Material & Process Influences on Conductive Anodic Filamentation (CAF)

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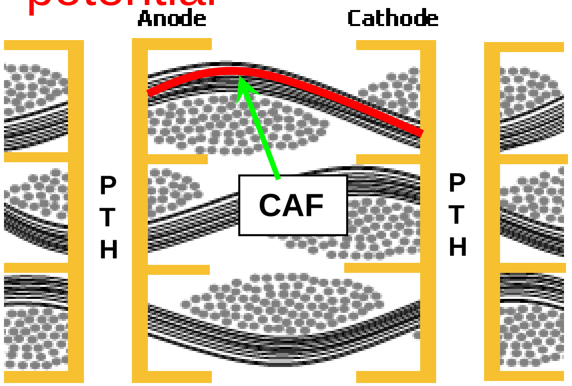
History

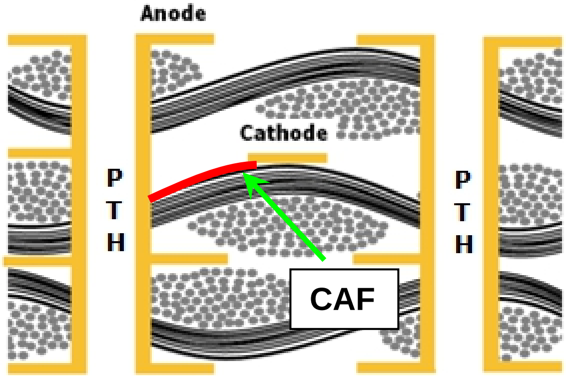
- In the late 1970s an abrupt unpredictable loss of insulation resistance was observed in PCBs, which were subject to hostile climatic conditions of high relative humidity and temperature while having an applied voltage.
- The loss of resistance, even leading to a short circuit was observed to be due to the growth of a subsurface filament from the anode to the cathode.
- The term “Conductive Anodic Filamentation” (CAF) was coined.

Classic CAF Formation

Bell Laboratories investigated the mechanism of CAF formation and found the following characteristics;

- Moisture absorption occurs under high humidity conditions
- Physical degradation of glass/epoxy bond (silane)
- An electrochemical pathway develops and electrochemical corrosion occurs
  - Water acts as an electrolyte, the copper circuitry becomes the anode and cathode, and the operating voltage acts as the driving potential





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General CAF

- **CAF is and electrochemical process, it requires the following to occur:**
  - Electrolyte – Water
  - Voltage bias – Force that drives the reaction
  - “Pathway” – A way for the ions to move from the anode to the cathode
- **The following factors accelerate CAF formation**
  - Higher water content
  - Higher Voltage levels
  - Higher temperature (increases reaction rate of corrosion)
- **CAF is a catch all for any internal drop in resistance during THB testing**
  - May include:
    - Surface failures
    - Test equipment issues
    - Material defects
    - Fabrication defects
    - Classic CAF
- **Determination and interpretation of the results of CAF testing can be challenging**

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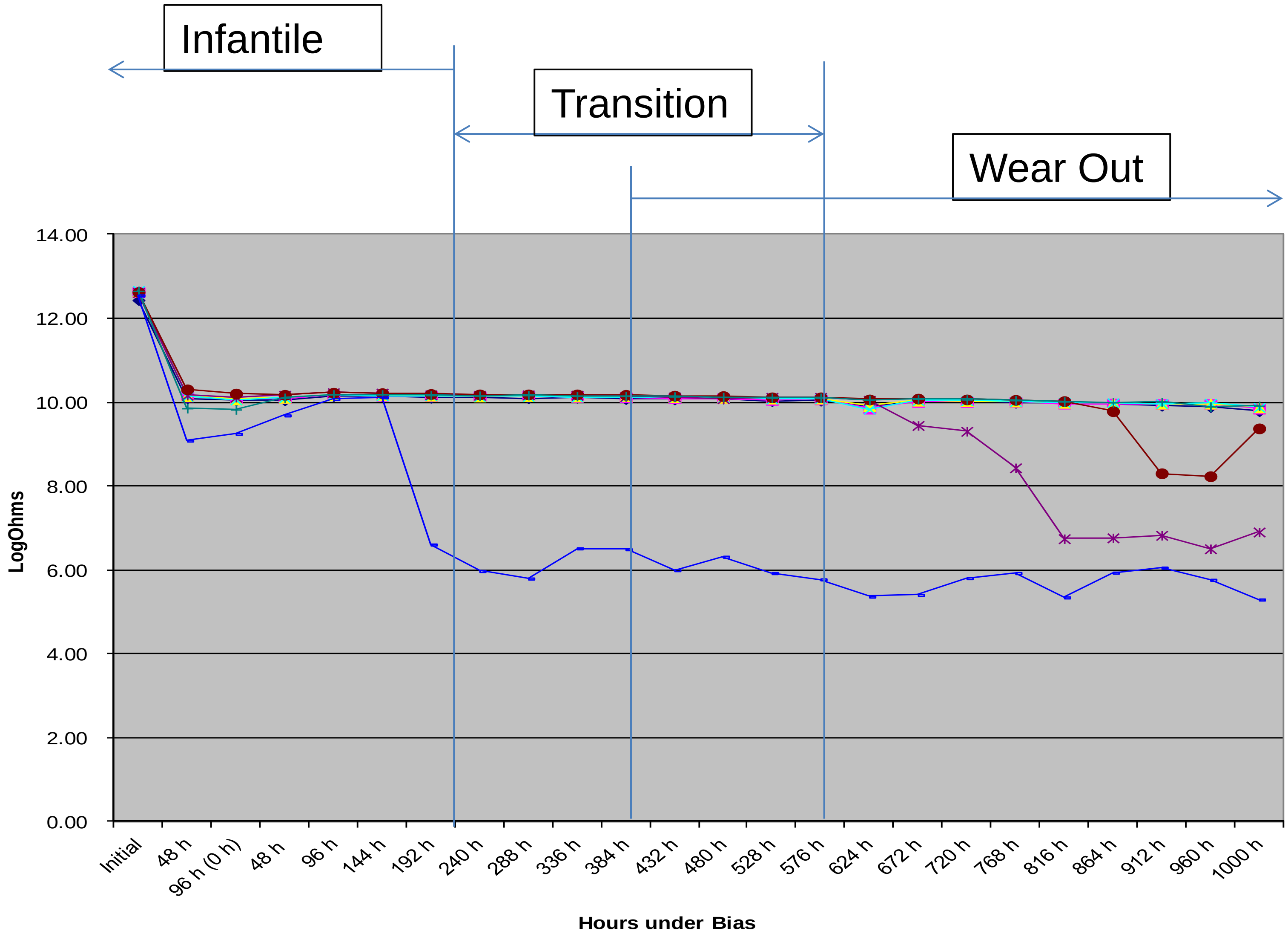
CAF Testing

- **CAF testing utilizes a number of different forms of THB methods**
  - THB = Temperature, Humidity, Bias
    - Temperature vary 45-85C are used
    - Humidity is normally 65% or 80-85%
    - Time of bias, 500-1000 hrs most common
    - Voltage varies, 10-100V most common
- **Well run testing has the following conditions**
  - Soak period before application of bias to allow the test vehicles to equilibrate (48-96 hrs typical)
  - Bias period with regular resistance measurements
    - More frequent is considered better
  - A recovery period without bias at ambient environmental conditions

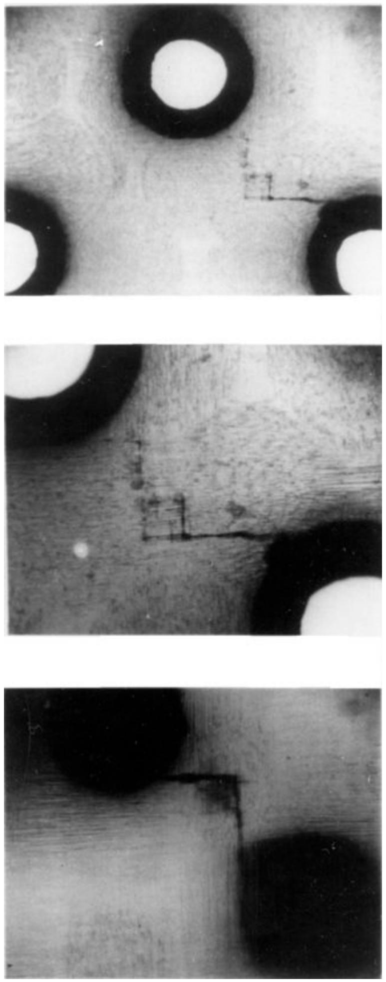
CAF Resistance Plot Example

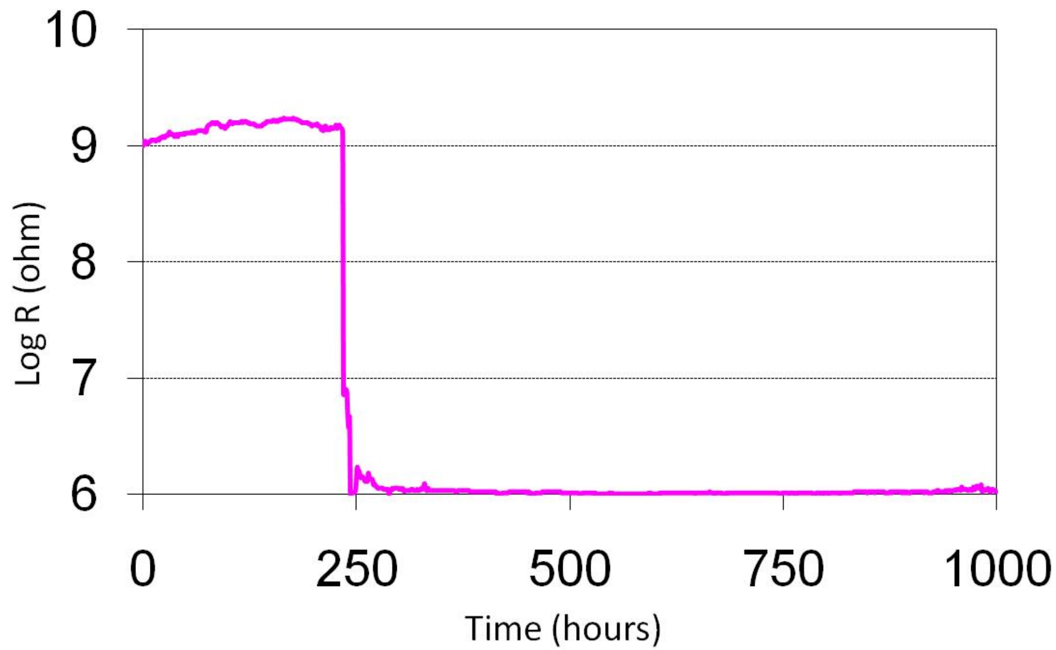


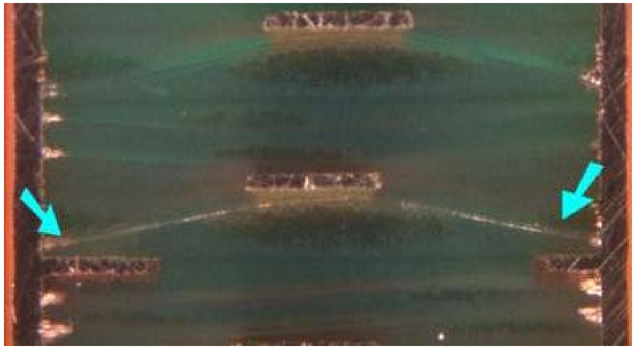
Failure Types and Common Causes

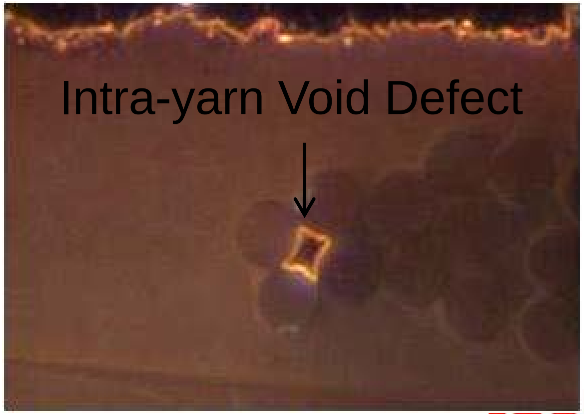
- **Infantile Failures**
  - Pre-existing defects between features under bias
    - Voids, contamination, fracturing, wicking, misregistration
- **Transition**
  - Partial defects – Incomplete bridging between features under bias
  - Early CAF failures
- **Wear out**
  - Materials CAF resistance capability
- ***Note-Comments based on failure analysis of CAF test coupons***

CAF Failure (example)









Factors influencing CAF

- **“A bad fabricator can make a good material bad. A good fabricator can’t make a bad material good.”**
  - OEM quote after early CAF study

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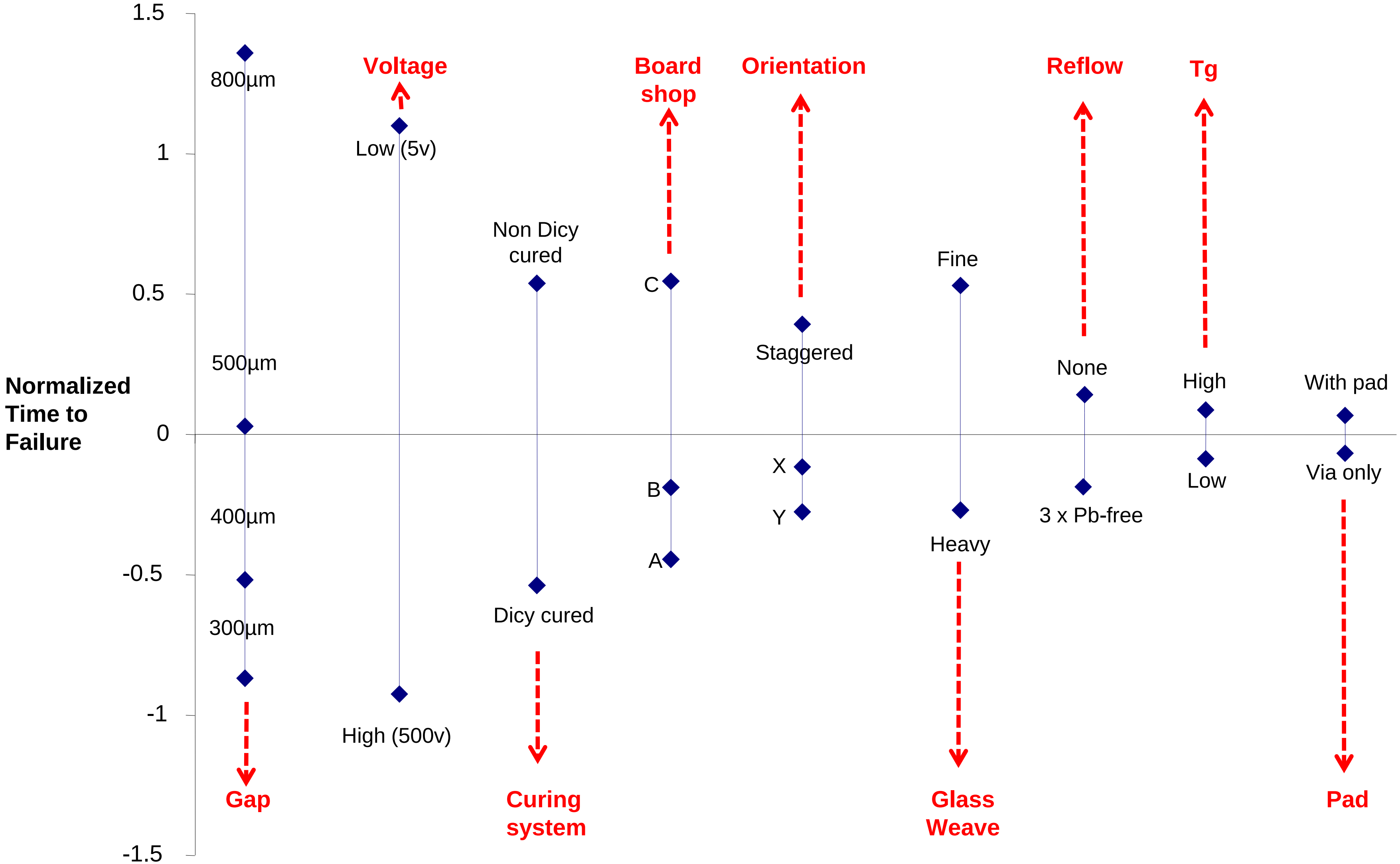
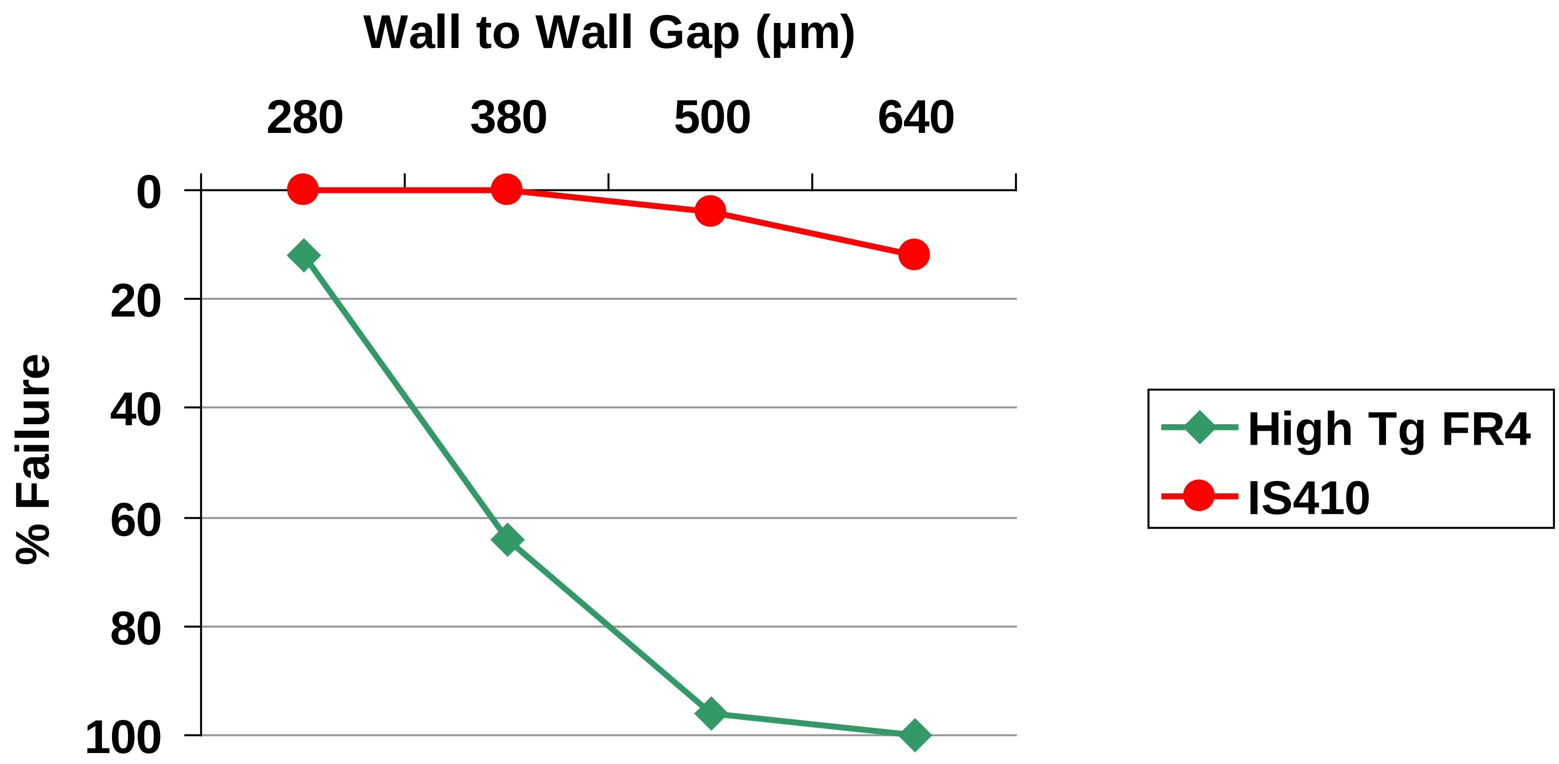
Factors Affecting CAF Resistance High Voltage Automotive DOE



Data source Brewin, Zou and Hunt, National Physical Laboratory and Isola

CAF Performance
Phenolic IS410 vs. Dicy-cured FR-4



IS410 (phenolic cured) vs. High Tg FR4 (dicy cured)
HASL Finish; 100 V Bias;
500 hour test; 25 coupons

Design Factors

- **Key item is geometry of areas between voltage biased features**
- **Distance – How far apart are they**
  - Smaller is worse
- **Number of opportunities per part**
  - All adjacent biased features (closely spaced) count
  - Number of glass layers
- **Orientation**
  - X-Y in grid – Follows glass yarn directions
  - X-Y off grid – Rotated or staggered grid systems
  - Z-axis

PCB Fabricator Issues

- **Fabricators main negative impact is in two areas: distance between bias elements and pre-existing pathways**
- **Distance between bias elements impacts**
  - Registration – Hole to internal feature
  - Drill deflection – Hole to Hole
  - Wicking – Hole to Hole distance
- **Pre-existing pathways**
  - Glass stop – lack of resin/glass voids
  - Fill voids
  - Delamination
  - Wicking – May cause a pathway
  - Contamination

Factors Affecting CAF Performance from the Laminate Manufacturing Perspective

- **Glass Cloth/Silane coating**
  - Good fiber cleanliness – allows complete wetting and bonding
  - Compatible silane finish – enhances resin wetting and maintains strong bonding
  - Good fiber distribution – Promotes complete resin wetting
  - Hydrolysis resistance – Maintains strong glass-resin bond under THB conditions
- **Resin formulation**
  - Low moisture absorption
  - Chemical stability – hydrolysis resistance
    - Dicy vs Phenolic FR-4 material
  - Resin component purity
    - Low ionic content and low content of unreacted materials
- **Laminate thermal resistance**
  - High decomposition temperature
    - Prevent resin breakdown – loss of good dielectric properties
  - Delamination resistance

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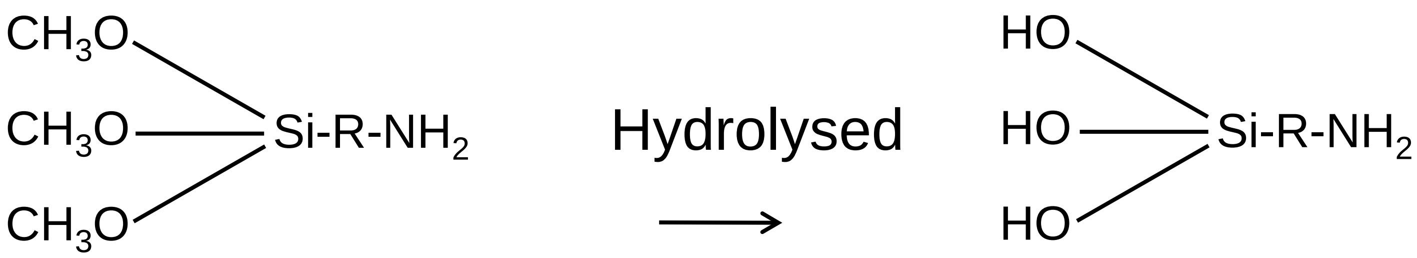
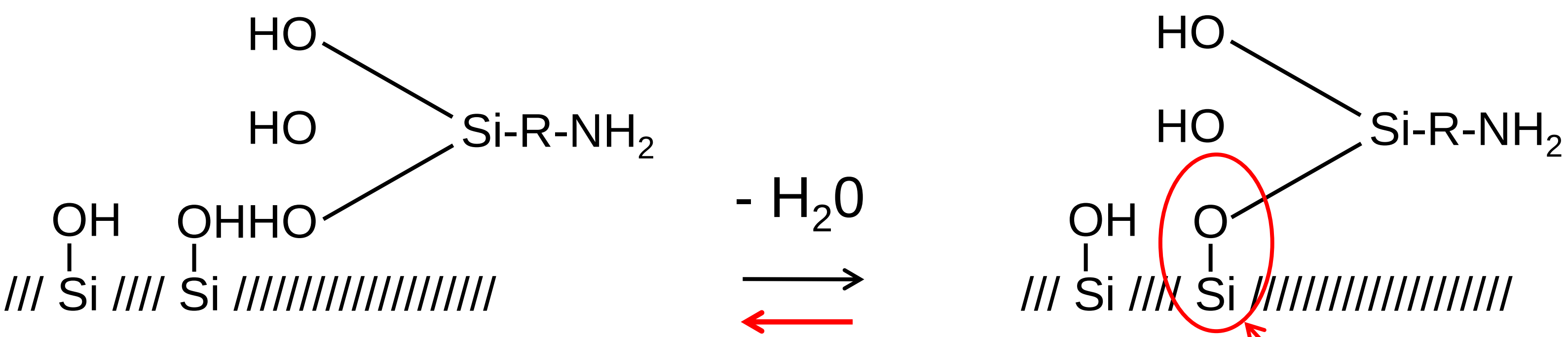
Silane Finish Mechanism



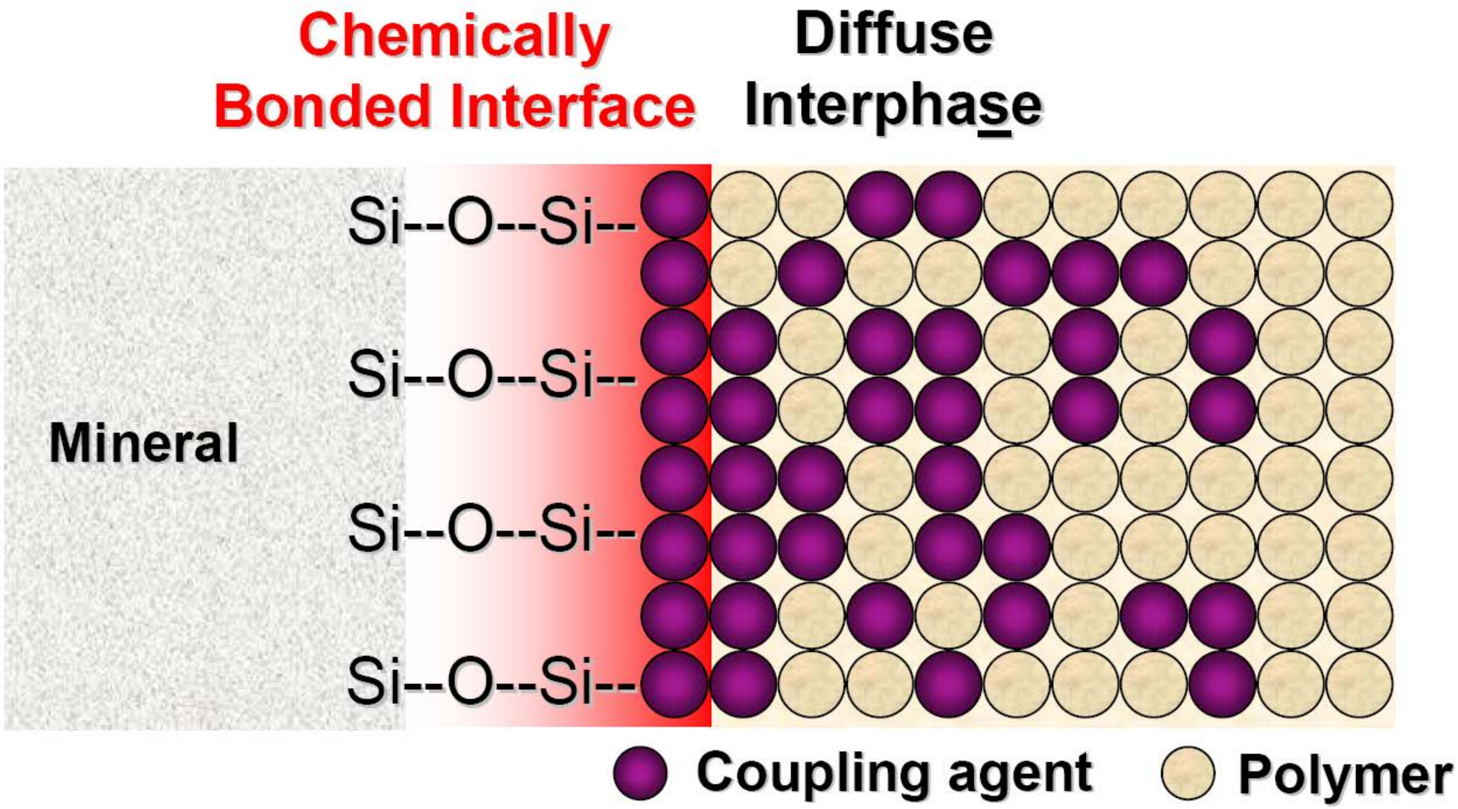
Methoxy Amino Silane



Moisture can reverse this reaction.

Chemical bond

Silane Finish Coupling



Courtesy of Dow Corning Corporation

Glass Wetting Comparison

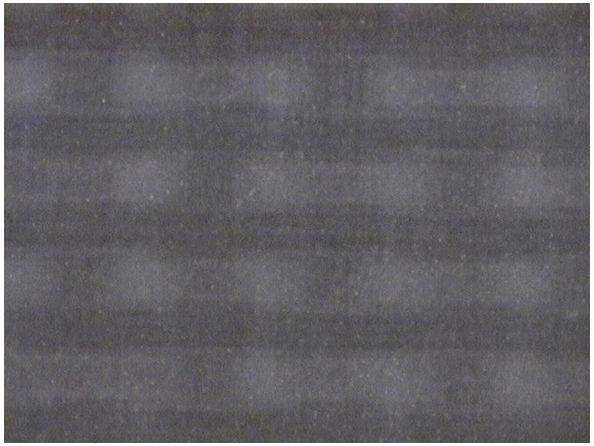
Finish“A”

Finish “B”

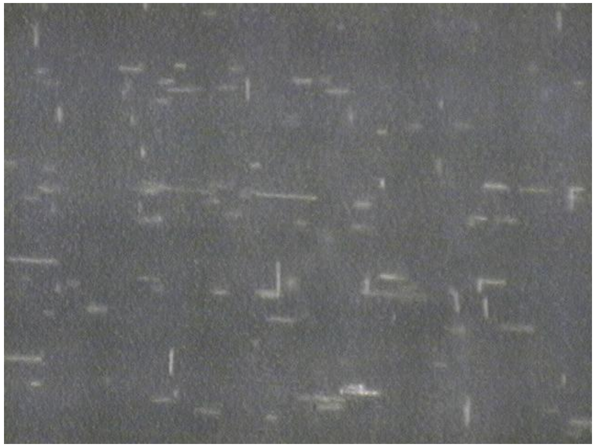
Elapsed time (seconds)	2	4	6	8	10

Photos courtesy of
Isola Fabrics s.r.l.

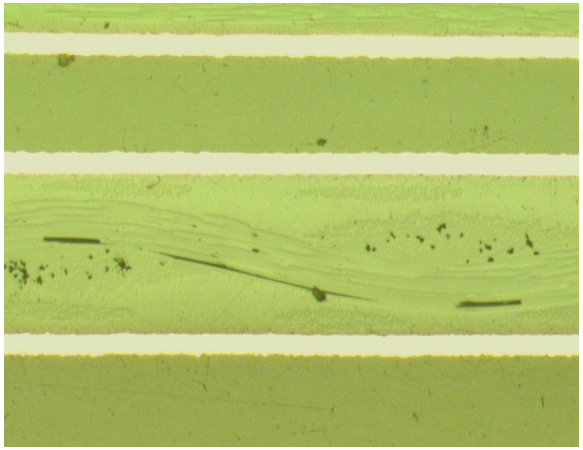
Glass Wet Out



Laminate – Complete Wet Out



Laminate – Poor Wet Out



Cross Section – Poor Wet Out

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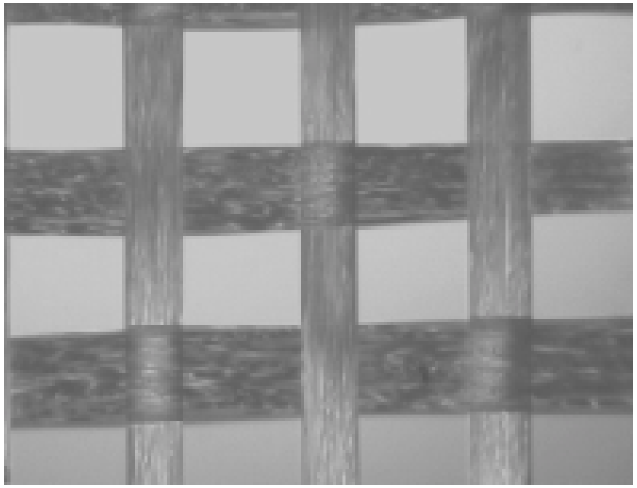
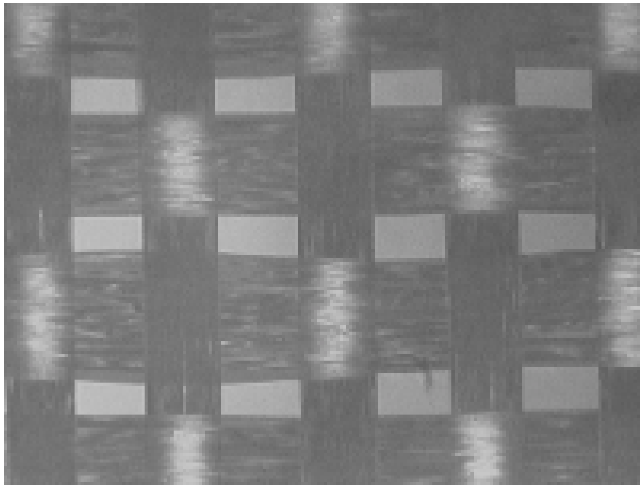
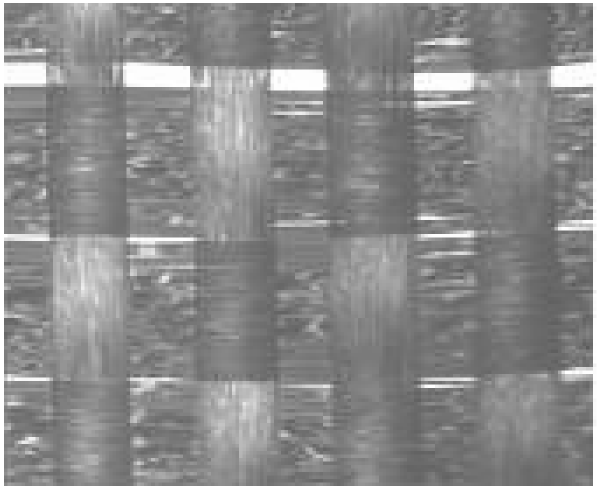
Glass Fibre Distribution



Standard Fabric



Square weave Fabric



Spread Fibre Fabric

3,310 **1680** **279**

Air Permeability [l/dm²/min 200mm (Pa)]

The fibre distribution is assessed online using an air permeability tester. This measure the air flow through the glass fabric in litres/dm² per minute at constant pressure

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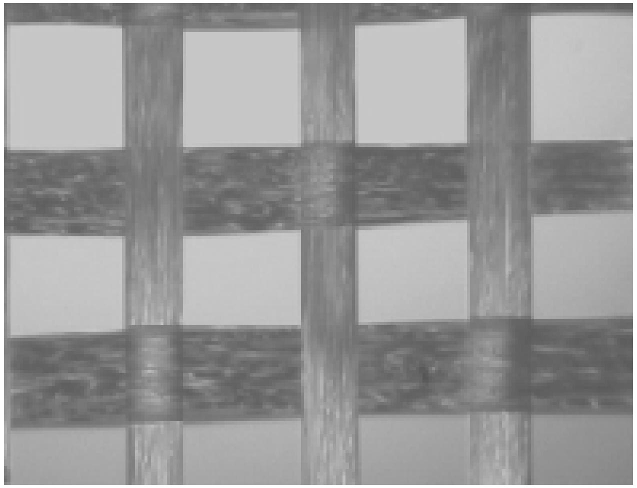
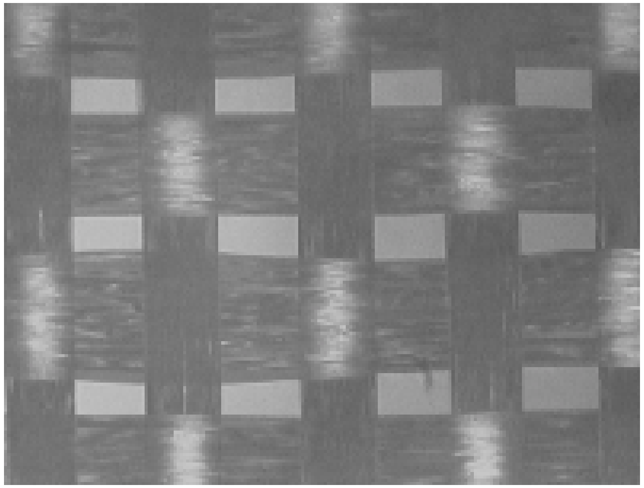
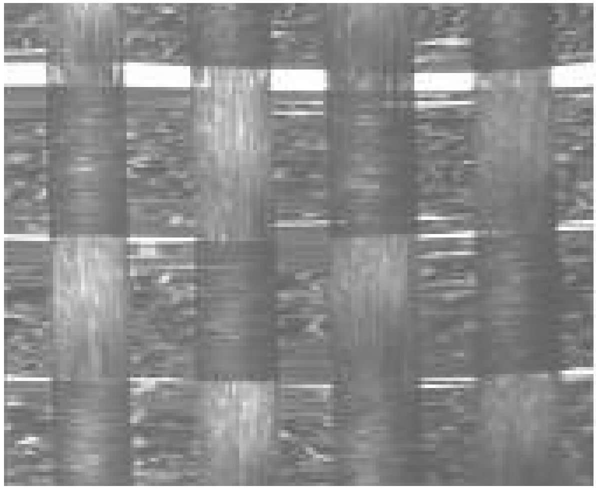
Glass Fibre Distribution



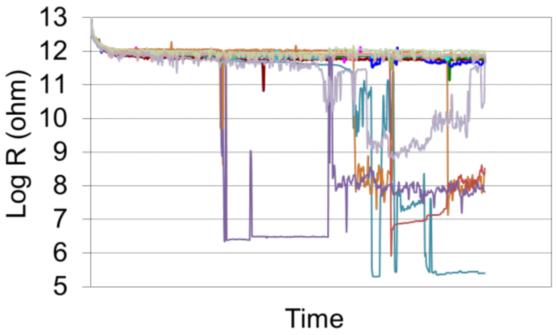


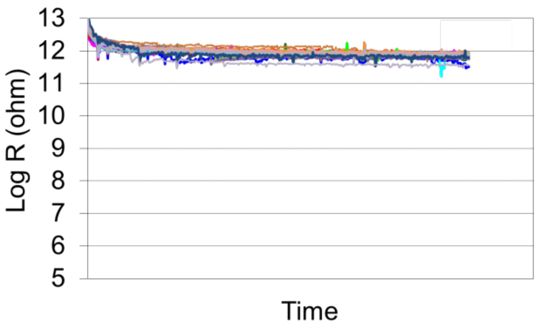


Standard Fabric

Square weave Fabric

Spread Fibre Fabric





Indicative comparative CAF test results 85°C/85%RH 200V bias. 200µm gap

Analyzing CAF tests

- **There are two major approaches to analyzing CAF tests**
  - CAF resistance of material system
  - Capability of fabricated PCB's
- **CAF Resistance is a way to determine if the material system is susceptible to CAF formation, or not susceptible**
  - It does not focus on defect based failures
  - It measures how stable a material is during THB testing and if the material is degraded by THB testing
- **CAF Quality is the failure rate model for a material**
  - Many of the failures are related to defects in tested vehicles

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CAF Quality - Failure Rate

- **This is the most common CAF testing approach used**
  - Failure analysis should always be run on this type of testing, to determine cause of failures
- **Since this approach, in most cases, measures the defect density in products, it is really a quality indicator more than reliability measure**
- **Failures in this testing are real failures and should be understood**
  - Root cause and elimination
- **The results are often not related to the CAF Resistance of a material system**

Intrinsic CAF Resistance

- **This approach looks at the response of the material ignoring defect failures and analyzing residual data**
- **Slope of the Log resistance over time**
  - Measures the change in the material properties over time in THB conditions
  - Good indicator of material resistance to CAF formation
- **Change in coupon resistance at ambient conditions, before and after THB exposure**
  - Determines if material is permanently degraded by the THB testing
  - Good measure for silane compatibility or hydrolysis sensitivity

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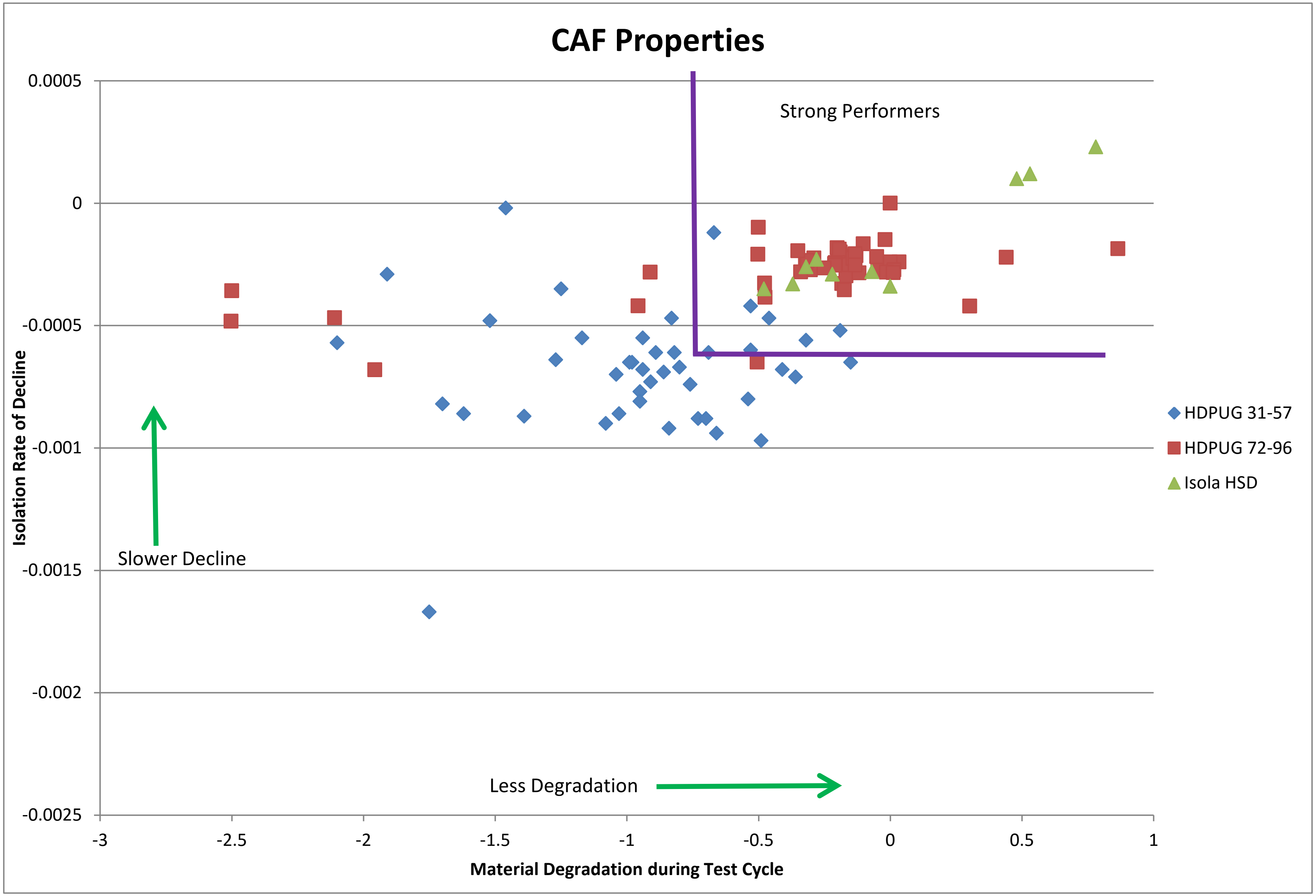
Analysis Example

		Failure Rates			Slope	Ambient Resistance Change
Fabricator	Material	0-200 hrs	200-500 hrs	500-1000 hrs	Log ohm/1000 hrs	Final R - Initial R (log Ohms)
A	A	0%	0%	0%	-0.5	-1
A	B	30%	5%	0%	-0.3	-0.75
B	A	50%	10%	0%	-0.7	-1
A	C	0%	5%	15%	-1.5	-2.5

- **Fab A/Material A**
  - No defects – Good CAF Quality
  - Low negative slope, moderate resistance change – CAF Resistant material
- **FAB A/Material B**
  - High initial defects, reduced with time – Poor CAF Quality
  - Good late failure rate, good slope and resistance change – CAF Resistant
- **FAB B/Material A**
  - Many early defects, compared to Fab A. Fab B has quality issues or received bad material.
- **FAB A/Material C**
  - Good early defects, defects increased with time – Poor Capability
  - Defect increased with time, steep negative slope, large resistance change – Not CAF Resistant

CAF Resistance Chart
(All samples same Test Vehicles and after 6xReflow)



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Summary Raw Material

- **The key to very high CAF performance is the optimization of the key material factors**
- **Example Isola HSD (High Speed Digital) Material family**
  - Proprietary resin system is thermally stable, maintaining CAF properties after reflow
  - Cured resin system absorbs low moisture levels
  - Silane finish tested for good manufacturing performance and good CAF resistance
- **The keys are**
  - materials that are not susceptible to moisture related breakdown
  - maintain integrity after temperature exposure and THB exposure

Summary: Influences on CAF

- **Laminate Material Considerations**
  - Resin formulation
  - Laminate thermal resistance
  - Glass fiber wet out
  - Glass fabric style and finish
  - Glass fabric fiber distribution
- **Design**
  - Geometry factors, such as hole-to-hole distance and grid layout
  - Applied voltage
  - Via polarity
- **Board Shop**
  - Each board shop has a different level of capability
  - The PCB fabrication process can significantly impact CAF performance
  - Selecting a CAF-resistant material does not guarantee a CAF-resistant PCB

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CAF Risk Management

- **Design is the most cost effective approach**
  - Minimize adjacent bias locations
    - Power-Ground pins
  - Maximize gap between bias locations
    - Or rotate off grid
- **Select materials with good CAF resistance**
- **Select PCB fabricators with proven track record in CAF testing**

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