# Lead Free Assembly:
# A Practical Tool For Laminate Materials Selection

Erik J. Bergum
David Humby
Isola

**Abstract:** The impending European RoHS legislation, restricting the use of lead containing solders, has generated tremendous concern and confusion throughout the electronics industry supply chain. One of these areas of concern is the viability of existing Printed Wiring Board (PWB) substrate materials to withstand the elevated assembly temperatures required for soldering lead free alloys. Much has been written about how and why PWBs fail under lead free assembly conditions, how specific laminate base materials affect this, and about possible solutions. However, very little has been written regarding development of a comprehensive solution set for selection of "Lead Free Capable" laminate base materials. This paper builds on the previous works of the authors and others to define a "best practice" methodology to be used in determining selection criteria for such materials.

**Introduction:** As a laminate supplier to the PWB industry, possibly the most frequently asked question we get today is, "Are your laminates lead free capable?" or some variation on this theme. The answer is a qualified "Yes", and sometimes "No". The real answer is much more complex and depends on a combination of variables. For example, the answer can and usually should be, different, when posed by a company working with consumer electronics in contrast to a company involved with very complex high layer count telecom products. The demands and expectations for these diverse segments of the electronics industry do not lend themselves to a single technical solution, let alone a single solution that is cost effective.

The real challenge for laminate base materials is driven by the higher temperatures required to reflow lead free solders. Traditional Tin / Lead alloys (Sn/Pb) melt at 183 C and are reflowed at a peak temperature of 210-235 C. Typical Tin / Silver / Copper alloys (Sn/Ag/Cu) melt at approximately 217 C and are reflowed at a peak temperature of 235-260 C. It is the higher peak reflow temperatures required for lead free solders that present the real challenges for laminate base materials. These challenges take three distinct forms:

1. Interconnect survivability of the assembly process
2. Substrate survivability of the assembly process (i.e. delamination and blister resistance)
3. PWB performance in actual use, post assembly

These three challenges, along with the ability of a given laminate material to meet them, are affected by multiple variables from a pure laminate property standpoint. Figure #1 shows an example of one way to view the challenges and the laminate properties that affect them.

Material Challenges for Lead Free Assembly

| **CHALLENGES:<br>Lead Free assembly temperatures** | | |
|---|---|---|
| **Through hole survivability and reliability** | problems | **Catastrophic Failure (i.e. delamination / blistering)** |
| **Z-Axis expansion<br>Thermal stability** | mechanisms | **Thermal stability** |
| **Z-Axis expansion<br>Tg<br>Td** | key laminate property | **Td** |
| **DESIRED RESULT:<br>Assembly survival - PWB performance in actual use** | | |

Figure #1

The ability of a laminate to meet these challenges can be viewed as the "performance entitlement" of that laminate. Every laminate, by virtue of its fundamental properties, has a specific performance entitlement. Some of the key properties that need to be considered in making an informed choice of laminates for lead free assembly applications are shown in figure #2.

Key Laminate Performance Factors and Impact

| LAMINATE PERFORMANCE FACTORS | PERFORMANCE IMPACT |
|---|---|
| Glass Transition Temperature (Tg) | Impacts Z-axis expansion and mechanical performance. A higher Tg is generally better for lead free assembly. Primarily relates to interconnect reliability. |
| Z-Axis Expansion | Low Z-axis expansion is desirable for interconnect reliability. Can be improved through the use of "fillers". |
| Decomposition Temperature (Td) | A high Td is desirable. Primarily impacts catastrophic laminate failure but does play a roll in PTH reliability and performance in actual use, post assembly. |

Figure #2

PWB processes, PWB design and the assembly process all have their own inherent entitlements. It is the interaction between the PWB and the laminate entitlements that determines the ultimate lead free capability. These interactions are obviously complex, but the ultimate goal is that laminate and each process step produce an entitlement, sufficient to allow the next step to proceed. Therefore, the further back in the supply chain, the greater the pressure for a high entitlement relative to the end need. It is understanding this need, and how to make good material selection decisions, that we will focus on.

**Demand and Development of a "Tool":** For the last several years the PWB industry has been literally begging for a way to make good decisions on selection of materials for lead free applications. At this time the authors are aware of no such practical tool in general use. To develop such a tool, a team of nine "experts" with approximately 200 years of combined applicable PWB, laminate, assembly and other related experience was formed. This team, along with input from customers, OEMs and assistance from sister companies in the chemistry (Enthone) and assembly (Alpha) industries has developed such a tool.

The intent in developing a practical tool was to come up with a simple method for dealing with the multitude of variables of PWB design and assembly. Figure #3 shows the basic color-coding selected for this. Figure #4 shows an example of the actual chart format. In the horizontal axis it divides PWBs into thickness categories and in the vertical axis it differentiates by number of reflow processes.

Color Code Key

| **Color Code** | **Application Recommendation** |
|---|---|
| | Material generally recommended for applications of this type |
| | Material may be acceptable for applications of this type, but is not generally recommended |
| | Not recommended |

Figure #3

Example
Peak Reflow Temperature Range: 235-260 C
Please consult the “PWB Design Considerations” section before using this tool

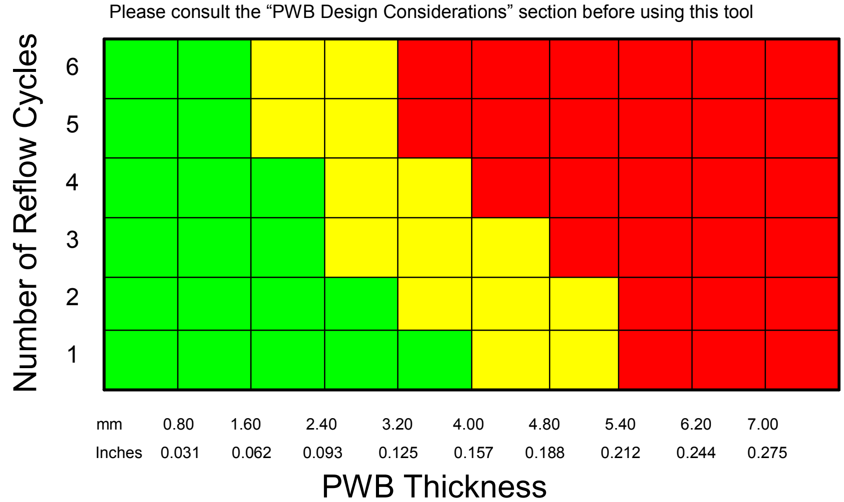


Figure #4

Like any tool, this one comes with a “safety warning”:

*The following tool has been developed based on considerable data, from various sources, and practical application experience. It is intended to serve as a general guide for typical PWB applications. No such tool can address all possible technology and design demands. As such, it is the users responsibility to confirm acceptability of any material recommended using this tool, for its intended PWB application.*

The safety warning, of course, begs the question, what is a typical PWB?; The team agreed there is no such thing, but set out to define what at least is "normal" for a given thickness range. This was defined as follows in figure #5

"Typical" PWB Feature for Tool Reference

Please consult the "PWB Design Considerations" section before using this tool

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Layers | 2-6 | 2-8 | 2-14 | 2-18 | 6-22 | 10-26 | 10-30 | 14-34 | 14-40 | 14-50 |
| Micro Vias | Yes | Yes | No | No | No | No | No | No | No | No |
| Cu Wt (oz) | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 | <2 |
| RC % | 35-55 | 35-55 | 35-55 | 35-55 | 45-60 | 45-60 | 45-60 | 45-60 | 45-60 | 45-60 |
| Aspect Ratio | <3:1 | <5:1 | <8:1 | <10:1 | <10:1 | <10:1 | <10:1 | <10:1 | <10:1 | <10:1 |
| Retained Cu % | < 50 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 | <25 |
| PTH Cu (µm) | >18 | >18 | >25 | >25 | >25 | >25 | >25 | >25 | >25 | >25 |
| Surface Finish | Ni/Au, Silver, Tin, OSP | | | | | | | | | |
| Lamination Cycles | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Mixed Materials | No | No | No | No | No | No | No | No | No | No |
| Blind and Buried Vias | No | No | No | No | No | No | No | No | No | No |
| External Planes | No | No | No | No | No | No | No | No | No | No |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| mm | 0.80 | 1.60 | 2.40 | 3.20 | 4.00 | 4.80 | 5.40 | 6.20 | 7.00 |
| Inches | 0.031 | 0.062 | 0.093 | 0.125 | 0.157 | 0.188 | 0.212 | 0.244 | 0.275 |

PWB Thickness

Figure #5

Many PWB designs fall outside what is defined as typical or normal here. Therefore, the team developed ways to "adjust" the selection tool for aspects of PWB design, processing and other attributes. The basic concept for these adjustments is shown in figure #6 and the specific recommendations for adjustments are shown in figure #7.

## Example Material – Application Adjustments
## Peak Reflow Temperature Range: XXX

Please consult the "PWB Design Considerations" section before using this tool

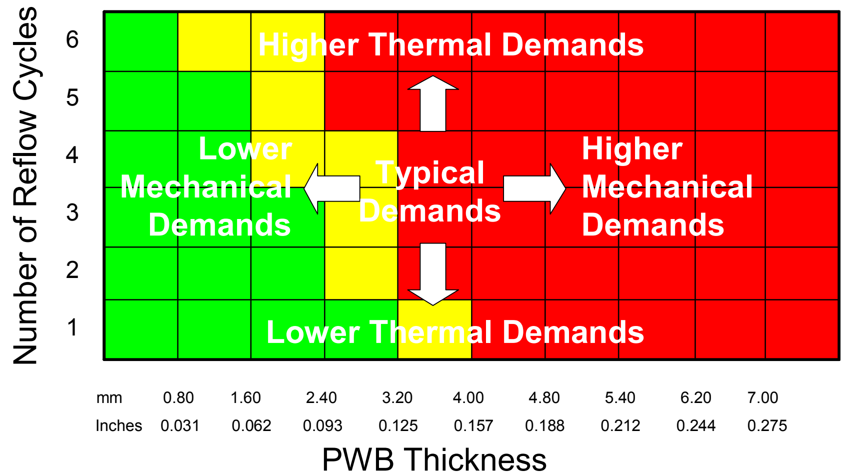


Figure #6

## PWB Adjustments For Tool Reference

Please consult the "PWB Design Considerations" section before using this tool

| | |
|---|---|
| Layers | If greater than typical consider moving up and right on charts |
| Micro Vias | For PWBs thicker than 1.60mm 0.062 inches additional evaluation may be required |
| Cu Wt | If greater than 2 Ounce (70 micron) consider moving up and right on charts |
| RC | If greater than maximum range consider moving right on charts |
| Aspect Ratio | If greater than maximum range consider moving right on charts |
| Retained Cu | If greater than maximum consider moving up and right on charts |
| PTH Cu (µm) | If less than typical consider moving up and right on charts |
| Surface Finish | If HASL or Reflowed Solder consider moving up on chart for each cycle (treat as an additional reflow cycle) |
| Multiple Lamination Cycles | If multiple lamination cycles consider moving up on chart for each additional cycle (treat as an additional reflow cycle) |
| Mixed Materials | If mixed material use lowest performing material as reference and consider moving up and right on that chart |
| Blind and Buried Vias | If yes consider moving up and right on charts |
| External Planes | If yes consider moving up and right on charts |

Figure #7

For the purposes of this paper, we will use five Brominated FR4 materials with various properties to demonstrate the approach. Descriptions and key properties of these materials are shown in figure #8.

Key Laminate Performance Data

| Description | Tg (C) | Z-CTE (50-260C) | Td (C) | Polyclad Grade |
|---|---|---|---|---|
| Traditional Dicy cured FR4, 4101A/21 | 140 | 4.2% | 320 | 240/226 |
| Filled, mid-performance, Dicy cured FR4, 4101A/97 | 150 | 3.4% | 340 | 254 |
| Filled, mid-performance, Phenolic cured FR4, 4101A/97 | 150 | 3.4% | 350 | 250HR |
| Traditional high performance, Dicy cured FR4, 4101A/24 | 175 | 3.5% | 310 | 370 |
| Filled, high performance, Phenolic cured FR4, 4101A/98 | 180 | 2.7% | 350 | 370HR |

Figure #8

Figures #9 through #13 show the suitability of these five materials for lead free reflow applications.

Traditional Dicy Cured FR4 – IPC 4101/21
Peak Reflow Temperature Range: 235 – 260° C
Please consult the "PWB Design Considerations" section before using this tool

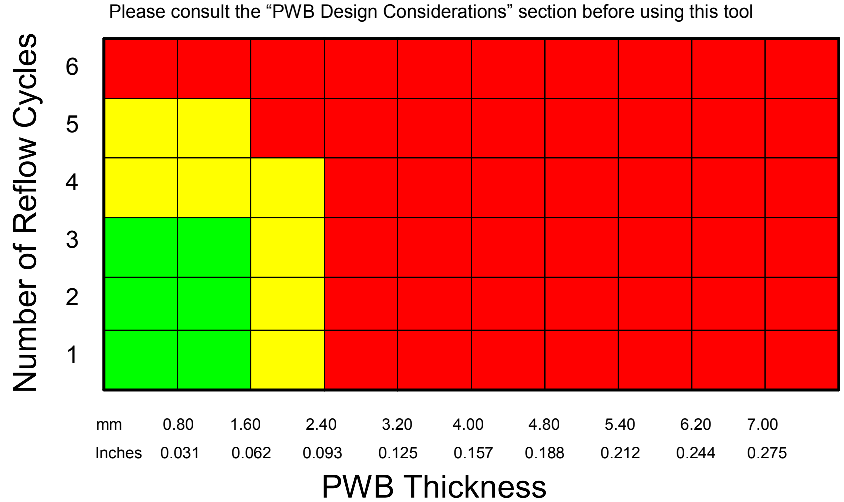


Figure #9

Filled, Mid Performance, Dicy Cured FR4 – IPC 4101/97
Peak Reflow Temperature Range: 235 – 260° C
Please consult the “PWB Design Considerations” section before using this tool

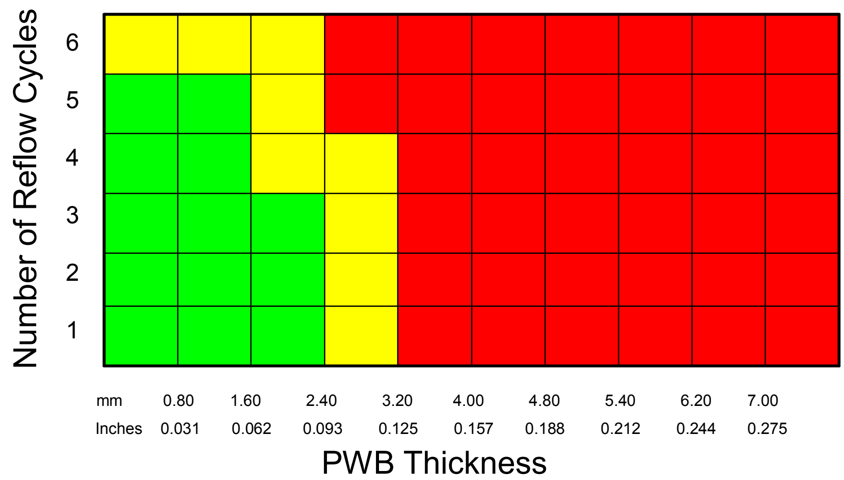


Figure #10

Filled, Mid Performance, Phenolic Cured FR4 – IPC 4101/97
Peak Reflow Temperature Range: 235 – 260° C
Please consult the “PWB Design Considerations” section before using this tool

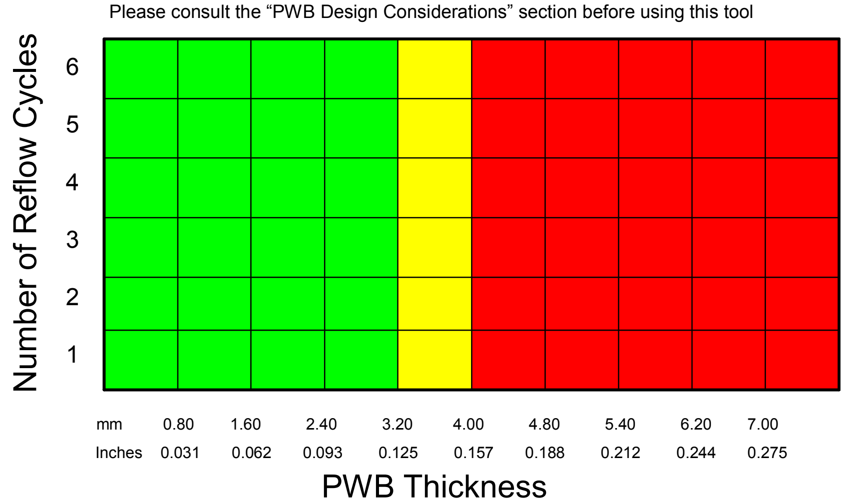


Figure #11

Traditional High Performance, Dicy Cured FR4 – IPC 4101/24
Peak Reflow Temperature Range: 235 – 260° C
Please consult the "PWB Design Considerations" section before using this tool

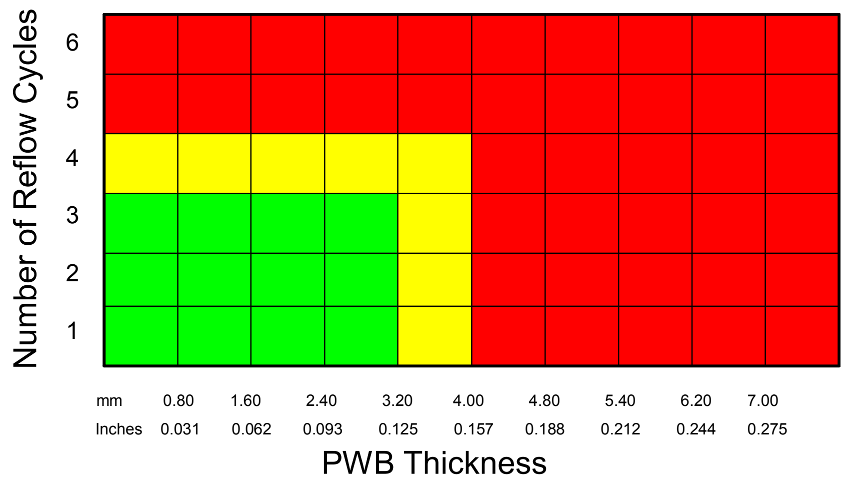


Figure #12

Filled High Performance, Phenolic Cured FR4 – IPC 4101/98
Peak Reflow Temperature Range: 235 – 260° C
Please consult the "PWB Design Considerations" section before using this tool

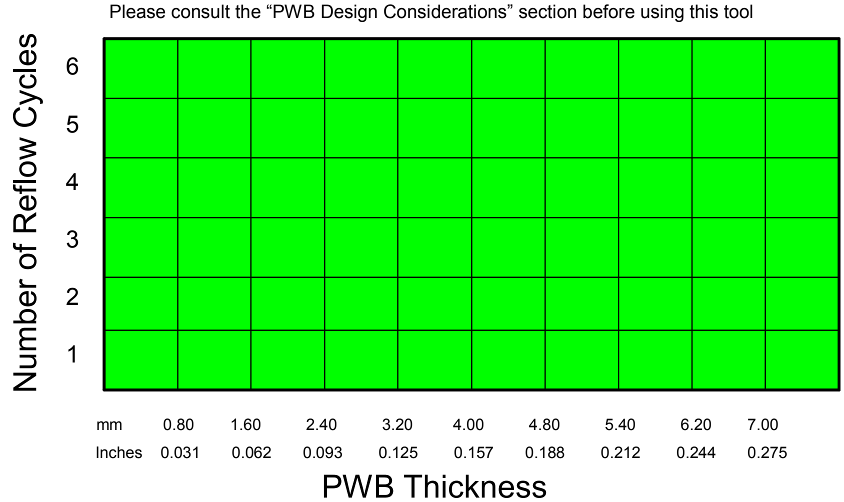


Figure #13

Based on these figures it is also possible to make specific recommendations as to the "best" or recommended material for a specific application. These recommendations are based on the team's analysis of cost versus performance of the various options. This information is shown in Figure #14.

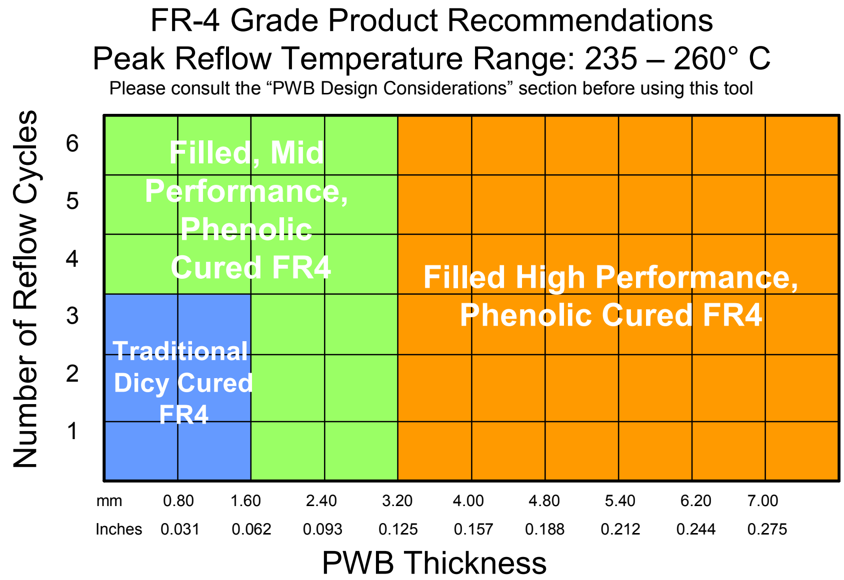


Figure #14

**Real World Applications:** A simple case study from real world application of this tool is probably in order to illustrate its use. Recently, we were presented with a problem PWB built using a traditional, high Tg, dicy cured FR4 (using another laminate suppliers material) that was failing for delamination in a lead free assembly process. Some of the key features of the PWB, as they relate to how it differed from a “typical” PWB as defined in figure #5 and the recommended adjustments suggested in figure #7, are shown in Figure #15.

Case Study

| **PWB Design Feature** | **Attribute** | **Recommended Adjustment** |
|---|---|---|
| Thickness | 2.50mm (0.098 inches) | - |
| Number of Reflows | 3 | - |
| Material | High performance FR4, 4101A/24 | - |
| Surface Finish | Lead Free HASL (HASL not typical) | Treat as an additional reflow cycle |
| Layer Count | 20 (<18 Typical) | Consider moving up and right on chart |

Figure #15

Figure #16 shows the results of making the adjustments suggested and does in fact predict that the traditional, high Tg, dicy cured FR4 material used is not a good choice in this application and would be expected to fail.

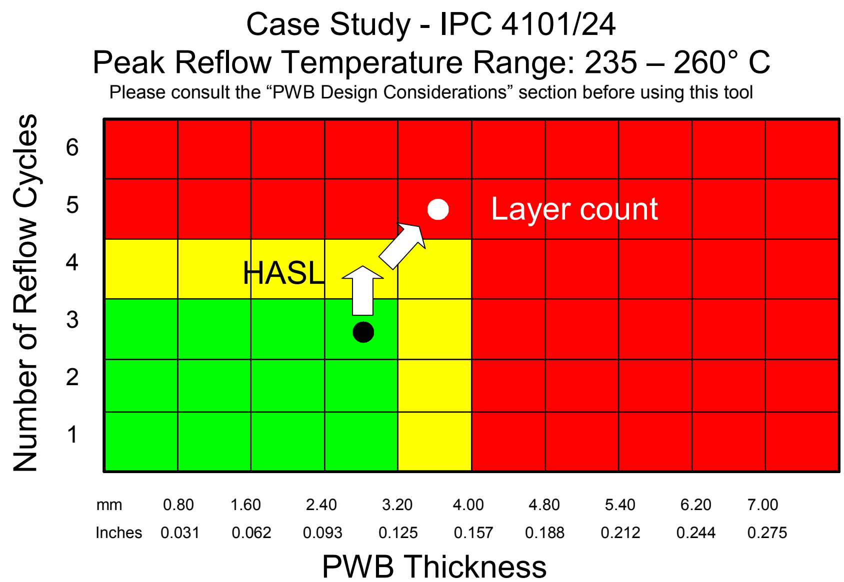


Figure #16

A number of other failures and successes have been post mortemed in this manner and the tool seems to be a good predictor of actual results.

**Conclusions and Future Work:** Studies of lead free assembly are an ongoing part of the PWB industry and will be for the foreseeable future. Currently the company the authors represent is in the midst of a major assembly study to correlate analytical data to actual reflow performance and is involved in numerous other internal and industry studies. As with any tool of this nature, as more data is available the tool will be updated to include the best information available. The intention is to make this a "living" tool.

Similar tools for halogen free materials and high performance electrical materials at both SN/PB reflow temperatures and at lead free reflow temperatures are available from the authors on request.

## References:

[1] Bergum, Erik, Application of Thermal Analysis Techniques to Determine Performance Entitlement of Base Materials Through Assembly, IPC Expo, 2003

[2] Kelley, Edward, An Assessment of the Impact of Lead-Free Assembly Processes on Base Material and PCB Reliability, IPC Expo, 2004