iNEMI HFR-Free PCB Materials Team Project: An Investigation to Identify Technology Limitations Involved in Transitioning to HFR-Free PCB Materials

John Davignon, iNEMI Chair
Intel Corporation
Hillsboro, OR

Abstract:

In response to a growing concern within the Electronic Industry to the transition to Halogen-Free laminates (HFR-Free) within the Client Market space (Desktop and Notebook computers) iNEMI initiated a HFR-Free Leadership Workgroup to evaluate the readiness of the Industry to make this transition. The HFR-Free Leadership WG concluded that the electronic industry is ready for the transition and that the key electrical and thermo-mechanical properties of the new HFR-Free laminates can meet the required criteria. The HFR-Free Leadership WG verified that the laminate suppliers can meet the capacity demands for these new HFR-Free laminates and developed a "Test Suite Methodology" (TSM) that can facilitate the comparison and choice of the right laminate to replace brominated FR4 in the Client space.

Introduction:

In 2009 the Industry was transitioning towards environmentally responsible designs and evaluating the elimination of Brominated Flame Retardants (BFR) from their Printed Circuit Board (PCB). Figure 01 depicts the Brominated Flame Retardant (TBBPA) used in most halogenated FR4 laminates.

The European Union's Restriction on the use of certain Hazardous Substances (RoHS) Directive prohibits the use of polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) in nonexempt electronic equipment. These compounds, used as flame-retardants, have been shown to present unacceptable risks to human health and the environment. Although PBBs and PBDEs are typically not used in circuit board materials, stakeholders were beginning to urge the electronics industry to take a precautionary stance on the use of other non-regulated halogenated organic substances, such as brominated epoxies for circuit board applications. Although there was no legislation to ban all Brominated Flame Retardants (BFR), NGO pressure (Green Meter etc) continued to put pressure on the OEM/ODM's.

For this reason, many companies had set their own specific transition dates to move to HFR-Free technology. This had, however, created some confusion in the supply chain since these dates varied by company. To alleviate this issue, iNEMI initiated the HFR-Free Leadership Project with two workgroups, a Signal Integrity WG and a PCB Materials WG. The goal of the project was to identify the feasibility of the supply chain to support the OEM / ODM / EMS / Supplier transition to these new materials. This paper discussed the finding of the PCB Materials WG.

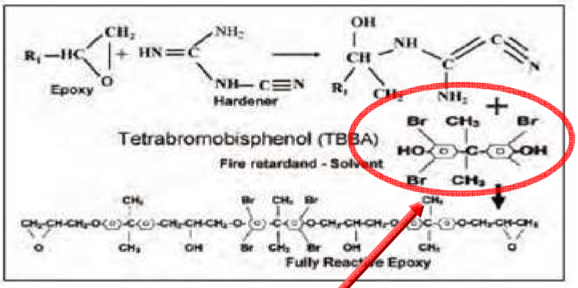


Figure 01: Tetrabromo bisphenol-A (TBBPA) the current BFR for most FR4 laminate epoxy systems

Some of the concerns voiced by the Industry included;

- A potential reduction in performance margin from the FR4 laminates being used was initially observed. High-speed bus designs could become problematic due to electrical properties of these HFR-Free materials.
- Multiple variations of flame retardants are being used and resulting in a wider fluctuation of supplier to supplier PCB electrical performance compared to FR4 designs
- Difficulty in understanding the new HFR-Free laminates properties and the ability to readily compare laminates and choose the right laminate to replace FR4 based on datasheets supplied by the laminate suppliers
- Lack of data on the HFR-Free thermo-mechanical reliability
- Unsure about the HFR-Free supply chain readiness and supply capability to support a HFR-Free Transition.

Consortia objectives and Goals:

1. Identify the technology readiness, supply chain capability, and reliability characteristics for HFR-Free alternatives to conventional printed circuit board materials and assemblies (electrical and mechanical properties)

2. Define technology limits for HFR-Free materials across all market segments with initial focus on client platforms (desktop, notebook) in the 2011 timeframe

3. Define and implement quantifiable data into the HFR-Free Laminate Suppliers Datasheets that will assist in material selection by users

4. Define a "Test Suite Methodology" which meets the quality and reliability requirements of the chosen market segments

5. Ensure the Industry laminate suppliers have the capability and capacity to support the industry HFR-Free laminate requirements

PCB Materials WG Strategy/Approach:

To accomplish these goals the PCB Materials WG was formed with 18 participating companies including laminate suppliers, test houses, ODM and OEMs. The PCB Materials WG project was divided into two phases. Phase #1 developed the Test Suite Methodology and Phase #2 applied the Test Suite Methodology to evaluate the HFR-Free laminates supplied by the PCB Materials WG members

The PCB Materials WG members developed the following strategy.

1. Define Initial Areas of Concern within the Electronics Industry
    - List material properties/areas of concern that need a modified range of values
2. Define Metrologies & Test Methods to quantify these material properties at laminate supplier
    - Review existing test methods from all Industries
    - Develop new test methods if needed
3. Design Test Structures and Test Suite Construction/Lay up to model a Notebook product
4. Test and Evaluate coupon design, metrology and performance
5. Build Test Vehicle's with the 9 chosen laminates, test and evaluate performance
6. Incorporate the Tech Suite Methodology into laminate datasheets
7. Work with Supply Chain to verify capacity of the laminate supply
8. Deliver the Test Suite and Test Methods to the Industry

The PCB Materials WG held a series of meetings in the US and Asia that collected over 27 concerns of the Global Industry to the transition to HFR-Free laminates. Table 01 lists these Areas of Concern. These concerns were analyzed, rated as to level of concern and compiled into subcategories that could be quantifiably validated by a test method.

Table 01: List of Global Electronic Industry Concerns

	Basic Materials Properties	*Rating*
1	Micro and macro hardness	🟨
2	Glass transition temperature (Tg)	🟦
3	Decomposition temperature (Td)	🟦
4	Moisture absorption	🟥
5	Fracture Toughness of Resin / Resin Cohesive Strength	🟦
6	Stiffness	🟨
7	Dk & Df	🟥
8	Coefficient of thermal expansion (z-axis and x-, y-axes)	🟥
9	Flexural strength	🟨
	Thermo-Mechanical Performance	
10	Pad Cratering (brittle fracture)	🟥
11	Shock & Vibe and Drop test data	🟦
12	Transient Bend	🟦
13	Copper Pad Adhesion (CBP/Hot Pin Pull/ Shear or Tensile)	🟦
14	CAF resistance	🟥
15	Long term life prediction, such as IST or thermal shock test.	🟥
16	Plastic and elastic deformation characteristics	🟨
17	Co-Planarity Warpage characteristics	🟦
18	Delamination characteristics under stress conditions	🟥
	Process/Manufacturing	
19	PCB fabrication process, drill wear, lamination & desmear	🟦
20	Punchability/Scoring/Breakoff Performance	🟨
	Assembly Process	
21	Lead Free Reflow Test	🟥
22	Rework (Pad Peeling)	🟥
	Other Concerns	
23	Resin system dependency/hardening/curing agents	🟨
24	Affect of Fillers	🟦
25	UL Fire ratings (V0-V1)	🟥
26	Electrical Properties (UL CTI rating)	🟨
27	MOT Maximum Operating Temperature	🟦

Low	🟨
Medium	🟦
High	🟥

27 Areas of Concern were defined and ranked according to Risk or Priority of the Concern by a broad section of the PCB Industry

Phase #1: Test Suite Methodology Development

In order to accomplish the Consortia's Goals #3 & #4 the PCB Materials WG developed the "Test Suite Methodology" which facilitates the comparison of material properties and performance for a specific market sector.

- Chose a single test method that relates to one or more industry concerns and can be quantified
- Develop the test structures/coupons needed to complete the test method
- Develop a representative test board construction for the market segment under evaluation (Notebook/Desktop)
- Complete testing at several sites (2-3) and combine data

Test Methods

The PCB Materials WG narrowed the concerns and test methods down to 14 test methods. These Test Methods were modified when required to precisely define the equipment, test structure, pre conditioning and test methodology to assure that each test site results were comparable.

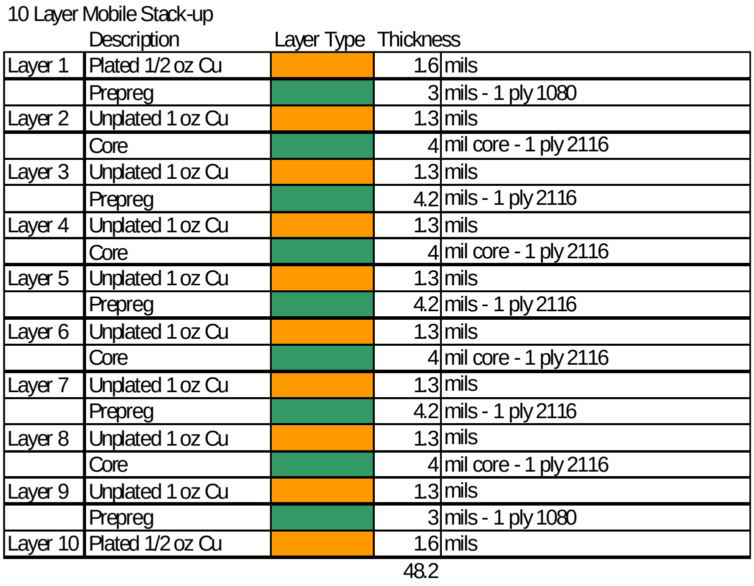
The PCB Material WG did not address some of the concerns that were the responsibility of other industry organizations, such as Underwriters Laboratory (UL) or basic material interactions with PCB fabrication. Table 02 describes the final set of Test Methods adopted by the Materials WG.

Table 02: Final set of Test Methods used in the evaluation

Test Methods Under Evaluation		
Glass Transition Temperature (Tg)		**Stiffness/Flexural Strength**
Decomposition Temperature (Td)		**Rework (Pad Peeling)**
Coefficient of Thermal Expansion (x,y,z)		**Interconnect Stress Test (IST)**
Moisture absorption		**Conductive Anodic Filament (CAF)**
Pad Adhesion (CBP/Hot Pin Pull)		**Lead Free Reflow Test: Delamination**
Permittivity (Dk)		**Charpy Impact Test**
Total Loss (Df)		**Simulated Reflow Test**

Test Vehicle

It was a major focus of the PCB Materials WG that each concern/test method could give a quantifiable value that could be compared. To accomplish this task the PCB Materials WG developed a test vehicle construction that modeled a 10 layer Notebook construction and developed or modified test coupon designs to match this construction. This 10 layer construction, the specific test method and modified coupons were used for all laminate evaluations so that direct comparisons were possible. The glass styles and copper weights were designated and the construction is shown in Figure 02.



10 Layer Mobile Stack-up

	Description	Layer Type	Thickness	
Layer 1	Plated 1/2 oz Cu	🟧	1.6	mils
	Prepreg	🟩	3	mils - 1 ply 1080
Layer 2	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 3	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	4.2	mils - 1 ply 2116
Layer 4	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 5	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	4.2	mils - 1 ply 2116
Layer 6	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 7	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	4.2	mils - 1 ply 2116
Layer 8	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 9	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	3	mils - 1 ply 1080
Layer 10	Plated 1/2 oz Cu	🟧	1.6	mils
			48.2	

Figure 02: Test Vehicle Construction for the TSM (10 layer, .048")

Testing and test site

Although a full Gage R&R would have been desirable for each test method, due to time constraints, the PCB Materials WG decided to have 3 test sites if possible for each test method. This would allow a snapshot of the reproducibility and repeatability of the test method. The three sites were important for analyzing the precision of the test methods. It became apparent that even with the same test method and test structures some of the test methods gave a wide range of values. Detailing all pre conditioning and equipment set up is critical to success. As, an example the Cold Ball Pull methodology is very dependent on the prior Ball Attach Method. The PCB Materials WG even found that the same test method performed on different equipment could produce substantial differences.

Set Technology Envelope/Test Methods for Laminates

Although the Technology Envelope that relates to reliability requirements and use conditions is different for each OEM and product line, the use of the TSM allows each laminate user to give quantifiable feedback and direction to the laminate supplier as to which properties/responses are the best for their products. This guidance will help the laminate suppliers to understand which properties to modify without degrading other important properties. This is a large improvement over the existing system that does not have this set of checks and balances, or ability to quantify improvements without costly test vehicles data.

Incorporate Tech Envelope into laminate datasheet.

One of the major goals of the project was to get quantifiable and correlateable data into the laminate datasheets so PCB designers, purchasing agents, and others who have to make laminate decisions could easily compare properties and responses and determine the best laminate choice for their products without extensive testing of each laminate. To this fact, each of the PCB Materials WG laminate suppliers has committed to supply the iNEMI "Test Suite Methodology" data upon request.

Verify Supply Chain Capability and Capacity of HFR-Free Laminate

One of the major drivers for the PCB Materials WG was the concern by the ODM/OEM's that the laminate suppliers were not and could not ramp these new HFR-Free laminates for a full transition. The PCB Material WG believes that partly because of the emphasis of this consortia and the interaction between the customer and suppliers, the laminate suppliers in the PCB Materials WG have doubled their production and shipments in the past 3 years. Table 03 shows the growth of HFR-Free laminates shipped by the consortia laminate suppliers members.

Table 03: Growth of HFR-Free laminate shipped 2008-2011

Total % of HFR-Free/FR4 Laminates shipped				
Year	2008	2009	2010	2011 (Q1-3)
HFR-Free shipped as a % of Total Laminates MM²	8%	10%	15%	17%

Phase #2: Test Suite Methodology Results for HFR-Free vs. Brominated FR4 baseline

The second phase of the project evaluated the Test Suite Methodology using 6 HFR-Free laminates with 3 brominated FR4 laminates as the baseline. Figures 3-14 show the conclusions of the laminate testing and test method analysis.

Glass Transition Temperature (Tg)

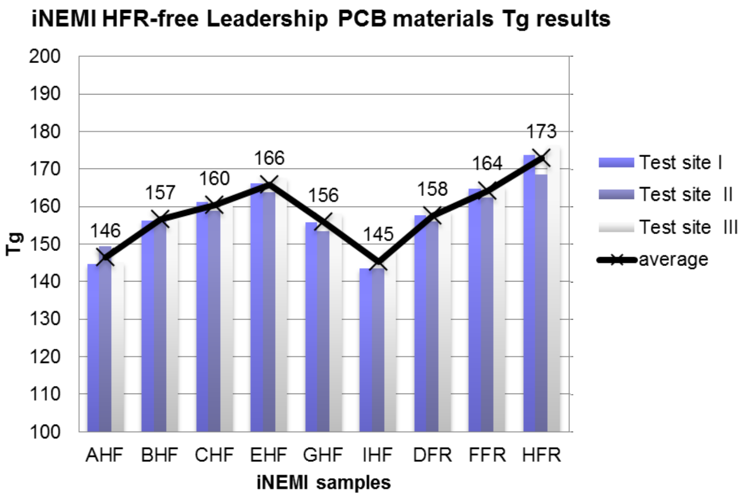


Figure 03: Glass Transition Temperature (Tg)

Conclusions

- The Tg of the laminates was within the acceptable range for the Client space (mid Tg). Tg is market sector dependent and there is no good/bad specification or value
- There is no indication that Tg is directly dependent on the flame retardant use in the polymer. Usually the presence of flame retardants (Halogenated or Non-halogenated) is not involved with the reactive functional groups for the polymer chain cross-linkage which is the important factor for Tg of the resin system.
- Therefore, Tg does not depend on whether the polymer is halogenated or not.
- The variation/range is equal for both BFR and HFR-Free laminates

Decomposition Temperature (Td)

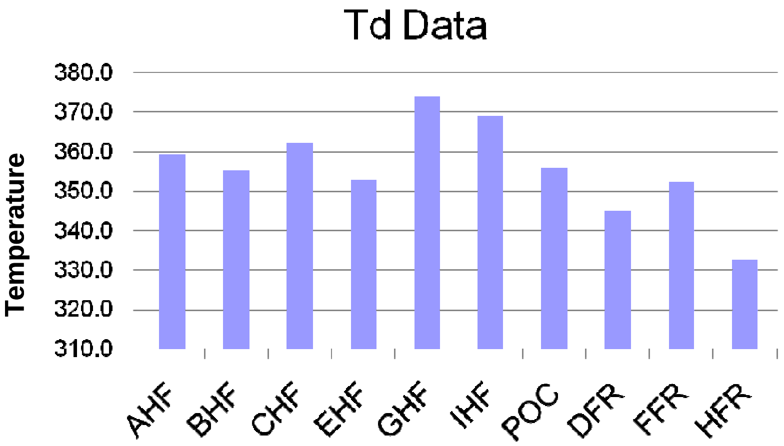
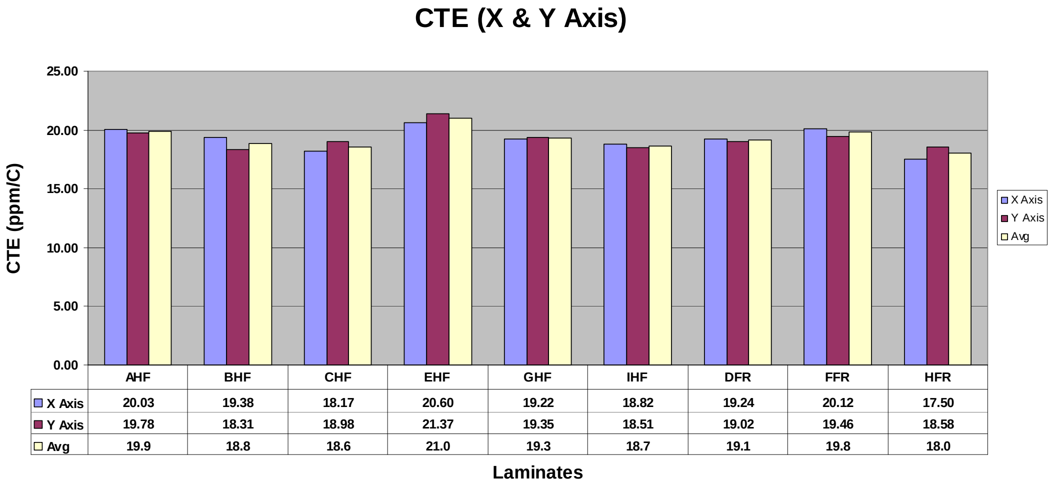


Figure 04: Decomposition Temperature (Td)

Conclusions

- The Td values of HFR-Free material are significantly higher than those of the halogenated laminates, reflecting the differences in chemistry between the two material classes.
- HFR-Free materials are thermally more stable than the halogenated.
- The range of variation in Td is similar to that among the halogenated materials

Coefficient of Thermal Expansion in X & Y Axis (CTE)



	AHF	BHF	CHF	EHF	GHF	IHF	DFR	FFR	HFR
X Axis	20.03	19.38	18.17	20.60	19.22	18.82	19.24	20.12	17.50
Y Axis	19.78	18.31	18.98	21.37	19.35	18.51	19.02	19.46	18.58
Avg	19.9	18.8	18.6	21.0	19.3	18.7	19.1	19.8	18.0

Figure 05: Coefficient of Thermal Expansion in X & Y Axis (CTE)

Conclusions:

- Average CTE measurements for HFR-Free materials are not significantly different from FR4
- CTE is most probably driven by the glass style used rather than resin class

Coefficient of Thermal Expansion in the Z-Axis (CTE Z-Axis)

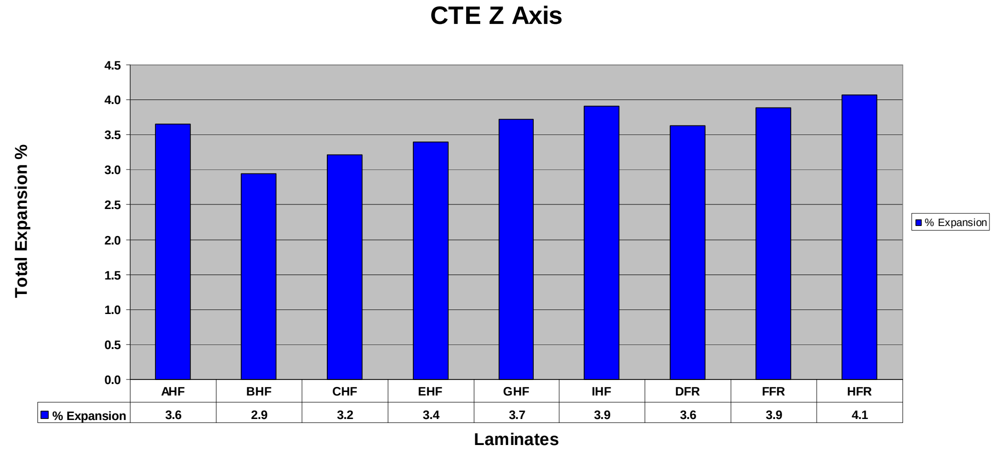
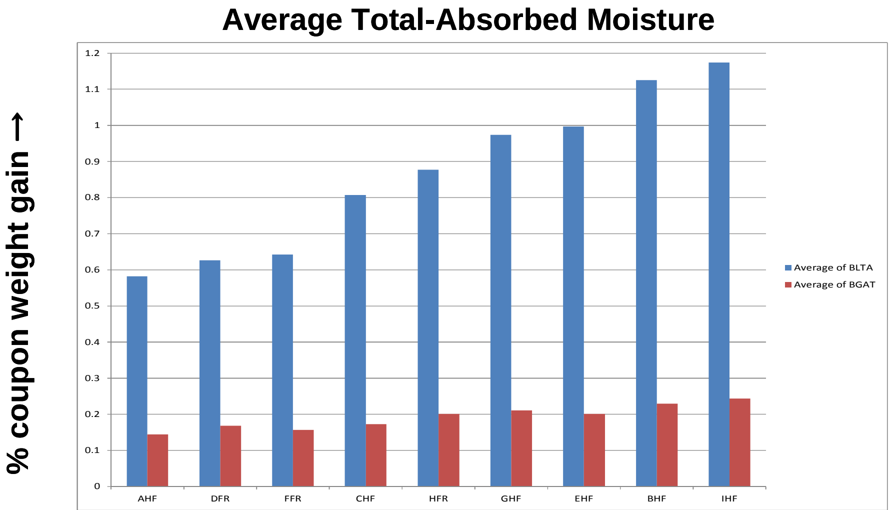


Figure 06: Coefficient of Thermal Expansion in the Z-Axis (CTE Z-Axis)

Conclusions:

- Average Z-axis total expansion is approximately 10% less for HFR materials when compared with brominated FR4.
- This lower CTE is attributed to the higher volume & types of fillers in HFR-Free than FR4
- The overall average Z-axis HFR-Free CTE <Tg is 62 ppm/oC compared to 73 for FR4
- The overall average Z-axis HFR-Free CTE >Tg is 253 ppm/oC compared to 284 for FR4

Moisture Absorption:



	Bare Lam Total	Bare Lam Bonded	BGA Total	BGA Bonded
Max %	1.403	0.221	0.288	0.111
Min%	0.571	0.023	0.134	0.015

Figure 07: Moisture Absorption:

Conclusions:

- HFR-Free has higher moisture absorption than FR4. Testing did not go to saturation
- Total absorbed moisture between HFR-Free & FR4 is significantly different
- Bonded moisture between bare HFR-Free & FR4 laminates is significantly different

Cold ball Pull (CBP) for Pad Adhesion & 6X Lead Free Rework Cycles

Comparisons for all pairs using Tukey-Kramer HSD		
Level	Mean	Std-Dev
DFR	**1412**	**89**
CHF	**1239**	**118**
IHF	**1184**	**99**
HFR	**1142**	**76**
GHF	**1129**	**55**
FFR	**1050**	**105**
BHF	**1048**	**84**
AHF	**929**	**90**
EHF	**900**	**117**

Level	Pull force Delta (PA-RWK)
DFR	**118**
CHF	**136**
IHF	**167**
HFR	**28**
GHF	**71**
FFR	**34**
BHF	**2**
AHF	**49**
EHF	**92**

Comparisons for all pairs using Tukey-Kramer HSD		
Level	Mean	Std-Dev
DFR	**1293**	**128**
HFR	**1170**	**73**
CHF	**1103**	**86**
GHF	**1058**	**100**
BHF	**1051**	**137**
IHF	**1017**	**111**
FFR	**1016**	**117**
AHF	**880**	**65**
EHF	**808**	**96**

Figure 08: Cold ball Pull (CBP) for Pad Adhesion & 6X Lead Free Rework Cycles:

Conclusions:

- The Cold Ball Pull Method (CBP) does differentiate materials but not material class. i.e. HFR-Free vs. FR4.
- Multiple reflow can slightly degrade the CBP force but does not significantly alter the ranking of the materials.
- Cold Ball Pull method is very dependent upon the Ball Attach method and technique
- The CBP data was normalized to a 16 mil pad size. Controlling pad size for testing or normalizing data to a single pad size is critical for comparison

Permittivity (Dk) and Loss Tangent (Df)

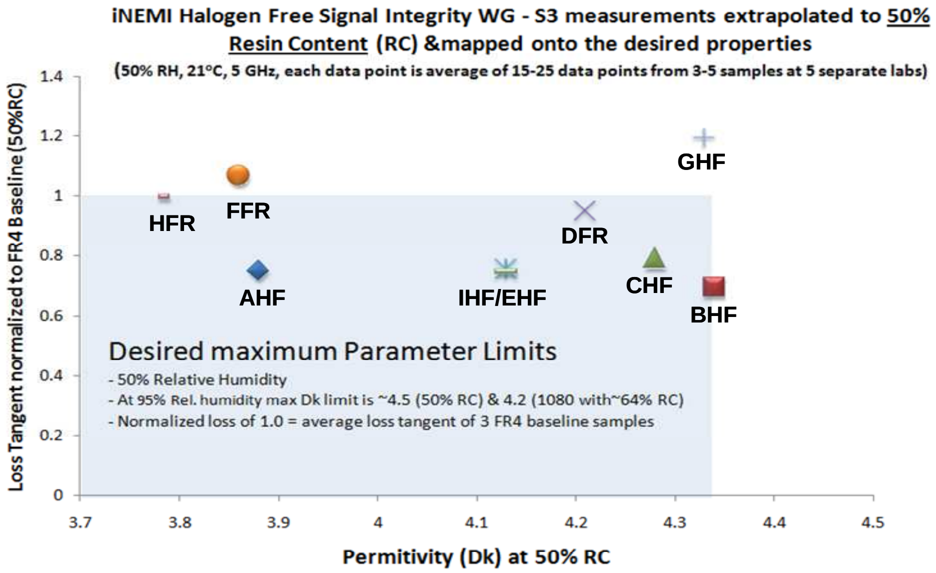
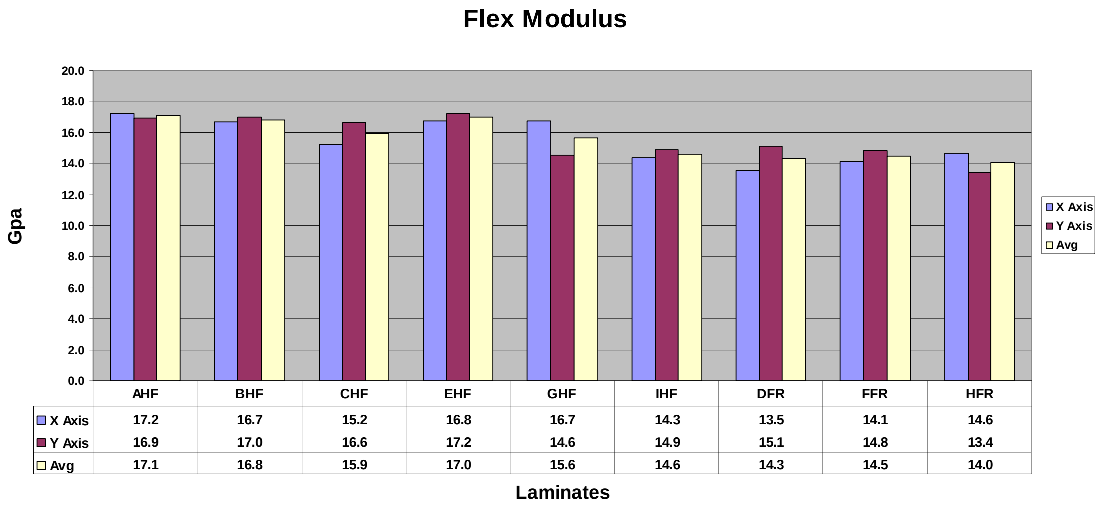


Figure 09: Permittivity (Dk) and Loss Tangent (Df):

Conclusions:

- HFR-Free Laminates today tend have increased permittivity (Dk) over FR4
- HFR-Free Laminates today tend have decreased loss (Df) over FR4
- 2011 Client Platforms simulation and preliminary validation suggests the defined envelope will meet the platform requirements with 5 out of 6 HFR-Free laminates evaluated

Flex Modulus



	AHF	BHF	CHF	EHF	GHF	IHF	DFR	FFR	HFR
X Axis	17.2	16.7	15.2	16.8	16.7	14.3	13.5	14.1	14.6
Y Axis	16.9	17.0	16.6	17.2	14.6	14.9	15.1	14.8	13.4
Avg	17.1	16.8	15.9	17.0	15.6	14.6	14.3	14.5	14.0

Figure 10: Flex Modulus

<u>Conclusions:</u>

- HFR-Free Flexural modulus values are statistically different and slightly higher than the FR4
- The higher modulus of the HFR-Free materials is attributed to the higher loading of in-organic fillers in the HFR-Free materials.
- Flexural modulus values doesn't significantly differ in X & Y directions

Charpy Impact Test

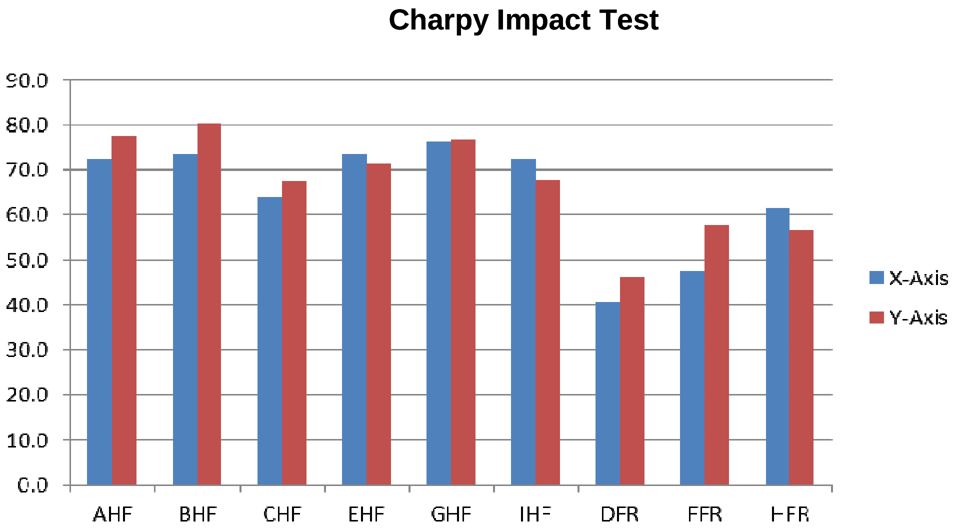


Figure 11: Charpy Impact Test

<u>Conclusions:</u>

- Overall, HFR-Free materials exhibit higher impact strength than FR4 material
- The higher impact strength of the HFR-Free materials is attributed to the higher loading of in-organic fillers in the HFR-Free materials.
- The test method appears to be able to differentiate between materials
- Additional work needs to be done to determine the applicability of Charpy test results to fracture events in the boards as a result of performance testing (i.e. shock, drop, bend, etc.)

Interconnect Stress Test (IST)

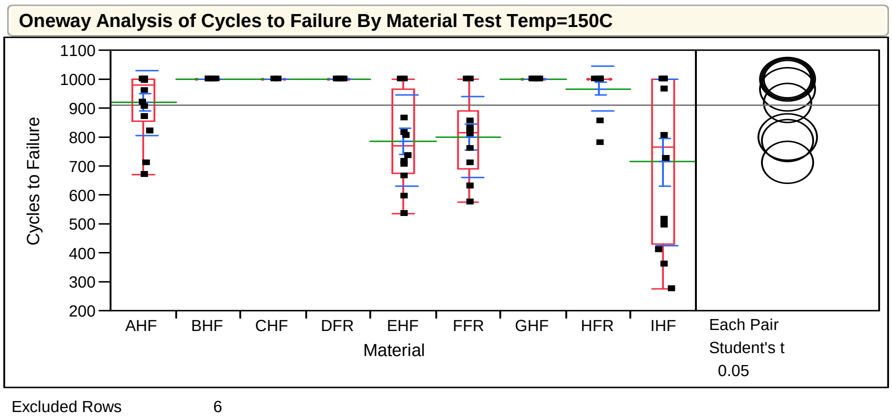


Figure 12: Interconnect Stress Test (IST):

Conclusions:

- All materials showed acceptable via reliability performance for Client type product designs (>500 cycle average)
- Test temp of 150C unable to adequately differentiate between materials after 1000 cycles of test
- Test vehicle construction is too thin .048" current aspect ratio not appropriate to elicit failure at 1000 cycles, would need to increase cycles to failure that the PCB Materials WG thought was not reasonable
- Expected failure modes seen in all materials with failures (barrel cracks)

Conductive Anodic Filament (CAF)

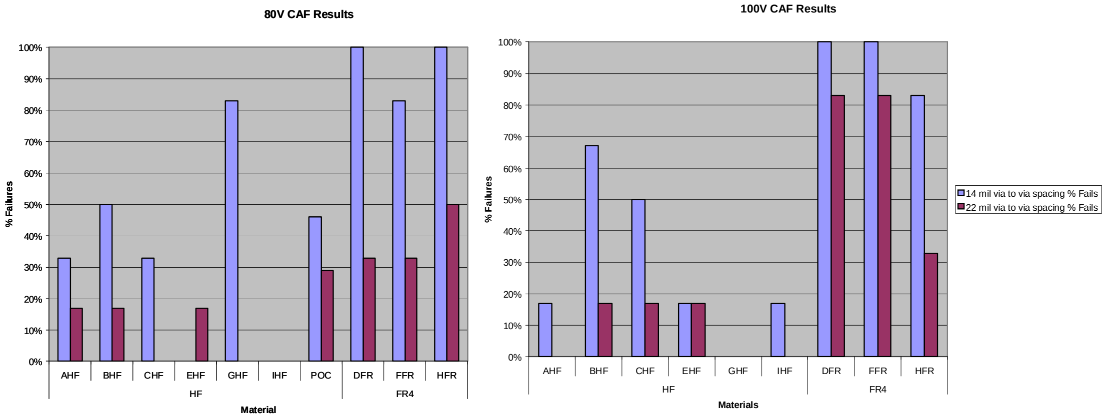


Figure 13: Conductive Anodic Filament (CAF)

Conclusions:

- HFR-Free materials outperformed their brominated FR4 counterparts for both bias levels (80 vs. 100 volts).
- The 22 mil via to via spacing outperformed the 14 mil via to via spacing as expected.
- The 80V 14 mil via to via spacing data for GHF appears to be an outlier. NOTE: No failures seen for 100 V or 22 mil spacing
- Graph is showing the percentage of failures before 1000 hours

Plated Hole Thickness and Wicking of Test Coupons

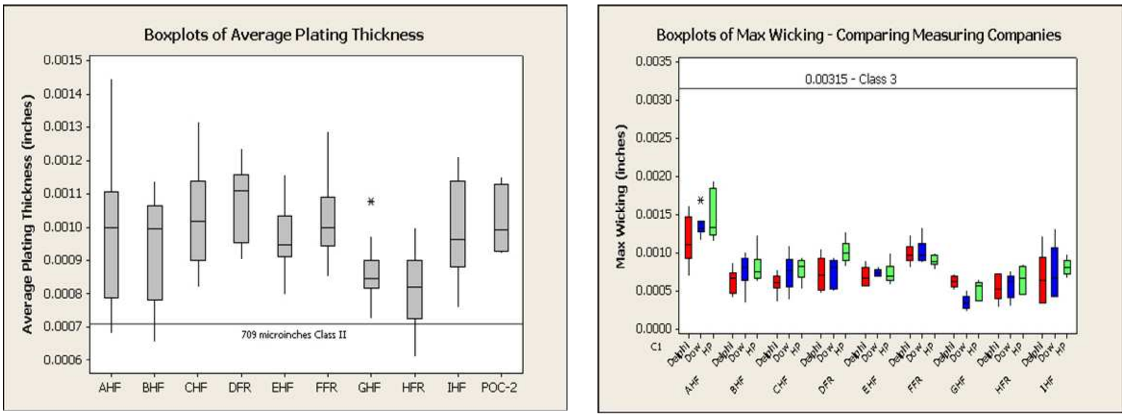


Figure 14: Plated Thru Hole Thickness and Wicking of Test Coupons

<u>Conclusions:</u>

- Hole Wall Pull Away was minimal after six Pb-free reflow exposures
- The data supports the validity of the coupons for the IST and CAF testing
- AHF, BHF and HFR had a few outliers for plating thickness
- All suppliers passed the IPC Class 3 copper wicking specification

Summary:

The iNEMI HFR-Free Leadership WG believes that HFR-Free Laminates are ready for the Client space transition

<u>Reliability:</u>

- Due in part from the emphasis of this consortia, the laminate suppliers have modified their initial HFR-Free offerings and the laminates in the study now have properties that equal or exceed the BFR version. The use of the TSM will continue to allow for quantifiable discussion on desired properties with quantifiable values/targets while providing baseline data to assure that other properties are not detrimentally affected by any other property changes.

<u>Capacity:</u>

- The growth of HFR-Free laminates has increased over the past several years with PCB Materials WG laminate members doubling (2X) the amount of shipped laminate. The laminate suppliers now have the knowledge and ability to further increase the HFR-Free laminate supply when required.

<u>Commitment:</u>

- Each Laminate Supplier in the PCB Materials WG has committed to supplying the TSM data for HFR-Free Laminates upon request. Although more work is required to fine tune the TSM system, it is a big step for the industry in providing a dataset that can be directly compared by designers and others needing laminate data information.

<u>Test Suite Methodology</u>:

- The Test Suite Methodology (TSM) has been successful in allowing direct comparison of desired laminate properties by providing quantifiable values that are directly correlateable

- The TSM has added none traditional performance data to the Laminate suppliers data sheets. Although the PCB Materials WG has tried to keep the PCB fabrication and laminate property interaction to a minimum, these new systems do provide insight into some of the industry's present problems, such as Pad Cratering and resin/glass strength.

- Several of the new Test Methods will require more evaluation before full acceptance by the Industry, for example the Charpy Impact test method.

- Some TSM structures and the stack-up/construction would have to change to accommodate higher layer count/thicker PCB's for other market sectors. Some of the test structures, such as the IST test structure or temperature needs to be modified in light of it's applicability to the thin (.048") stack up/construction

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References:

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An Investigation to Identify Technology Limitations Involved in Transitioning to HFR-Free PCB Materials

iNEMI HFR-Free Leadership Program

Program Manager: Stephen Tisdale, Intel

HFR-Free PCB Materials

Chair: John Davignon, Intel

Presented at APEX 2012, Feb 29, 2012

Agenda

- *Introduction/Objectives*
- *Strategy/Industry Concerns*
- *Test Suite Methodology*
- *Test Method Results (9 laminates)*
- *Suppliers Capacity*
- *Summary /Conclusions*

Introduction

The Industry is transitioning towards environmentally responsible designs and the elimination of Halogenated Flame Retardants (HFR-Free) from their Printed Circuit Board (PCB)

Although there is no pending legislation to ban all Brominated Flame Retardants, NGO pressure continues (Green Meter etc)

The iNEMI HFR-Free Leadership WG has spent the last 2 years investigating Low Halogen laminates for the Client space.

This presentation outlines the results of the investigation for 6 HFR-Free and 3 Halogenated (BFR) laminates.

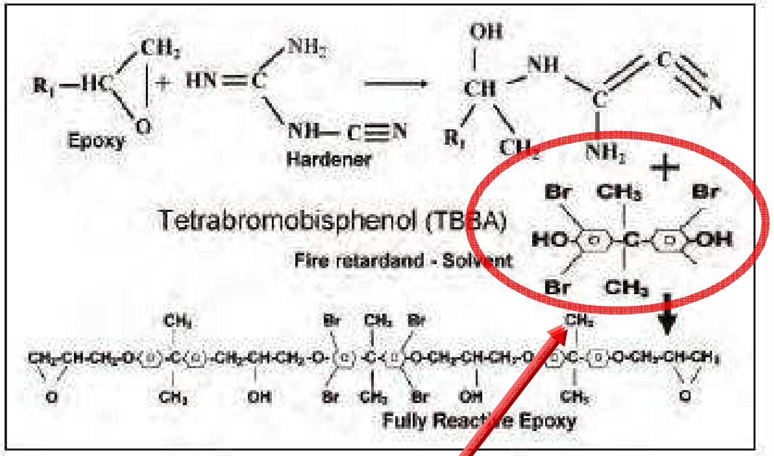
Consortium Objective & Goals

Identify the technology readiness, supply chain capability, and reliability characteristics for "HFR-Free" alternatives to conventional printed circuit board materials and assemblies (electrical and mechanical properties)

- **Define technology limits for HFR-Free materials across all market segments with initial focus on client platforms (desktop, notebook) in 2011 timeframe**
- **Define and implement quantifiable data into the HFR-Free Laminate Suppliers Datasheets that will assist in material selection by users**
- **Define a "Test Suite Methodology" which meets the quality and reliability requirements of the chosen market segments**
- **Ensure the Industry Laminate Suppliers have the capability and capacity to support the industry HFR-Free laminate requirements**

HFR-Free - What Changed in the Transition?

Low-Halogen changes the flame retardant used for epoxy laminate (FR4) materials



Phosphorous Compound	Nitrogen Compound	Inorganic Fillers (metal hydroxide)
Formation of carbonized layer to cover surface	Generating incombustible gas	Releasing water at high temperature
Additive type: Phosphorous compound Reactive type: Phosphate	Reactive type	Additive

Tetrabromo bisphenol-A (TBBPA) is the current halogenated flame retardant for all laminate epoxy systems

New non-Halogenated flame retardants are varied in both material types and percentages

HFR-Free PCB laminates contain reactive and additive components

iNEMI HFR Leadership PCB Materials WG

iNEMI HFR-Free PCB Materials WG Strategy

1. Define Initial Areas of Concern (27 areas generated)
2. Define Metrologies & Test Methods to quantify these Material Properties at Laminate Supplier
3. Design Test Structures and Test Suite Construction/Lay up
4. Test and Evaluate Coupon design, metrology and performance (POC)
5. Build TV's with the 9 chosen laminates, test and evaluate performance
6. Incorporate "Tech Suite Methodology" into laminate datasheets
7. Work with Supply Chain to verify Capacity of Laminate Supply
8. Deliver the Test Suite and Test Methods to the Industry

PCB Materials Industry 27 Areas of Concerns

	Basic Materials Properties	***Rating***
1	Micro and macro hardness	🟨
2	Glass transition temperature (Tg)	🟦
3	Decomposition temperature (Td)	🟦
4	Moisture absorption	🟥
5	Fracture Toughness of Resin / Resin Cohesive Strength	🟦
6	Stiffness	🟨
7	Dk & Df	🟥
8	Coefficient of thermal expansion (z-axis and x-, y-axes)	🟥
9	Flexural strength	🟨
	Thermo-Mechanical Performance	
10	Pad Cratering (brittle fracture)	🟥
11	Shock & Vibe and Drop test data	🟦
12	Transient Bend	🟦
13	Copper Pad Adhesion (CBP/Hot Pin Pull/ Shear or Tensile)	🟦
14	CAF resistance	🟥
15	Long term life prediction, such as IST or thermal shock test.	🟥
16	Plastic and elastic deformation characteristics	🟨
17	Co-Planarity Warpage characteristics	🟦
18	Delamination characteristics under stress conditions	🟥
	Process/Manufacturing	
19	PCB fabrication process, drill wear, lamination & desmear	🟦
20	Punchability/Scoring/Breakoff Performance	🟨
	Assembly Process	
21	Lead Free Reflow Test	🟥
22	Rework (Pad Peeling)	🟥
	Other Concerns	
23	Resin system dependency/hardening/curing agents	🟨
24	Affect of Fillers	🟦
25	UL Fire ratings (V0-V1)	🟥
26	Electrical Properties (UL CTI rating)	🟨
27	MOT Maximum Operating Temperature	🟦

Low	🟨
Medium	🟦
High	🟥

27 Areas of Concern were defined and ranked according to Risk and / or Priority of the Concern by a broad section of the PCB Industry

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iNEMI Test Suite Methodology (TSM)

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Test Suite Methodology

- A single test method was chosen that related to one or more industry concerns and could give quantifiable values
- The test structures/coupons needed to complete the test method were designed
- A representative test board construction for the market segment under evaluation was developed (Notebook/Desktop)
- Testing was completed at several sites (2-3) and the data was combined

Test Methods Under Evaluation

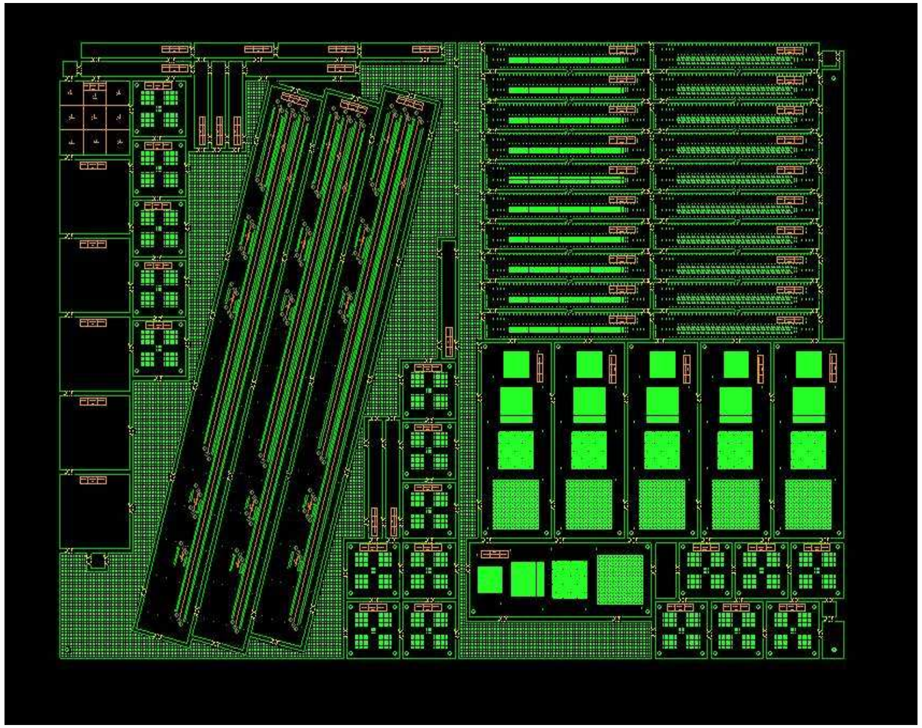
Glass Transition Temperature (Tg)		Stiffness/Flexural Strength
Decomposition Temperature (Td)		Rework (Pad Peeling)
Coefficient of Thermal Expansion (x,y,z)		Interconnect Stress Test (IST)
Moisture absorption		Conductive Anodic Filament (CAF)
Pad Adhesion (CBP/Hot Pin Pull)		Lead Free Reflow Test: Delamination
Permittivity (Dk)		Charpy Impact Test
Total Loss (Df)		Simulated Reflow Test

Test Suite Methodology

Stack up and test board layout

10 Layer Mobile Stack-up

	Description	Layer Type	Thickness	
Layer 1	Plated 1/2 oz Cu	🟧	1.6	mils
	Prepreg	🟩	3	mils - 1 ply 1080
Layer 2	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 3	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	4.2	mils - 1 ply 2116
Layer 4	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 5	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	4.2	mils - 1 ply 2116
Layer 6	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 7	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	4.2	mils - 1 ply 2116
Layer 8	Unplated 1 oz Cu	🟧	1.3	mils
	Core	🟩	4	mil core - 1 ply 2116
Layer 9	Unplated 1 oz Cu	🟧	1.3	mils
	Prepreg	🟩	3	mils - 1 ply 1080
Layer 10	Plated 1/2 oz Cu	🟧	1.6	mils
			48.2	



Test Methods Results for 9 Laminates
6 HFR-Free
3 BFR Baseline

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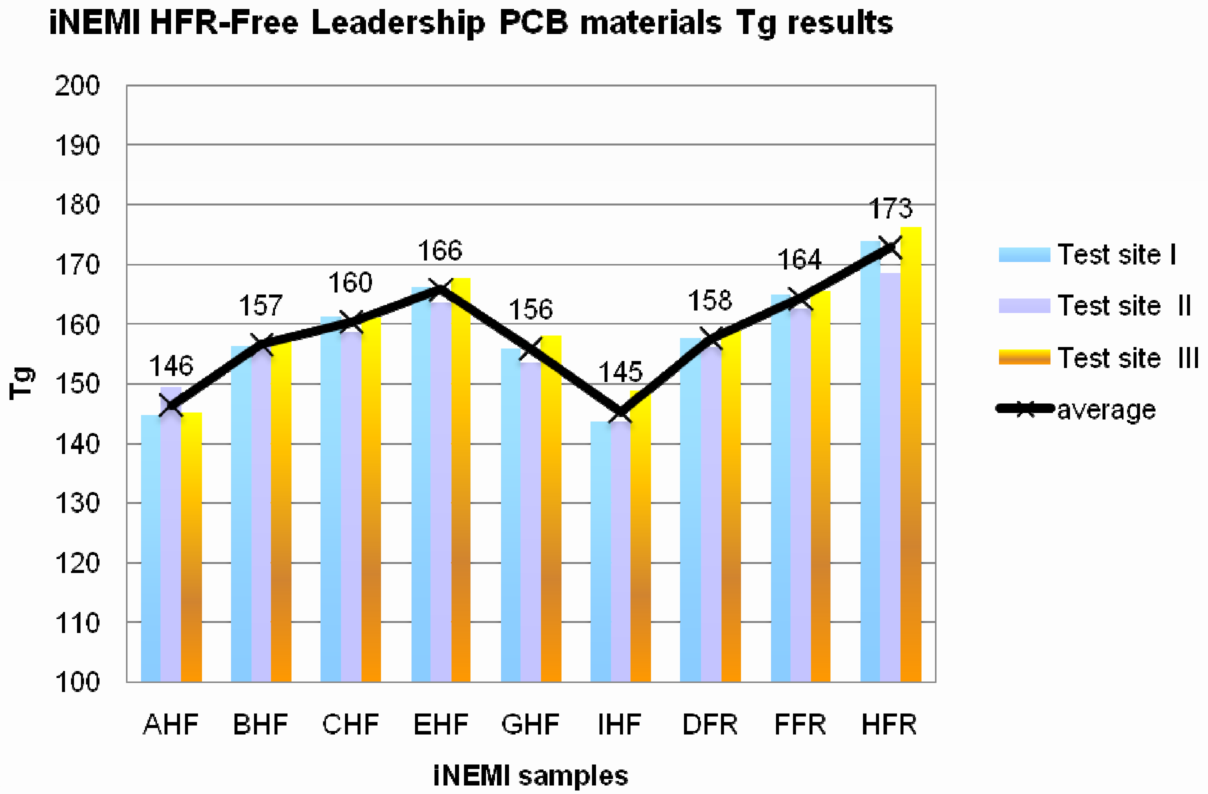
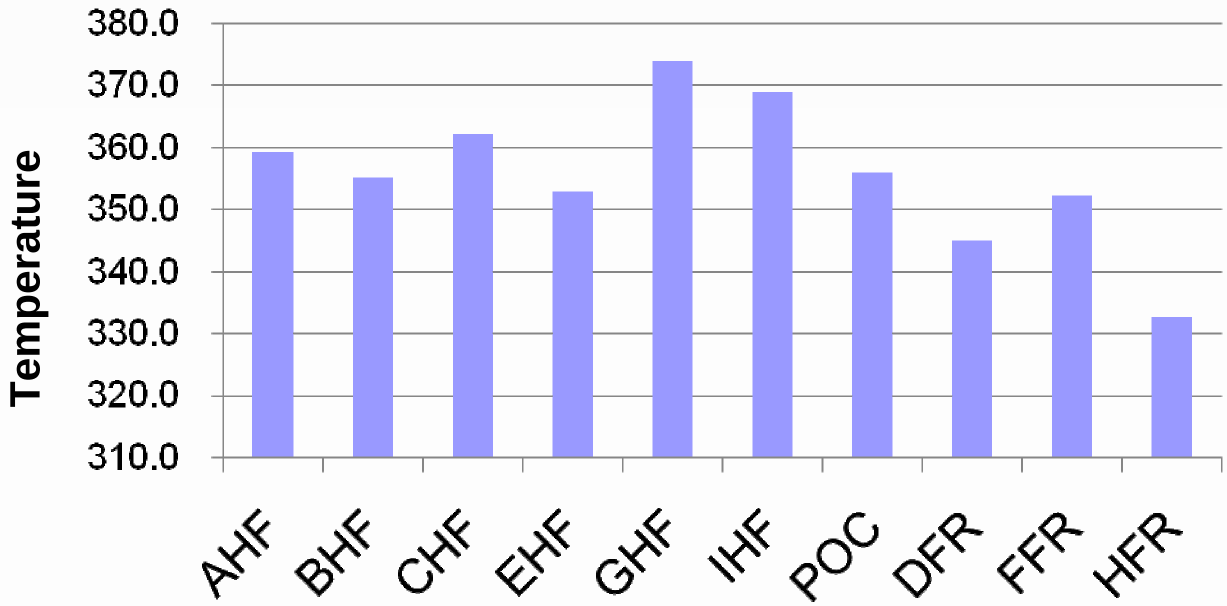


Conclusions

- **The Tg of the laminates were within the acceptable range for the Client space (mid Tg). Tg is market sector dependent**
- **There is no indication that Tg is directly dependent on the Flame Retardant use in the polymer.**

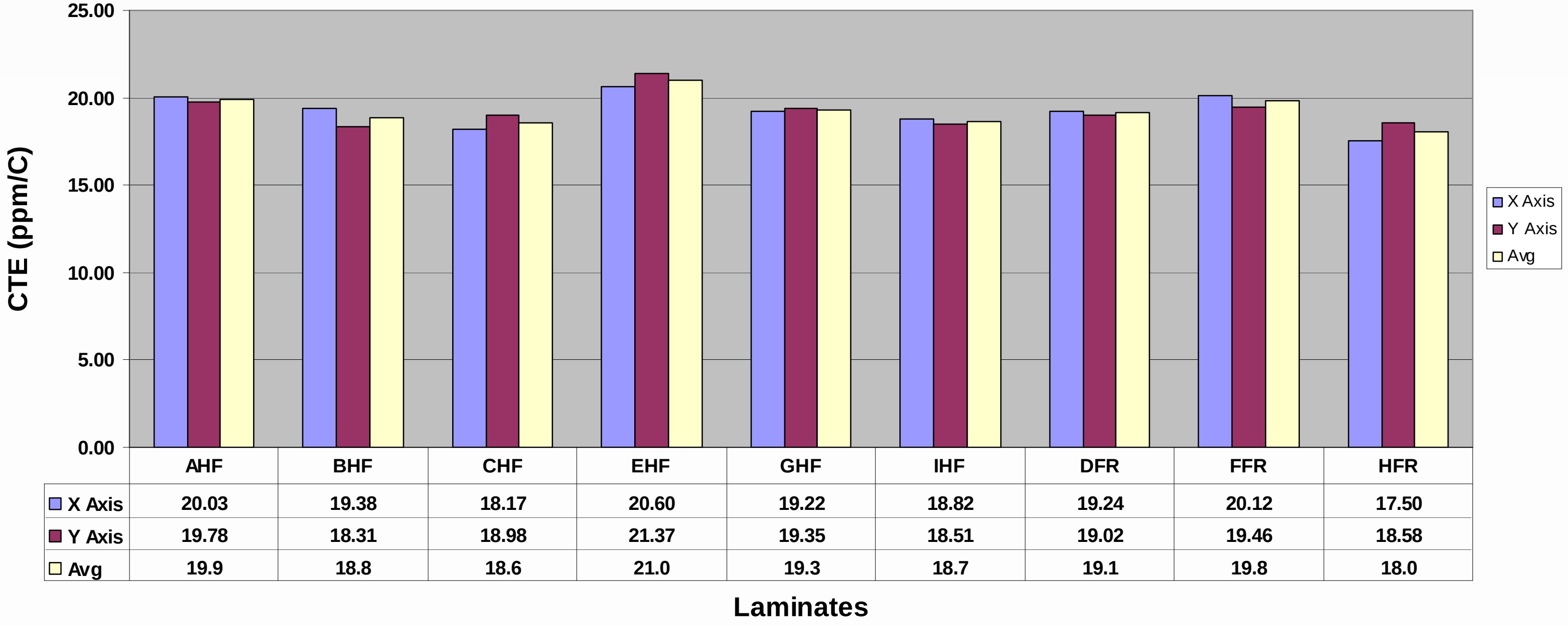
Td Data



Conclusions

- The Td values of HFR-Free material are significantly higher than those of the Halogenated laminates, reflecting the differences in chemistry between the two material classes
- HFR-Free materials are thermally more stable than the Halogenated materials

CTE (X & Y Axis)

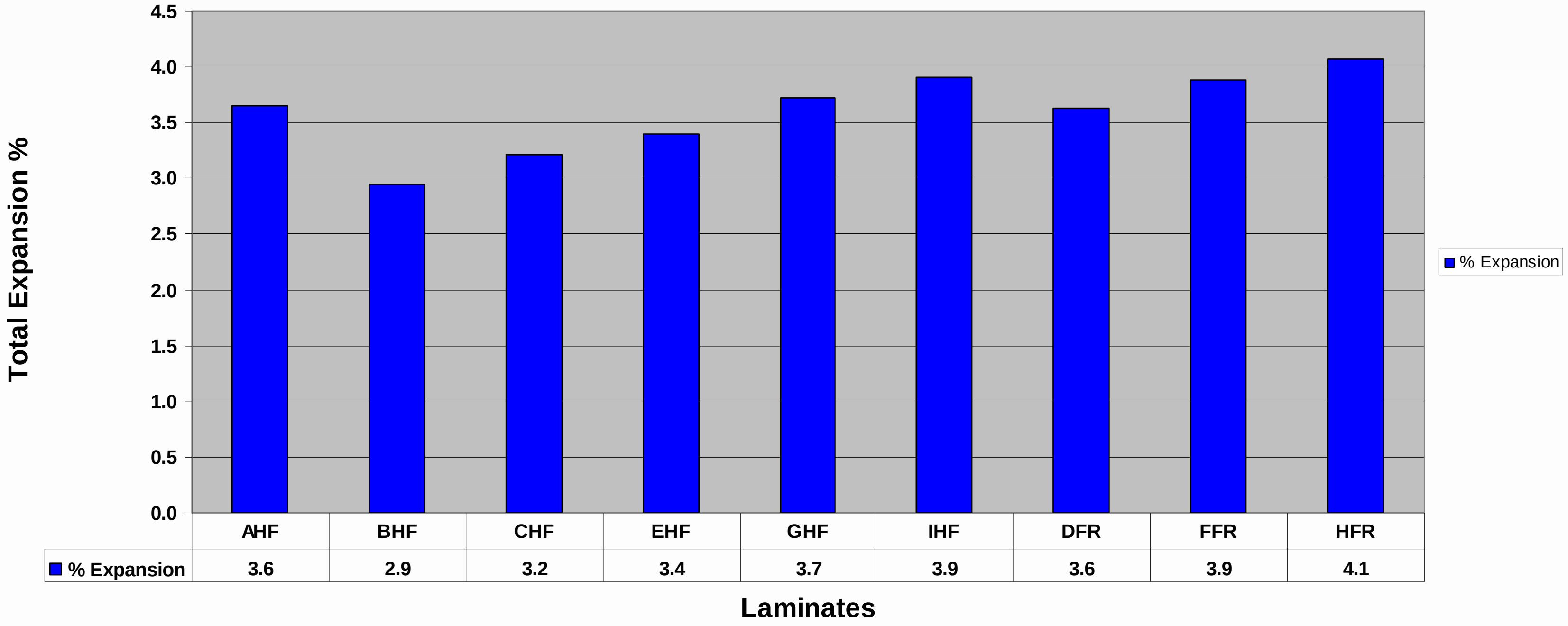


	AHF	BHF	CHF	EHF	GHF	IHF	DFR	FFR	HFR
X Axis	20.03	19.38	18.17	20.60	19.22	18.82	19.24	20.12	17.50
Y Axis	19.78	18.31	18.98	21.37	19.35	18.51	19.02	19.46	18.58
Avg	19.9	18.8	18.6	21.0	19.3	18.7	19.1	19.8	18.0

Conclusions:

- **Average CTE measurements for HFR-Free materials are not significantly different from brominated FR4 materials**
- **CTE is most probably driven by the glass style used rather than resin class**

CTE Z Axis

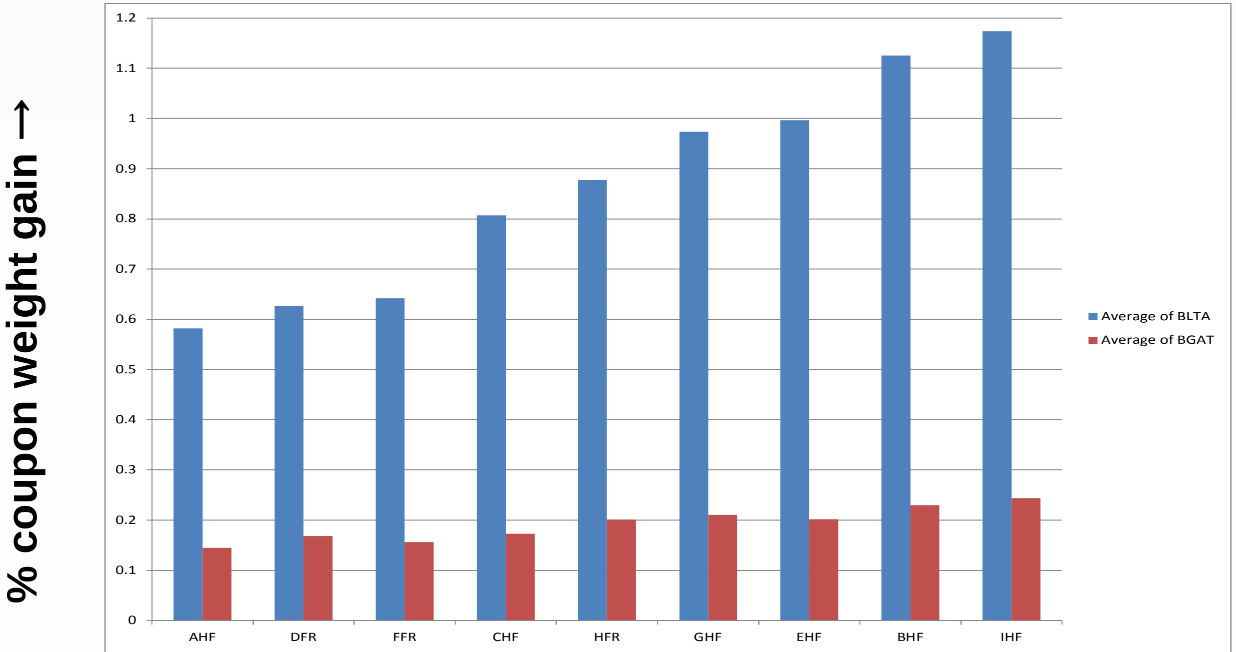


	AHF	BHF	CHF	EHF	GHF	IHF	DFR	FFR	HFR
■ % Expansion	3.6	2.9	3.2	3.4	3.7	3.9	3.6	3.9	4.1

Conclusions:

- •Average Z-axis total expansion is approximately 10% less for HFR-Free materials when compared with Brominated FR4.
- •This lower CTE is attributed to the higher volume & types of fillers in HFR than FR4
- •The overall average Z-axis HFR-Free CTE <Tg is 62 ppm/^{o}C compared to 73 for FR4
- •The overall average Z-axis HFR-Free CTE >Tg is 253 ppm/^{o}C compared to 284 for FR4

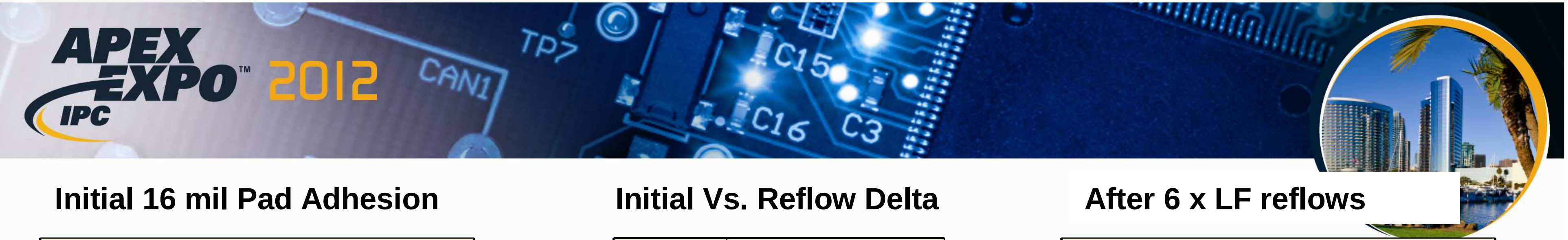
Average Total-Absorbed Moisture



	Bare Lam Total	Bare Lam Bonded	BGA Total	BGA Bonded
Max %	1.403	0.221	0.288	0.111
Min%	0.571	0.023	0.134	0.015

Conclusions:

- HFR-Free has higher moisture absorption than FR4. (Testing did not go to saturation)
- Total absorbed moisture between HFR-Free & FR4 is significantly different
- Bonded moisture between bare HFR-Free & FR laminates is significantly different



Initial 16 mil Pad Adhesion

Comparisons for all pairs using Tukey-Kramer HSD		
Level	Mean	Std-Dev
DFR	**1412**	**89**
CHF	**1239**	**118**
IHF	**1184**	**99**
HFR	**1142**	**76**
GHF	**1129**	**55**
FFR	**1050**	**105**
BHF	**1048**	**84**
AHF	**929**	**90**
EHF	**900**	**117**

Initial Vs. Reflow Delta

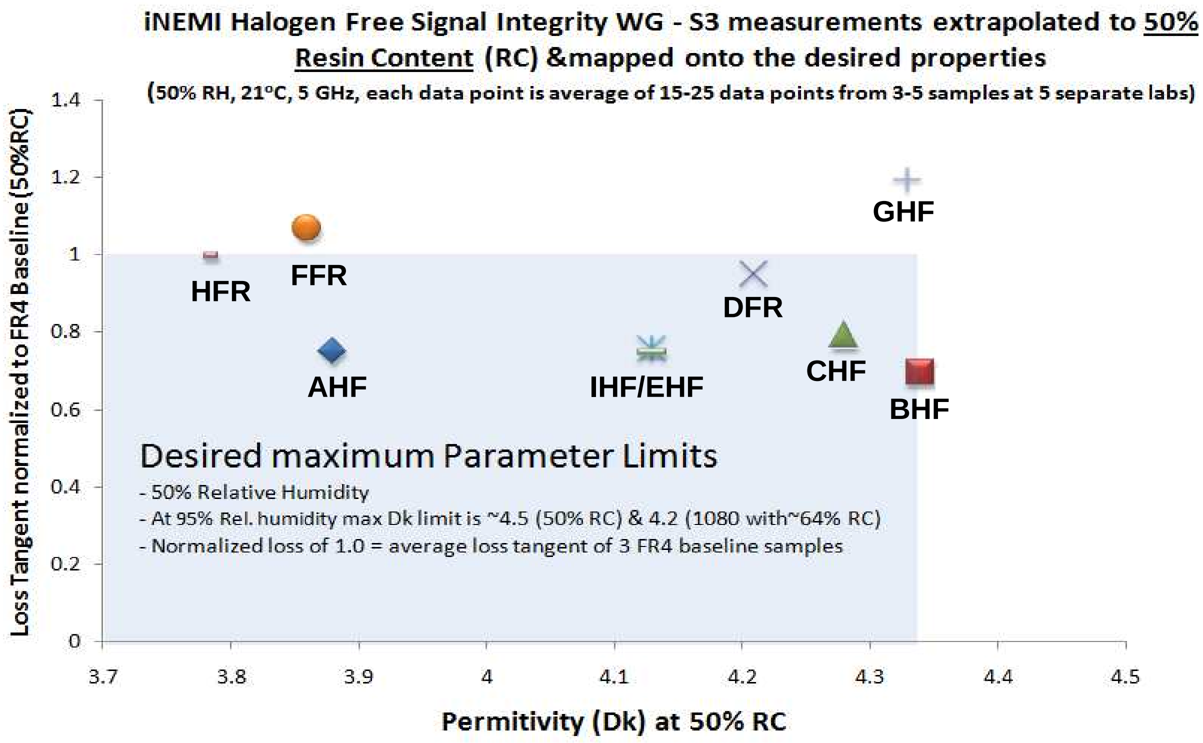
Level	Pull force Delta (PA-RWK)
DFR	**118**
CHF	**136**
IHF	**167**
HFR	**28**
GHF	**71**
FFR	**34**
BHF	**2**
AHF	**49**
EHF	**92**

After 6 x LF reflows

Comparisons for all pairs using Tukey-Kramer HSD		
Level	Mean	Std-Dev
DFR	**1293**	**128**
HFR	**1170**	**73**
CHF	**1103**	**86**
GHF	**1058**	**100**
BHF	**1051**	**137**
IHF	**1017**	**111**
FFR	**1016**	**117**
AHF	**880**	**65**
EHF	**808**	**96**

Conclusions:

- **The Cold Ball Pull Method (CBP) does differentiate materials but not material class. i.e. HFR-Free vs. FR4.**
- **Multiple reflows can slightly degrade the CBP force, but does not significantly alter the ranking of the materials.**
- **Cold Ball Pull method is very dependent upon the Ball Attach method and technique**



iNEMI Halogen Free Signal Integrity WG - S3 measurements extrapolated to 50% Resin Content (RC) &mapped onto the desired properties

(50% RH, 21°C, 5 GHz, each data point is average of 15-25 data points from 3-5 samples at 5 separate labs)

Desired maximum Parameter Limits

- 50% Relative Humidity
- At 95% Rel. humidity max Dk limit is ~4.5 (50% RC) & 4.2 (1080 with~64% RC)
- Normalized loss of 1.0 = average loss tangent of 3 FR4 baseline samples

Consortium Dk/Df limits

- **Dk<4.35 at 50% resin content (RC) & 50% relative humidity (RH)**
- **Dk<4.35 at 50% RC & 95% RH**
- **Losses =< FR4 baseline at 50% RC & 50% RH**

Conclusions:

- **HFR-Free Laminates tend have increased permittivity (Dk) over FR4**
- **HFR-Free Laminates tend have decreased loss (Df) over FR4**
- **2011 Client Platforms simulation and preliminary validation suggests the defined envelope will meet the platform requirements with 5 out of 6 HFR-Free laminates tested**

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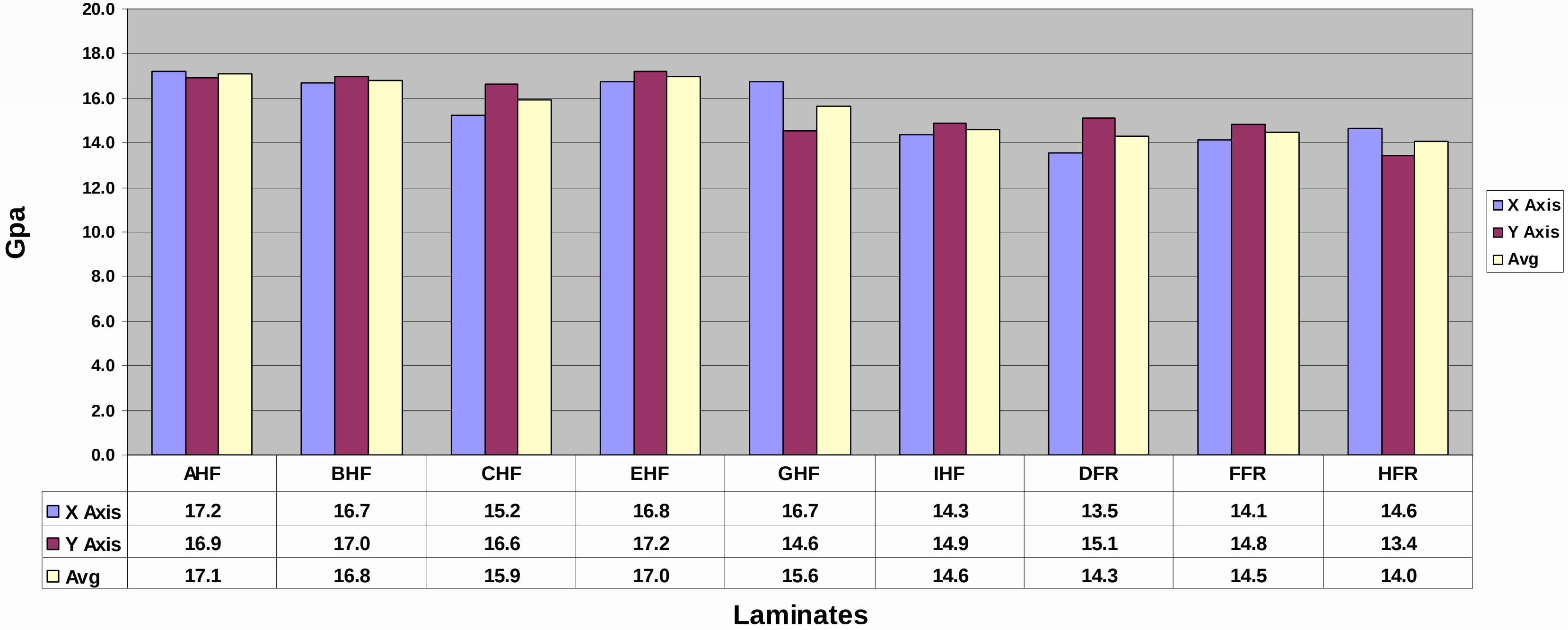
Flex Modulus

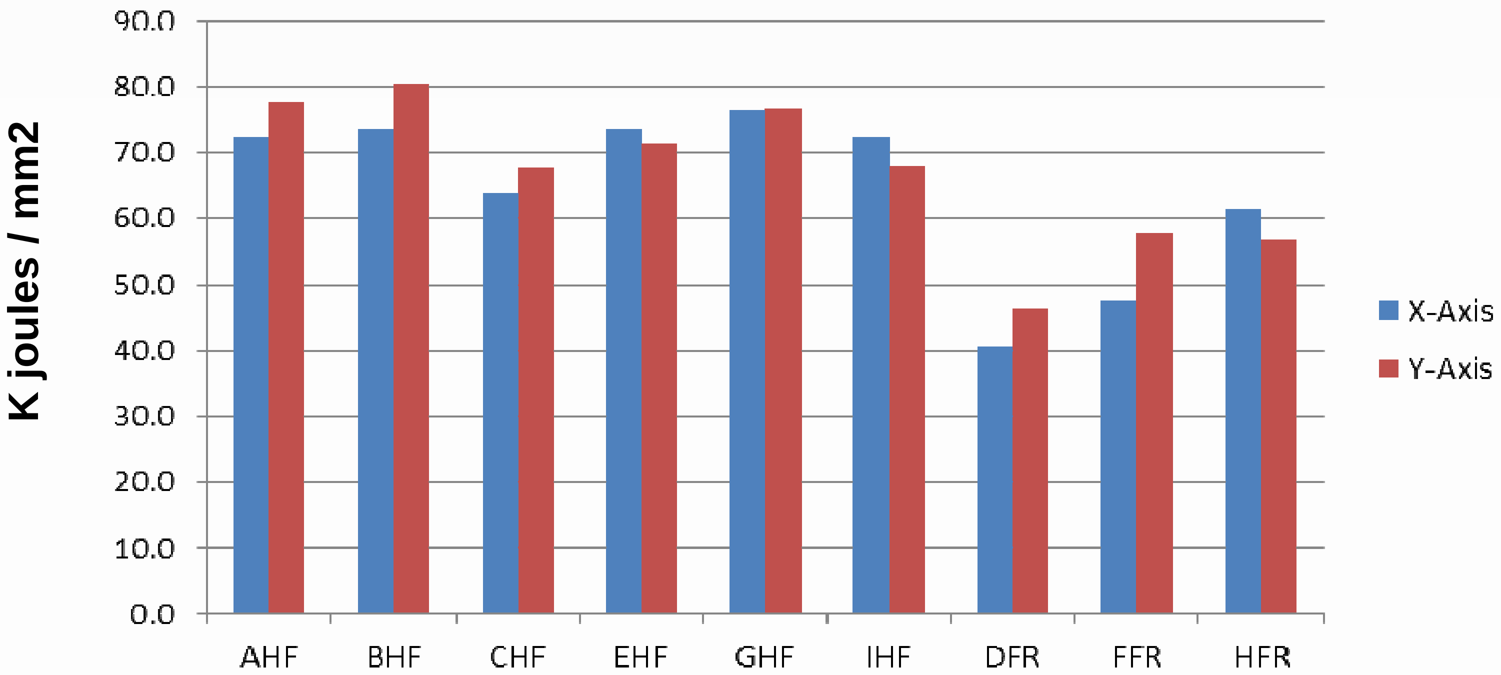


	AHF	BHF	CHF	EHF	GHF	IHF	DFR	FFR	HFR
X Axis	17.2	16.7	15.2	16.8	16.7	14.3	13.5	14.1	14.6
Y Axis	16.9	17.0	16.6	17.2	14.6	14.9	15.1	14.8	13.4
Avg	17.1	16.8	15.9	17.0	15.6	14.6	14.3	14.5	14.0

Conclusions:

- **HFR-Free Flexural modulus values are statistically different and slightly higher than the FR4**
- **The higher modulus of the HFR-Free materials is attributed to the higher loading of in-organic fillers**
- **Flexural modulus values doesn't significantly differ in X & Y directions**

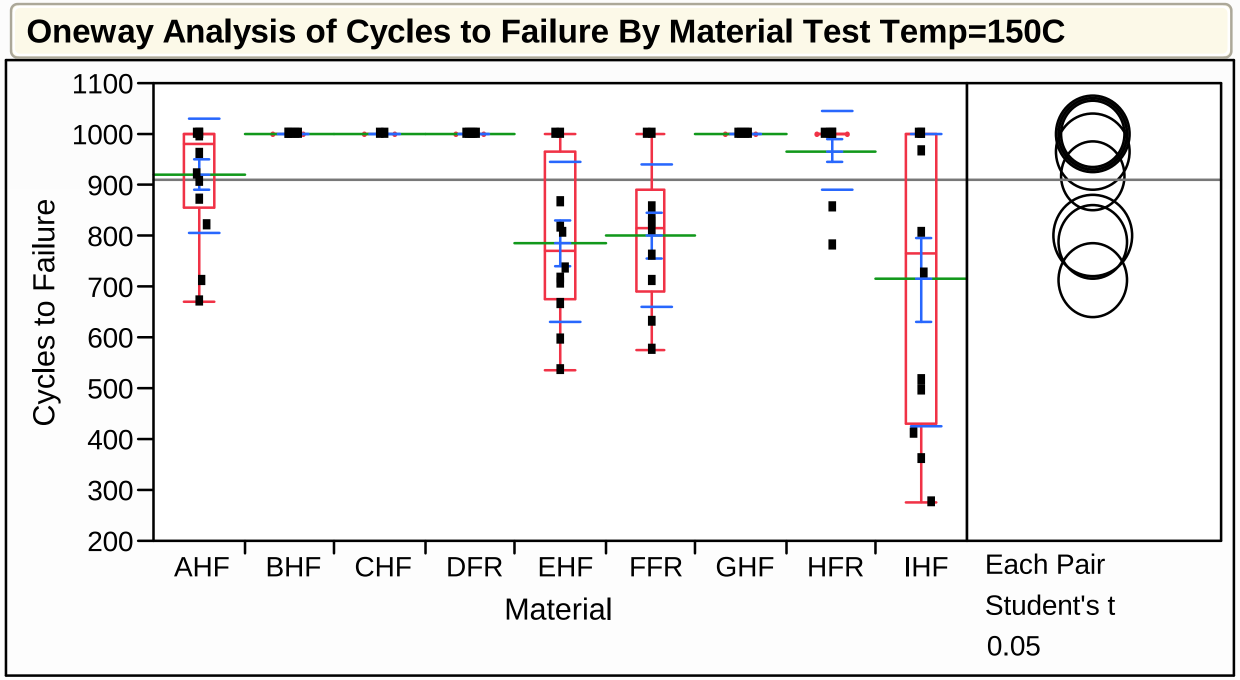
Charpy Impact Test



Conclusions:

- HFR-Free materials exhibit higher impact strength than FR4 material
- The higher impact strength of the HFR-Free materials is attributed to the higher loading of in-organic fillers
- The test method appears to be able to differentiate between materials

IST Cycles


Oneway Analysis of Cycles to Failure By Material Test Temp=150C

Excluded Rows 6

Conclusions:

- **All materials showed acceptable via reliability performance for Client type product designs (>500 cycle average)**
- **Test temp of 150C unable to adequately differentiate between materials after 1000 cycles of test**
- **Expected failure modes seen in all materials with failures (barrel cracks)**

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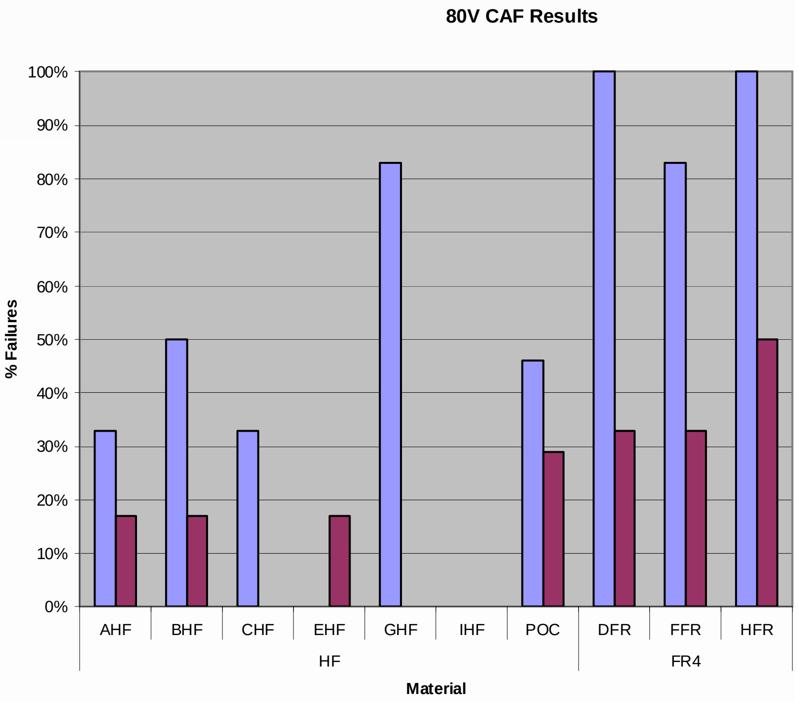
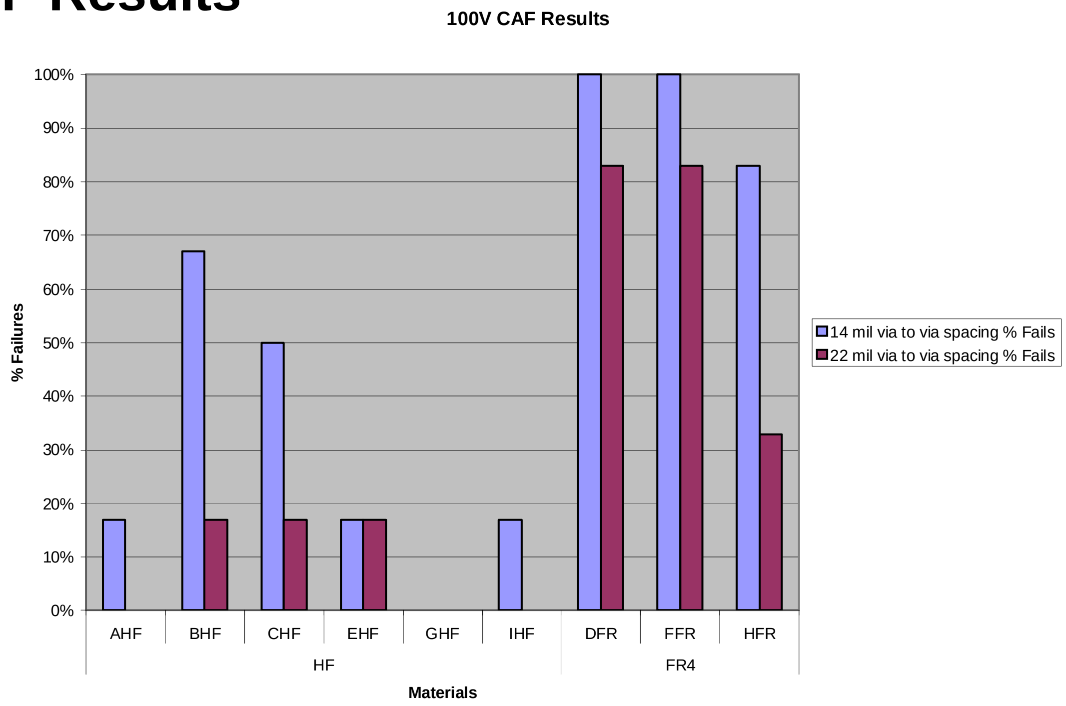
CAF Results





Conclusions:

- **HFR-Free materials outperformed their brominated FR4 counterparts for both bias levels (80 vs. 100 volts).**
- **22 mil via to via spacing outperformed 14 mil via to via spacing as expected.**
- **80V 14 mil via to via spacing data for GHF appears to be an outlier.**

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Suppliers HFR-Free Laminate Capacity (2008 -2011)

HFR-Free laminate materials shipped have doubled in the past 3 Years

Total % of HFR-Free/FR4 Laminates shipped				
Year	2008	2009	2010	2011 (Q1-3)
HFR-Free shipped as a % of Total Laminates MM²	**8%**	**10%**	**15%**	**17%**

Summary/Conclusions

Conclusion: HFR-Free Transition Readiness

The iNEMI HFR-Free Leadership WG believes that HFR-Free Laminates are ready for the Client space transition

Reliability:

•Due in part from the emphasis of this consortia, the laminate suppliers have modified there initial HFR-Free offerings and the laminates in the study now have properties that equal or exceed the BFR version.

Capacity:

•The growth of HFR-Free laminates has increased over the past several years with WG laminate members doubling (2X) their capacity

Commitment:

•Each Laminate Supplier in the WG has committed to supplying the TSM data for HFR-Free Laminates upon request.

The iNEMI High Reliability WG is extending HFR-Free alternatives for other high end market sectors

Conclusion: Test Suite Methodology

- The Test Suite Methodology (TSM) has been successful in allowing direct quantifiable comparison of desired laminate properties

- The TSM has added non-traditional performance data to the Laminate suppliers data sheets

- Several of the new Test Methods will require more evaluation before full acceptance by the Industry

- Some TSM structures and the stack-up/construction would have to change to accommodate higher layer count/thicker PCB

Firms Participating in the Program

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intel

hp invent

lenovo

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iNEMI HFR-Free Leadership PCB Materials WG

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- Jason Zhang, Foxconn
- Bill Weng & Anderson Chen, ITEQ
- Yu Xi, Quanta
- Bill Birch, PWB Interconnects
- Jim Arnold & David Godlewski, iNEMI

Questions?