Lead Free Assembly Impacts on Laminate Material Properties and "Pad Crater" Failures

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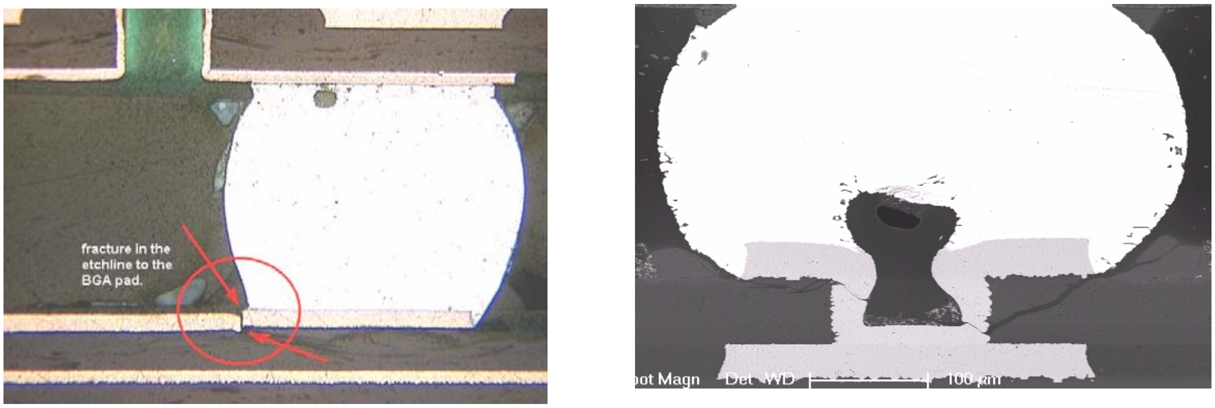
Abstract
Printed circuit board (PCB) feature sizes are decreasing to support increasing density thrusts for electronic products and packaging. The transition to lead-free products has changed the stress conditions that are generated at the second level interconnects as a result of "stiffer" lead-free solder joints and greater CTE mismatches between the components and the PCB as a result of the higher assembly temperatures. New laminate materials have been introduced to survive the higher lead-free assembly temperatures. The confluence of all these factors has shifted the primary failure mode in mechanical shock testing for BGA joints from solder fractures in tin lead soldered product to laminate fractures of the metal defined PCB pads (or what Intel calls "Pad Cratering") for lead-free product.

This paper will review the fundamental drivers that have increased the risk of "Pad Cratering" with the transition to lead-free assembly. In it we will examine and compare the thermal and mechanical material property differences between standard and high Tg FR4 laminate materials after boards are subjected to lead free assembly conditioning. The thermal and mechanical properties will also be compared against the relative "pad crater" response for the test vehicles used in the experiments. This paper will review the metrology methods employed to determine the differences and quantify the results. The paper will also review the effect of tested design changes on "pad cratering" response. The ultimate goal of the project is to identify key thermal/ mechanical laminate properties and metrologies which can define limits and quantify a product's susceptibility to "pad cratering". Additionally, we will examine the sources and extent of variation in the properties for the purposes of providing modeling inputs for the development of predictive mechanical models for "pad cratering". This paper is a first step in the development process.

Introduction
The transition to lead-free PCBs has required a great deal of development resources through out the industry to deal with issues that have arisen with the elimination of lead in the fabrication of the PCB and its assembly. The impact to laminate materials has been a particular concern with regards to their survivability at the higher lead-free assembly temperatures. This paper focuses on a laminate condition we call "Pad Cratering" or pad lifting that has seen a dramatic increase in occurrence as products have switched to lead-free. A pad crater is a defect or flaw created in the PCB by the mechanical fracture of the laminate resin due to PCB flexure during manufacturing, shipping, or handling stresses. Pad craters are typically found during X-section optical microscopic examination of the component post mechanical stress testing (such as shock and vibration). PCB pad craters are expected to limit the PCB reliability performance in two failure modes. The resulting failure modes can either be an open circuit due to the breaking of the connecting trace or via to the cratered BGA pad (see figures 1A & 1B), or the fracture can create a pathway for metal migration between 2 biased copper structures on the board resulting in a short (see figure 2). For a detailed discussion on "pad crater" reliability risks, refer to Mukadam et al (1).



Figures 1A and 1B – Open failures resulting from Pad crater circuit fractures.

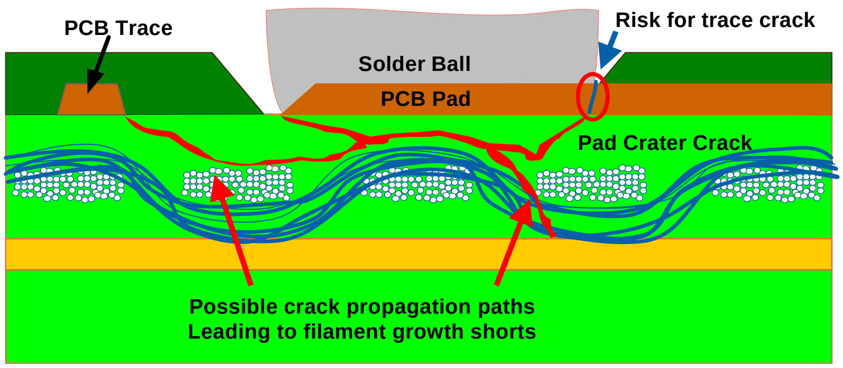


Figure 2 – Diagram of potential shorting pathways created by Pad cratering

Reliability testing experienced a dramatic shift to the pad crater failure mode with the transition to lead-free product and assembly. An examination of the fundamental drivers to this issue supports the increase in occurrence. The first driver is the change in stiffness of the solder itself. The lead-free alloys are stiffer and therefore transfer more stress to the PCB pad interface at a given strain level. This issue is illustrated in figure 3. The second driver is the change in delta T that the PCB sees in assembly from the solidification of the molten solder to room temp. The higher delta T for the lead-free assembly process creates a greater X/Y CTE mismatch between the PCB and the component imparting greater stress on the solder joints.

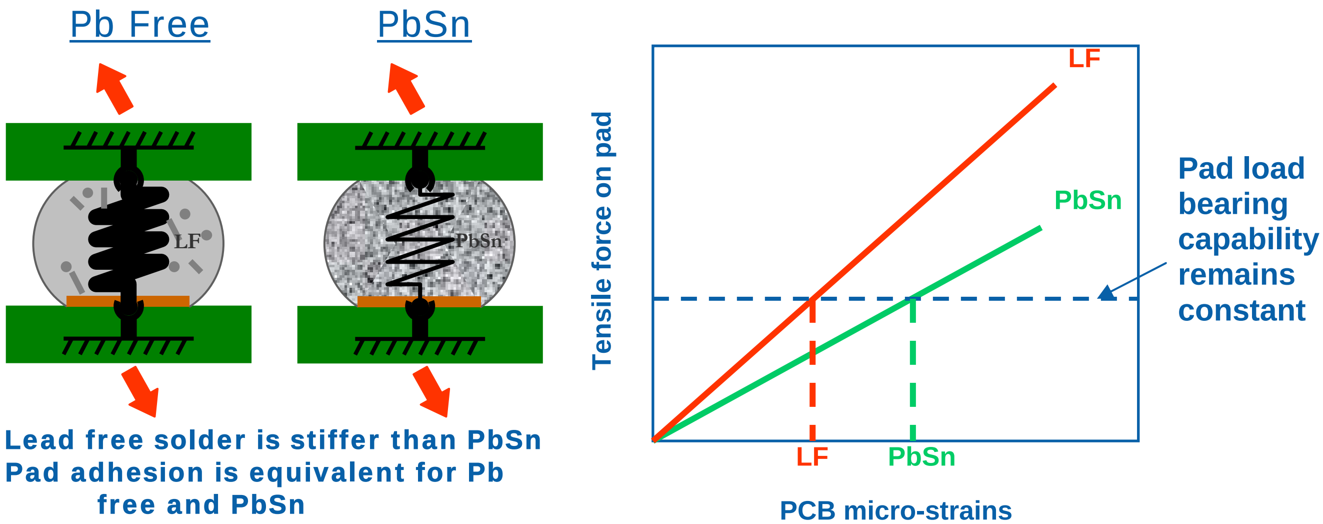


Figure 3 - Stiffer lead-free solder transfers more stress and reduces the load bearing capability of the pad.

The general technology direction for PCB product raises concern for the decreased mechanical margins these fundamental drivers have created. Increasing density in PCB designs is driving smaller features or attachment pads for components. The smaller pads have less adhesion area and can't support as much loading as their larger predecessors. Couple this with the increased stress/strain load driven by the change to lead-free solder and assembly, and the increase in pad crater failures is no surprise. The following case study focuses on how different PCB material sets common in the industry respond to the pad cratering failure mode.

Pad Crater Case Study

The case study was a manufacturability assessment of product boards using a common LGA socket component. The study examined 2 populations of boards with different bend limits, one of which resulted in an electrical failure after In Circuit Test (ICT). The resulting failure mode was identified as pad cratering. Further examination of the populations showed the groups were split by PCB suppliers which built the boards. Boards from 2 suppliers did not exhibit the problem, while boards from 2 other suppliers consistently showed the problem. This led to an investigation of the differences between each of the supplier's boards. Overall board thickness measurements indicated no significant difference between the nominally 62 mil boards. Flexural modulus measurements indicated a significant difference (~25%) between the supplier's boards which passed and the supplier's boards which failed ICT for pad cratering (see figure 4).

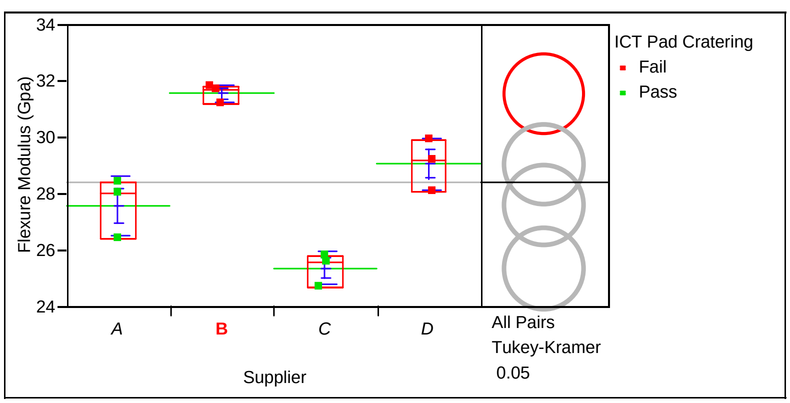


Figure 4 - Flexural Modulus Response of the 4 supplier's boards in the case study

TMA test results for Tg of the resin indicated that the 2 suppliers whose boards did not exhibit the problem had used a standard FR4 with a Tg of <140C, while the suppliers whose boards had showed failures had used a high Tg FR4 with a Tg of >150C (see figure 5).

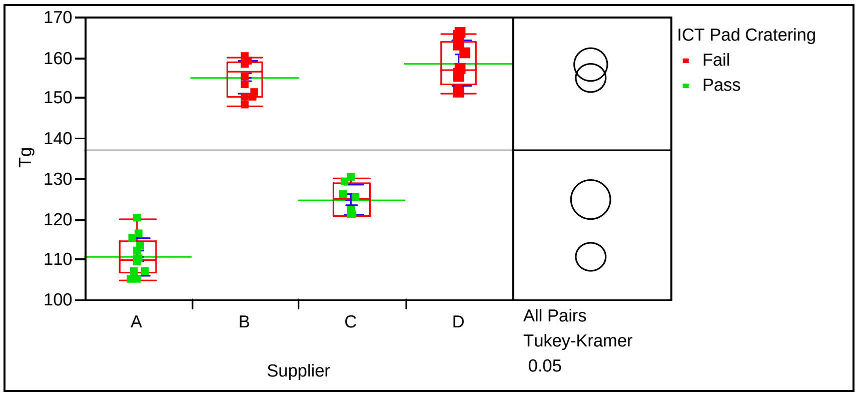


Figure 5- Tg results for the 4 supplier's boards in the case study

Resin micro hardness data indicates that the high Tg FR4 boards from the suppliers which exhibited the ICT pad crater problem were harder than the standard Tg FR4 boards from the suppliers which passed, suggesting a more brittle behavior of the high Tg FR4 resin (see figure 6).

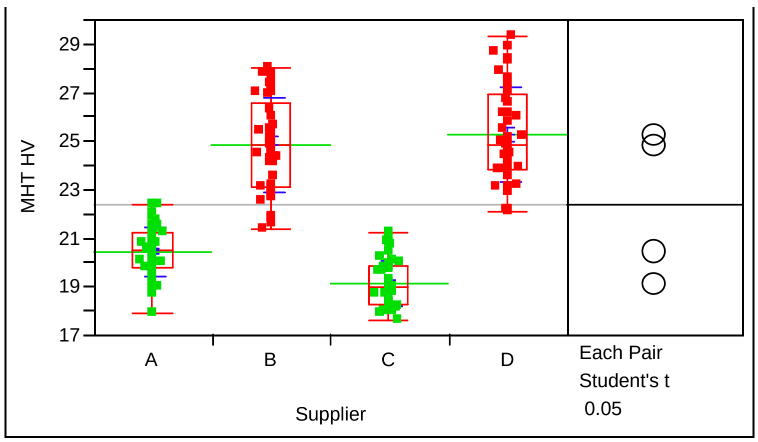


Figure 6 – Resin micro hardness results for the 4 supplier's boards in the case study

A cross-section evaluation of the 4 supplier's PCB stack-ups indicated some differences in the construction of each of the supplier's boards as shown in figure 7. The glass reinforcement weave structure is the primary driver of the Ex, Ey in-plane modulus for a fixed copper design pattern. "Pad Cratering" is a localized effect initiating in the top layer of resin at the PCB surface. The outer most two dielectric layers on each side of the boards were equivalent in glass/resin construction, thus it is unlikely that Ex, Ey in plane modulus differences would have a strong influence on "Pad Crater" susceptibility.

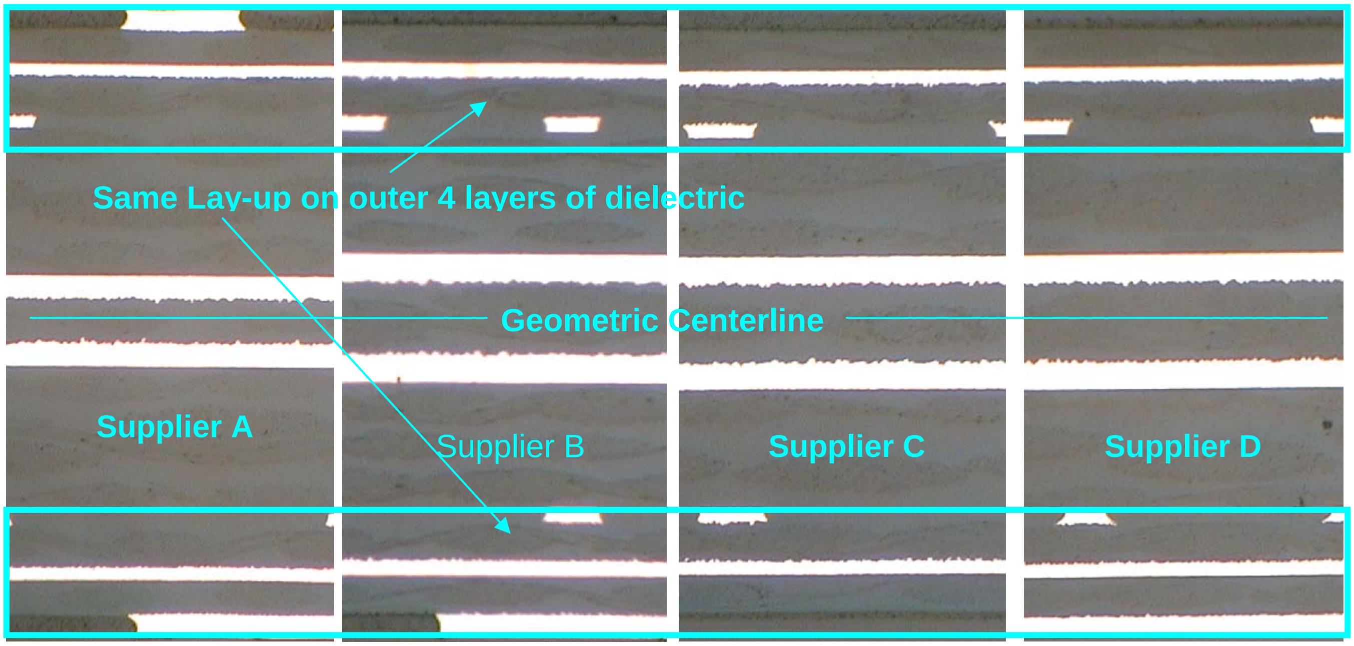
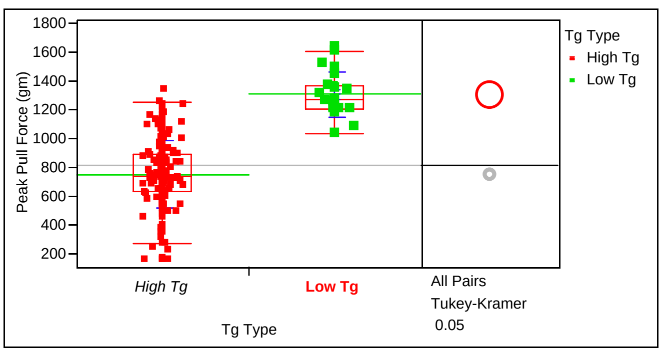


Figure 7 – Cross section photos of the 4 supplier's board stack-ups examined in the case study

The findings of the case study coincided with a previous study using Cold Ball Pull (CBP) to examine second level interconnect joint strength. In that study there was a significant difference in the PCB joint side laminate material performance when looking at standard vs. high Tg FR4 material. Figure 8 shows significantly lower cold ball pull peak load values for high Tg FR4 vs. standard FR4 material when looking at pad crater failure mode data.



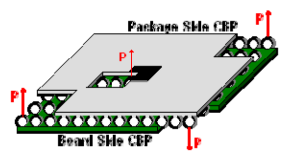


Figure 8 – PCB-side Pad Crater Cold Ball Pull peak pull force for High Tg FR4 vs. Standard FR4

The choice of PCB laminate resin type appears to have a significant impact on the pad crater susceptibility based on the findings of this case study. Continued investigation of PCB material property and structural characteristics are in progress to confirm these results and identify other modulating factors with respect to Pad Crater performance. The impact of PCB resin type also raises a question as to the amount of material property variability which currently exists in industry between different materials, constructions, and fabricators.

PCB Material Property Variation Test Set-up

The range of variation in the PCB material properties of interest was studied through the use of a common test vehicle used for the evaluation of mechanical performance of laminates. Figure 9 shows an example of the Material Evaluation Board (MEB) which was used in this testing. The MEB board provided a consistent circuit pattern design across multiple suppliers and laminate materials allowing the focus of the material property variation to be on the stack-up, laminate material, and supplier contributions.

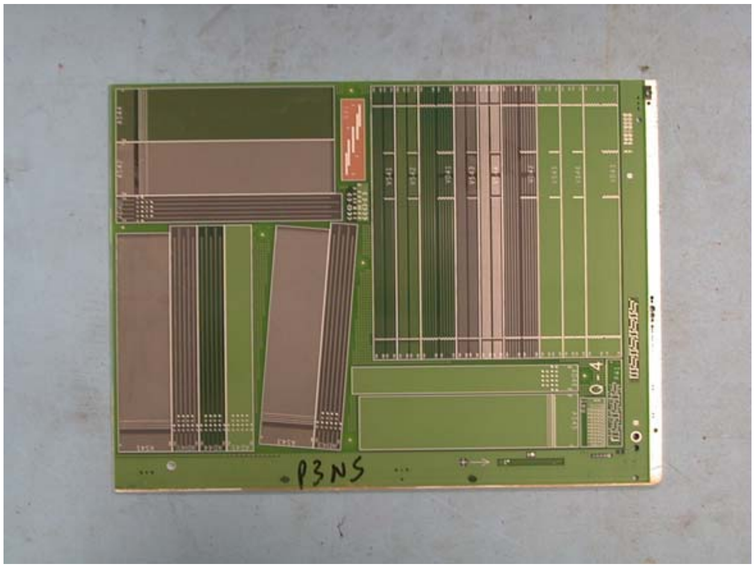


Figure 9 - MEB test board photo

A variety of testing metrologies were used to evaluate the following PCB material properties:

- Glass Transition Temperature (Tg)
- Flexure Modulus (Efx, Efy)
- In-Plane Elastic Modulus (Ex, Ey)
- Shear Modulus (Gxy)
- Resin Micro hardness (HV)
- Poisson's Ratio (nu_{xy})
- Coefficient of Thermal Expansion (CTE)
- Thermal Gravimetric Analysis (TGA) Weight Loss

Metrology Descriptions

- Instron Load Frame: Elastic modulus and Poisson's ratio in the X-Y plane (Ex, Ey, nu_{xy}) were measured via ASTM D3039 test method using a 0.75" wide by 5" long specimen and 62mil strain gauge. Shear in the X-Y plane (Gxy) was measured using ASTM D3518 with similar specimen geometry. Reliable out of plane data (Ez) is not currently available due to metrology limitations, ultrasound measurements indicates ~1.5<Ez<2.5GPa, but measurement accuracy is unknown, further investigation of Ez measurement methods is in progress. Flexural Modulus was measured via ASTM D790 test method.
- TGA: Thermo-gravimetric Analyzer measures the amount and rate of change in weight of the sample with respect to temperature and/or time in a controlled atmosphere. Miniature-sized PCB samples were prepared & subjected to multiple thermal cycles (room temp to 300C @ 10C/min) while capturing the weight loss at the end of each thermal cycle per the IPC TM650 2.4.24.6 test method.
- TMA: Thermo-mechanical Analyzer measures Z-axis material deformation under controlled conditions of force and temperature. Force can be applied in compression, flexure, or tension modes using different probes. TMA measures intrinsic material properties *(e.g., expansion coefficient, glass transition temperature, Young's modulus)*, plus processing / product performance parameters *(e.g., softening points)*. In this study, small PCB samples (6mm X 6mm, 2 samples per each laminate type) were heated up from room temperature (25C) to 260C & Tg, CTE values were calculated based on probe displacement data per the IPC TM650 2.4.24C test method.
- MHT: Microhardness measures a materials resistance relative to another significantly harder material or indentor with a given geometry by applying a load for a given amount of time, then measuring the area of the indentation created. The surface area of the indentation is found from its diagonal length, which the user measures through the microscope on the microhardness tool. Samples cut out from the PCB were molded in epoxy & metallographic cross-sectioning was performed to ensure a regular & smooth surface for microhardness test.

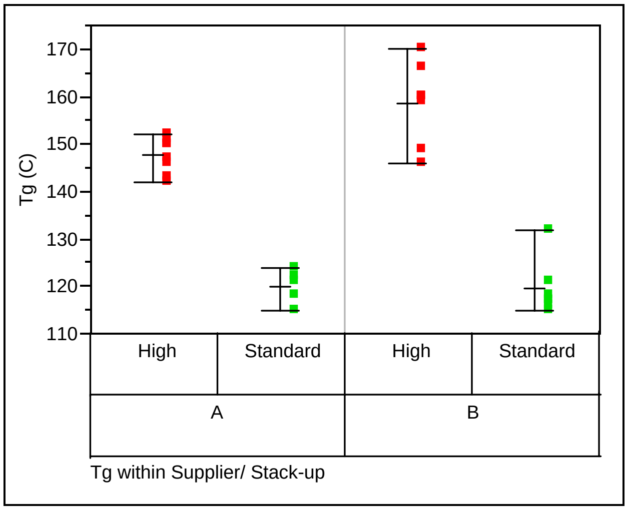
Materials Testing Results

As mentioned earlier, an MEB test vehicle was used to evaluate the variation in laminate material properties. Table 1 lists the initial MEB test board configurations that were analyzed in this study.

Table 1 - List of MEB board configurations in initial study

Supplier/ Stack-up	Layers	Layer 1 to 2, n to n-1 Prepreg	Thickness (mils)	Material Type
A	8	1080	0.077	Standard FR4
A	8	1080	0.077	High Tg FR4
B	8	1080	0.077	Standard FR4
B	8	1080	0.077	High Tg FR4

Z-axis CTE and Tg: The results of the TMA testing of each of the MEB board configurations confirmed the use of high Tg FR4 and Standard Tg FR4 materials where requested (see figures 10A and 10B). The actual results were slightly different than the reported values on the material data sheets for each material set.



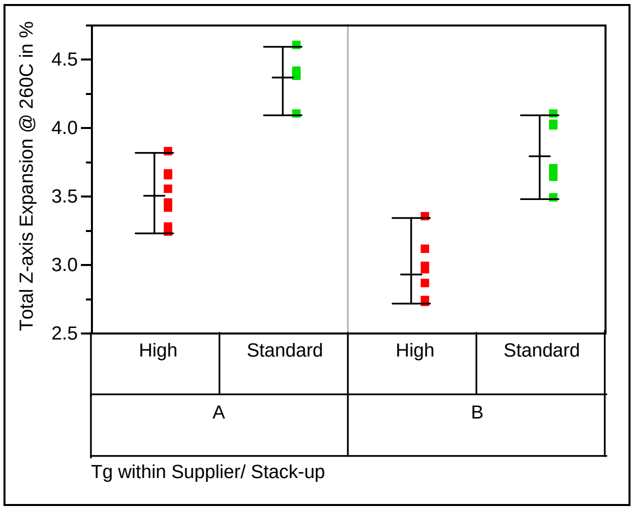


Figure 10A & 10B - Glass transition (Tg) and Total Z-axis CTE values of MEB Boards

Instron Load Frame Testing: The results of the flexural modulus testing are shown in figure 11. The high Tg FR4 PCB materials are consistently stiffer than Low Tg materials, for a given stack-up/supplier.

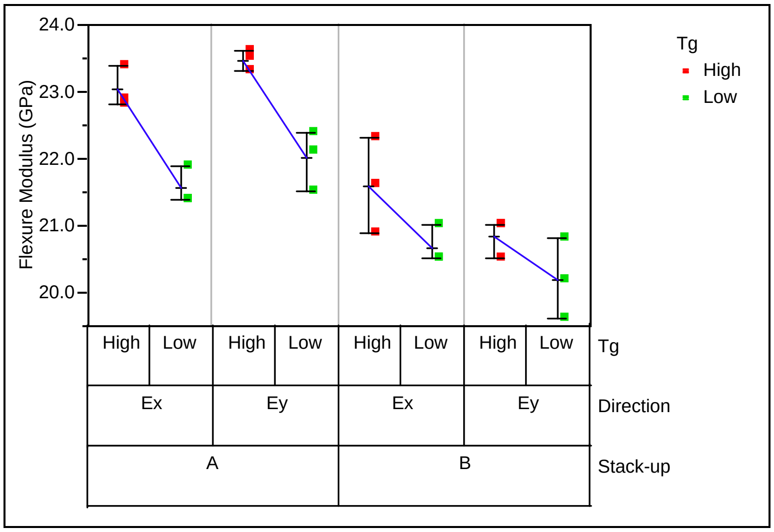


Figure 11 - MEB Flexural Modulus Data

The shift in flexure modulus by stack-up/supplier is probably due to differences in the PCB stack-up between the suppliers as shown in figure 12. The glass construction and number of glass plies in each stack up differ which may account for the resulting differences in stiffness. The specific type of standard or high Tg FR4 resin also differed, which may also impact the material properties. These influences are not well understood or quantified at this time, and are still under investigation.

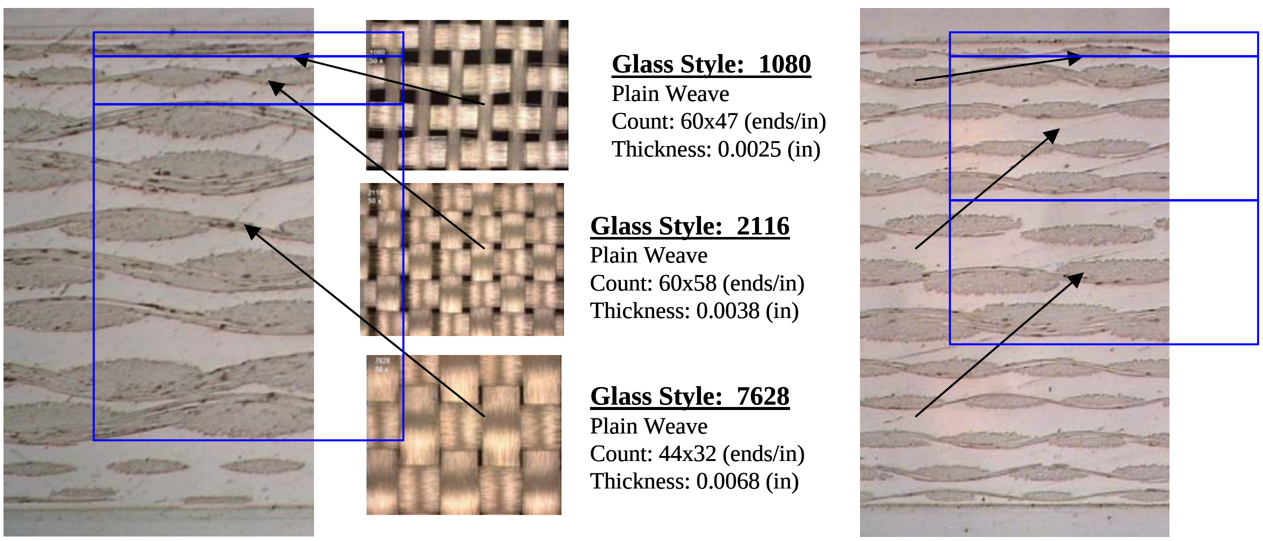


Figure 12 – MEB (A left & B right) stack-ups are visibly different.

Flexure modulus is a combination of more basic properties (i.e. Elastic Modulus, Shear Modulus, and Poisson's Ratio in the X, Y, & Z directions), and serves as an indicator of changes in specific material properties. The Instron data showed similar differences in the basic Ex, Ey, Gxy mechanical properties as shown in figures 13A and 13B. The Poisson's Ratio was equivalent for all 4 MEB boards.

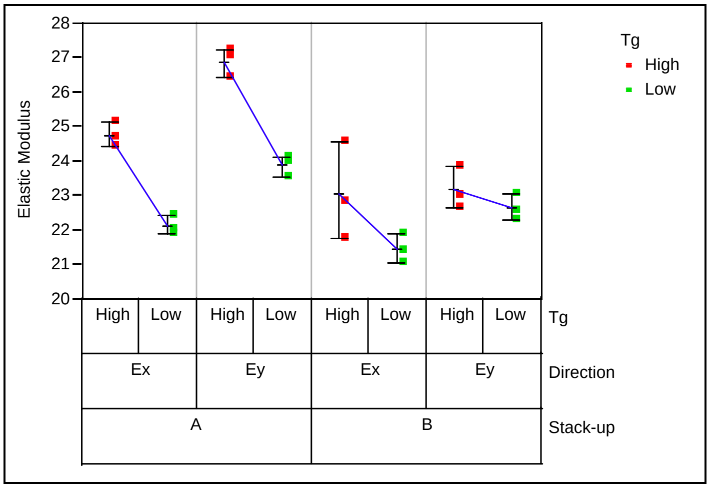


Figure 13A - MEB Elastic Modulus Data

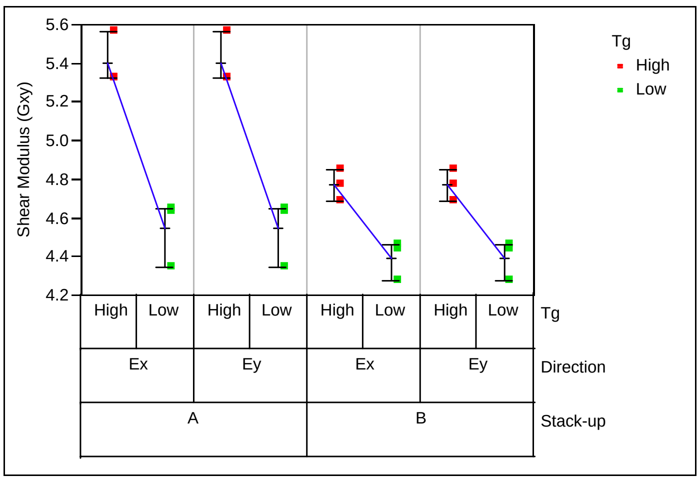


Figure 13B - MEB Shear Modulus Data

<u>MHT</u>: The microhardness of the resin in the surface layer of the different MEB builds was tested before and after different numbers of Pb-free reflows. The data is shown in the figure 14, and matches the case study data, where high Tg FR4 resin exhibits higher hardness values than the standard Tg FR4 resin.

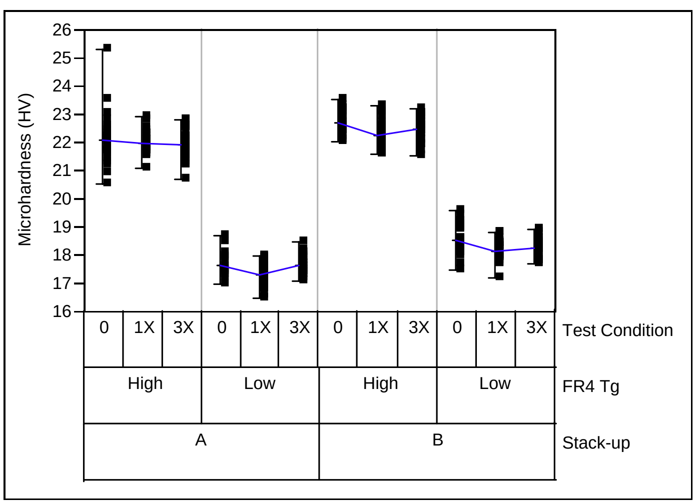


Figure 14 – Microhardness data for each MEB test configuration

TGA: There were no significant differences observed in weight loss during thermal degradation testing after 2 thermal cycles when testing was halted. Testing was not conducted beyond 2 thermal cycles because affected product had not gone beyond 2 thermal cycles in assembly.

Correlation of Flexure Modulus to Transient Bend Strain Performance

The three main factors driving both transient bend response and flexural stiffness are Ex, Ey, and Ez based on experimental and finite element modeling data. Ex and Ey are not expected to change significantly and are not directly related to Pad Crater. Out of plane elastic modulus (Ez) is related to Pad Crater in the sense that the damage initiates in the resin. Fit model effect screening of mechanical test data indicates that Elastic Modulus values (Ex, Ey, and Ez) are significant factors impacting board flexure response and strain response as shown in Figures 15A and 15B. Prior analytical work in composite mechanics, Paul et al (2), also confirms this finding.

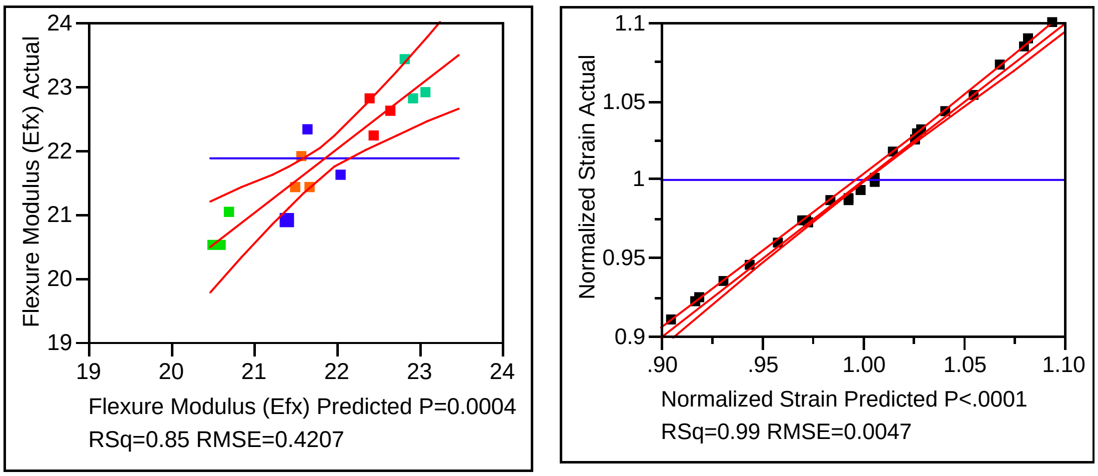


Figure 15A & 15B – Finite Element Fit Models - Flexure Modulus Results (left), Transient Bend Strain Results (right)

The impact of these mechanical property values on Transient Bend testing was evaluated using ABAQUS to model a standard BGA package in spherical bend. The fit model and Pareto are shown in Figures 16A and 16B. The Transient Bend model indicates ~ +/-10% variation in strain response due to mechanical property variation observed in MEB testing. The MEB testing was a limited set of test variables, so PCB materials in general may have a wider range of variation. The significant impact factors are Elastic Modulus values in the Ex, Ey, & Ez directions. Since reliable Ez measurements are not currently available ultrasound and moiré metrologies are being investigated to better define this variation.

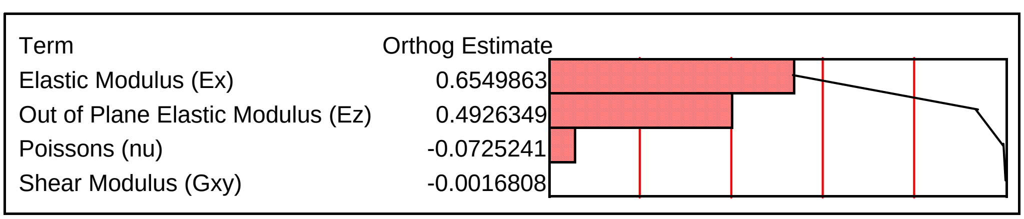


Figure 16A – Flexure Test Data Fit Model

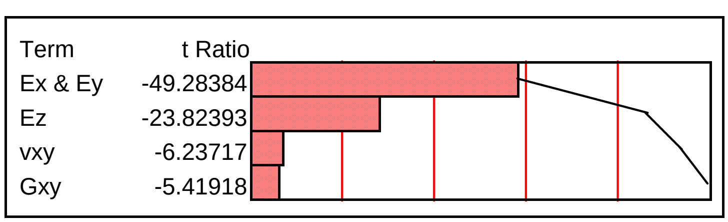


Figure 16B – Transient Bend Finite Element Fit Model

The MEB boards tested had the same copper artwork, and samples were cut from the same board locations which normalized the copper content and geometry as constants in this study. Changes in Elastic Modulus (Ex, Ey, Ez) would be driven by glass fiber stack-up and resin type, given a constant copper content and PCB geometry. The impact of fiber and resin on in-plane mechanical properties (Ex, Ey) can be approximated by the Law of Mixtures due to the planar orientation of the PCB structure as stated in Equation 1.

$$E_{x,y} = E_{fiber}V_{fiber} + E_{resin}V_{resin} + E_{Cu}V_{Cu}$$ Equation 1

Out of plane modulus (Ez) is governed by the Transverse Law of Mixtures due to the planar stacking pattern of PCB layers as stated in Equation 2.

$$\frac{1}{E_z} = \frac{V_{fiber}}{E_{fiber}} + \frac{V_{resin}}{E_{resin}} + \frac{V_{Cu}}{E_{Cu}}$$ Equation 2

.

The elastic modulus of Copper (~120 GPa) and glass fiber (~70 GPa) are significantly larger than that of the resin (~3 GPa). This allows simplification of Equations 1 and 2 into Equations 3 and 4 below.

$$E_{x,y} = E_{fiber}V_{fiber} + E_{Cu}V_{Cu}$$ Equation 3

$$\frac{1}{E_z} = \frac{V_{resin}}{E_{resin}}$$ Equation 4

Equation 3 indicates that glass fiber and copper are primary drivers for in plane elastic modulus. However this analysis does not take into account random distributions of copper planes, via holes, and other PCB design features. The MEB test data held volume fraction of the resin/glass ratio and distribution of copper in the PCB design reasonably constant allowing an assessment of the glass fiber weave impact on $E_{x,y}$. Equation 4 indicates Elastic Modulus of the resin is the primary driver for variation in the out of plane modulus E_z for the MEB test data. The MEB test results and previous research, Mao et al (3), support this approach and laminate resin type has also been linked to Pad Crater susceptibility based on PCB structure and manufacturing test studies.

Flexure Data across several variables

Additional MEB builds consisting of different board thicknesses, more suppliers and resin types, different outermost dielectric constructions, and different layer counts were subjected to flexure testing. A global look at the data in figure 17 indicates there are many modulating factors for flexure modulus. The separation of high and low Tg FR4 results by flexural modulus still remains as a dominant factor, with high Tg FR4 builds having higher flexural modulus values. The build exceptions (S4P, H1V, and P3N) which do not follow the global Tg trend highlight the fact there are other factors besides material Tg which also impact the flexural modulus of the board.

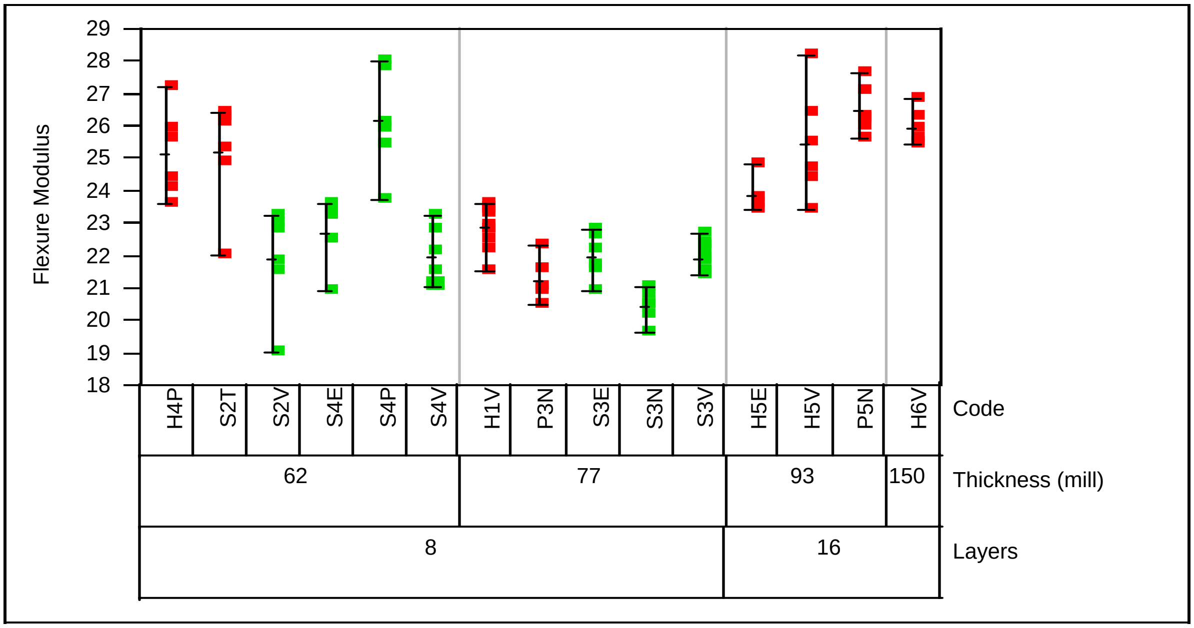


Figure 17 – All MEB board builds Flexure Modulus data (red = high Tg FR4, green = low Tg FR4)

Conclusions

The testing we have done to date has resulted in the following conclusions:

1) High Tg FR4 resin is more susceptible to Pad Crater failures than Low Tg FR4 resin materials with all other factors held constant. This finding suggests that switching to a high Tg FR4 resin solely for the purpose of Pb-free assembly may have negative impacts to your board reliability.
2) PCB construction and resin type modulate PCB material properties for a given copper distribution and geometry. Resin type has been identified as a significant impact to Pad Crater performance, but the impacts of layer count, thickness, and in-plane geometry features and Cu distribution need further investigation.
3) Flexure modulus, Tg, micro hardness, and Cold Ball Pull data follow consistent trends and appear to be sensitive metrologies to Pad Crater performance in the manufacturing environment.
4) Strain limit performance variation can be approximated by variation in flexure modulus. Flexure modulus measurements can serve as a screening tool for the PCB impact on strain limit performance.
5) The Law of Mixtures approach appears to be a reasonable first order approximation of PCB strain behavior. The Law of Mixtures assumptions can be used to simplify FEA and analytical predictive modeling efforts, at least for purposes of a first order evaluation.

The goal of understanding the material limits with respect to pad cratering, and identifying key material properties will lead to the potential development of better laminate materials for use. The pad crater defect involves many variables beyond the selection of the laminate. Board and component design, solder alloy, assembly, and test procedures all play a role in the quality outcome of the board. Additional investigation of each of these elements is needed in an effort to understand their role in pad cratering. This paper is intended to provide an overview of Intel's work to date and a basis for the further testing and validation of these observations and conclusions. Pad Cratering is an industry problem, and has been recognized as such by the formation of an industry work group further study the issue. The goal of the industry work group is to pursue the development of uniform defect reporting and investigate new metrologies to measure pad crater response. Intel is chairing the work group, and encourage other companies to join in the investigation, either as part of the work group or individually. Publishing test results will increase the industry learning and identify solution paths as product roadblocks arise.

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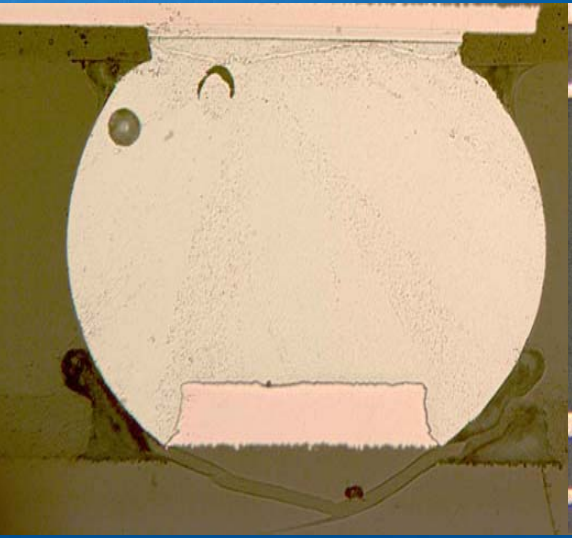
Agenda

- **Introduction**
  - Definition of a Pad Crater
  - Quality and Reliability Risks
  - Lead-free Pad Crater Drivers
- **Case Study**
- **Material Variation Testing**
- **Transient Bend Model Correlation**
- **Flexure Data Across Several Variables**
- **Conclusions**
- **Industry Recommendations**
- **Call to Action**
- **Q&A**

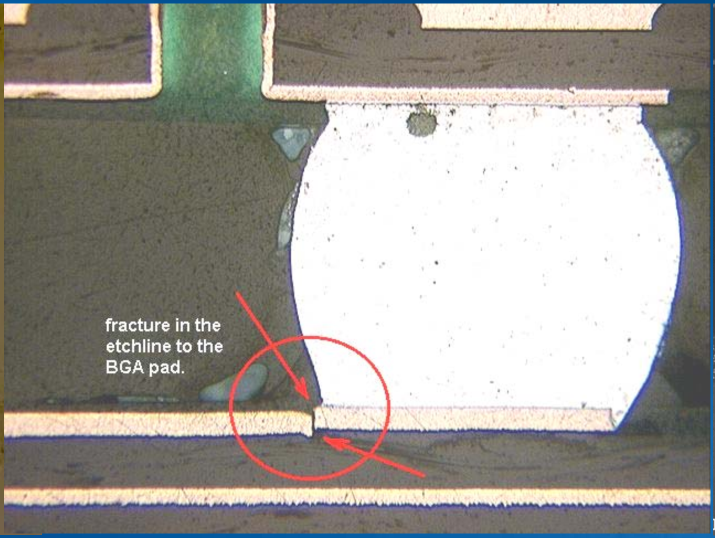
4

Introduction

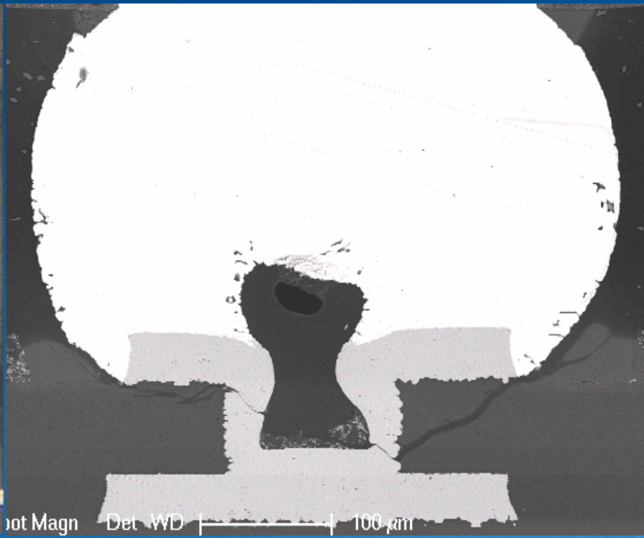
- **Definition of a Pad Crater -** ***A separation of the pad from the PCB resin / weave composite or within the composite immediately adjacent to the pad. Also known as a "laminate crack" or "pad lifting".***
- **Pad craters are the predominant failure mode for metal defined BGA pads during reliability testing of Lead Free product.**



Post shock testing – Nonfunctional pad – No electrical failure



Post shock testing – Functional pad – Open Failure



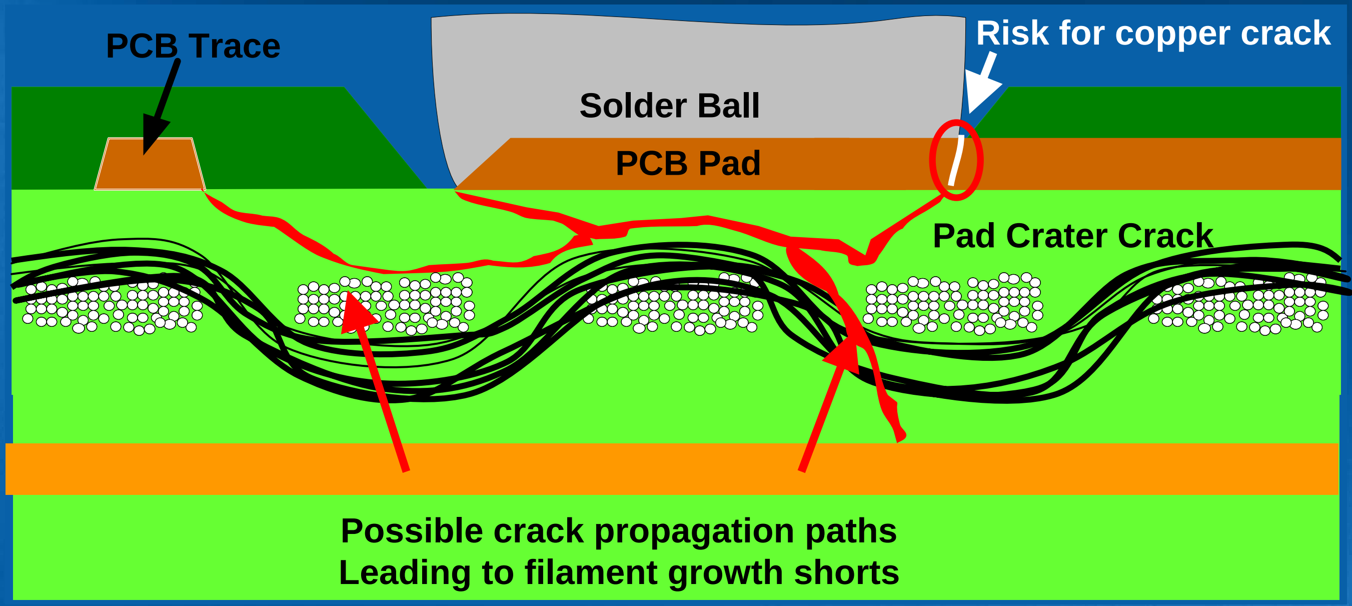
Post shock testing – Functional microvia in pad – Open Failure

5

Reliability Risks of Pad Cratering

- **The 2 major reliability risks with pad craters are:**

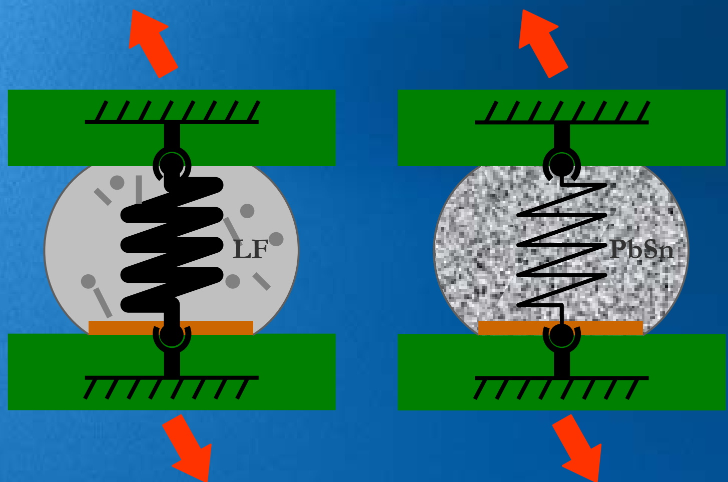
1. **Copper crack occurs where the trace or microvia intersects the cratered pad causing an open circuit.**

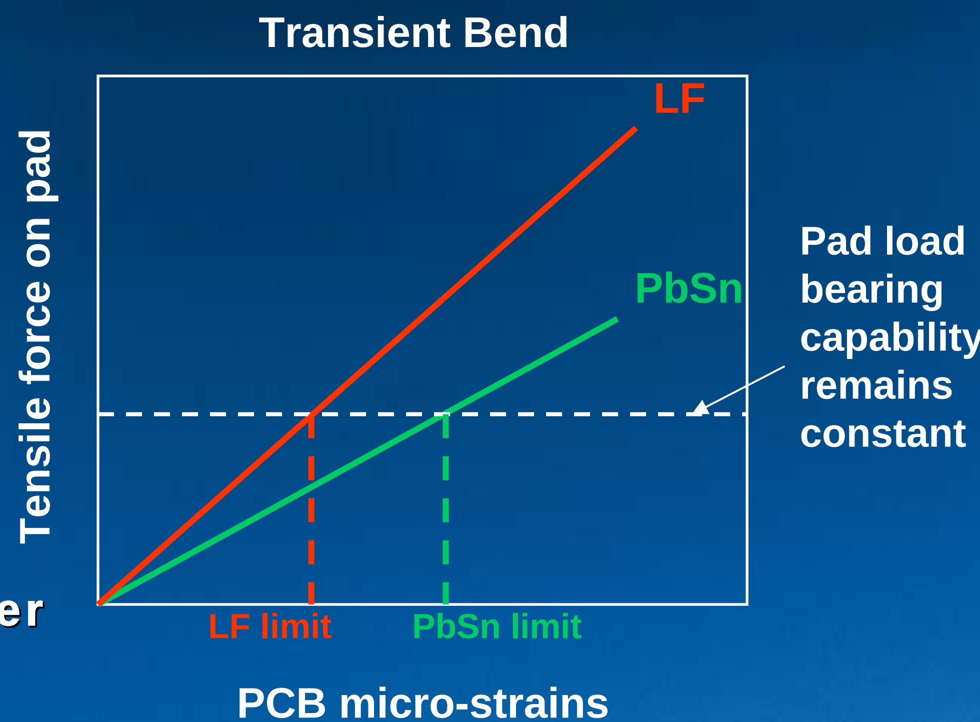


2. **Laminate cracks provide a pathway for conductive filament growth leading to a short within the PCB *(Conductive Anodic Filament growth)***

Pad Craters Drivers – Solder Type

Pb Free | PbSn

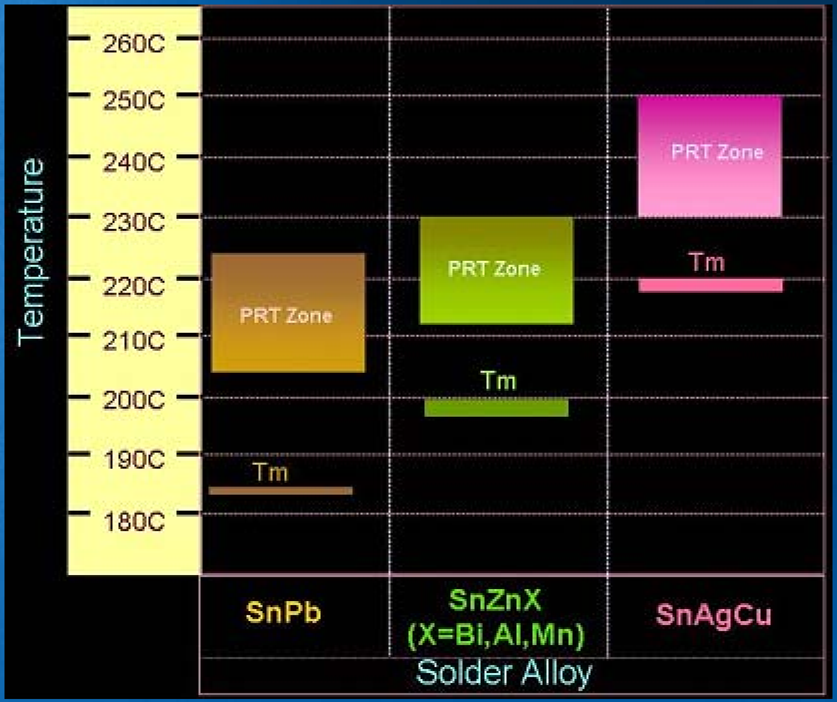




1. **Lead free solder is stiffer than PbSn**
2. **Pad adhesion is equivalent for Pb free and PbSn**

The transition to Lead-free solders has increased the probability of pad crater failures

Pad Craters Drivers – Assembly Temperature

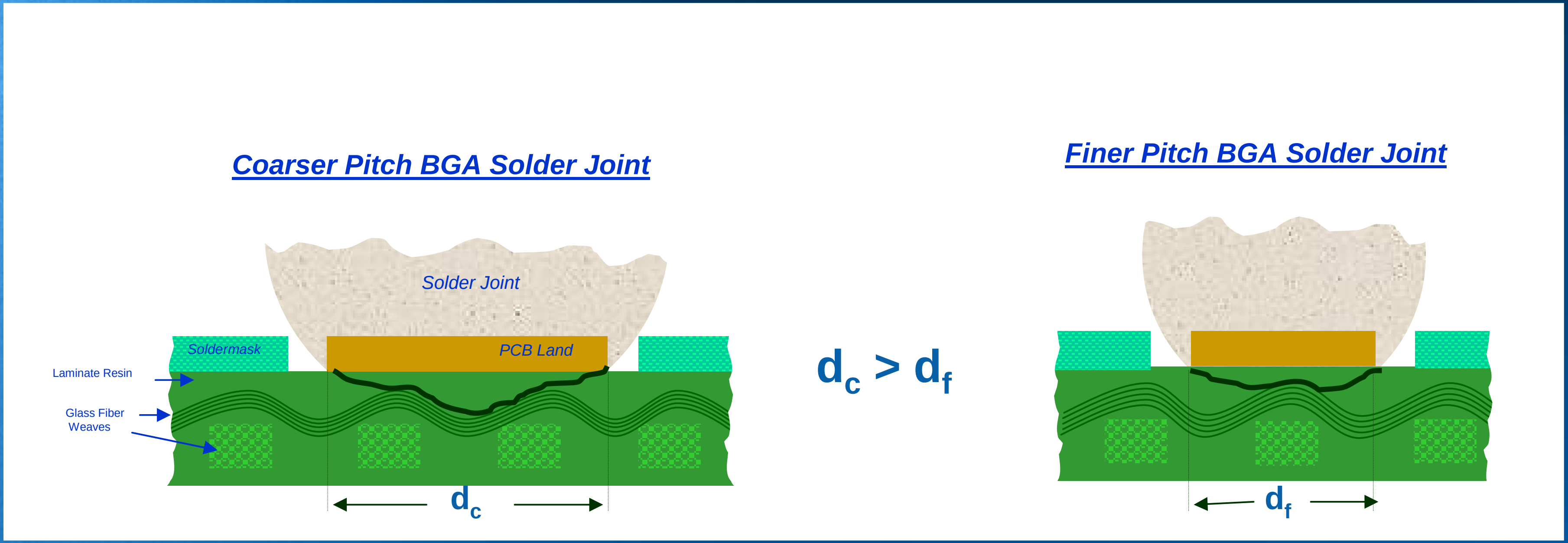


Melting Points and Process Temperature Ranges for Solder Alloys

Up to 34C Delta T between SnPb and Lead-free alloy melting points

- **Delta in X / Y CTE mismatch higher with lead –free assembly temperatures creating higher stresses in the joint**

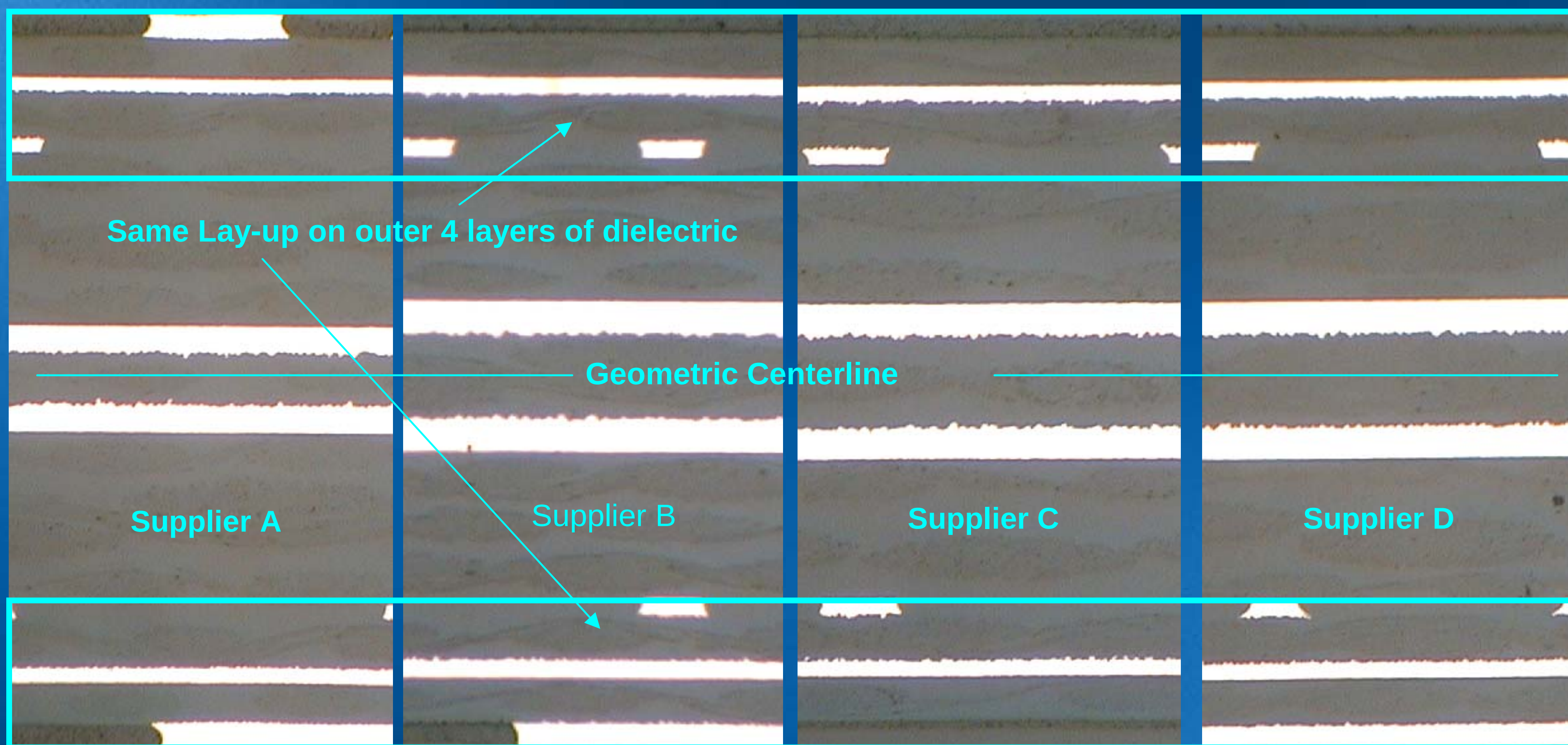
Pad Crater Drivers - Design



- ➢Smaller package pitch drives smaller PCB lands
- ➢Smaller PCB lands result in less fracture distance for pad craters
- ➢Smaller PCB lands result in reduced adhesion area creating a higher mechanical stress profile for the same loading conditions

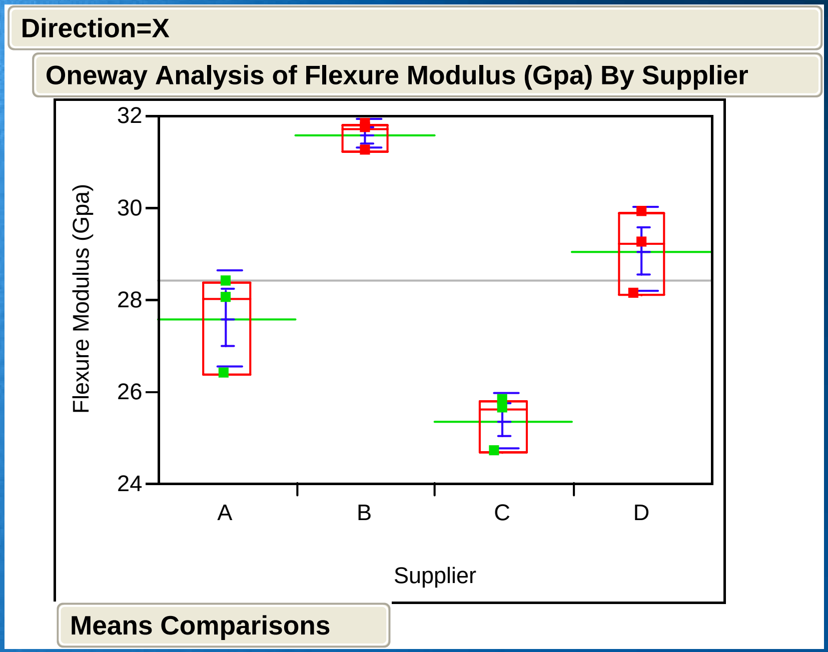
Pad Crater Case Study

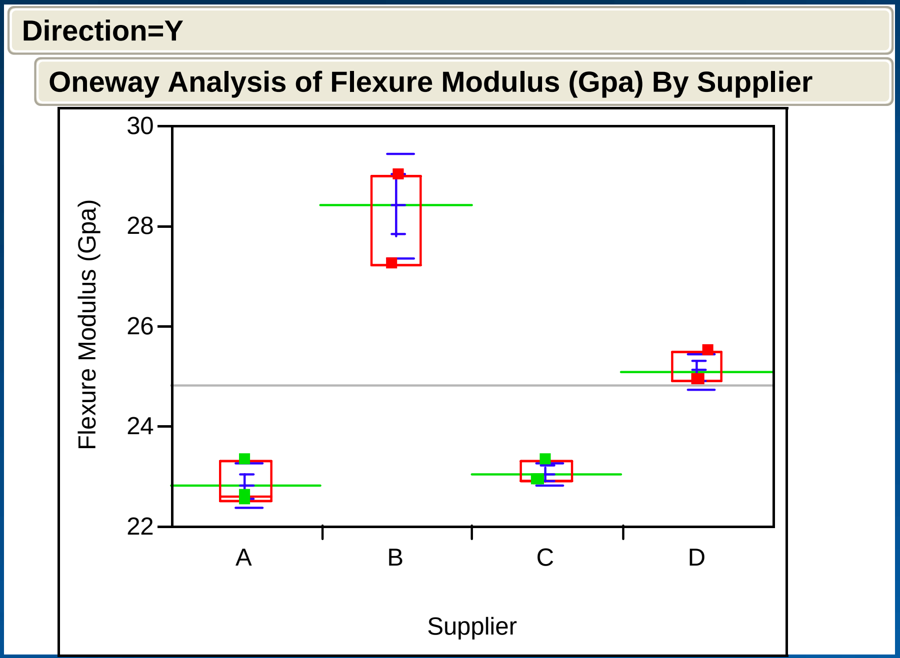
Background – Pad cratering observed after ICT testing on boards from suppliers B and D, but not on boards from suppliers A and C.



X-section photo of 4 suppliers boards showing stack-up similarities and differences

Pad Crater Case Study

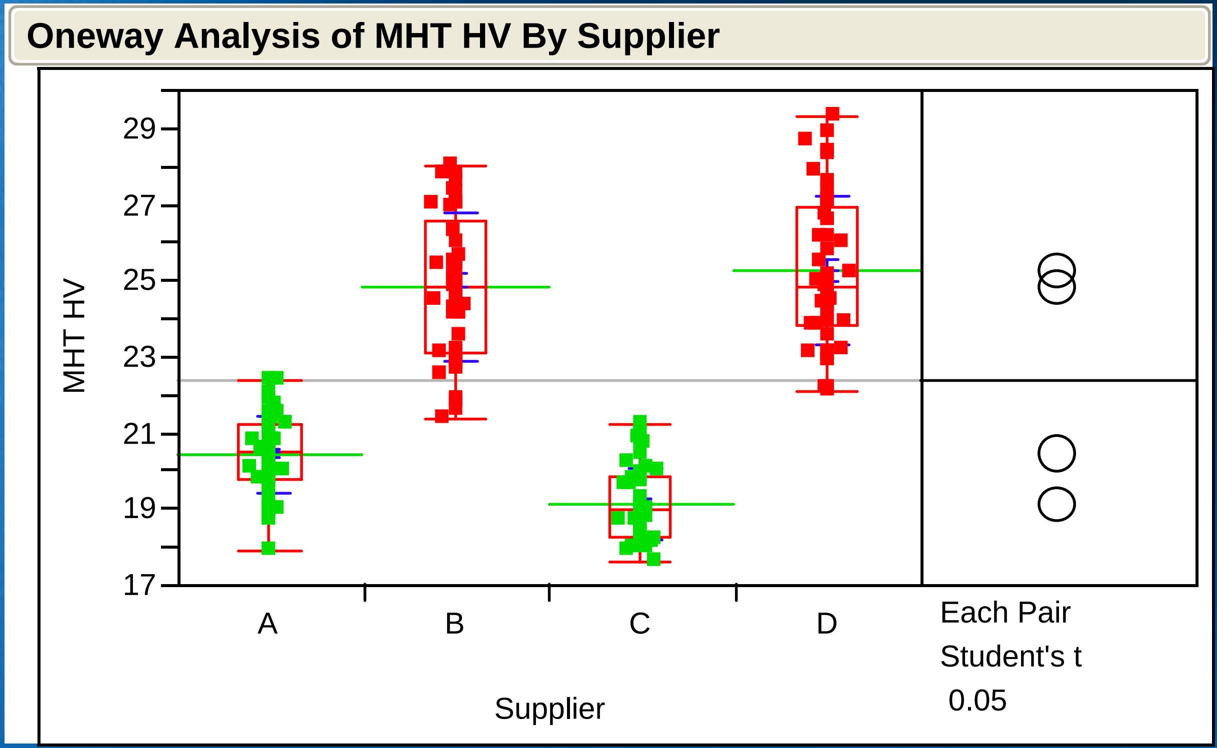




- No Pad Craters
- Pad Craters Observed

❖ **Flexural Modulus values in both X and Y directions are lower for board lots (suppliers A and C) which exhibited better performance for pad cratering**

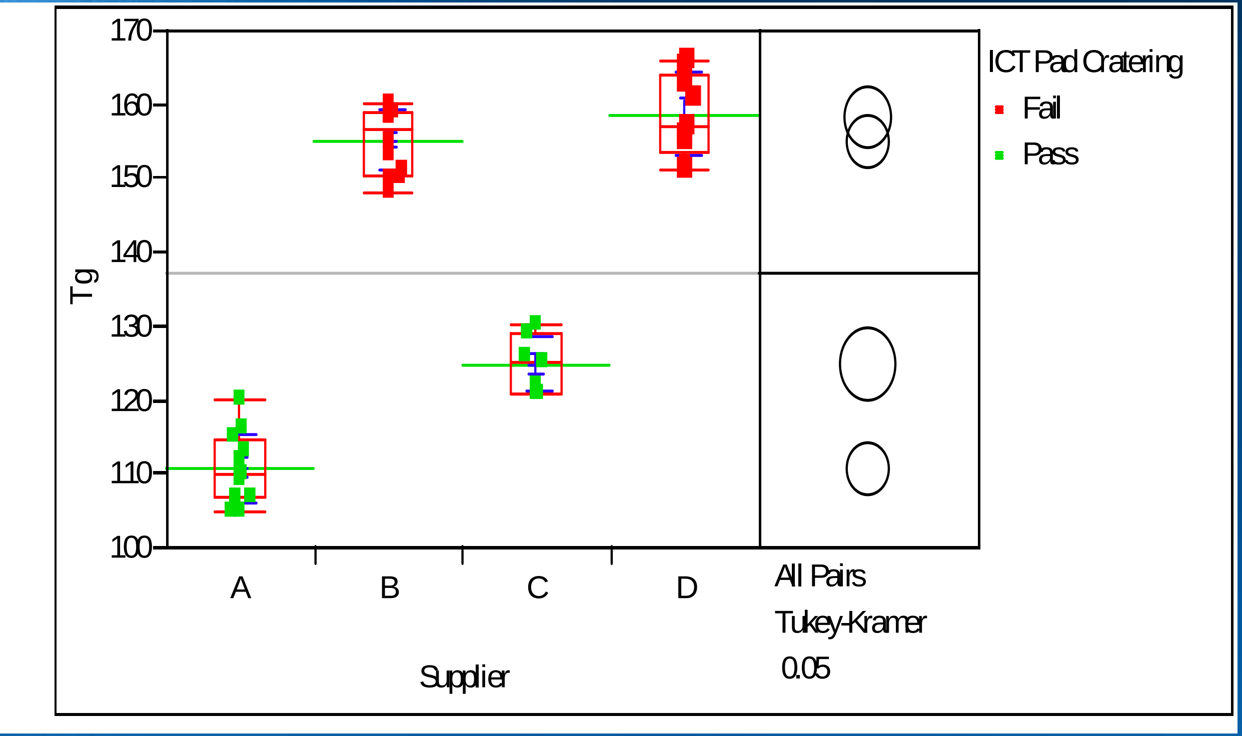
Pad Crater Case Study



■No Pad Craters
■Pad Craters Observed

- Resin micro hardness values are lower for board lots (suppliers A and C) which exhibited better performance for pad cratering

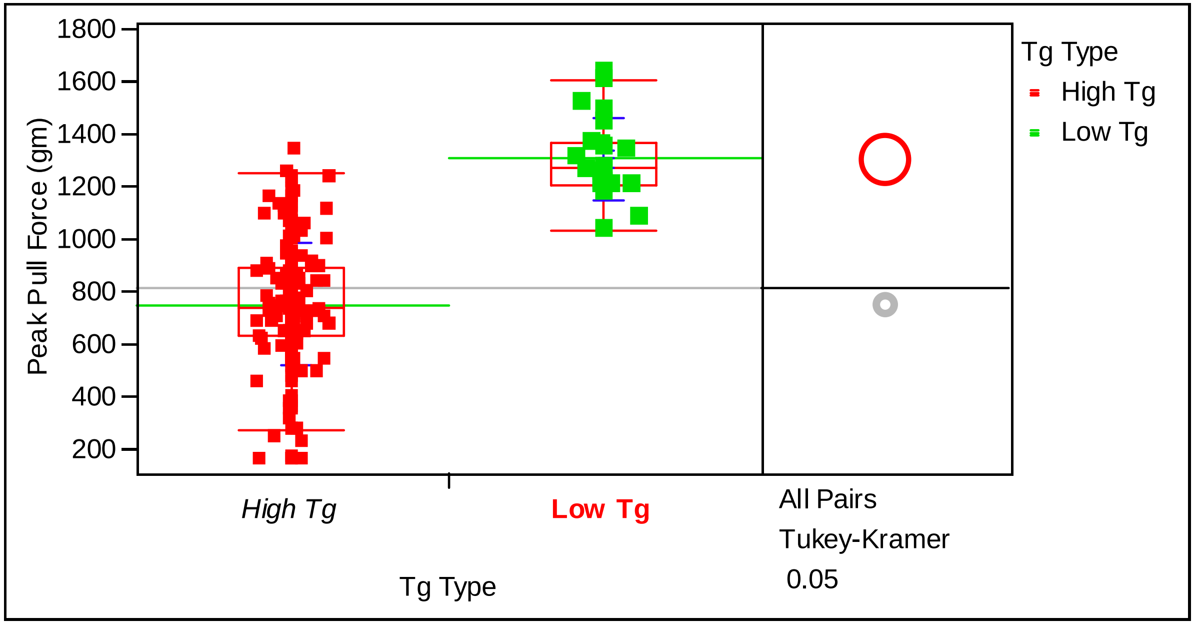
Pad Crater Case Study



- No Pad Craters
- Pad Craters Observed

- Failed boards used high Tg FR4 material (>150C).
- Passing boards used Standard Tg FR4 material (<140C).

Pad Crater Case Study



- **Cold Ball Pull pad crater failure data indicates a higher peak force is required for standard Tg FR4 laminate vs. High Tg FR4**

Pad Crater Case Study

Conclusion:

- Flexure modulus, resin micro hardness, laminate Tg, and cold ball pull strength all correlate to pad crater performance.

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Material Property Variation Testing

Purpose:
Examine material property variation at the same supplier using standard and high Tg FR4 laminates.

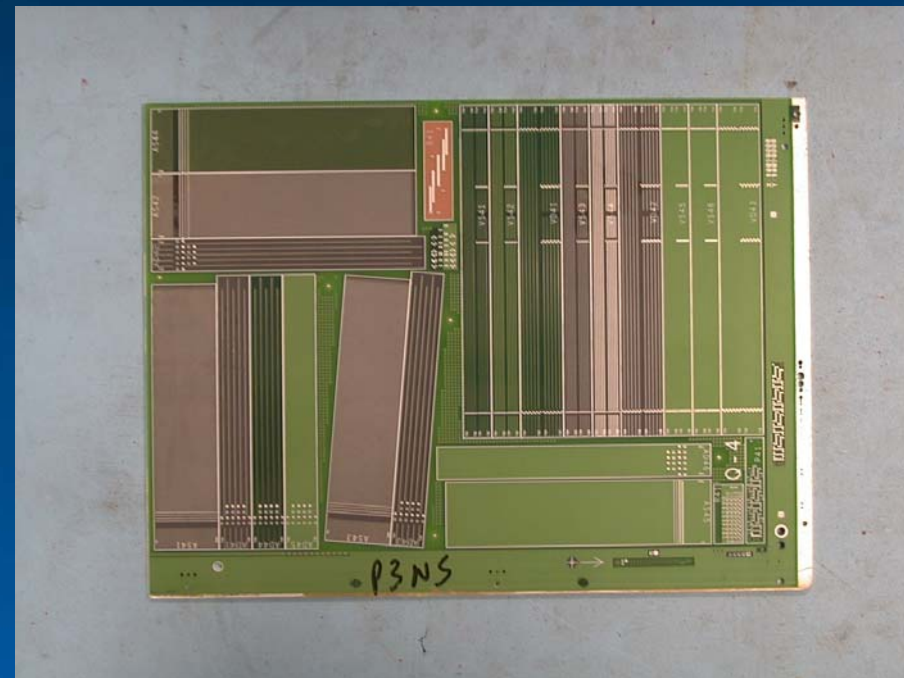

Photo of MEB test board design used in study

Supplier/ Stack-up	Layers	Layer 1 to 2, n to n-1 Prepreg	Thickness (mils)	Material Type
A	8	1080	0.077	Standard FR4
A	8	1080	0.077	High Tg FR4
B	8	1080	0.077	Standard FR4
B	8	1080	0.077	High Tg FR4

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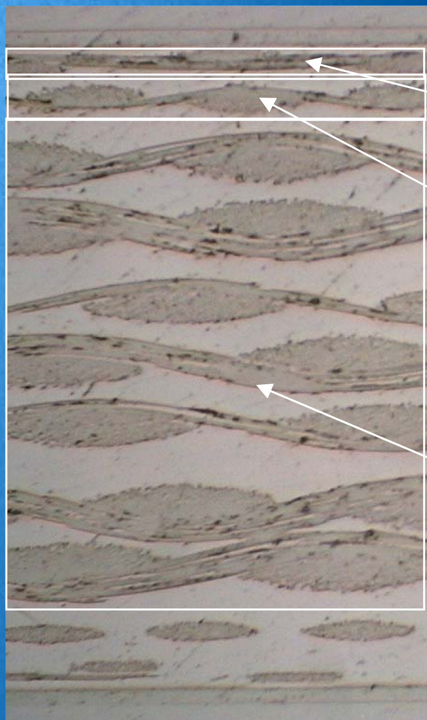
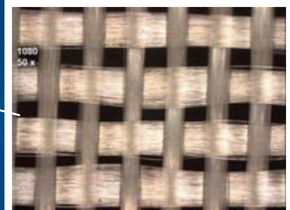
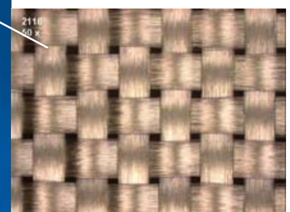
Material Property Variation Testing



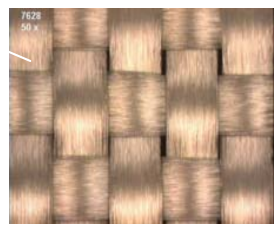
Supplier A stack-up



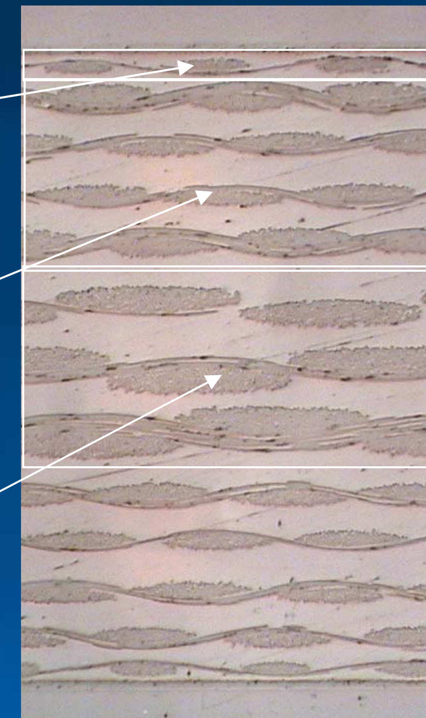
Glass Style: 1080
Plain Weave
Count: 60x47 (ends/in)
Thickness: 0.0025 (in)



Glass Style: 2116
Plain Weave
Count: 60x58 (ends/in)
Thickness: 0.0038 (in)



Glass Style: 7628
Plain Weave
Count: 44x32 (ends/in)
Thickness: 0.0068 (in)



Supplier B stack-up

Each supplier used a slightly different stack-up than the other, but both builds of the same supplier were identical stack-ups

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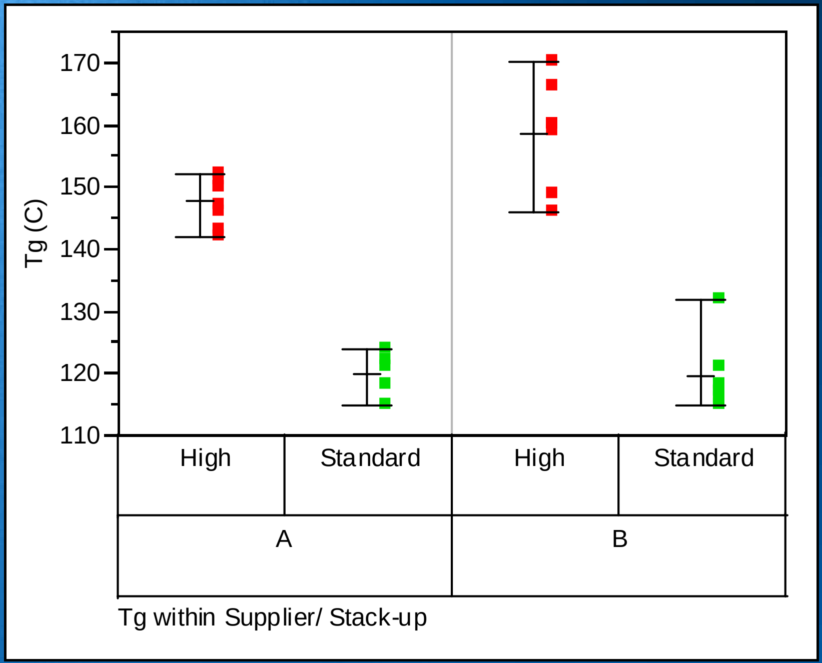
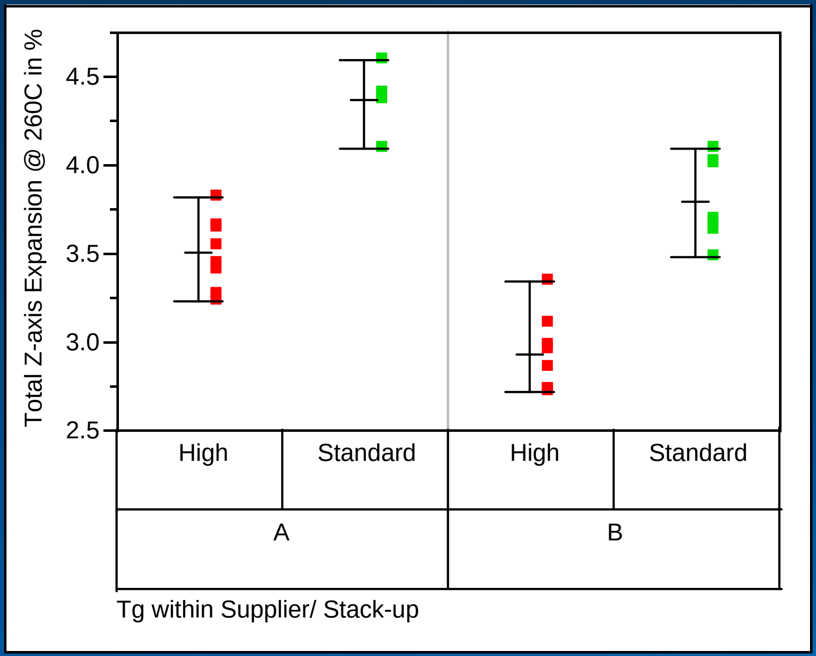
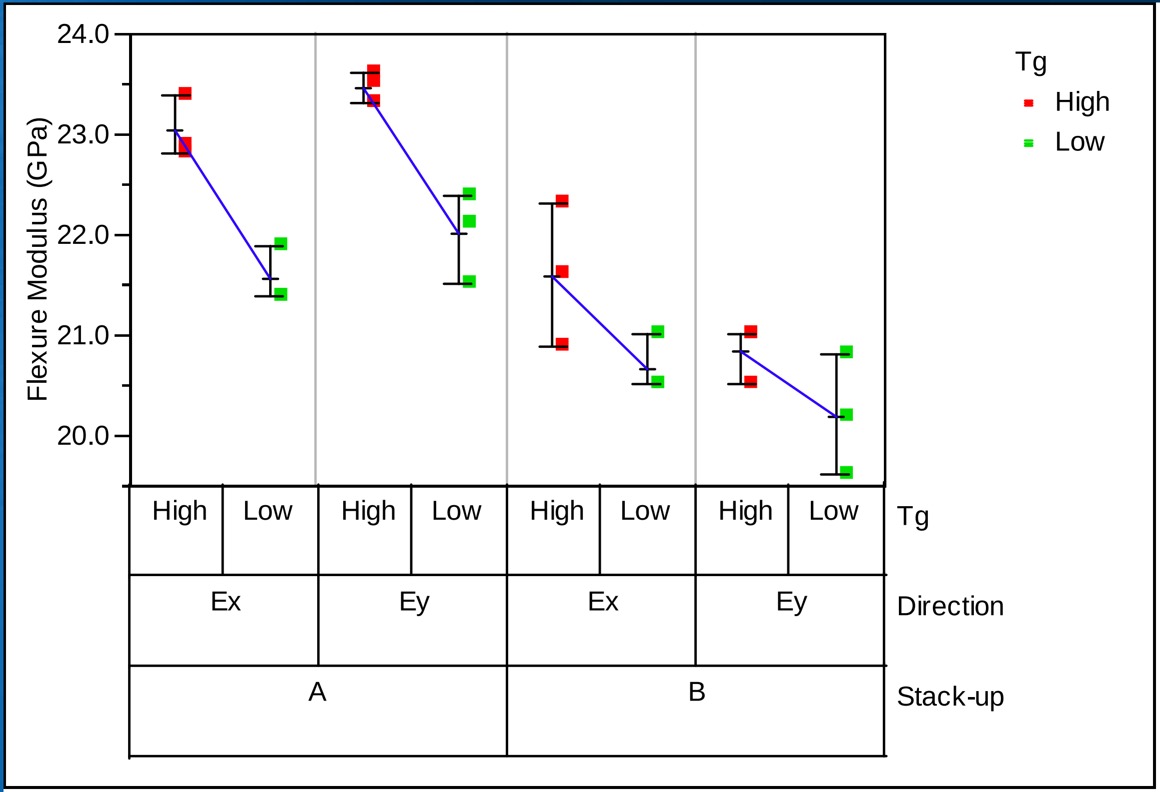
Material Property Variation Testing





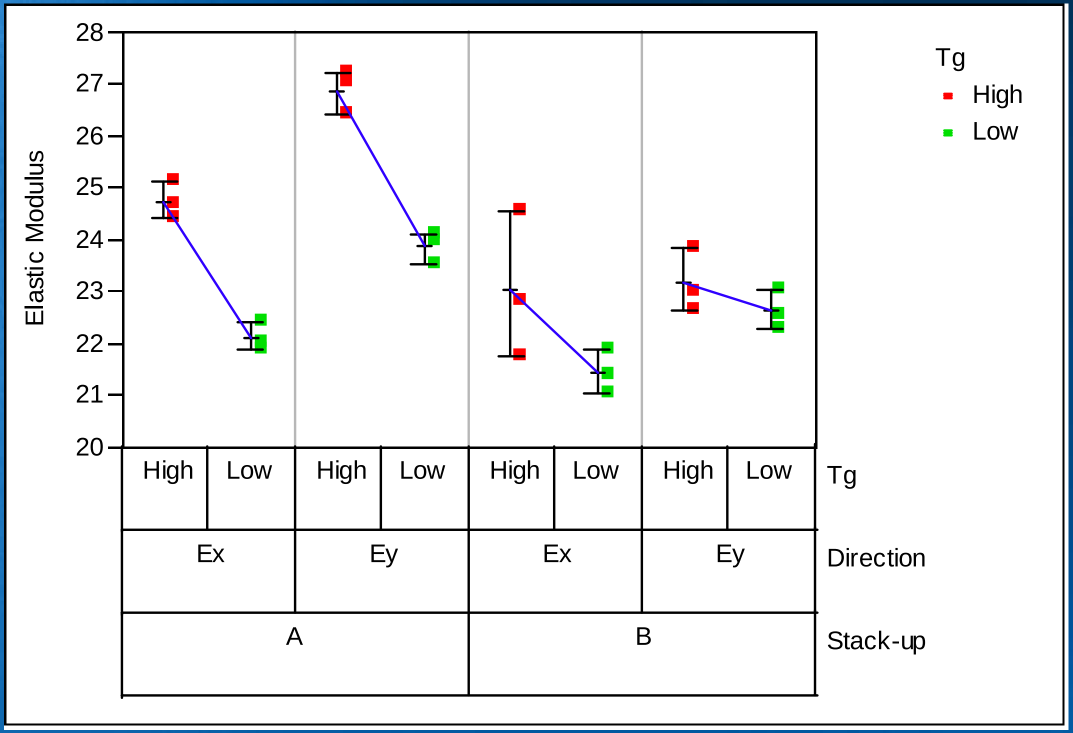
- **TMA testing of Tg and CTE values confirmed the material sets were as requested**

Material Property Variation Testing



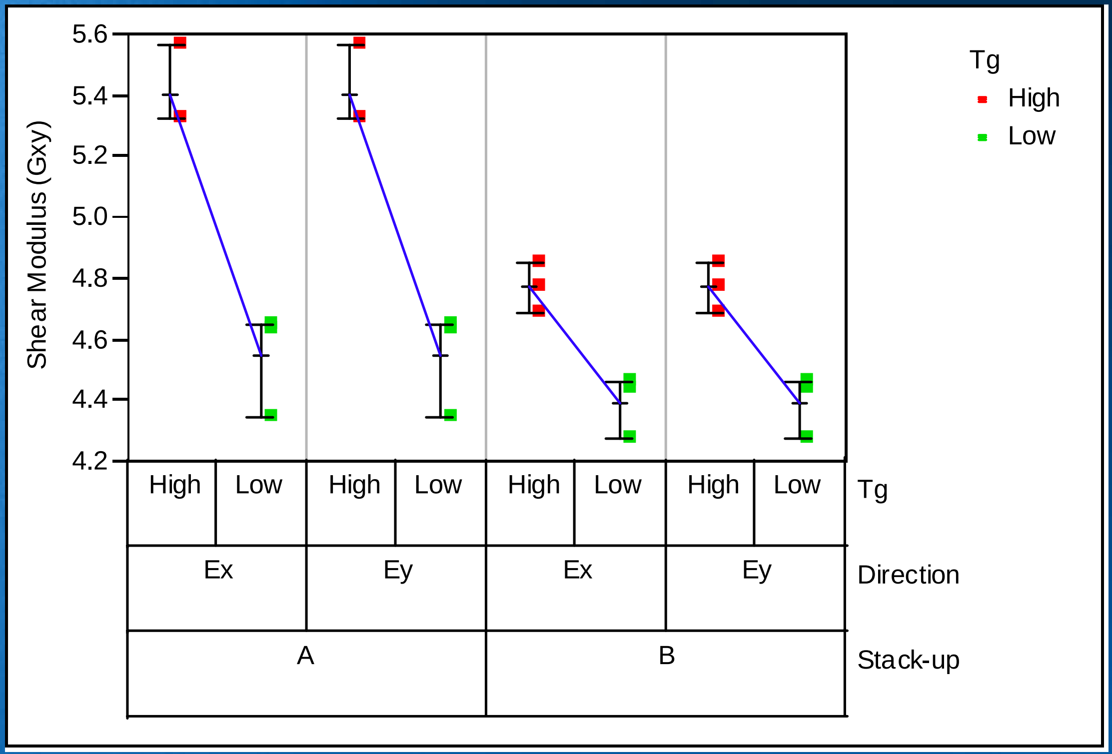
- Flexural modulus results were consistent with previous case study data with higher values for high Tg FR4
- Flexure modulus is a combination of more basic properties (i.e. Elastic Modulus, Shear Modulus, and Poisson’s Ratio in the X, Y, & Z directions), and serves as an indicator of changes in specific material properties.

Material Property Variation Testing



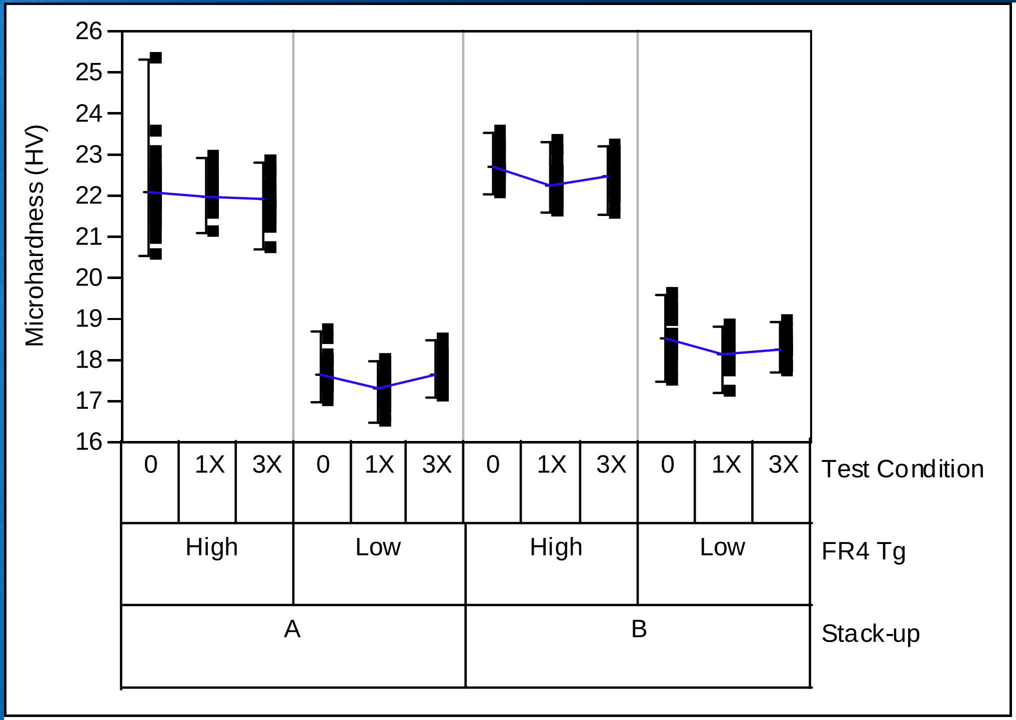
- Elastic modulus results show the same separation of data (high Tg FR4 demonstrating higher modulus than standard FR4) as the Flexural modulus

Material Property Variation Testing



- Shear Modulus results show the data trend (high Tg FR4 demonstrating higher modulus than standard FR4) as the Elastic and Flexural modulus

Material Property Variation Testing



- Resin micro hardness shows a clear separation of data for high Tg FR4 (higher values) vs. standard Tg FR4
- The number of reflows did not affect the hardness values over the range tested

Material Property Variation Testing

Conclusions:

- The material property variation followed the same data trends seen in the case study.
  - High Tg FR4 showed higher flexure modulus and resin micro hardness.
- The different stack-ups gave slightly different flexure modulus values

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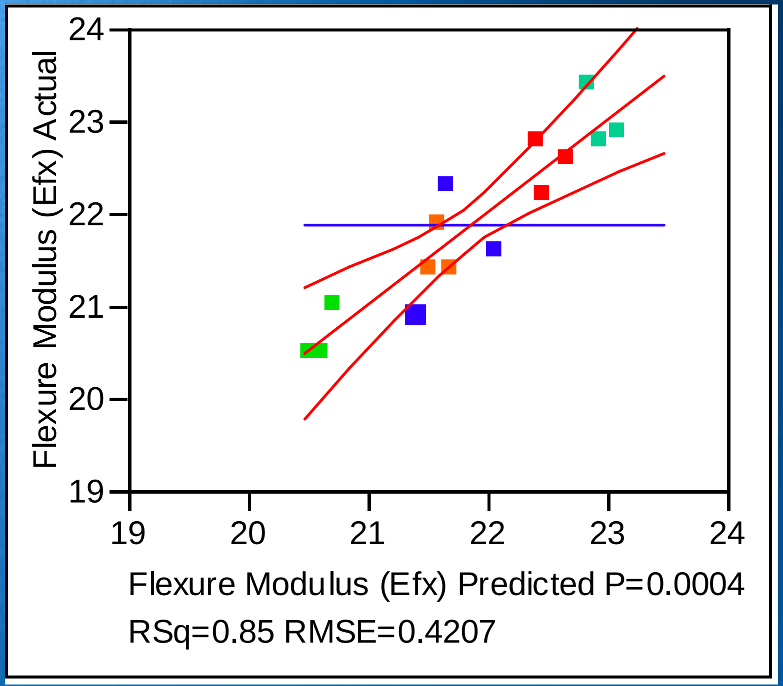
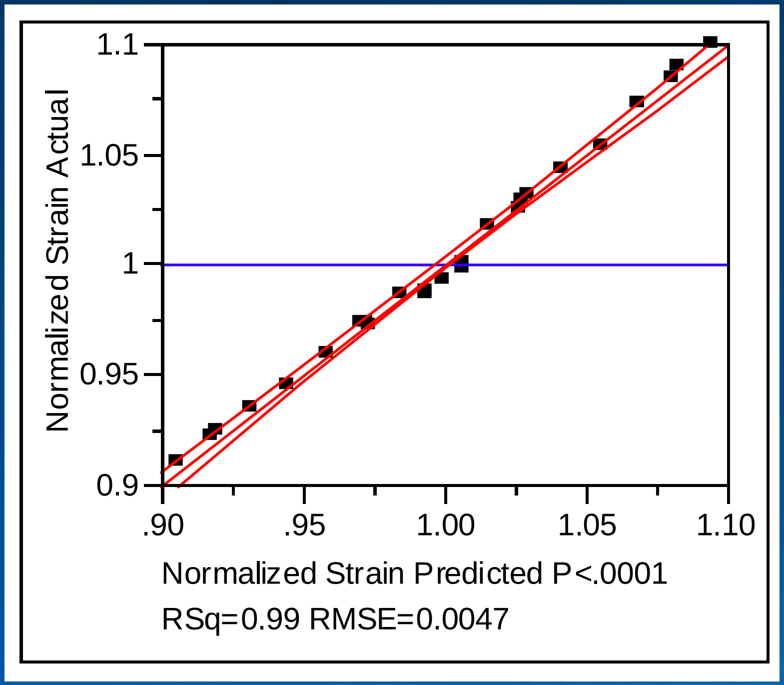
Transient Bend Model Correlation

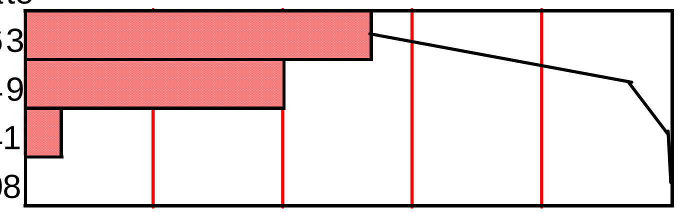




- **Modeling results for flexural modulus and transient bend strain show good correlation to actual data using the base material inputs of elastic modulus, shear modulus, and Poisson's Ratio.**

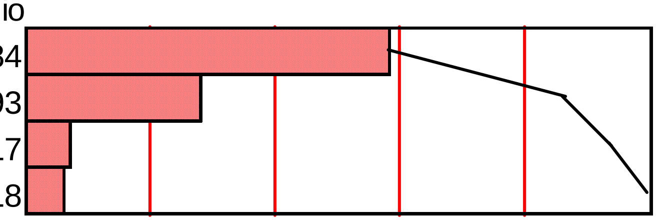
Transient Bend Model Correlation

Term	Orthog Estimate
Elastic Modulus (Ex)	0.6549863
Out of Plane Elastic Modulus (Ez)	0.4926349
Poissons (nu)	-0.0725241
Shear Modulus (Gxy)	-0.0016808



Flexure Test Data Fit Model

Term	t Ratio
Ex & Ey	-49.28384
Ez	-23.82393
vxy	-6.23717
Gxy	-5.41918



Transient Bend Finite Element Fit Model

- **The fit model paretos for both flexural modulus and transient bend strain show elastic modulus to be dominating factors**

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Transient Bend Model Correlation

- The impact of fiber and resin on in-plane mechanical properties (Ex, Ey) can be approximated by the Law of Mixtures due to the planar orientation of the PCB structure as stated in Equation 1.

$$E_{x,y} = E_{fiber}V_{fiber} + E_{resin}V_{resin} + E_{cu}V_{cu} \quad \text{Equation 1}$$

- Out of plane modulus (Ez) is governed by the Transverse Law of Mixtures due to the planar stacking pattern of PCB layers as stated in Equation 2.

$$1/E_z = V_{fiber}/E_{fiber} + V_{resin}/E_{resin} + V_{cu}/E_{cu} \quad \text{Equation 2}$$

- The elastic modulus of Copper (~120 GPa) and glass fiber (~70 GPa) are significantly larger than that of the resin (~3 GPa). This allows simplification of Equations 1 and 2 into Equations 3 and 4 below.

$$E_{x,y} = E_{fiber}V_{fiber} + E_{cu}V_{cu} \quad \text{Equation 3}$$

$$1/E_z = V_{resin}/E_{resin} \quad \text{Equation 4}$$

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Transient Bend Model Correlation

Conclusions:

- Strain limit performance variation can be approximated by variation in flexure modulus.
- Flexure modulus measurements can serve as a screening tool for the PCB impact on Transient Bend performance.

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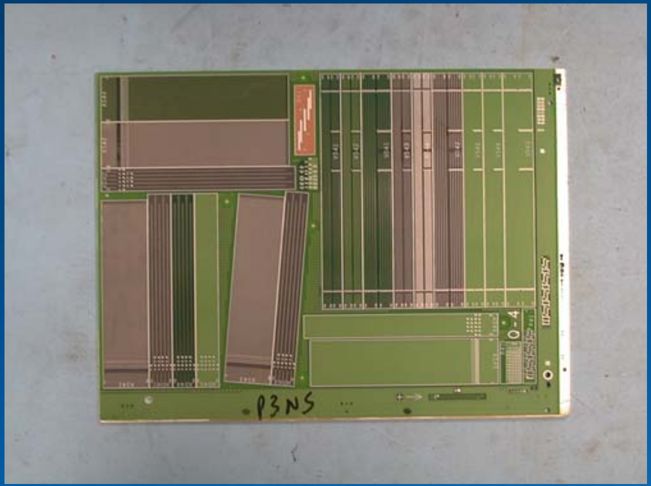
Flexure Data Across Several Variables

Multiple iterations of the MEB test board were tested for flexure modulus

- Different Thicknesses
- Different Suppliers
- Different Laminate Materials
- Different Layer Counts
- Different Stack-ups



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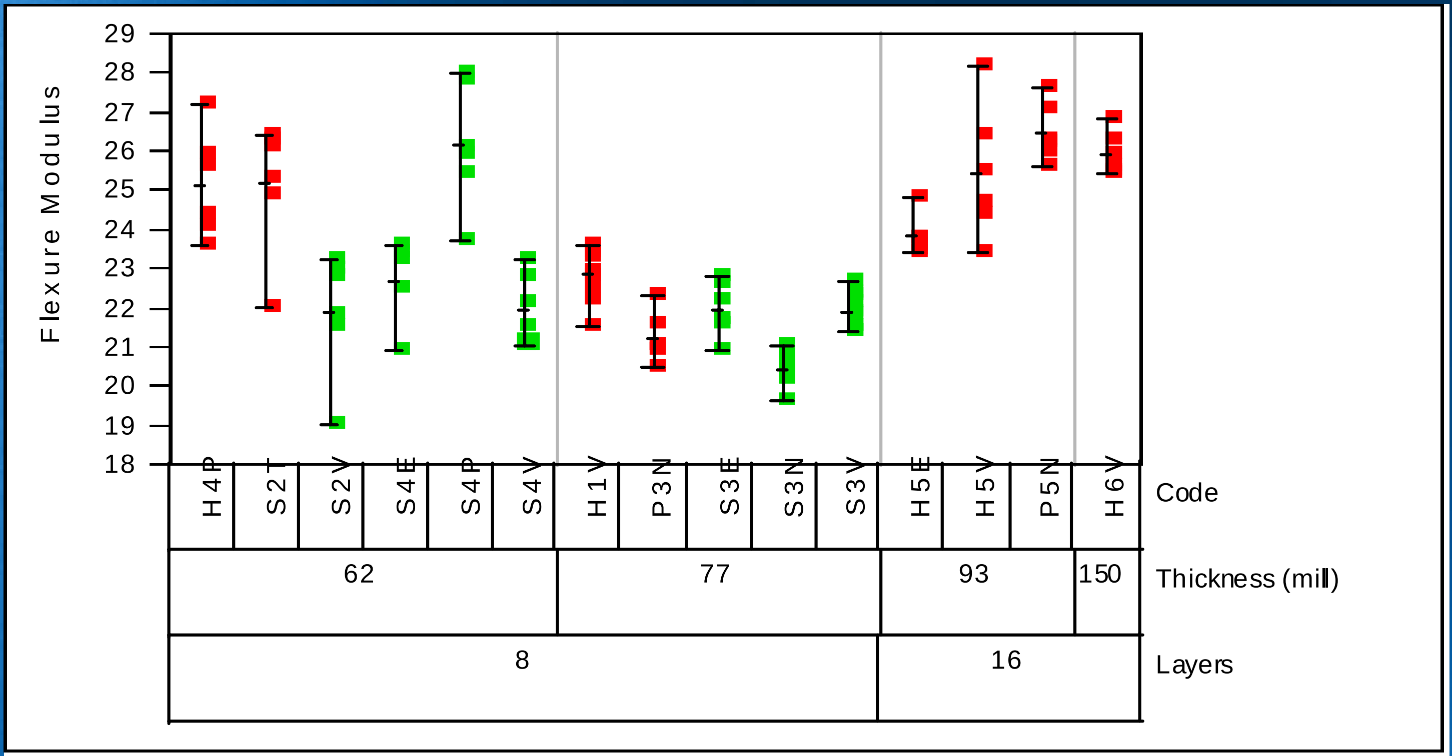
Flexure Data Across Several Variables



Flexure Modulus data – All MEB builds (red = high Tg FR4, green = low Tg FR4)

Conclusion:

- ➢ **Laminate Tg is a dominant factor, but not the only factor which affects flexural modulus**

Conclusions

- High Tg FR4 resin is more susceptible to Pad Crater failures than Low Tg FR4 resin materials with all other factors held constant.
- Flexure modulus, Tg, micro hardness, and Cold Ball Pull data follow consistent trends and appear to be sensitive metrologies to Pad Crater performance in the manufacturing environment.

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Industry Recommendations

- Drive the use of Low Tg FR4 for all product <0.070” thick for pad crater reliability improvements.
- Drive improvement in the pad crater mechanical performance of high Tg FR4 materials to increase mechanical margins for product where high Tg FR4 is required.

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Call to Action

We want you!

- Share or discuss similar pad crater experiences or material testing with Intel Corporation
- Join the Industry Pad Crater Work Group

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Q&A

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