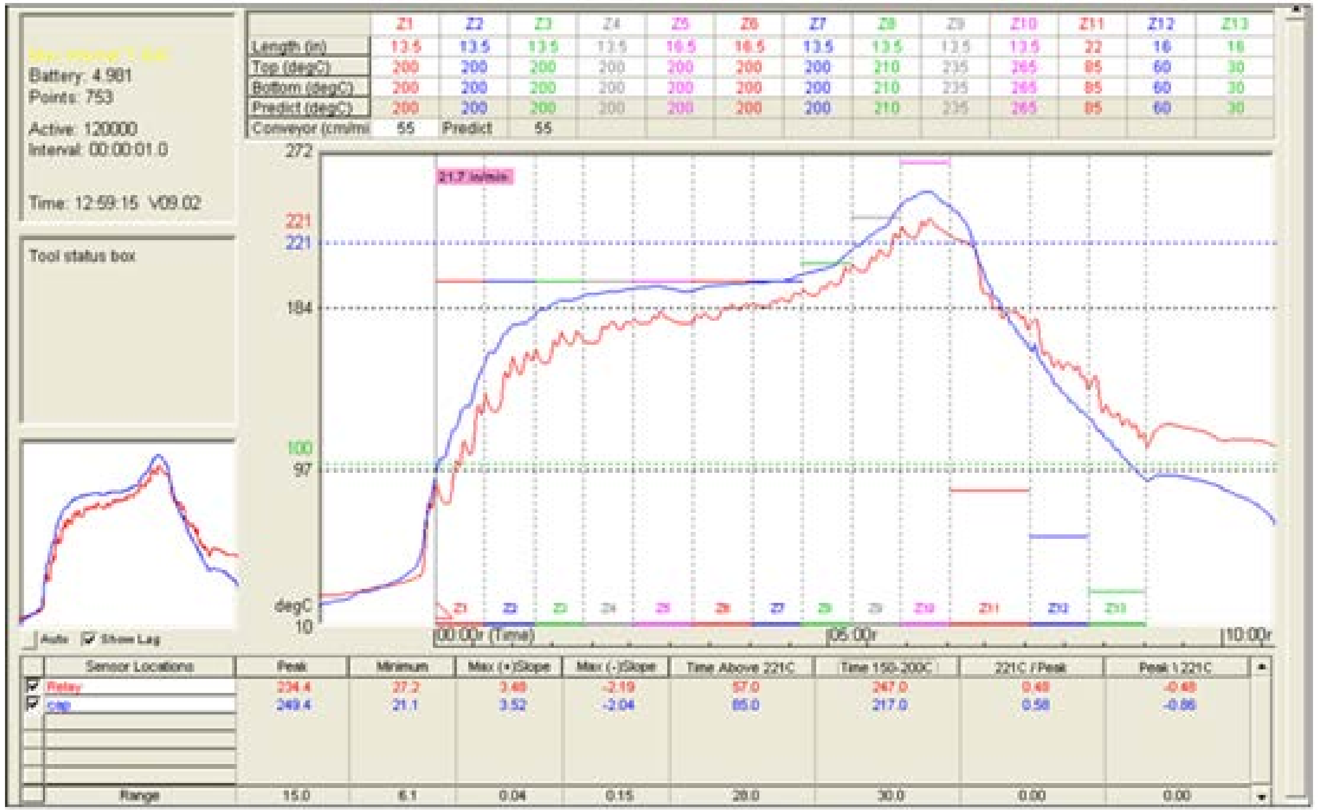

| | Peak | Max Rising Slope | Max Falling Slope | Rising Time Between 175/217 | Total Time Above 217 |
|---|---|---|---|---|---|
| 1 | 246.0 | 3.04 | -3.66 | 55.87 | 90.87 |
| 2 | 236.8 | 2.41 | -1.84 | 51.01 | 77.23 |
| 3 | 230.2 | 2.09 | -1.67 | 49.78 | 69.39 |
| 4 | 234.6 | 2.30 | -1.80 | 49.25 | 70.38 |
| 5 | 240.5 | 2.76 | -2.16 | 53.57 | 77.60 |
| 6 | 247.8 | 2.94 | -3.09 | 55.99 | 85.67 |
| 7 | 248.8 | 2.81 | -2.44 | 57.63 | 88.39 |
| 8 | 230.8 | 2.23 | -1.25 | 54.26 | 70.50 |
| 9 | 243.3 | 2.91 | -2.53 | 59.28 | 81.76 |
| TC Mean | 239.9 | 2.61 | -2.27 | 54.07 | 79.09 |
| TC Range | 18.6 | 0.95 | 2.41 | 10.03 | 21.48 |

**Max peak temp:** 250°C

**Temperature variation:** Up to 18°C

# Introduction

Example thermal profile of a highly dense assembly:




**Max peak temp:** 250$^{o}$C

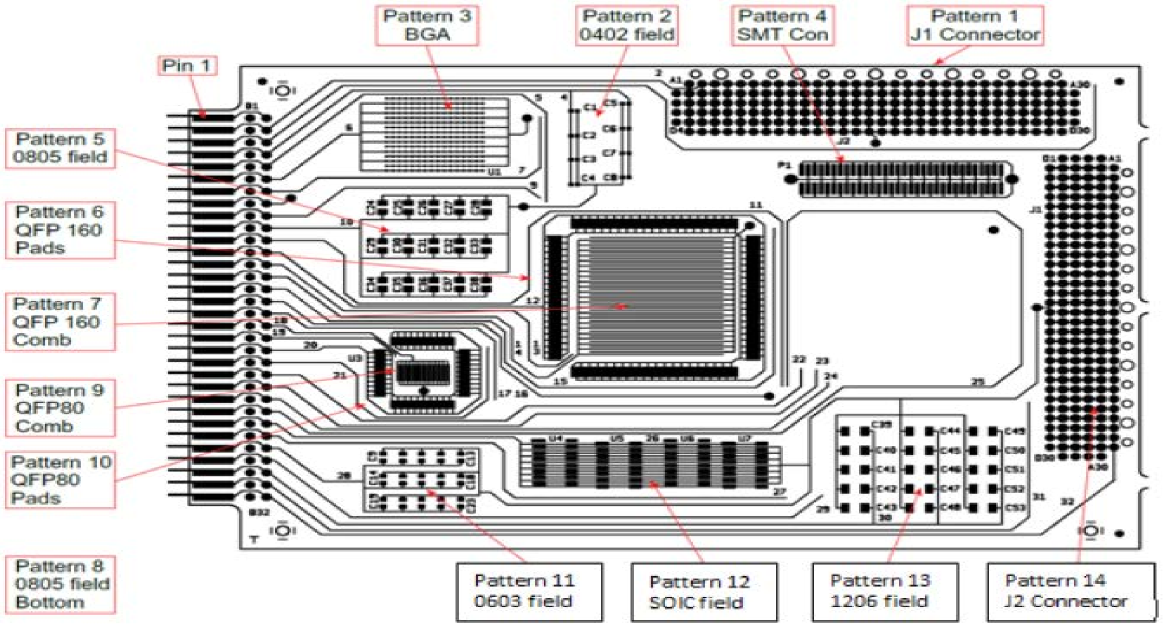
**Temperature variation:** Up to 15$^{o}$C

# Introduction

- Purpose of the technical study to:
  - Evaluate the effect of temperature variation on assembly reliability focusing on No-Clean solder pastes
  - Investigate if ionic activators may be left behind when the peak temperature is not realized and thermal variations exist
  - Determine whether SIR values will get impacted
  - Determine if post solder cleaning improves SIR values

# Introduction

- IPC-B-52 test vehicle was used
  - Reduced the recommended peak leaded and lead-free temperature by 10°C and 15°C each
  - Evaluate its effect on surface temperature and subsequent SIR test



# Thermal Profile Variation and PCB Reliability

- Introduction
- **Methodology**
- Results
- Conclusion

# Methodology

- Six (6) No-Clean solder pastes were used

| No-Clean Solder Paste Types | |
|---|---|
| **Lead-free** | Paste A |
| | Paste B |
| | Paste C |
| **Leaded** | Paste D |
| | Paste E |
| | Paste F |

# Methodology

- Three (3) test vehicles were prepared for each paste
  - Reflowed at manufacturers recommended profile
  - Two additional reflow profiles targeting 10$^{o}$C and 15$^{o}$C lower peak temperatures
  - Targeting above peak temperature not considered assuming temperature sensitive components exist

# Methodology

- Thirty (30) test vehicles were employed
  - Five (5) process conditions were evaluated for each paste

| Process Conditions | | |
|---|---|---|
| 1 | Recommended ramp reflow profile | Not Cleaned |
| 2 | Ramp reflow profile variation (-10°C peak) | Not Cleaned |
| 3 | Ramp reflow profile variation (-10°C peak) | Cleaned |
| 4 | Ramp reflow profile variation (-15°C peak) | Not Cleaned |
| 5 | Ramp reflow profile variation (-15°C peak) | Cleaned |

# Methodology

| Recommended Leaded Reflow Oven Settings (°C) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 | Zone 8 | Zone 9 | Zone 10 | Cooling |
| Top | 90 | 100 | 130 | 150 | 160 | 170 | 180 | 190 | 210 | 235 | 3 Zones |
| Bottom | 90 | 100 | 130 | 150 | 160 | 170 | 180 | 190 | 210 | 235 | 3 Zones |
| | Fan Speed at 50% | | | | | | | Fan Speed at 60% | | | |

| Recommended Lead-free Reflow Oven Settings (°C) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 | Zone 7 | Zone 8 | Zone 9 | Zone 10 | Cooling |
| Top | 100 | 120 | 150 | 180 | 190 | 200 | 210 | 230 | 245 | 255 | 3 Zones |
| Bottom | 100 | 120 | 150 | 180 | 190 | 200 | 210 | 230 | 245 | 255 | 3 Zones |
| | Fan Speed at 50% | | | | | | | Fan Speed at 60% | | | |

# Methodology

| | | |
|---|---|---|
| **Cleaning Equipment Operating Parameters** | Equipment type | Spray-in-Air Inline |
| | Cleaning Agent | Aqueous based Cleaning Agent |
| | Concentration | 15% |
| | Conveyor Belt Speed | 1 ft/min |
| | Pre-wash Pressure (Top/Bottom) | 50 PSI / 40 PSI |
| | Wash Pressure (Top/Bottom) | 80 PSI / 70 PSI |
| | Wash Hurricane Pressure (Top/Bottom) | 40 PSI / 40 PSI |
| | Cleaning Temperature | 150°F |
| **Rinse** | Rinsing Agent | DI-water |
| | Rinse Pressure (Top/Bottom) | 80 PSI / 70 PSI |
| | Rinse Hurricane Pressure (Top/Bottom) | 40 PSI / 40 PSI |
| | Rinsing Temperature | 150°F |
| | Final Rinse Pressure (Top/Bottom) | 30 PSI / 20 PSI |
| | Final Rinse Temperature | Room Temperature |
| **Drying** | Drying Method | Hot Circulated Air |
| | Drying Temperature | 160°F-190°F |

# Thermal Profile Variation and PCB Reliability

- Introduction
- Methodology
- **Results**
- Conclusion

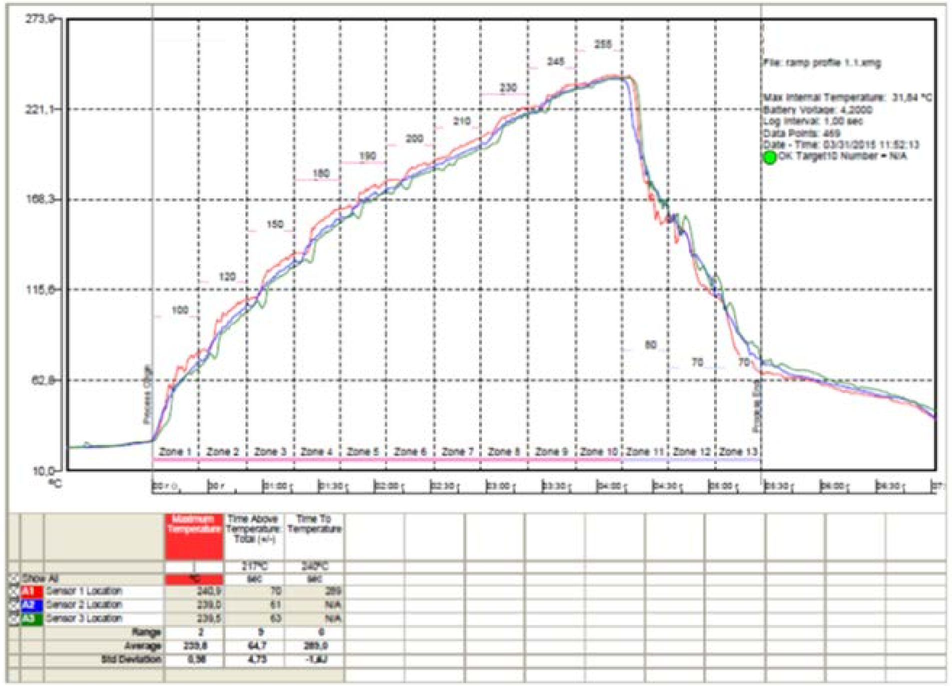
# Results

| Reflow Profile Variations | | | |
|---|---|---|---|
| | Max Temp (°C) | ΔT for Max Temp (°C) | TAL (sec) |
| **Lead-free Solder Paste** | | | |
| **Recommended ramp reflow profile** | 239.8 | - | 64.7 |
| **Ramp reflow profile variation (-10°C peak)** | 228.6 | -11.2 | 17 |
| **Ramp reflow profile variation (-15°C peak)** | 224.6 | -15.2 | 13.3 |
| **Leaded Solder Paste** | | | |
| **Recommended ramp reflow profile** | 217.3 | - | 65.3 |
| **Ramp reflow profile variation (-10°C peak)** | 206.2 | -11.1 | 25.7 |
| **Ramp reflow profile variation (-15°C peak)** | 202.4 | -14.9 | 19 |

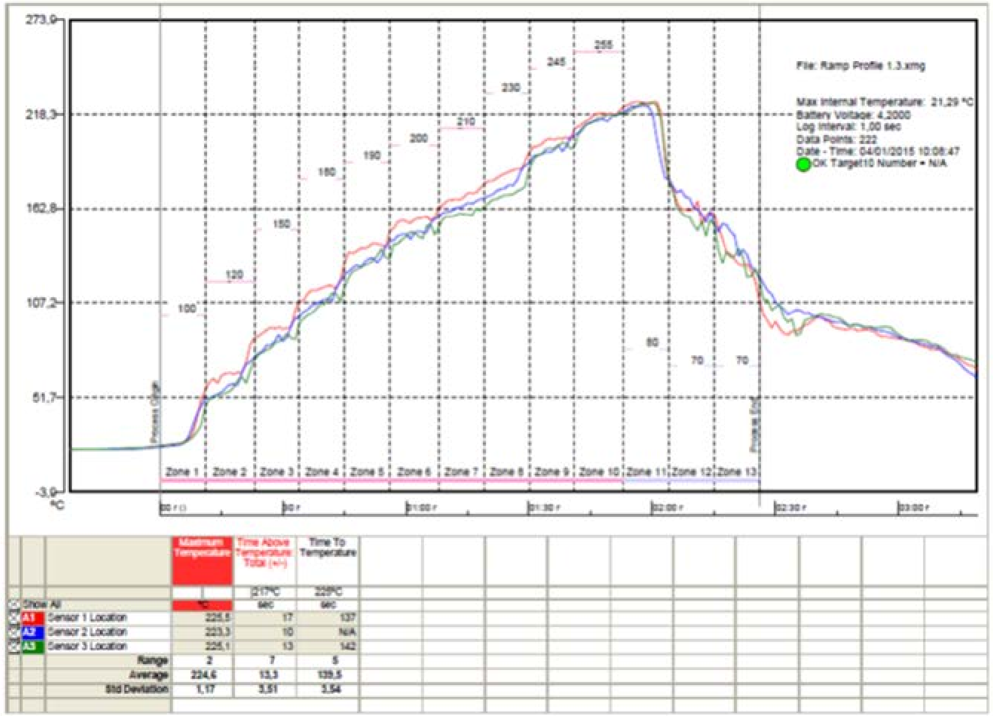
- TAL: Time Above Liquidus
- Liquidus temperature is 217°C and 183°C for the lead-free and leaded pastes respectively

# Results

- Lead-free Ramp Profile



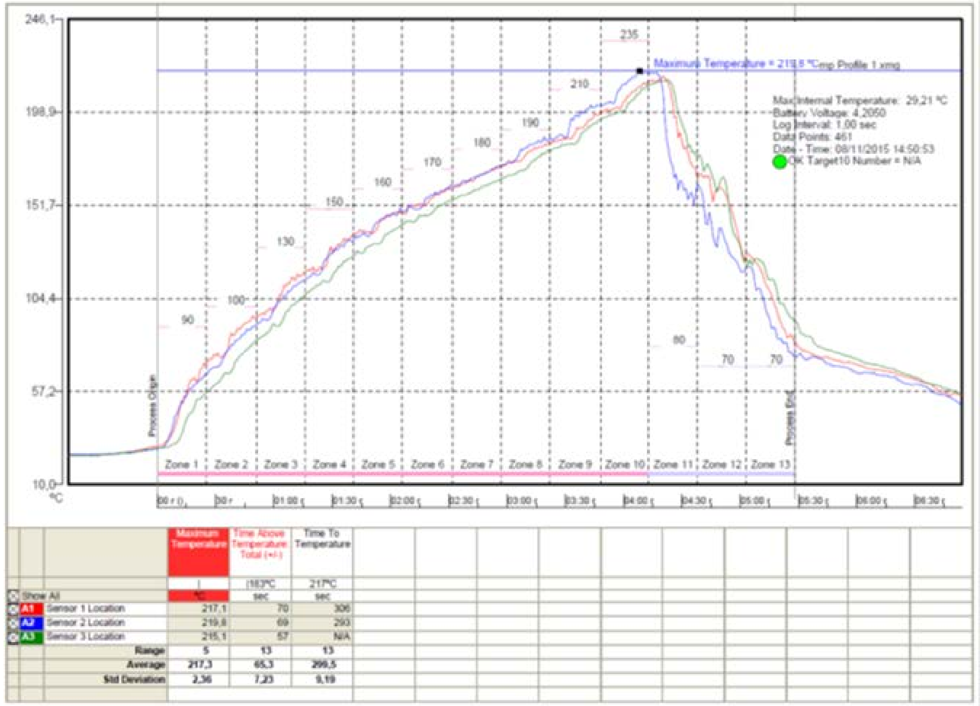

Recommended Reflow Profile



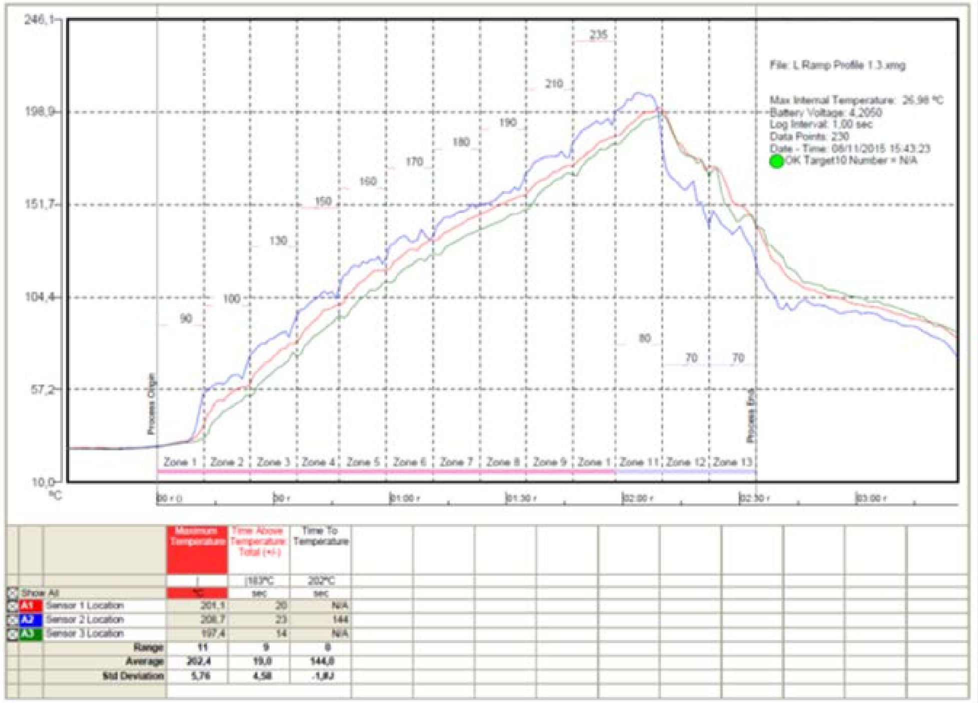

Reflow profile variation (-15ºC target)

# Results

- Leaded Ramp Profile




Recommended Reflow Profile




Reflow profile variation (-15°C target)

# Results

- Simulated reflow profiles that averaged -11$^{o}$C and -15$^{o}$C below peak temperature
- Five (5) test vehicles were prepared for each paste type
  - Three (3) exposed to the manufacturers' recommended ramp profile and the -10$^{o}$C and -15$^{o}$C ramp profile variations, were not cleaned
  - Two (2) exposed to the -10$^{o}$C and -15$^{o}$C ramp profile variations, were cleaned
- Thirty (30) test vehicles were reflowed and subjected to SIR analysis

# Results

- SIR Test Results

| Solder Paste Type | | Reflow Profile | Cleaned | SIR Test Result |
|---|---|---|---|---|
| Lead-free | Paste A | LF Ramp | No | Pass |
| | | LF Ramp (-10°C) | No | Pass |
| | | LF Ramp (-10°C) | Yes | Pass |
| | | LF Ramp (-15°C) | No | Pass |
| | | LF Ramp (-15°C) | Yes | Pass |
| | Paste B | LF Ramp | No | Pass |
| | | LF Ramp (-10°C) | No | Fail |
| | | LF Ramp (-10°C) | Yes | Pass |
| | | LF Ramp (-15°C) | No | Fail |
| | | LF Ramp (-15°C) | Yes | Pass |
| | Paste C | LF Ramp | No | Pass |
| | | LF Ramp (-10°C) | No | Pass |
| | | LF Ramp (-10°C) | Yes | Pass |
| | | LF Ramp (-15°C) | No | Pass |
| | | LF Ramp (-15°C) | Yes | Pass |

# Results

- Result: Lead-free Pastes
  – All pastes reflowed at the manufacturers' recommended profile had passing SIR results
  – Ramp reflow profile variation had no effect on the SIR results with Paste A and C
  – Ramp reflow variations at -10$^{o}$C and -15$^{o}$C with Paste B resulted in failed SIR results for the test vehicles that were not cleaned

# Results

- SIR Test Results

| Solder Paste Type | | Reflow Profile | Cleaned | SIR Test Result |
|---|---|---|---|---|
| Leaded | Paste D | L Ramp | No | Pass |
| | | L Ramp (-10°C) | No | Fail |
| | | L Ramp (-10°C) | Yes | Pass |
| | | L Ramp (-15°C) | No | Fail |
| | | L Ramp (-15°C) | Yes | Pass |
| | Paste E | L Ramp | No | Pass |
| | | L Ramp (-10°C) | No | Pass |
| | | L Ramp (-10°C) | Yes | Pass |
| | | L Ramp (-15°C) | No | Pass |
| | | L Ramp (-15°C) | Yes | Pass |
| | Paste F | L Ramp | No | Pass |
| | | L Ramp (-10°C) | No | Pass |
| | | L Ramp (-10°C) | Yes | Pass |
| | | L Ramp (-15°C) | No | Fail |
| | | L Ramp (-15°C) | Yes | Pass |

# Results

- Result: Leaded Pastes
  - All pastes reflowed at the manufacturers' recommended profile had passing SIR results
  - Ramp reflow profile variation had no effect on the SIR results for Paste E
  - Ramp reflow variations at $-10^{o}C$ and $-15^{o}C$ with Paste D resulted in failed SIR results for the test vehicles that were not cleaned
  - Paste F only had failing SIR results for the $-15^{o}C$ in which the test vehicle was not cleaned

# Thermal Profile Variation and PCB Reliability

- Introduction
- Methodology
- Results
- **Conclusion**

# Conclusion

- Maximum board temperature and TAL are each critical to the formation of proper solder joint and inert resin layer
- Reflow optimization can be challenging given board density and component temperature sensitivity
  - Resulting in uneven PCB surface temperature
  - For No-Clean solder pastes, exposed flux activators may be present as a result

# Conclusion (cont.)

- All solder pastes passed SIR when reflowed with the recommended profile
- Lead-free Pastes A, C and Leaded Paste E had passing SIR results when soldered with reflow profiles that were 10$^{o}$C and 15$^{o}$C below the recommended peak temperatures
- Lead-free Paste B and leaded Pastes D & F failed SIR tests when reflowed below the recommended peak temperature and not cleaned although each paste passed SIR if cleaned post reflow and prior to the SIR tests

# Conclusion (cont.)

- Assemblies exposed to the manufacturers' recommended reflow profile resulted in passing SIR results
- Few solder pastes exposed to lower than recommended peak reflow temperatures resulted in SIR failure
- Effective post reflow assembly cleaning can ensure a passing SIR result and resulting product reliability

# Thank you!
# Questions?

Jigar Patel

ZESTRON Americas