Lead Free Assembly: Identifying Compatible Base Materials for Your Application

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Abstract
Whether based on good science or not, the elimination of lead from electronic equipment as a result of the European RoHS legislation is a reality. Even those market segments with exemptions meant to last several years are being pushed towards Lead Free assembly sooner than expected due to component availability concerns and constraints within the electronics manufacturing services industry. The most common question asked of base material suppliers is 'what laminate can I use?' From the standpoint of '**compliance**,' most laminate materials are acceptable. Most materials do not contain lead or the other restricted metals. The brominated flame retardant used in most laminates is NOT restricted either. However, in terms of '**compatibility**,' the answer is very complex. This is the result of several factors. First, PWB design and construction will have a significant impact on the base material properties required. Thin, low layer count PWBs may have different requirements than very thick, high layer count PWBs. Copper weights, aspect ratios and other design features will also have an impact. End use application and the associated requirement for long-term reliability will also impact the decision-making process. The requirements for a cell phone, video game or even a computer motherboard will be very different than those for high-end servers, telecommunications gear, avionics, and critical medical and automotive electronics. Last, not all Lead Free assembly processes are the same. Some designs will experience peak temperatures of 245°C while others will experience peak temperatures of 260°C. Some PWBs may experience 2-3 thermal cycles, others up to 5-6, or even more depending on how many reworks are allowed. All of this makes it impossible to recommend one base material for all applications without either under specifying the laminate material and risking defects during assembly or later on in the field, or over specifying the material and paying too much for the material or limiting availability. The purpose of this paper is to summarize the critical laminate properties, present test data showing the impact of higher temperatures, and introduce a laminate material selection approach designed to help answer the question regarding what laminate material should be considered for a given application.

Introduction
The primary issue for base materials is the higher peak temperature required in Lead Free assembly processes. Eutectic tin/lead (Sn/Pb) solder has a melting point of 183°C and peak assembly temperatures commonly reach 230-235°C. The primary alternatives to Sn/Pb are tin/silver/copper alloys (Sn/Ag/Cu, or 'SAC' alloys) with melting points around 217°C. While some products may experience peak temperatures around 245°C, more complex products will have to survive peak temperatures of 260°C. These higher temperatures are required not only for the assembly processes, but for any rework cycles as well. As we will discuss shortly, these higher temperatures have a significant impact on traditional FR-4 materials, since in this temperature range, traditional FR-4 materials generally begin to exhibit some level of resin decomposition. In addition, exposure to these higher temperatures puts increased thermal stress on the bonds between the resin and fiberglass reinforcement as well as the resin and copper foil interface. Table 1 summarizes the key issues for each of the main components used to manufacture laminates for printed circuits.

A very critical point that must be emphasized with respect to these issues is that laminate manufacturers can easily make improvements in one property, but often this can adversely affect other important properties. For example, it is relatively easy to formulate a resin system with a very high time to delaminate in conventional T260 or T288 tests. However, this is often achieved at the expense of other (i.e. mechanical) properties and may make the material more difficult to use successfully in conventional PWB manufacturing processes, or without sacrificing design flexibility. Therefore, achieving the best ***balance of properties*** to meet the needs of the OEM, EMS and PWB manufacturer is absolutely critical.

Critical Laminate Properties
Figure 1 illustrates what can happen to a PWB upon exposure to 260°C. This advanced-technology backplane was manufactured using a conventional high-Tg FR-4, and then evaluated in a thermomechanical analyzer (TMA) by ramping the temperature to 260°C and measuring how long it took for the sample to delaminate. The charred and degraded resin and delaminations evident in the picture occurred after 2 minutes at 260°C. Figure 2 shows a cross-section of a relatively simple 4-layer PWB that used another conventional high-Tg FR-4 and was then processed through Lead Free assembly with a peak temperature of 260°C. In this PWB, delaminations occurred at the resin-to-internal copper interface as well as the resin-to-glass interface. In addition, assuming a PWB does survive Lead Free assembly, a second key question is 'has long-term reliability of the PWB been compromised?'

Table 1 – Primary Lead Free Issues For Base Material Components

Component	Lead Free Assembly Impact	Potential Solutions	Related Considerations
Resin System	Peak assembly temperatures can reach point where resin decomposition begins. Higher temperatures result in increased thermal expansion and stress on plated holes as a result.	Formulate resin system with higher decomposition temperatures. Formulate for lower coefficients of thermal expansion.	Reformulation can affect electrical properties. Can also impact mechanical properties and PWB manufacturability.
Fiberglass Cloth	Thermal & mechanical stress on resin-to-glass bond.	Cleanliness and choice of proper coupling agent more important.	Loss of resin-to-glass adhesion through thermal cycling could impact CAF resistance.
Copper Foil	Thermal & mechanical stress on resin-to-copper bond.	Copper nodularization and treatments for improved adhesion.	May impact conductor losses, especially at high frequencies[i].

Substantial work describing the impact of Lead Free assembly temperatures on the base materials and finished PWBs has been gathered recently[ii, iii, iv, v]. These works have identified the critical base material properties that must be considered when selecting a material for Lead Free assembly applications, and therefore, only a summary is provided here in Table 2.

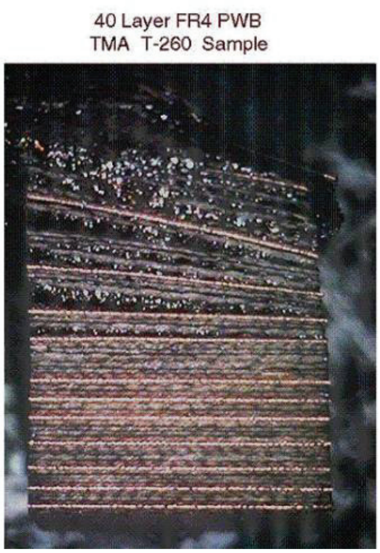

Figure 1 – Backpanel Made From Conventional High-Tg Material After 2 Minutes of T260 Testing

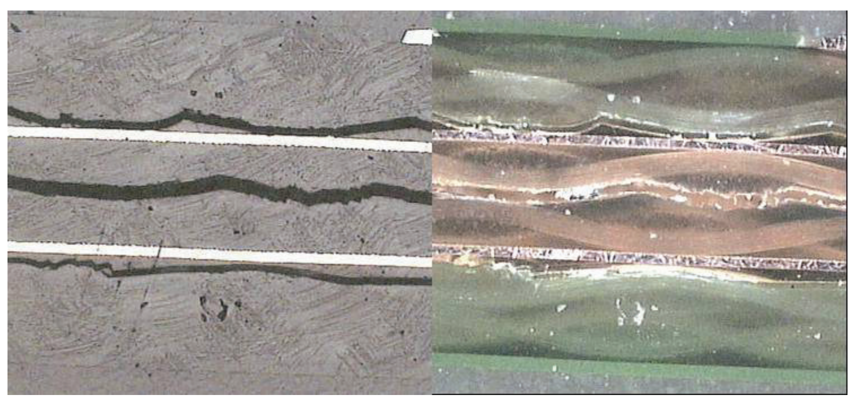

Figure 2 – PWB made From High-Tg FR-4 After Lead Free Assembly With A 260^{o}C Peak Temperature

Table 2 – Critical Base Material Properties For Lead Free Assembly Applications

Property	Definition	Issue
Decomposition Temperature, Td	Measures weight loss from resin degradation as a function of temperature. Td is typically defined as the point at which 5% of the original mass is lost to decomposition, but other levels can also be reported, e.g. 2%[vi].	Resin decomposition can result in adhesion loss and delamination. A 5% level of decomposition is severe, and intermediate levels are important for assessing reliability since peak temperatures in Lead Free assembly can reach onset points of decomposition.
Glass Transition Temperature, Tg	Thermodynamic change in polymer from a relatively rigid, glassy state, to a softened, more deformable state.	Several properties change as the Tg is exceeded, including the rate at which a material expands versus temperature. Modulus also decreases significantly as Tg is exceeded.
Z-Axis Expansion	Change in physical dimension (in Z-axis) as a function of temperature, expressed as a 'coefficient of thermal expansion' (CTE) or percentage expansion over a temperature range..	CTE values above Tg are much higher than below Tg. Expansion induces stress on plated vias. The higher temperatures of Lead Free assembly result in more total expansion for a given material.
Moisture Absorption	Tendency of a material to absorb moisture from the surrounding environment. Can be assessed by more than one method, including water soak or in an increased pressure & humidity environment.	Absorbed moisture can volatilize during thermal cycling and cause voiding or delamination. PWBs that initially survive assembly may exhibit defects after storage in an uncontrolled environment followed by assembly, as a result of moisture absorption. This should be considered when evaluating materials.
Time to Delamination	While not a fundamental property, measures the time for delamination to occur at a specific temperature, e.g. 260°C (T260) or 288°C (T288).	Related to decomposition temperature and adhesion between material components. Thermal expansion can also influence results. In multilayer PWBs, the treatment of the internal copper surfaces is also critical.

While glass transition temperature (Tg) and Z-axis expansion have been a focus of attention over the years, only with the introduction of Lead Free assembly has the decomposition temperature (Td) gained significant attention. While the decomposition temperature has always been important in terms of reliability, most people have used Tg as a proxy for material reliability. One reason for this is that other things being equal, a higher-Tg will result in less total thermal expansion, and therefore less stress on plated vias. What wasn't discussed is that it is common for conventional high-Tg FR-4 materials to exhibit somewhat lower decomposition temperatures than conventional 140°C Tg FR-4 materials. This is highlighted by the fact that most conventional 140°C Tg FR-4 materials exhibit longer T260 times than conventional high-Tg FR-4 materials. To highlight the importance of Td, examine Figure 3.

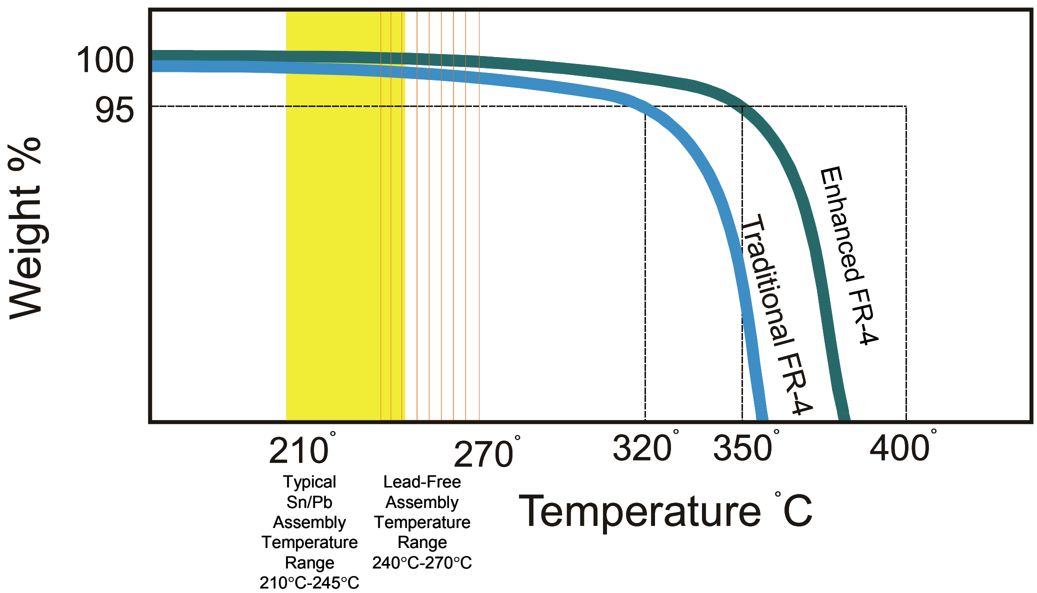

Figure 3 – Decomposition Curves for a Traditional and Improved FR-4 Material

The traditional high-Tg FR-4 materials we have become familiar with have Td values in the range of 290-310°C. Traditional 140°C Tg FR-4 materials are generally somewhat higher, with a typical example of a material with a Td of 320°C shown in Figure 3. In the typical tin-lead assembly environment, peak temperatures do not reach the point where decomposition is significant for either the traditional or enhanced products. However, in the Lead Free assembly environment, peak temperatures reach the point where a small, but significant level of decomposition can occur for the conventional materials, but not for the enhanced products. This seemingly small level of decomposition in the conventional products can have extremely significant effects on reliability, especially if multiple thermal cycles are experienced. Table 3 summarizes the properties of four commonly available FR-4 materials. The impact of decomposition temperature when these materials are exposed to different peak temperatures is highlighted in Figures 4 and 5. Figure 4 graphs cumulative weight loss (decomposition) for several products when cycled repeatedly to a peak temperature of 235°C. Clearly, there is little impact on resin decomposition when the peak temperature reaches 235°C. Figure 5 presents the same results when the peak temperature is increased to 260°C. Obviously, the increase in temperature to 260°C has a severe impact on resin decomposition for the traditional FR-4 materials, especially the conventional high-Tg material (Product C).

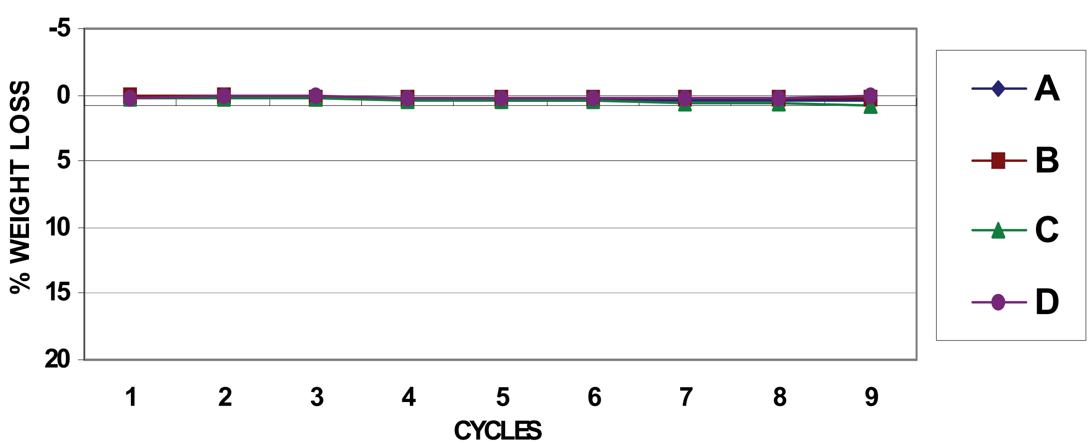

Figure 4 – Decomposition Through Multiple Cycles to 235°C

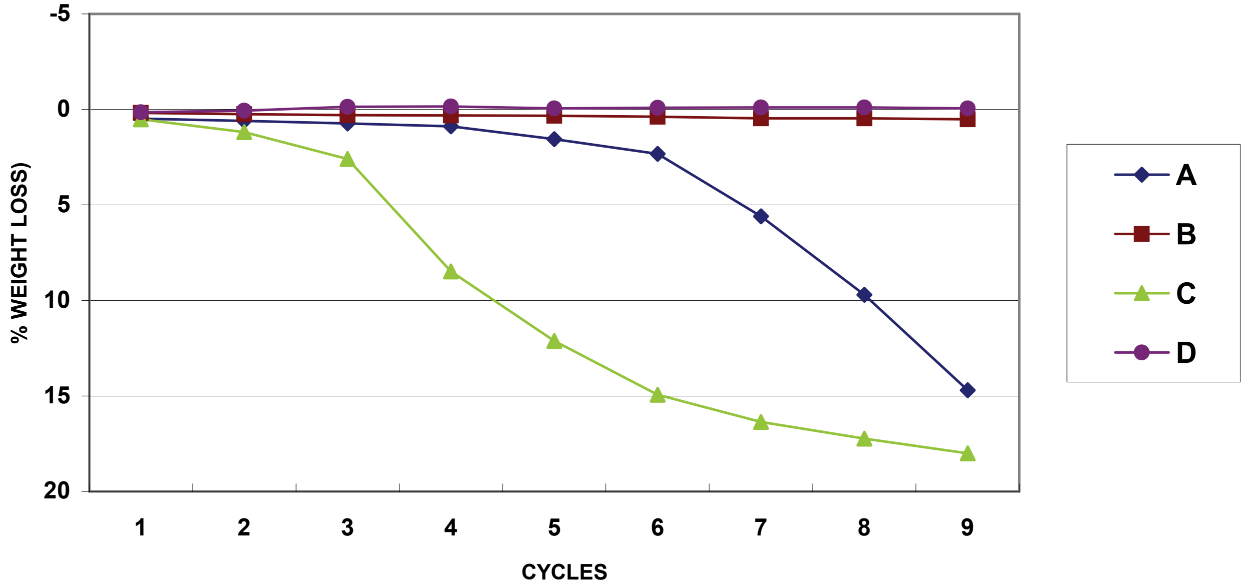

Figure 5 – Decomposition Through Multiple Cycles to 260°C

Table 3 – FR-4 Base Material Properties

Product	Description	Glass Transition Temp., °C	Decomposition Temp., °C	% Expansion, 50-260°C (40% Resin Content)
A	Conventional 140°C Tg FR-4	140	320	4.2
B	Improved Mid-Tg FR-4	150	340	3.4
C	Conventional High-Tg FR-4	175	310	3.5
D	Improved High-Tg FR-4	175	345	2.7

As stated above, the historical focus on Tg is probably the result of its effect on total Z-axis expansion. However, because of differences in CTE values, even the relationship between Tg and thermal expansion requires further analysis. Figure 6 shows Tg and thermal expansion data for the products in Table 3.

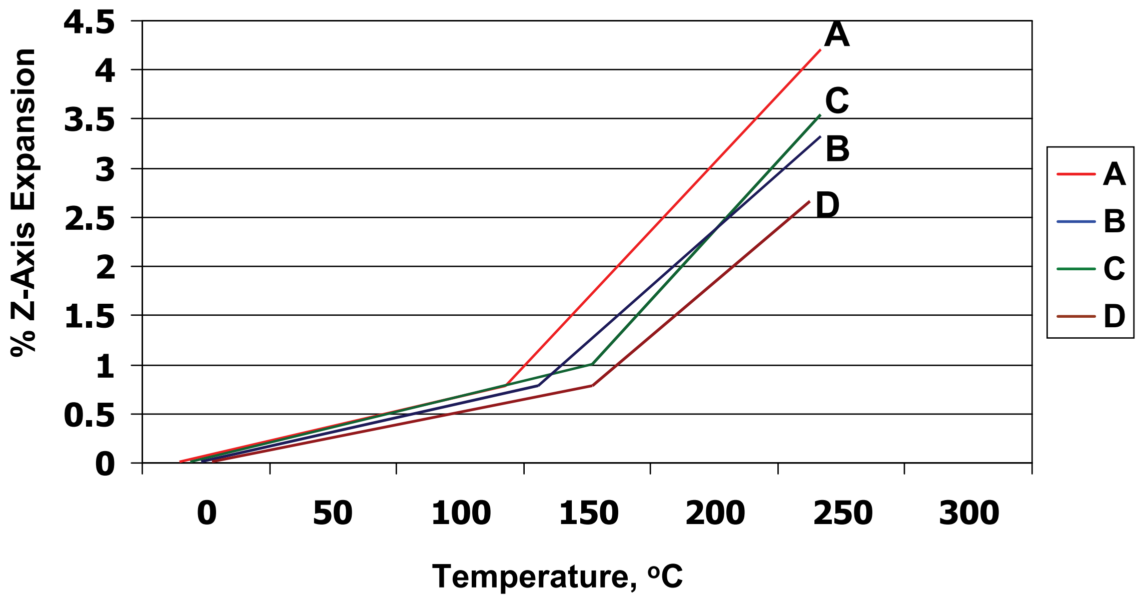

Figure 6 – The Impact of Tg and CTE Values on Total Expansion

From Figure 6, products with the same CTE values (A & C for example; note that above Tg the lines are parallel) will differ in total expansion based on their Tg values. For example, the conventional 175^{o}C Tg material (C) exhibits less total expansion than the conventional 140^{o}C Tg material (A) because the onset of the higher post-Tg rate of expansion is delayed by 35^{o}C. However, the 175^{o}C material with a lower CTE value (D) exhibits much less total expansion than the conventional 175^{o}C Tg material even though the Tg values are the same. Furthermore, the 150^{o}C Tg material with reduced CTE values (B) exhibits approximately the same total expansion (3.4%) as the conventional 175^{o}C Tg material (3.5%). However, with a decomposition temperature that is significantly higher, this mid-Tg FR-4 material is much more compatible with Lead Free assembly than the conventional 175^{o}C Tg material.

Impact on Printed Circuit Reliability

In addition to the works already cited, there have been excellent studies recently on the impact of Lead Free assembly specifically on PWB reliability[vii,viii,ix]. These works present statistical analyses showing the impact of Lead Free assembly on PWB reliability and reach important conclusions regarding the base materials. While there is not perfect agreement among all published works, the differences typically are the result of a different focus, e.g. whether the focus is on complex, thick PWBs with stringent reliability requirements versus relatively less complex PWBs with shorter intended field lifetimes or less stringent reliability requirements. Conclusions include:

- Most conventional high-Tg FR-4 materials are generally not compatible with Lead Free assembly, or can only be used successfully in a very limited range of applications.

- Conventional 140^{o}C Tg materials may still be suitable for PWB designs with limited thickness and reliability requirements, particularly when intermediate peak temperatures are used in assembly. This is largely the result of these materials having slightly higher decomposition temperatures than the higher-Tg equivalents.

- Tg and CTE values are important because of the effects on thermal expansion, especially in thicker PWBs, but the decomposition temperature seems to be generally more important in terms of Lead Free assembly compatibility.

- Mid-Tg FR-4 materials with high decomposition temperatures are viable products for many Lead Free assembly applications involving intermediate-complexity PWB designs.

- Materials with a high decomposition temperature, high-Tg and reduced CTE values are suitable for the broadest range of applications, including complex PWBs assembled at 260^{o}C peak temperatures.

- Balancing material properties with PWB manufacturability is critical. Materials that exhibit excellent properties have failed because of difficulties experienced when fabricating the PWB, e.g. fracturing in drilling, routing or scoring, difficulty in texturing drilled holes for copper plating, resin recession or hole wall pull-away during thermal stress.

In order to highlight a couple of these conclusions, consider the following tests. First, multilayer PWBs made from the materials in Table 3 were processed through IR reflow cycles at different peak temperatures. The PWB was a 10-layer, 0.093” (2.6mm) thick board ‘designed to fail’, meaning the copper weights and patterns, construction and resin contents were chosen so that the board would be more sensitive to thermal cycles. In addition, the dwell time at the peak temperature was 1.5 minutes. This allowed differences in material performance to be detected more clearly. Figure 7 graphs the percentage of boards surviving six reflow cycles without any evidence of blisters, measles, or delamination.

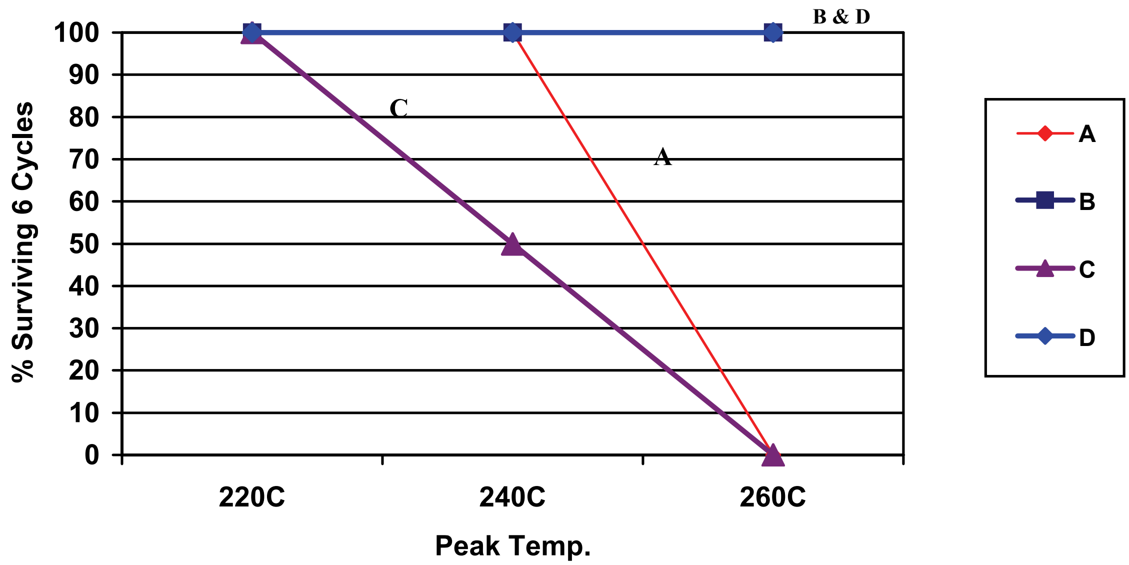

Figure 7 – Survival After Six Reflow Cycles At Different Peak Temperatures

Notably, the first material to exhibit defects is the conventional high-Tg FR-4 material. This material began to exhibit defects when the peak temperature reached 240°C. At a peak temperature of 260°C, the conventional FR-4 materials, both the 175°C Tg and the 140°C Tg products all exhibited evidence of defects. On the other hand, the materials with high decomposition temperatures, both the 150°C Tg and the 175°C Tg products all survived six cycles to 260°C.

In another test, three high-Tg materials were evaluated through IST testing[x]. This particular test provided insight into the effect of thermal expansion and decomposition temperature on long-term reliability, as assessed by the IST method. The materials are shown in Table 4.

Table 4 – Materials Evaluated Through IST Testing

Product	Description	Glass Transition Temp., °C	Decomposition Temp., °C	% Expansion, 50-260°C (40% Resin Content)
C	Conventional High-Tg	175	310	3.5
D*	High-Tg/High-Td	175	345	3.4
D	High-Tg/High-Td/Reduced CTE	175	345	2.7

Note that the Tg values are the same, but differences exist in decomposition temperatures and thermal expansion values. Product D* is similar to product D except that it has a higher level of thermal expansion. Product D* exhibits approximately the same thermal expansion as Product C, but Product D* has a higher decomposition temperature. Product D has both a high decomposition temperature and a very low level of thermal expansion. The PWB tested was a 14-layer, 0.120” (3.1mm) thick multilayer with 0.012” (0.30mm) diameter plated through holes. The average copper plating in the via was 0.8 mils (20.3 microns), although 1.0 mil (25.4 microns) had been requested. Figure 8 charts the average number of cycles to failure (10% resistance change in the plated via net) at various levels of preconditioning to simulate assembly cycle exposure.

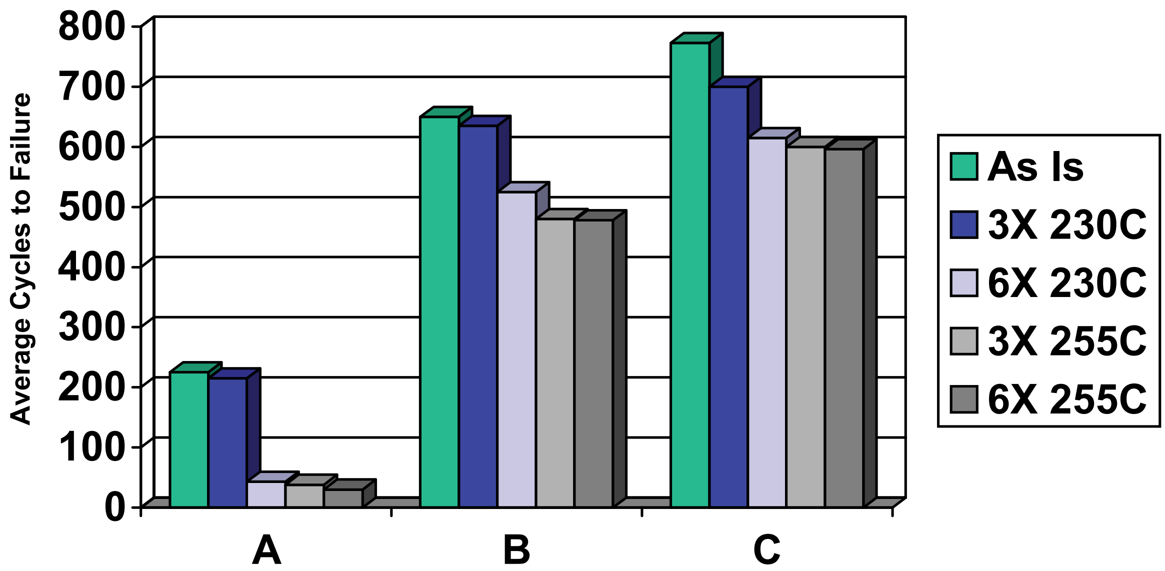

Figure 8 – IST Results for Three 175°C Tg Materials

Clearly, the two materials with improved decomposition temperatures exhibit much better performance than the conventional high-Tg product. Also, in comparing Product D to Product D*, it appears that the lower thermal expansion of Product D does offer improvement in the number of cycles to failure, but this improvement is smaller in comparison to the improvement due to the higher decomposition temperature, at least for this PWB design. The benefit of reduced thermal expansion becomes more important as the thickness of the PWB increases. In addition, the technique used to reduce the CTE values also provides benefits in PWB manufacturability.

Selecting The Right Base Material For Your Application

A very common request from PWB fabricators, EMS companies and OEMs is whether a given material is compatible with Lead Free assembly. While everyone is looking for a simple answer, the solution becomes complex because of the range of PWB designs (board thicknesses, layer counts, aspect ratios, via pitch, etc.) as well as the differences in Lead Free assembly processes, e.g. the specific peak temperature and number of thermal cycles a PWB will experience. In addition, people will generally want to use the least expensive material that is suitable for a given application. So while it is easy to specify an advanced product for Lead Free compatibility, the approach taken here is to balance cost and performance. In an attempt to simplify this discussion, a material selection tool has been developed which can be used to suggest what materials should be considered for a given application[xi].

This tool is based on data such as that presented here and in the references, as well as empirical results from prototype and production experience with Lead Free assembly applications. The experience of several people with ‘hundreds of years’ of combined experience has been leveraged in designing these tools. However, no such tool can address every specific application with 100% confidence. In addition, the capabilities of various PWB fabrication processes can also impact the performance of the finished PWB. So while these tools are based on considerable data and experiences from a number of sources, it is intended to serve as a general guide for typical applications, and as such, it remains the user’s responsibility to confirm acceptability of any material recommended. This is particularly true with respect to long-term reliability requirements. For example, the field reliability requirement for a cell phone PWB is going to be very different than for a very complex high-end computer or telecommunications infrastructure PWB.

The intent in developing this tool was to come up with a simple method for dealing with the multitude of variables in PWB design and assembly. Figure 9 shows the basic color-coding selected for this. Figure 10 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	Application Recommendation
	Material generally recommended for typical applications of this type
	Material may be acceptable for applications of this type, but is not generally recommended
	Not recommended

Figure 9 – Color Code Key

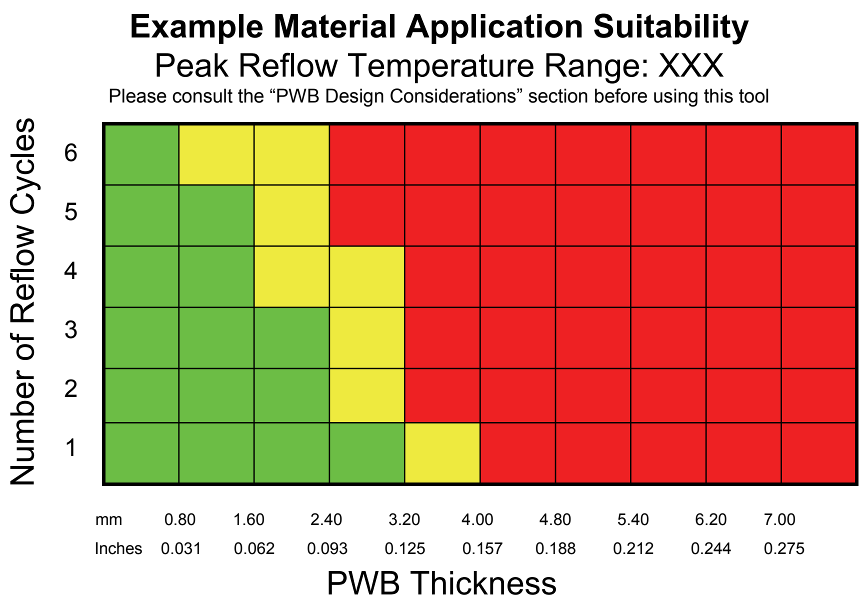

Figure 10 – Example of Chart Format

This format forces definition of a “typical” PWB design for each range of thickness shown on the X-axis. While this is very difficult and we realize that as soon as we attempt to define “typical”, most people will be able to think of ‘exceptions to the rules’, these represent what we think are fair descriptions of a broad range of products. In addition, you will see that an attempt is made to define a procedure for accommodating the exceptions. Figure 11 outlines the “typical” features for PWBs in each thickness range in the charts.

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

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

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 11 – "Typical" PWB Features for Selection Tool

In order to accommodate the exceptions to these criteria, a method was developed to "adjust" the selection tool based on specific design features or processing conditions. The basic concept for these adjustments is shown in Figure 12, and the specific adjustments are shown in Figure 13.

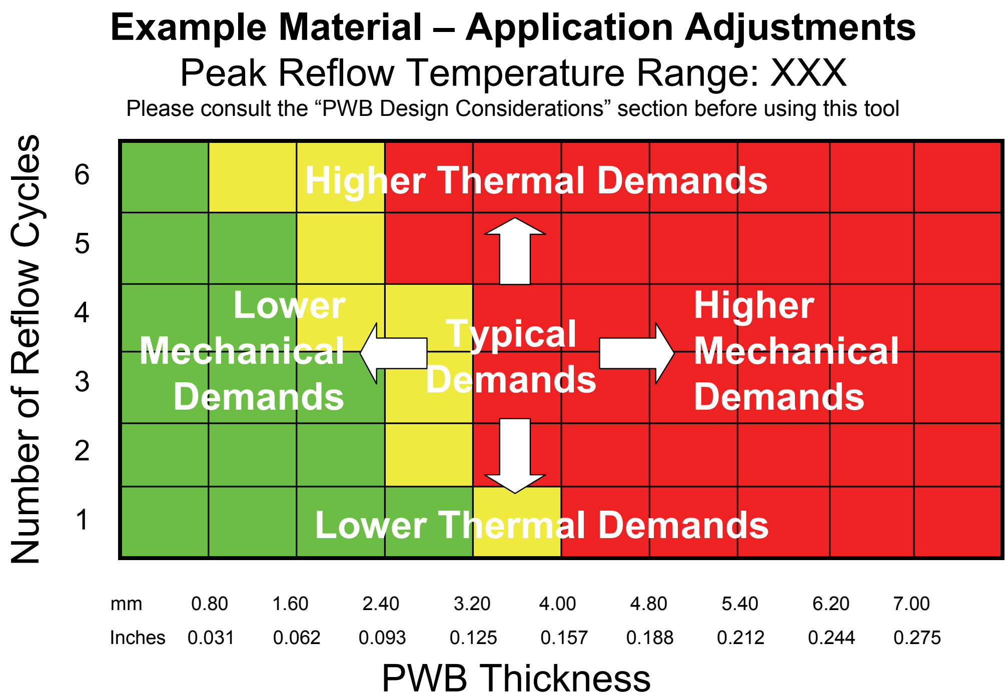

Figure 12 – Concept for Adjustments to Material Selection

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 13 – Adjustments Based on Design Features or Process Conditions

For the purposes of this paper, we will present the charts for the materials discussed earlier and summarized in Table 3. However, this same information is available for other products, including low Dk/Df materials and halogen-free materials. Figure 14 shows the charts for Product A with two different assembly temperature ranges, 210-235°C for tin-lead assembly and 235-260°C for Lead Free assembly.

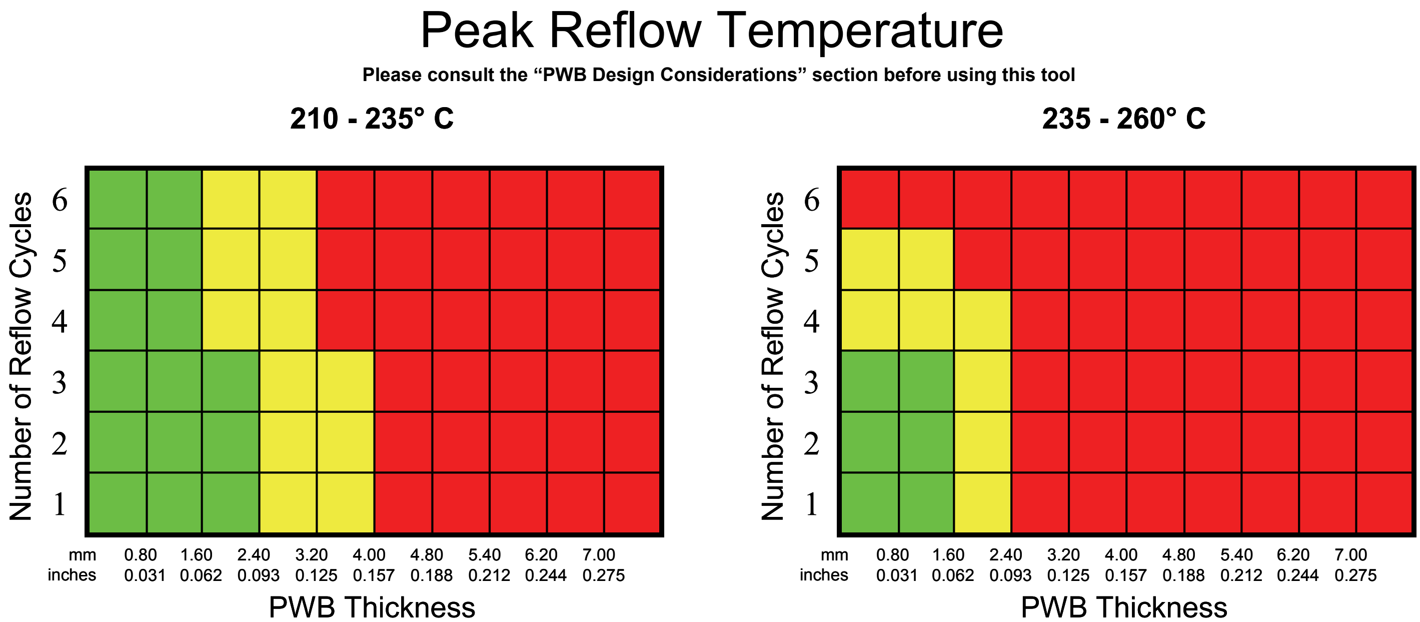

Figure 14 – Charts for Product A (140°C Tg Conventional FR-4)

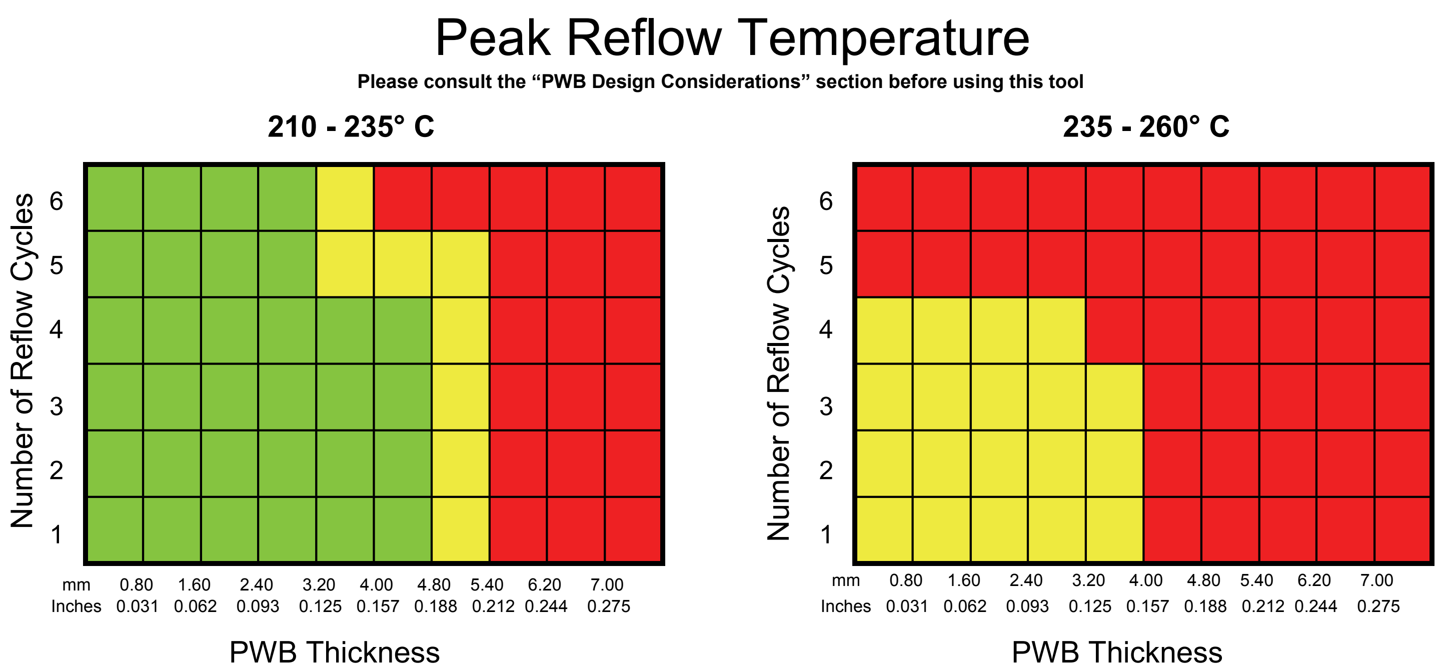

Figure 15 – Charts for Product C (175°C Tg Conventional FR-4)

As you can see when these charts are presented side-by-side, the range of designs that this product is deemed suitable for decreases as the assembly temperature increases. This should be expected of course, based on the earlier discussion of material properties. The other key point is that there may still be a group of products, albeit more limited, where a standard 140°C Tg material may be adequate and the most cost effective option. This may help clarify some of the confusion we have heard about whether standard FR-4 materials are Lead Free compatible or not. While we hate to give the answer 'it depends', the truth is that for specific designs with specific requirements for reliability, the answer is 'yes'. For other designs, applications, or reliability requirements, the answer is ‘no’. The value of this tool is that it attempts to define the range of PWB designs where specific materials may be considered.

Figure 15 presents similar charts for Product C, which is the higher-Tg conventional FR-4 material. This is where the conversation gets very complicated. From Table 3 you can see that the decomposition temperature for this product is 310°C, which is the lowest of the materials described. On the one hand, the higher-Tg of this product helps reduce the total amount of Z-axis expansion, and therefore stress on plated vias. On the other hand, the lower decomposition temperature makes this material the most sensitive to higher assembly temperatures. In fact, the range of 235°C to 260°C is a very broad temperature range for this product. Limited success may be seen when assembling at the low end of this range, but as temperatures increase, especially towards the high end of this range, we simply would not recommend that this product be considered, due to the potential for resin decomposition and resultant defects. Further, some of us would recommend that standard high-Tg FR-4 materials not be considered at all for Lead Free applications. Products B and D are significantly more robust in these applications. To make a long story short, extreme caution should be exercised if you are considering a conventional high-Tg FR-4 for a Lead Free application, and we recommend that you discuss this with your laminate material supplier. In contrast, consider the charts for Products B and D in Figures 16 and 17, respectively.

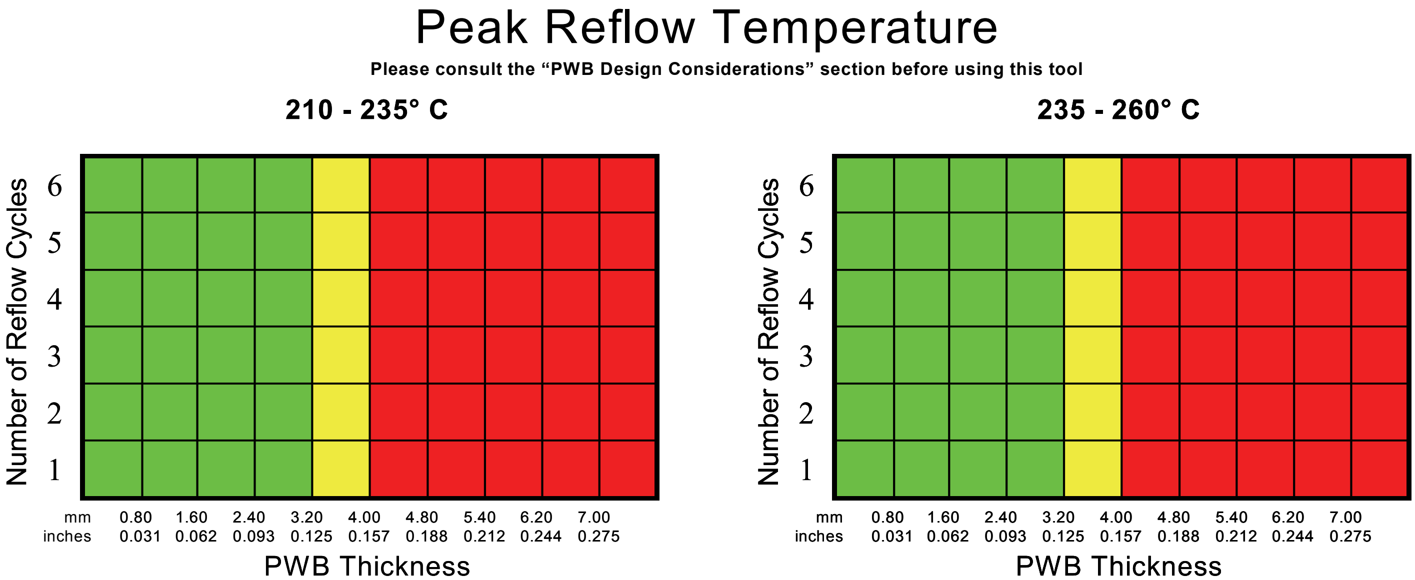

Figure 16 – Charts for Product B (Improved 150°C Tg FR-4)

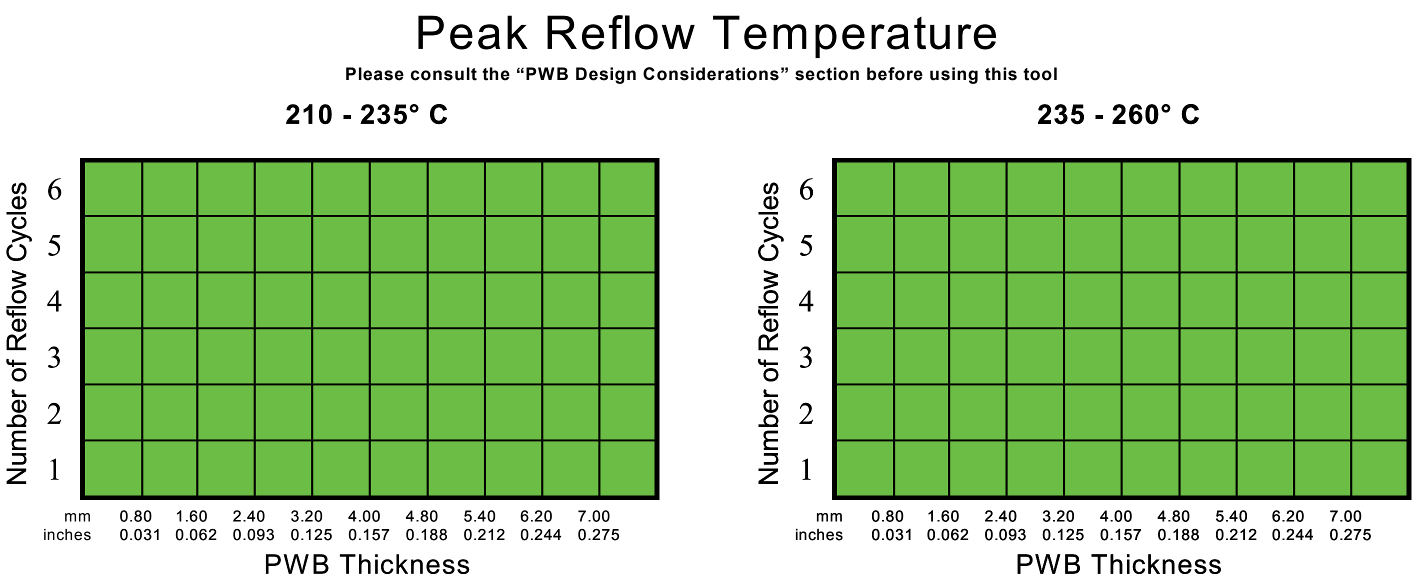

Figure 17 – Charts for Product D (Improved 175°C Tg FR-4)

Product B, while having a Tg of 150°C, is better suited for Lead Free assembly than Product C with its 175°C Tg. This is due the fact that Product B has a decomposition temperature approximately 30°C higher than Product C. In addition, as shown in Figure 6, Products B and C exhibit approximately the same total amount of thermal expansion in the range from 50°C to 260°C. You may notice that the charts for the different peak temperatures are shown to be the same for Product B in Figure 16. This is partly due to the limited experience to date with this product in thick PWB designs. In addition, at lower peak temperatures, the number of reflow cycles that this product can withstand can go beyond six for thinner PWBs. If the two charts extended beyond six cycles, more differences would be seen.

Finally, Product D, with the highest decomposition temperature and the lowest level of thermal expansion, is suitable for the broadest range of applications. This is illustrated in Figure 17. Furthermore, combining these recommendations allows us to make some general recommendations that also take material cost into consideration. Figure 18 summarizes the ‘cost versus performance’ recommendations for a starting point in Lead Free assembly applications.

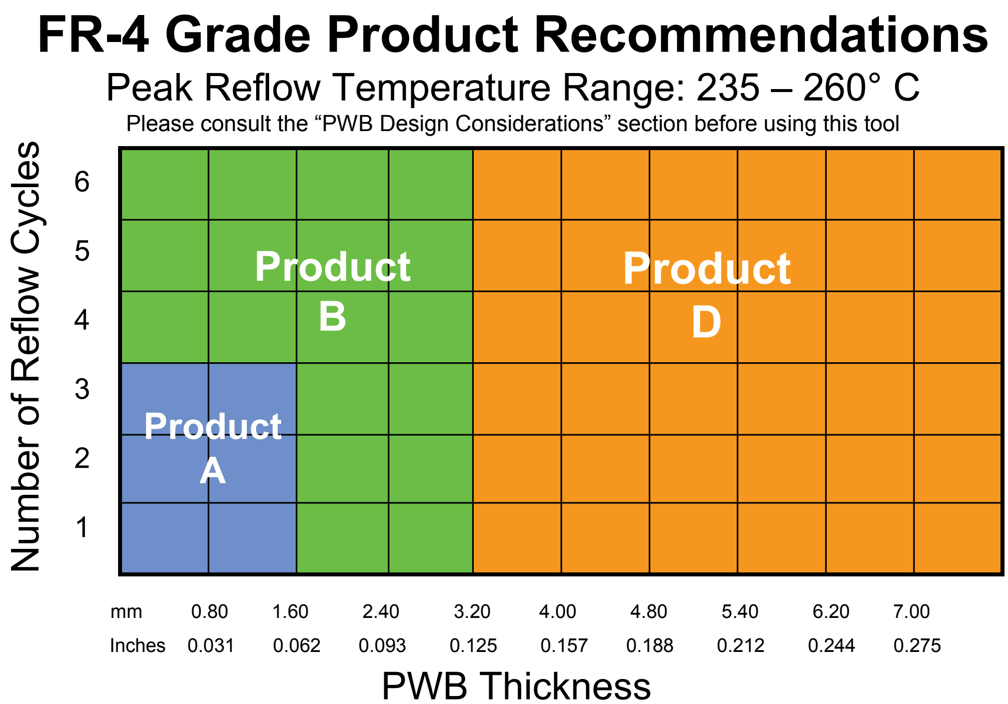

Figure 18 – Summary of FR-4 Product Recommendations in Lead Free Assembly

Application of This Tool

A simple example helps illustrate the practical application of this tool. A customer presented us with a PWB design that was being converted to a Lead Free assembly process. Some key features of the PWB as they relate to how it differed from a "typical" PWB as defined in Figure 11, and the recommended adjustments suggested, are shown in Table 5.

Table 5 – Example of PWB Being Converted to Lead Free Assembly

PWB Design Feature	Attribute	Recommended Adjustment
Thickness	1.60mm (0.062 inches)	-
Number of Reflows	3	-
Material	Conventional 140°C Tg FR-4	-
Surface Finish	Lead Free HASL (HASL not typical)	Treat as an additional reflow cycle
Layer Count	10 (</=8 Typical)	Consider moving up and right on chart

Figure 19 shows the results of making the adjustments suggested, and shows that this material is not recommended for this application. Figure 18 recommends that Product B be used in this application, and empirical evidence has shown that when the standard 140°C Tg material was used, some level of assembly related defects was observed. When Product B was used, no assembly related defects have been experienced.

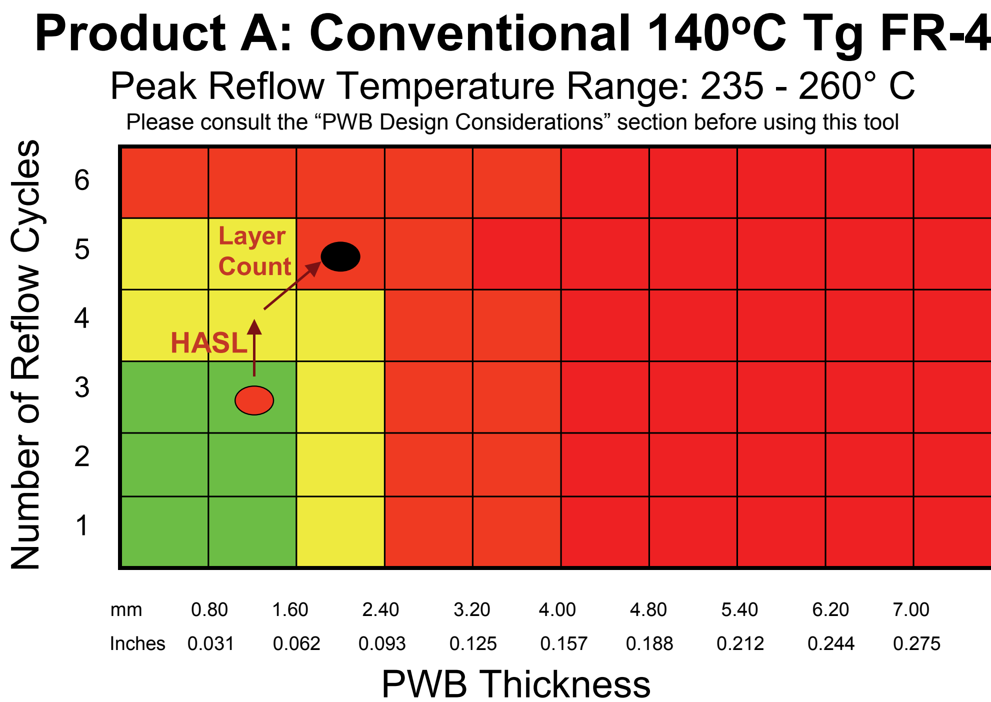

Figure 19 – Example of Practical Application of Tool

Conclusions and Future Work

The question of whether a given laminate material is compatible with Lead Free assembly can be very complex due to the many variables in PWB design and manufacturing. In addition, there are variations in Lead Free assembly processes. Specifically, peak temperatures, dwell times at peak temperatures, heat-up rates, cool-down rates, and rework processes can all vary and complicate this decision. As stated earlier, the temperature range from 235°C to 260°C is a critical range for laminate materials, and some materials may be moderately successful at the low end of this range, but fail at the higher end. Additional work investigating these assembly-related variables is underway.

Critical base material properties with respect to Lead Free assembly applications include:

- The decomposition temperature: further work is evaluating the rate of decomposition in the 235 to 260°C range.

- Thermal expansion properties: new materials have reduced levels of thermal expansion.

- Glass transition temperature: a higher glass transition temperature delays the onset of rapid thermal expansion and therefore reduces total expansion within a temperature range.

- Moisture absorption: In particular, if PWBs are stored in an uncontrolled or humid environment prior to assembly, drying of boards prior to assembly or selection of a material less prone to moisture absorption should be considered.

- Time to delamination, in particular T260 values, is a simple way to screen materials for compatibility with Lead Free assembly. However, the relevance of testing at higher temperatures or requiring excessive times is not clear.

- **Balancing these properties with the level of reliability required along with PWB manufacturability concerns is vital.**

Conclusions with respect to product-types for Lead Free assembly include:

- **Conventional high-Tg (170-175^{o}C) FR-4 materials** with decomposition temperatures of 290-310^{o}C may exhibit serious problems in Lead Free assembly applications and are not recommended.

- Many **conventional 140-145^{o}C Tg FR-4s** have slightly higher decomposition temperatures than the conventional high-Tg FR-4s, and may be suitable for relatively simple PWB designs of a limited thickness, especially if peak assembly temperatures do not reach 260^{o}C, but peak in the 240-245^{o}C range.

- **Mid-Tg (150-155^{o}C) FR-4** materials are also available and many have reduced CTE values. However, not all of these products have equivalent decomposition temperatures. So care must be taken to choose a product with an acceptable decomposition temperature for the specific application. The mid-Tg FR-4s with reduced CTEs and increased decomposition temperatures are performing significantly better than conventional high-Tg FR-4s in both Lead Free and Sn/Pb assembly processes.

- **High-Tg FR-4 materials with reduced CTEs and improved decomposition temperatures** are gaining widespread acceptance for a broad range of Lead Free assembly applications, especially when peak temperatures reach 260^{o}C and long-term reliability demands are critical.

The existing tools for base material selection for Lead Free assembly continue to be developed and improved as more data is collected and analyzed. Work on low-Dk/low-Df materials[xii] has been incorporated into these tools, as has work on new halogen-free materials.

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[i] Brist, Gary, Hall, Stephen, Clauser, Sidney, and Liang, Tao, "Non-Classical Conductor Losses Due to Copper Foil roughness and Treatment," ECWC 10/IPC/APEX Conference, February, 2005

[ii] Bergum, Erik, "Application of Thermal Analysis Techniques to Determine Performance of Base Materials Through Assembly," IPC Expo Technical Conference Proceedings, Spring, 2003.

[iii] Kelley, Edward, "An Assessment of the Impact of Lead Free Assembly Processes on Base Material and PCB Reliability," IPC/Soldertec Conference, Amsterdam, June 2004.

[iv] Hoevel. Dr. Bernd, "Resin Developments Targeting Lead Free and Low Dk Requirements," EIPC Conference, 2005

[v] Christiansen, Walter, Dave Shirrell, Beth Aguirre, and Jeanine Wilkins, "Thermal Stability of Electrical Grade Laminates Based on Epoxy Resins," IPC Printed Circuits Expo, Anaheim, CA, Spring 2001

[vi] An IPC Subcommittee is currently developing a standard test method for reporting of decomposition temperature. Several variables, such as sample preparation and rate of temperature increase can affect the reported value.

[vii] Freda, Michael, and Furlong, Jason, "Application of Reliability/Survival Statistics to Analyze Interconnect Stress Test Data to Make Life Predictions on Complex, Lead Free Printed Circuit Assemblies," EPC2004, October, 2004.

[viii] Brist, Gary, and Long, Gary, "Lead Free Product Transition: Impact on printed Circuit Board Design and Material Selection," ECWC 10/APEX/IPC Conference, February, 2005.

[ix] Ehrler, Sylvia, "Compatibility of Epoxy-Based PCBs to Lead Free Assembly," EIPC Winter Conference, 2005, & Circuitree Magazine, June 2005.

[x] IST procedure developed and offered through PWB Interconnect Solutions, Inc., www.pwbcorp.com.

[xi] Bergum, Erik J., and Humby, David, "Lead Free Assembly: A Practical Tool for Laminate Materials Selection," IPC-Soldertec, June 2005.

[xii] Kelley, Ed, and Hornsby, Ron, "Improved High Speed, Low Loss Materials for Lead Free Assembly Compatibility," APEX/IPC Conference Poster Session, February, 2005.