A DOE to assess PCB fabrication material design and process using IST (Interconnect Stress Testing) to improve fine pitch BGA via reliability

Mahesh Narayanaswamy and Reinaldo Gonzalez
GE Healthcare

Abstract

During the development of a new medical imaging system, via quality was identified as a potentially source of infantile failures. Premature via failures were precipitated in a critical 14 layer board, specifically in the 0.8 mm BGA vias with an aspect ratio of approximately 9:1. Failure analysis indicated two dominant failure mechanisms: dry film lock-in, and drill debris in the via barrel causing insufficient plating of the via sidewall. Dry-film lock-in was corrected by process control improvements at the fab supplier. The fab material was identified as a major driver in the presence of drill debris in the via barrel.

To address these infant mortality issues and to demonstrate long term via reliability, IST testing was identified as an industry recognized tool to quickly assess fab reliability. Three parameters were identified as key variables in fine-pitch via quality and reliability: fab resin material, inclusion of non-functional pads (NFP), and type of drill machine at the fab supplier. A DOE was developed to understand the influence of these factors on overall via reliability.

The following conclusions were observed. The lower CTE fab material outperformed the other fab materials in mean cycles to failure (CTF). In addition, an interesting result with NFPs was found. Contradictory to industry recommendations, the presence of NFPs actually improved the mean CTF for the same material and process. The drill machine had little to no influence on CTF for the same material and design. In addition, at the lead-free preconditioning temperature, separation of the glass fiber bundles was observed in most of the materials tested. An understanding of this phenomenon and the other failure modes is critical to developing a robust lead-free fab.

Introduction

With the increasing density of BGA packages and correspondingly higher via count, PCB fab reliability and specifically PCB via reliability is of utmost importance. This paper will deal with a circuit board having multiple 11x13, 143-pin BGA packages on a 0.8 mm pitch. The circuit board has well over 1000 vias in the BGA region alone and each signal in this area is critical to the performance of the board.

While testing these boards, two major failure modes were observed:

1) Dry film lock-in
2) Drill debris -> insufficient via plating

Dry film lock-in refers to the plugging of an unplated via hole by a piece of dry film during the removal of the dry film. This plugging of the via hole causes the via plating to be incomplete, resulting in an open connection. An example of dry film is shown below:

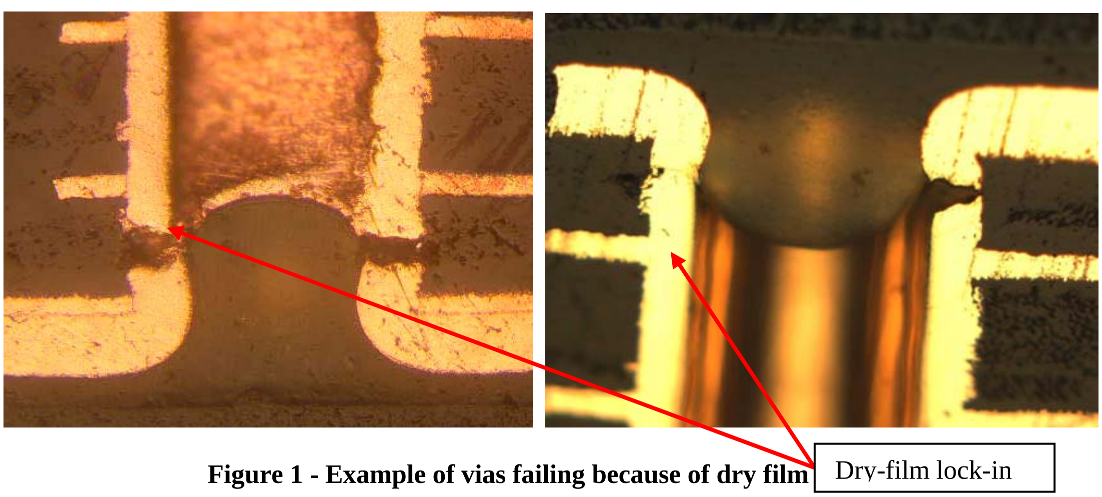

Figure 1 - Example of vias failing because of dry film

The root cause of this failure mode was a supplier process control issue that was successfully resolved. The second failure mode is a more generic failure category that results due to poor drilling and cleaning of the via. This causes drill debris to be captured within the via, forming bubbles or voids within the via that result in insufficient via plating. The plating becomes non-uniform due to the drill contaminants and can propagate into failures over time. Below are pictures showing examples of drill debris within the via hole:

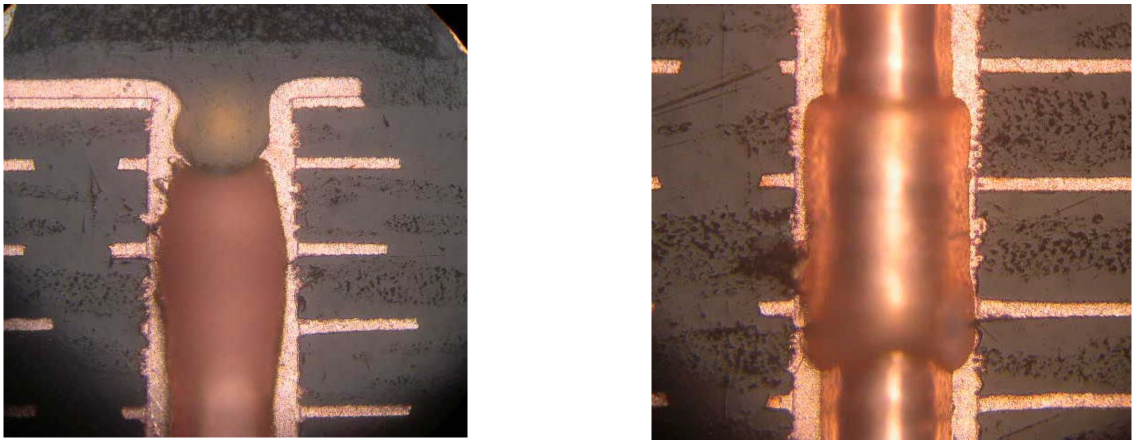

Figure 2 - Examples of defects that caused thin via plating.

Although these two failure modes can be categorized as infant mortality failures, the root causes behind these failures were helpful in examining the key factors in producing a quality fab material, namely materials, design, and process. For example, an agreed-upon hypothesis regarding the reason for the drill debris was the interaction of the heated drill with the fab material causing unwanted debris to form. In addition, the presence of non-functional pads creates discontinuities within the material which may cause localized heating within the via, contributing to additional debris.

An in-depth investigation was performed for selecting the proper PCB fab material, design, and process. To evaluate the materials, design, and process parameters, IST testing was selected as the reliability test method.

Background on IST Testing

IST (Interconnect Stress Testing) is a quick and powerful method for evaluating PCB fab reliability. IST uses a DC current-based heating method to quickly temperature cycle fab coupons from a range of ambient to ~150°C. During these cycles, resistance is measured on the power circuit and the measurement (sense) circuit to detect any change in resistance versus baseline levels. Failure is considered a 10% increase in resistance vs. baseline, although the resistance change threshold can be varied. The IST coupons are designed with daisy-chained vias such that the majority of the resistance is located within the via barrel [1].

Prior to the current-based thermal cycling, preconditioning of the test coupons can be performed to simulate solder reflow conditions. Preconditioning can be any amount of dwells (1, 2, 3, 6, etc) at a predetermined temperature (230°C, 260°C, etc) to simulate a typical PCB reflow environment.

In addition to preconditioning the test coupons, a procedure called prescreening allow for the selection of an appropriate test set of coupons from the coupons available. Prescreening involves measuring the overall resistance per coupon, and selecting a variety of coupons that comprises a representative population of sample coupons (i.e. large amounts of plating, small amounts of plating, etc). This is possible because resistance is inversely proportional to plating thickness, so the ability to grossly categorize plating thicknesses of coupons is possible and valuable to ensure a fair test.

IST has many benefits, including testing a large amount of cycles to failure (CTF) in a considerably shorter amount of time (500+ cycles in 1 day) as compared to conventional air-air thermal cycling. In addition, many of the parameters (preconditioning, resistance threshold, etc) are flexible and easily adaptable to the specific product environment and needs. Perhaps, most importantly, the CTF measurements and corresponding failure modes can be determined through cross-section autopsy work, and failure modes can accurately indicate weak points in the design, material, or processing of the PCB. Additionally, the CTF measurement can be compared to industry-wide IST results, and a qualitative comparison can be made as to whether the coupon "passed" or "failed" compared to similar coupons undergoing similar tests. This type of criteria is useful in using IST as a prescreening checkpoint for PCB's to go through [1].

Design of Experiments for IST Testing

After discovering the two failures modes in our circuit board, dry film lock-in and drill debris in the via, it was critical to acquire a thorough understanding of the factors that influence via quality. Below is a summary of the main factors in our process that affected via quality, summarized in a fishbone (cause & effect) diagram.

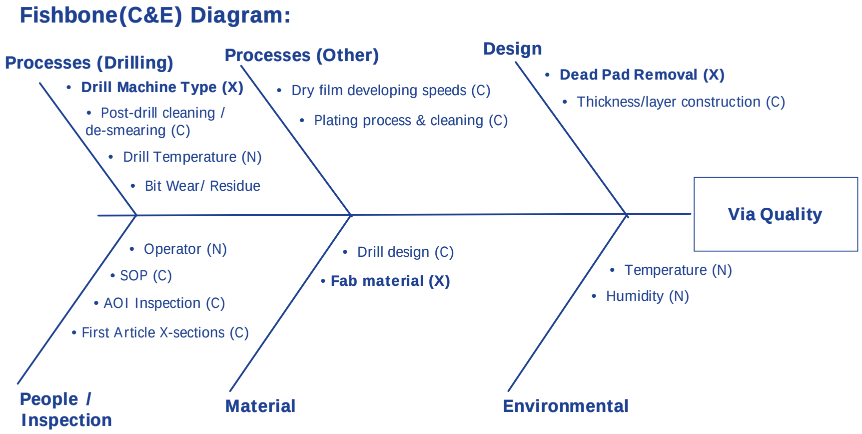

Figure 3 - Fishbone to choose critical parameters

From this fishbone diagram, three main factors were considered vital variables to ensuring via quality:

1) Fab material
2) Presence of non-functional pads
3) Drill Machine Type

In exploring the numerous PCB fab materials available, a few constraints were placed on our initial search. First, the fab must be lead-free compatible, which eliminated many of the traditional low T_g fab materials. During our search, many factors were considered, including:

1) Lead-free compatibility
2) Presence of filler material to lower z-axis CTE
3) T_g and T_d temperatures
4) CTE in-plane and z-axis (pre and post T_g)
5) Drill-ability of the material
6) Moisture absorption

Based on these factors and material availability, three materials were chosen to test with IST coupons. Their properties are below:

Sample ID	Direction	Inflection Temperature (C)	Average CTE Before Inflection (um/m*C)	Average CTE After Inflection (um/m*C)
Mat A	z	164	49	196
Mat B	z	158	62	238
Mat C	z	169	43	107

The value of non-functional pads within a via is a very debatable subject with compelling arguments on both sides of the issue. On one hand, the presence of non-functional pads is thought to increase the structural strength of the via, and increase resistance to stress. Conversely, removal of non-functional pads can improve drill-ability of the via hole and also allow for a more uniform stress distribution along the via.

Through experiments, the inclusion of non-functional pads in smaller, high-aspect ratio vias (0.2-0.5mm via diameter) has been shown to have a negative effect on reliability (10-30% reduction in long term performance). However, if the via size is large (>0.5 mm diameter), the presence of non-functional pads has been shown to have a positive effect (10-15% increase in performance) [2].

However, the value of non-functional pads is thought of as a 4th order effect [2]. The following are the important parameters in producing a quality and reliable via [2]:

1st order: Copper plating – Thickness and quality
2nd order: Material, board thickness, hole diameter, number of layers
3rd order: Surface finish, PTH metallization, foil thickness, construction, grid size
4th order: Design (pads vs. no pads, annular ring, anti-pad clearance, etc)

Based on this information, IST test coupons were created with and without non-functional pads.

In addition to material and design, looking at the PCB process was an important factor in our quest for the highest quality fab. The fab supplier used two types of drilling machines, with different drilling speeds, and we felt that the type of drill machine may be a critical factor in producing good quality vias.

Overall, using these three design parameters, the following fractional-factorial DOE was developed:

Design #	Material	Non-Functional Pads	Drilling Machine	# of coupons
1	A	Yes	#1	24
2	A	Yes	#2	24
3	B	Yes	#1	24
4	B	No	#1	24
5	B	No	#2	24
6	C	No	#1	24

Since our primary path choice was This particular DOE allowed us to compare materials A & B, and B & C, with the other factors unchanged. Additionally, we are able to observe the effect of non-functional pads using the same material and drilling machine.

The 24 coupons per design were used as follows:

1) 6 coupons – No preconditioning (as received)
2) 6 coupons – 3 cycles @ 230°C (tin-lead solder temperature)
3) 6 coupons – 3 cycles @ 260°C (lead-free solder temperature)
4) 6 coupons – 6 cycles @ 260°C (lead-free solder temperature)

Results of DOE

Material Comparison with Drill #1 and NFPs included
The Weibull plots are shown below:

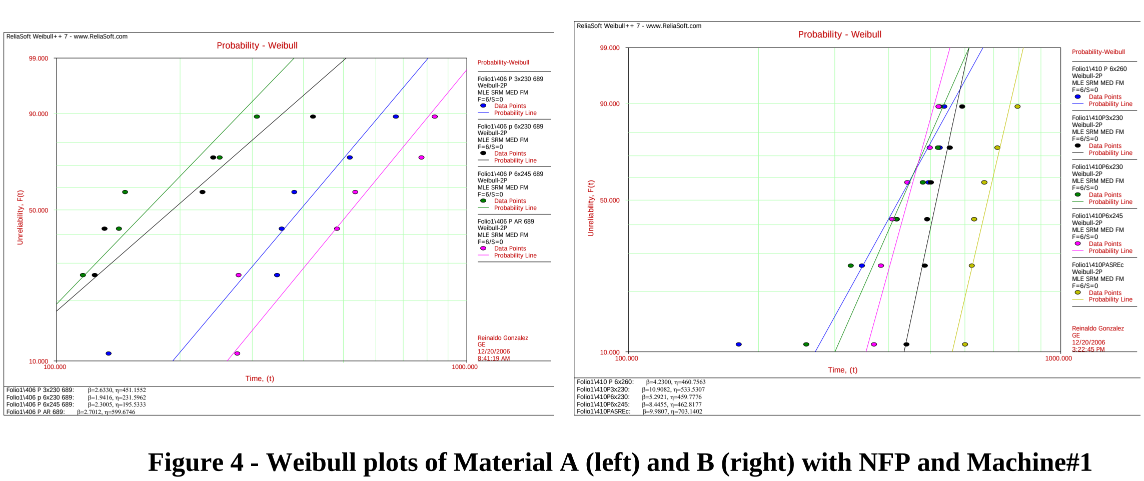

Figure 4 - Weibull plots of Material A (left) and B (right) with NFP and Machine#1

The 10% CTF data is summarized below:

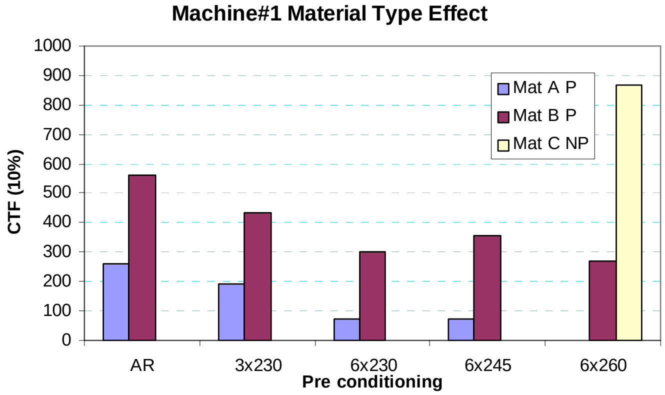

Figure 5 - 10% cycles to failure for the three materials tested. Materials A and B have NFP and Material C did not have NFP.

No failures were observed on Material C at the other preconditions. The test was stopped at 1000 cycles. The Weibull plots show that material B is superior to material A, it has higher Beta values and higher 10% CTF. Material C without NFP is superior to material B.

NFP Comparison with Material "B" and Drill #1

The Weibull plots are shown below:

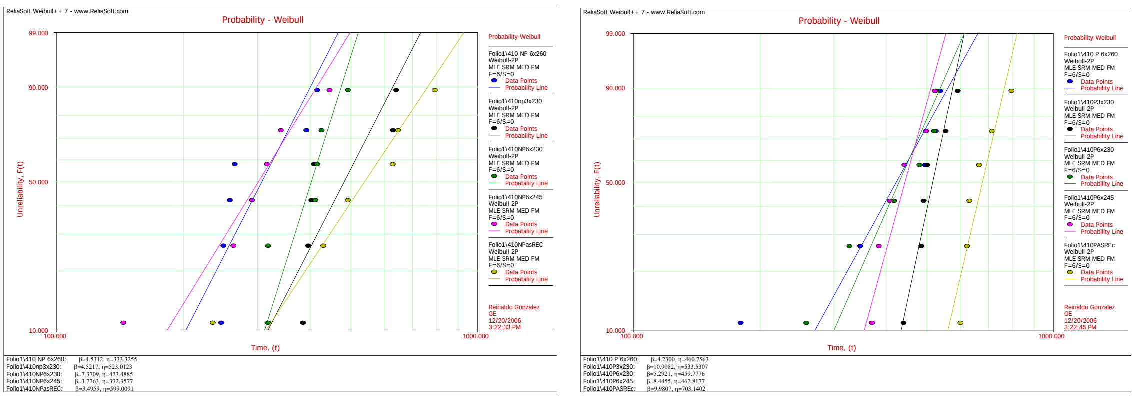

Figure 6 - Weibull plots of Material B Machine#1without (left) and with (right) NFP

The data shows that Material B with NFP has a larger characteristic life and also a higher wear out rate. To clearly see the difference the 10% CTF are shown below.

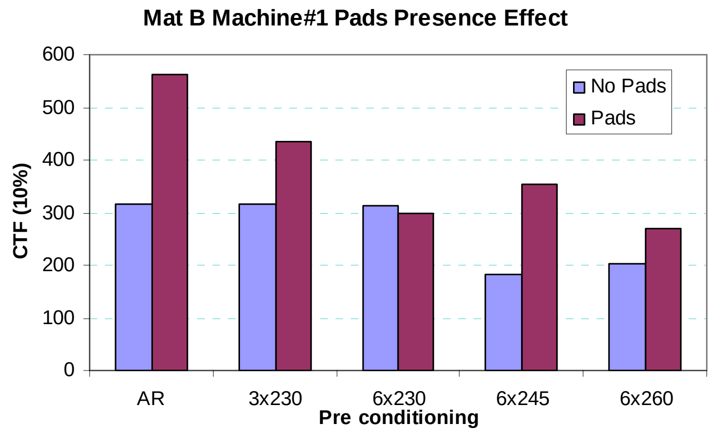

Figure 7 - 10% CTF for Material B, drill machine#1 with and without NFPs.

This result shows that pads provide a longer life on vias, the pads might be providing more support points adding strength to the structure. On the other hand, drilling through all these pads increases the chance of having process defects that usually show in the field as infant mortality failures.

Drilling Machine Comparison with Material "B" and Material "A"

The effect of drilling machine is not pronounced. Machine#1 is slightly superior to #2. See figure below for comparison

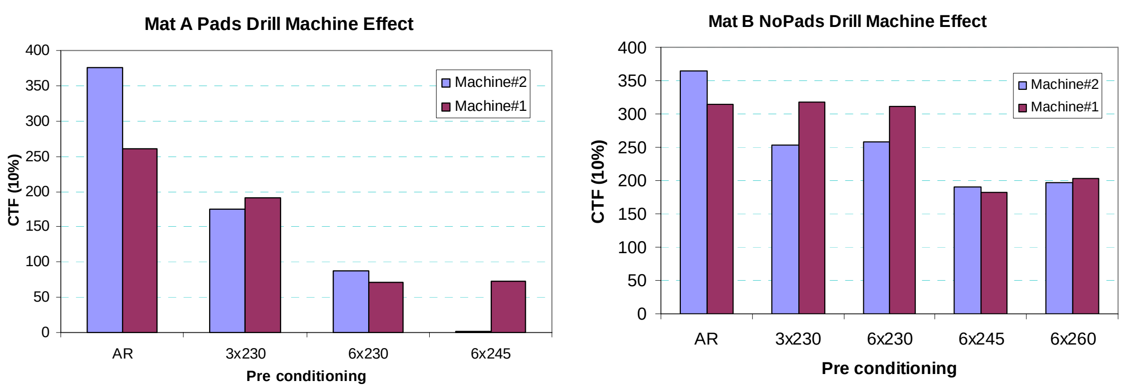

Figure 8 - Comparison of Machine drill for Mat A with pads (left) and for Material B without pads (rights)

Failure Modes

Microscopic examination of cross sections revealed five failure modes. The modes included crazing, metal fatigue, barrel cracks, corner cracks, and material break down. There was evidence of "stress relieving" delamination from the crazing. The summary below shows the failure modes observed for each material (A, B, C) and if the material had NFP (P, NP):

	A/P	B/P	A/P	C/NP	B/NP	B/P	B/NP	C/NP
IST	79	370	4	1000	224	180	246	895
PreCon	6 X 230	6 X 245C	6 X 245C	6 X 245C	6 X 260C	6 X 260C	6 X260C	6 X260C
Activity	10.0%	10.0%	10.0%	2.4%	10.0%	10.0%	10.0%	10.0%
Cu Thick	.001"	.001"	.001"	.0009"	.0012"	.0011"	.0011"	.0011"
Barrel C	X	X	X					
Metal F		X		X	X	X	X	X
Corner C						X		
Delam	No	Crazing	Break Dn	Crazing	Crazing	Crazing	Crazing	No

Figure 9 - Failure mode distribution for cross-sections taken

Overall, for Material A, the dominant failure mode was barrel cracking. For Materials B & C, the dominant failure mode was metal fatigue, and indication of via wear-out at end of life. Corner cracks were observed on Material B one cross-section. Crazing was evident in Materials B & C, which may have stress-relieved via and prolonged CTF data.

Metal Fatigue: Some of the cracks observed in these sections would be classified as metal fatigue. Metal fatigue cracks usually transverse the copper at a 20 to 50 degree angle. A metal fatigue crack will typically propagate between copper crystals; cracks are frequently closed at ambient temperatures. This type of failure mode is consistent with slowly accumulating resistance that accelerates over time.

Barrel Cracks –Barrel cracks are typically at right angles to the plane of the drilled holes; the crack runs through copper crystals and the crack is open, or gaping, at ambient temperature. The gaping crack imparts a degree of hysteresis in the coupon. In the cooling phase of the thermal cycle the resistance does not turn to the original measurements. A reluctance to return to the original condition is called hysteresis. Barrel cracks are observed in coupon with reduced IST cycles to failure.

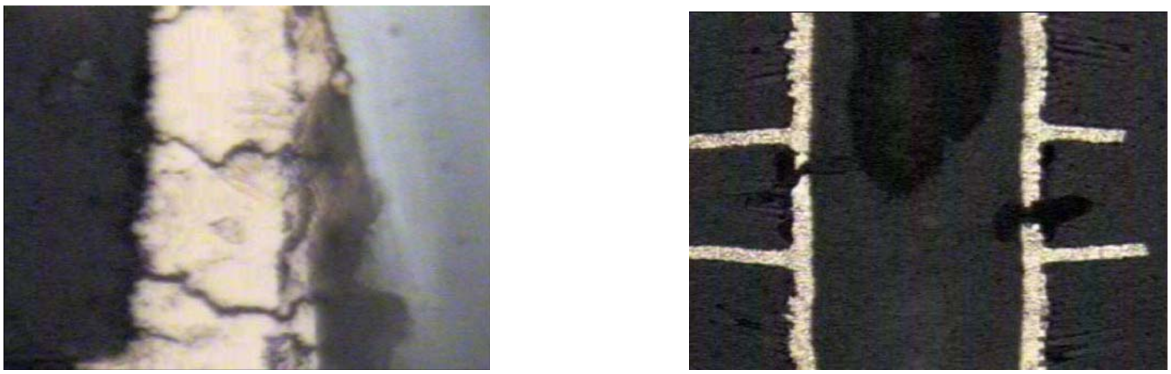

Figure 10 - On left metal fatigue on Material C, drill#1, with NFP after 1000 cycles. On right barrel crack on Material A, drill#1 with NFP, 6x230 condition, 79 CTF.

Corner Cracks and Pad Rotation– Corner cracks may be a result of pad rotation due to Z-axis expansion. The expansion of the dielectric material puts strain on the corner of the PTH producing a fracture line the proceeds up the face of the surface foil and then across the plated copper at a 45-degree angle. Relatively small cracks can cause a 10% increase in resistance. With the advent of lead free assembly failure modes are shifting from barrel cracks to corner cracks. Corner crack failures can be “wear-out” type failures where the copper at the corner is fatigued over time due to pad rotation from repeated Z-axis expansion associated with thermal cycling. Corner cracks are seen in many of the coupons preconditioned to 6 X 260C.

Material Breakdown - Dielectric material can breakdown when subjected to high temperatures over extended periods of time. This condition is considered a chemical breakdown of epoxy. This type of failure is seen more often where a less robust material is exposed to thermal excursions associated with lead-free assembly and rework. These failures are also associated with interconnect break down and post separation. This condition presents itself with round voids or cracks with rounded ends.

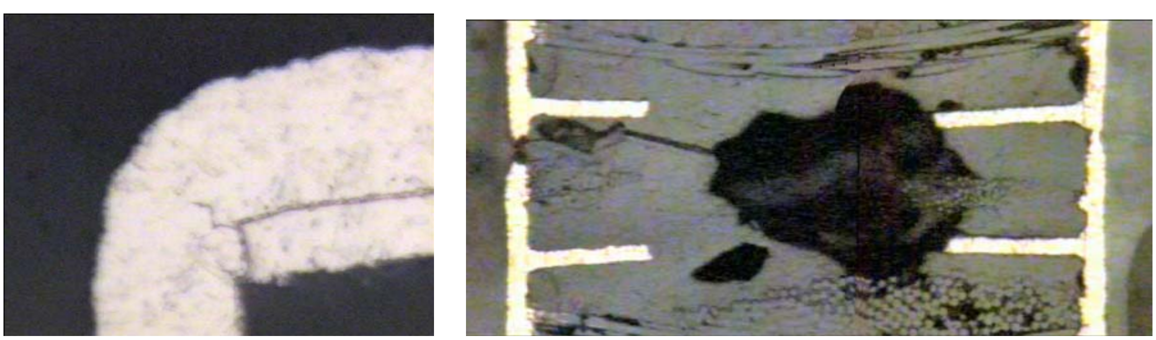

Figure 11 - On left corner crack on Material B, drill#1 with NFP, 180 CTF. On right material breakdown on material A, drill#2, with NFP, 6x245 condition 4 CTF.

Crazing - Fine cracks in the bond between the glass fibers and the dialectic produce a condition described as crazing. This condition is rejectable to IPC-A-600 if the crazing bridges the space between two conductors. In this study we believe that the presents of a significant amount of crazing has stress relieved the PTH and artificially extended IST cycles to failure.

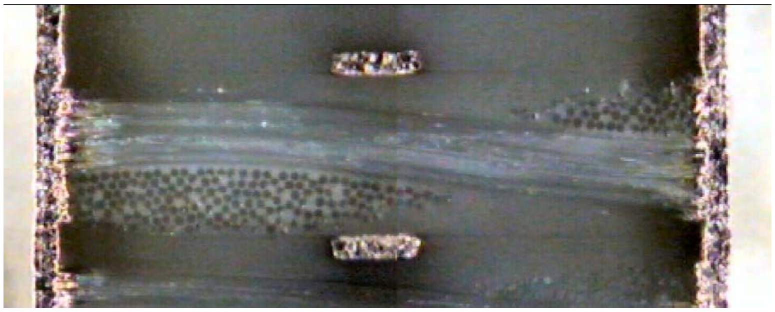

Figure 12 - Crazing seen in material B, drill#1, with NFP, 6x260 condition, 246 CTF

Thermal Cycle Results

The IST coupon testing is one of the better tests to help choose the optimum PCB configuration. This IST results can not be used to predict field behavior. Attempts have been made to use IST above the Tg to predict life, see ref (4). Testing above Tg shorten the test duration but at the same time add uncertainties of inducing artifacts.

The IST test is looking for end of life failures not for infant mortality. The failures described at the introduction are infant failures and were not seen during the IST testing.

The other option to find end of life failure modes is to perform thermal cycle on finished boards. The data below show the results with material B.

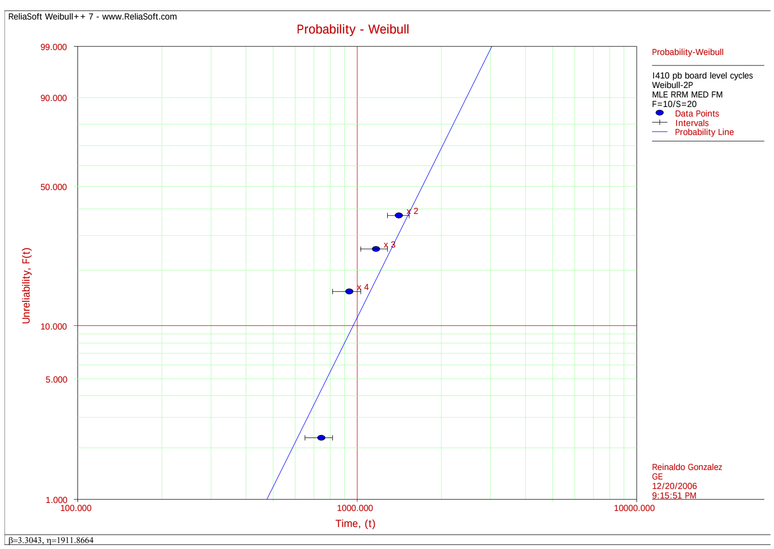

Figure 13 - CTF during thermal cycle testing on finished boards from –40C to 125C

The test conditions were –40C to 125C, 15 min dwell time and 30 C/min ramp rate. The failure mechanism was via cracking, see figures below.

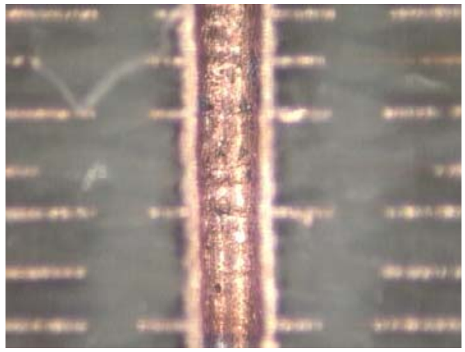

Figure 14 - Via crack (metal fatigue) failures during thermal cycle

Solder joint thermal cycle failures are affected by all of the thermal cycle parameters: dwell time, ramp rate, mean temperature and temperature range, see ref 5-9 and more so in lead free. PTH failures models such as CALCE FAST failure mode analyzer takes into account the temperature range, PTH geometry, and material properties. A comparison of the thermal cycle and the IST results does not show a good correlation. The finished boards were constructed with material B, drill#1 and half of NFP removed, and it is a thinner board. They went through only 1 precondition at 260C. To make a rough comparison, the 3x230 condition is used (to compensate for having higher temperature but only one time)

Test	Temp range (C)	Range mean (C)	Weibull Beta	63.5% CTF	10% CTF	Aspect ratio
IST	125	87.5	4.5	523	317	9:1
TC	165	42.5	3.3	1911	967	7:1

The table shows that TC provided a longer life. The beta parameters are comparable. Parameters in favor of a longer life are the lower range mean and the lower aspect ratio. A very critical parameter against a longer life is the temperature range. Other difference is that TC testing was done on finished boards with underfill and heatsink. So there are conflicting parameters to allow to draw any conclusion due to the several differences of the two configurations.

Conclusion

The following conclusions were observed.

1) The lower CTE fab material (Material C) outperformed the other fab materials in mean cycles to failure (CTF). Material B shows higher CTE than material A but a larger characteristic life. Supplier indicated that materials B and C leave drilling debris that is powder like compared to material A which leaves a gummier like debris. This might indicates why material B outperforms material A.

2) An interesting result with NFPs was found. Contradictory to industry recommendations, the presence of NFPs actually improved the mean CTF for the same material and process. This may be a result of the NFP adding mechanical structure to the BGA via region, allowing for less thermal expansion and greater CTF.

3) The drill machine had little to no influence on CTF for the same material and design.

4) In addition, at the lead-free preconditioning temperature, separation of the glass fiber bundles was observed in most of the materials tested. This separation may have stress-relieved the via region, and may have also prolonged CTF results. An understanding of this phenomenon and the other failure modes is critical to developing a robust lead-free fab.

5) Attempts to compare results to standard thermal cycle (TC) testing were not successful due to the differences in the board configurations.

Acknowledgements

Special thanks to Paul Reid at PWB corp. for insightful feedback and recommendations.

References

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[2] B. Birch, “Discussion on non functional pad removal / backdrilling and PCB reliability.” PWB Interconnect Solutions Inc., Ontario Canada. Available at HTTP: http://www.polarinstruments.com/support/reliability/pads-nopads.pdf

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[8] M. Osterman, “Effects of temperature cycle parameters on fatigue life on Pb-free SnAgCu Solders”, CALCE June 2005 Web Seminar.

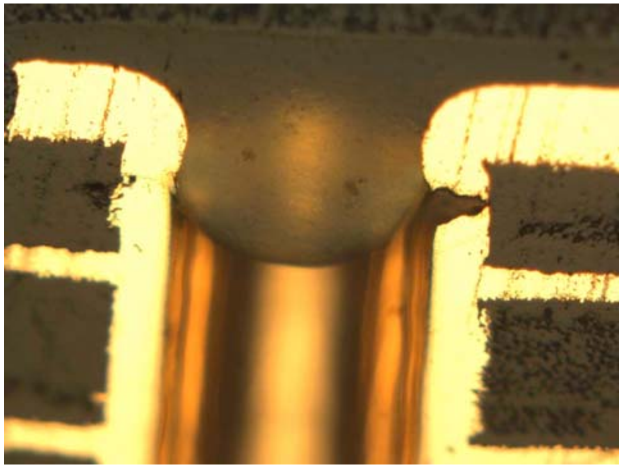
Agenda

1. Problem Statement - Via quality issues
2. IST Testing Overview
3. DOE Setup: Design, Materials, Process
4. IST Testing Results
    A. Cycles to Failure Results
    B. Failure Analysis
    C. Material Analysis
5. Thermal Cycling Results
6. Conclusions

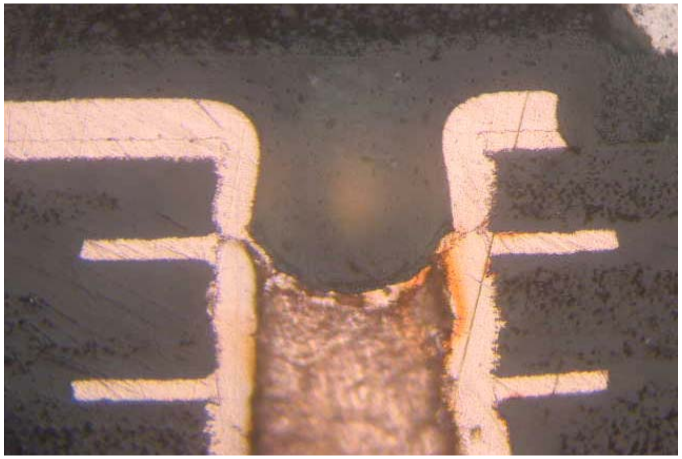
Circuit Board Properties

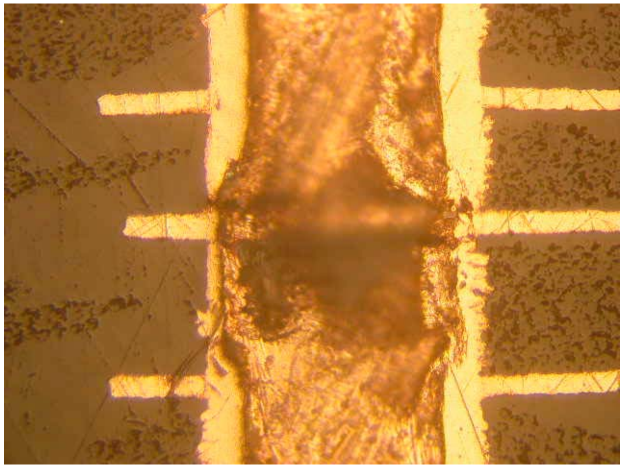
- 14 layers
- Via aspect ratio = 9:1
- 1000+ vias in BGA region
- Vias on 0.8 mm grid

PCB fab via quality issues

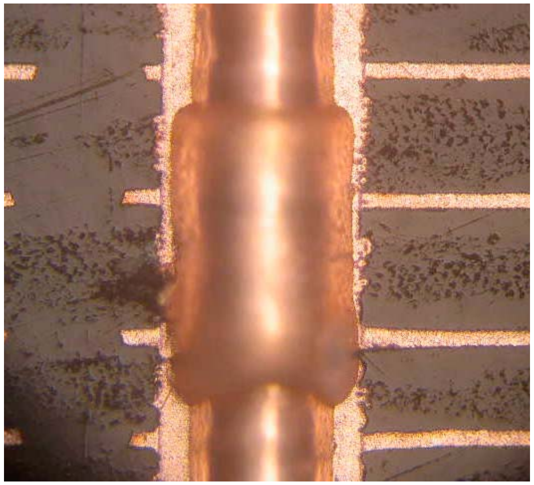


Dry Film Lock-In





Drill Defects (Debris, Etch Resist)



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IST Testing: What is IST?

1. There is a heating circuit and sensing circuit on the coupon. This allows for continuous resistance testing with power (heating Circuit) and without power (sense circuit). Failure is considered a 10% increase in resistance vs. baseline
2. **1 heating cycle = ambient to 150C**
3. **4 types of testing**
    1. As received - no pre-conditioning (measure cycles to failure)
    2. Preconditioning (3 cycles ambient - 230 C to simulate tin-lead assembly) - cycles to failure
    3. Preconditioning (6 cycles ambient - 230 C to simulate assembly + rework) - cycles to failure
    4. Preconditioning (6 cycles ambient - 260 C to simulate lead free) - cycles to failure
4. Also can test for registration issues and delamination issues with IST coupon
5. Can test for material Tg analysis using TMA & DMA methods
6. Majority of resistance is in via barrel, therefore resistance changes will correspond better to via failures/issues.
7. **Influence of IST failures (in order)**
    1. copper quality (copper purity and plating quality) - biggest factor
    2. fab material
    3. hole quality, dead pads, 3-point contact, de-smear, etc
8. Company has thermal imaging and x-sectioning as standard part of failure analysis, then performs more detail inspection of via to determine exact failure mode.

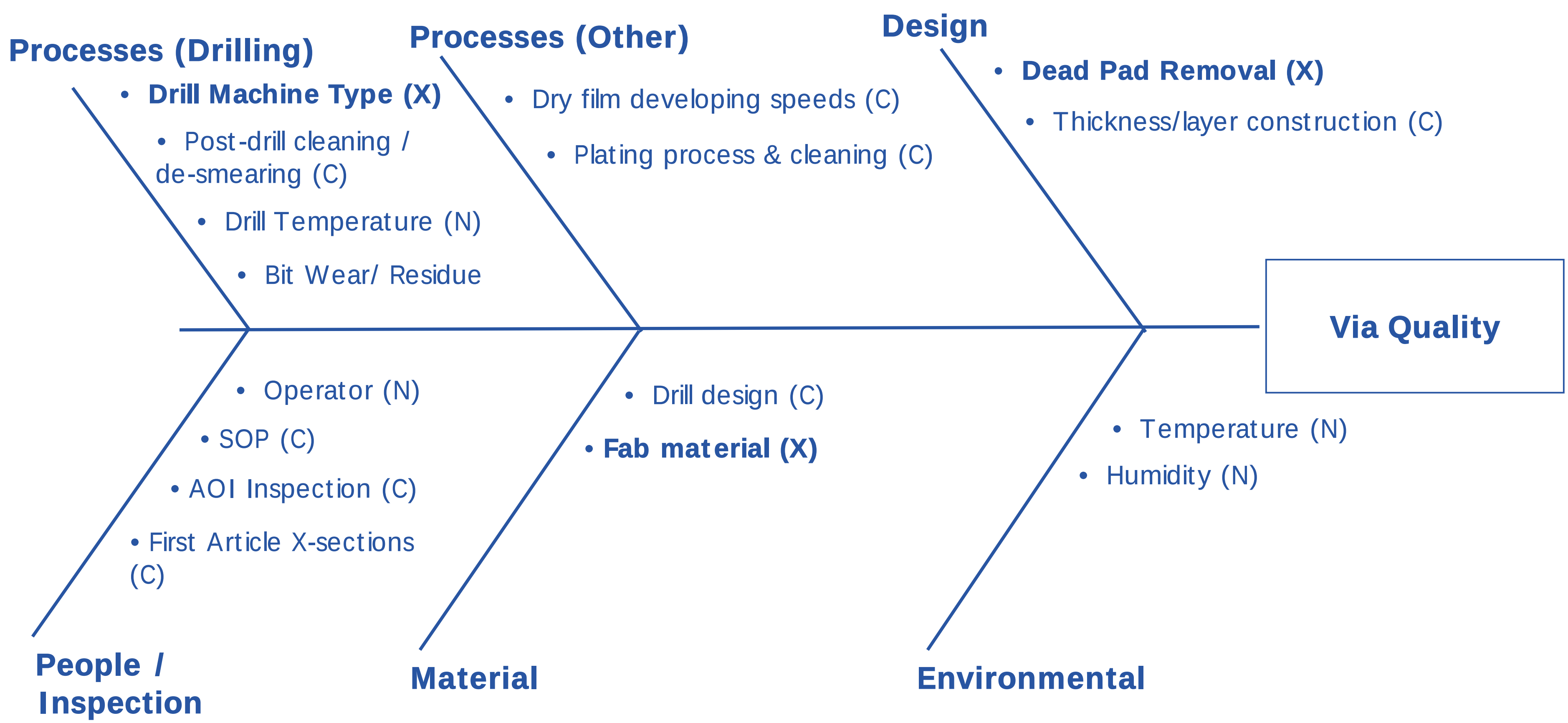
Step 4 - Develop Conceptual Design

DMADOV

What do we want to know?

What factors influence via quality?

Fishbone(C&E) Diagram:



What are the major factors that affect via quality?

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Design (Dead Pad Removal)

Dead Pad Removal Benefits

- Less drill bit heating (less drill debris potentially)
- No copper/FR4 discontinuities which may cause drill defects (nailheading, epoxy smearing,etc)
- Less process variation for drilling.
- Dead Pads are 4^{th} order effect & are not common in industry for high aspect ratio vias.

Dead Pad Removal Risks

- Potentially higher z-axis CTE expansion.
- Does copper provide mechanical structure to via?
- GEHC Component Review board recommends some amount of dead pads

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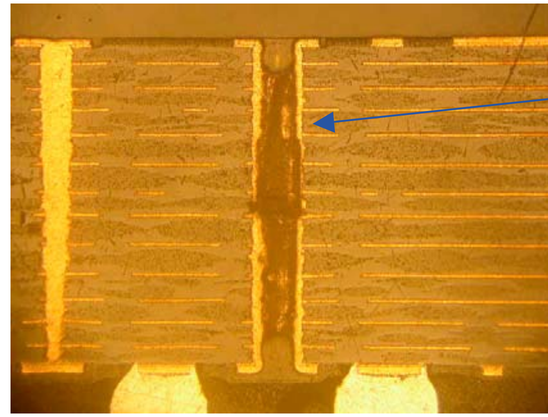
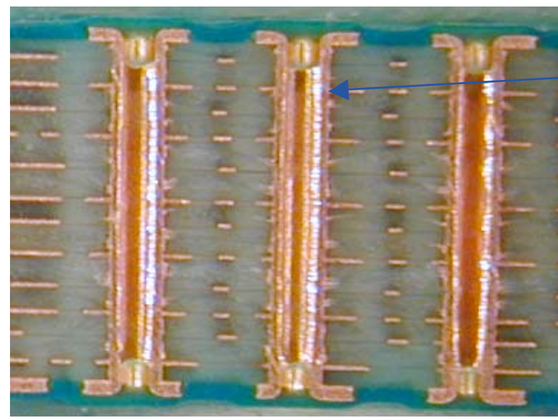
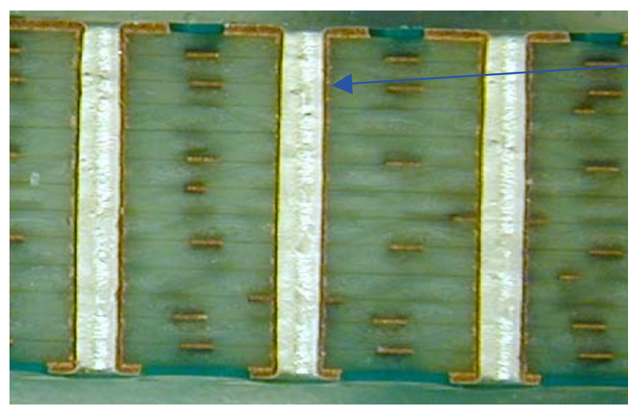


Dead Pads



Half Dead Pads



All Dead Pads Removed

Material Selection for DOE

Sample ID	Direction	Inflection Temperature (C)	Average CTE Before Inflection (um/m*C)	Average CTE After Inflection (um/m*C)
Mat A	z	164	49	196
Mat B	z	158	62	238
Mat C	z	169	43	107

Decision Factors:

1) Lead-free compatability
2) Presence of filler material to lower z-axis CTE
3) T_g and T_d temperatures
4) CTE in-plane and z-axis (pre and post T_g)
5) Drill-ability of the material
6) Moisture absorption

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IST Testing DOE

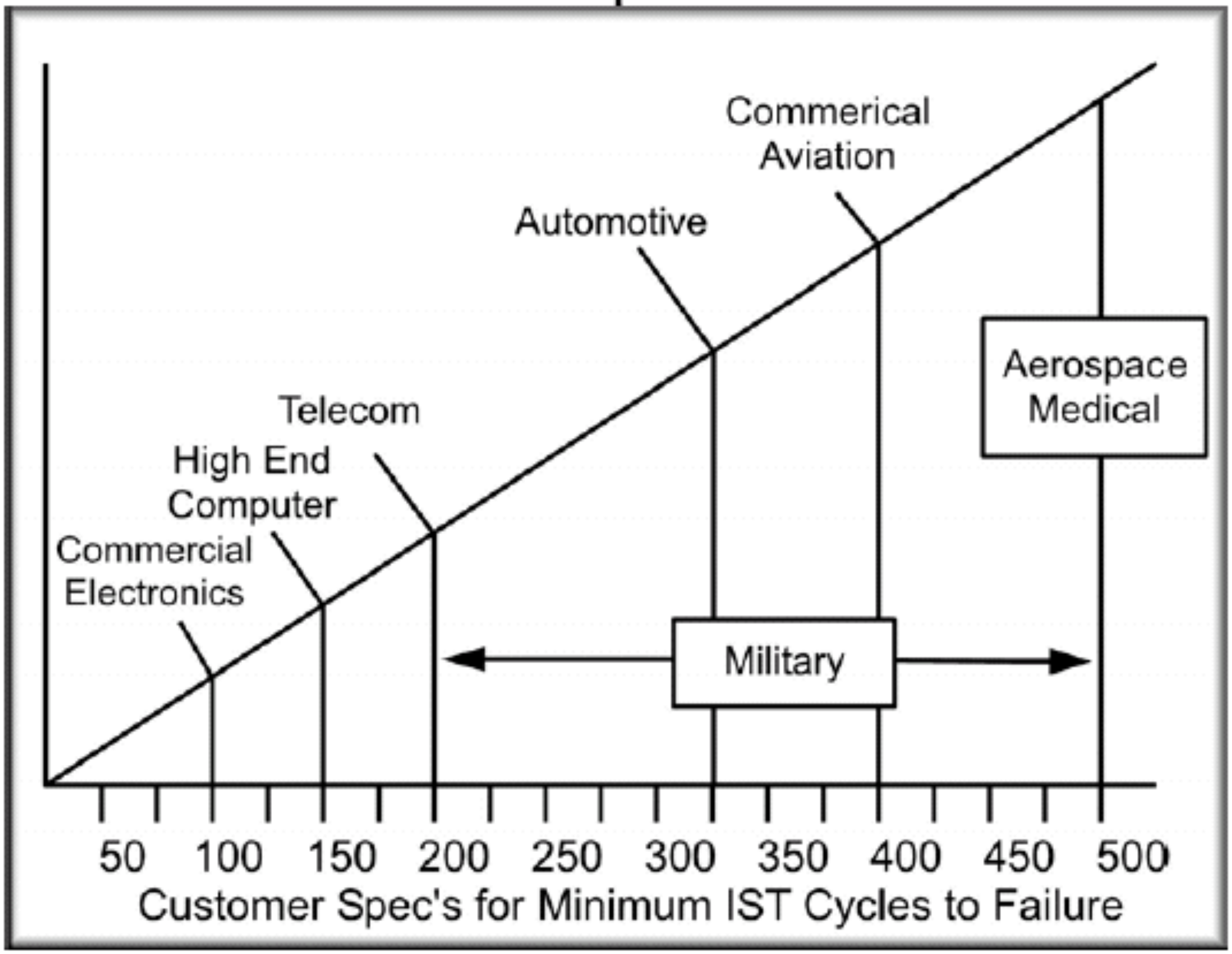
Design #	Material	Non-Functional Pads	Drilling Machine	# of coupons
1	A	Yes	#1	24
2	A	Yes	#2	24
3	B	Yes	#1	24
4	B	No	#1	24
5	B	No	#2	24
6	C	No	#1	24

The 24 coupons per design were used as follows:

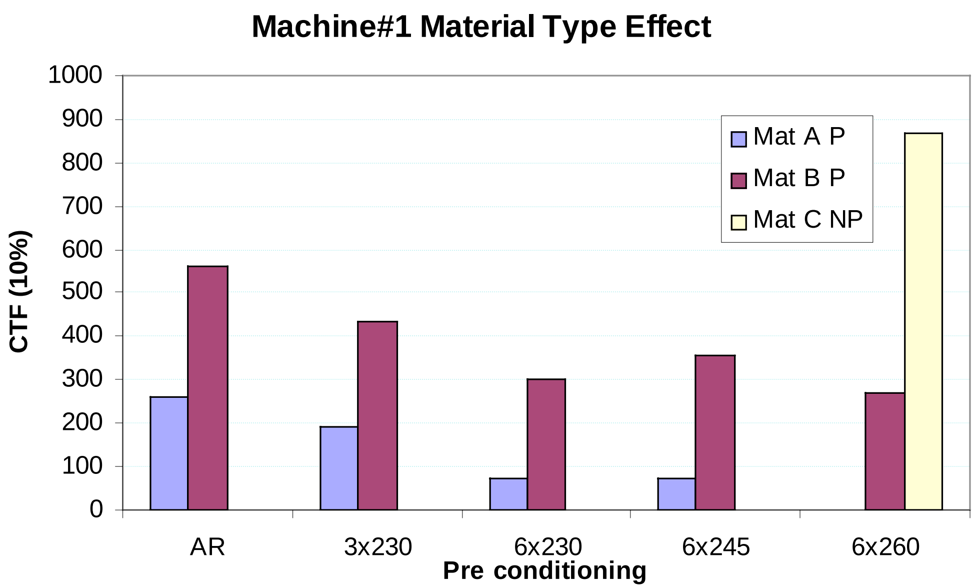
- 6 coupons – No preconditioning (as received)
- 6 coupons – 3 cycles @ 230C (tin-lead solder temperature)
- 6 coupons – 3 cycles @ 260C (lead-free solder temperature)
- 6 coupons – 6 cycles @ 260C (lead-free solder temperature)

IST Testing: Minimum Industry Requirement

Typical Minimum Requirement by Industry
Graph 4

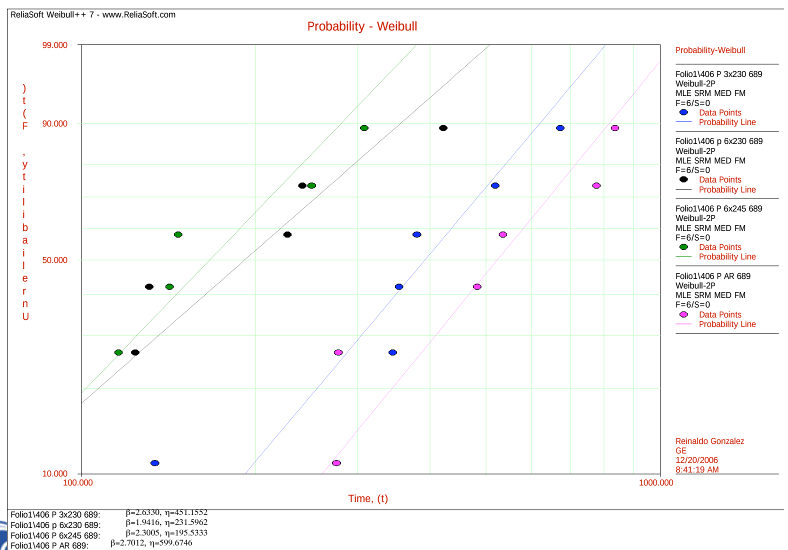


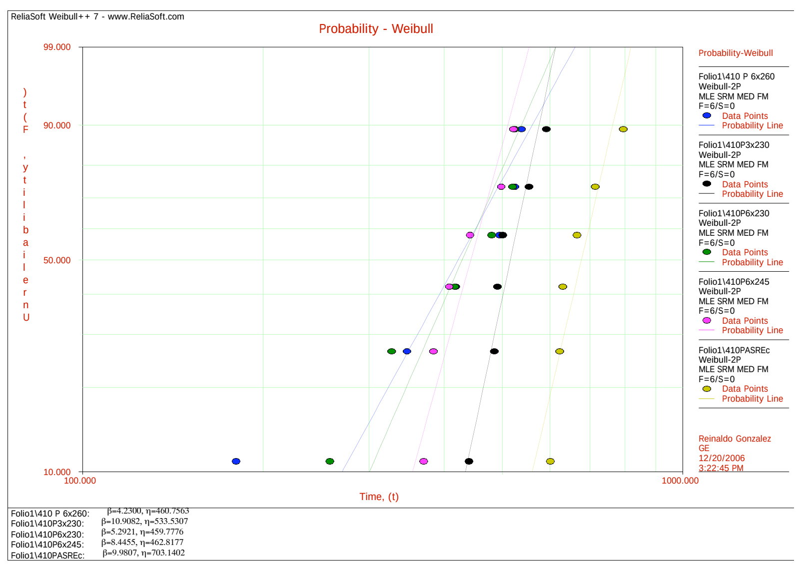
IST Testing Results – Material Effect



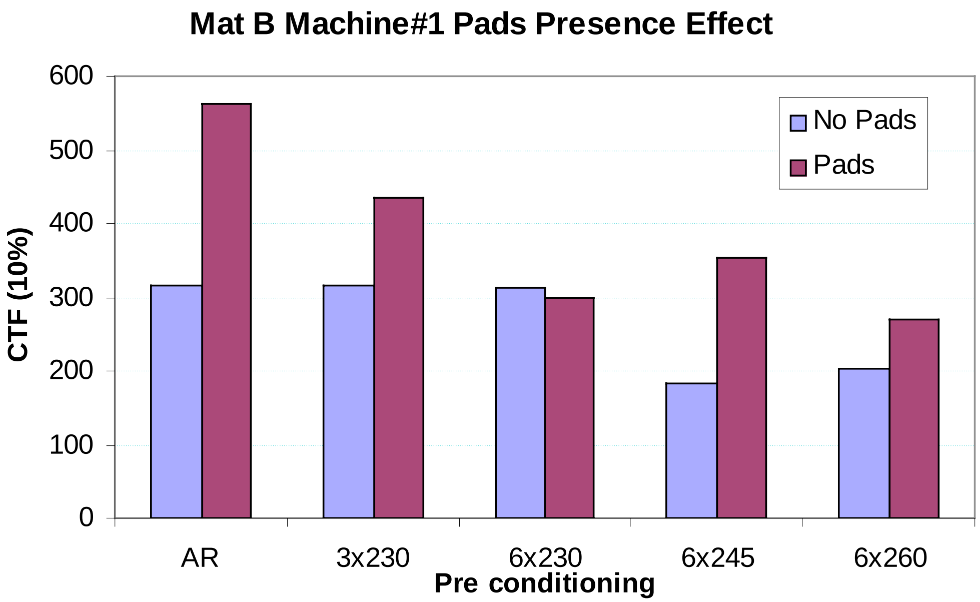
Summary

- Material C outperformed Materials A & B
- No failures observed with Material C at all preconditions except 6x260C
- Material B superior to Material A (higher Beta, CTF (10%) values)



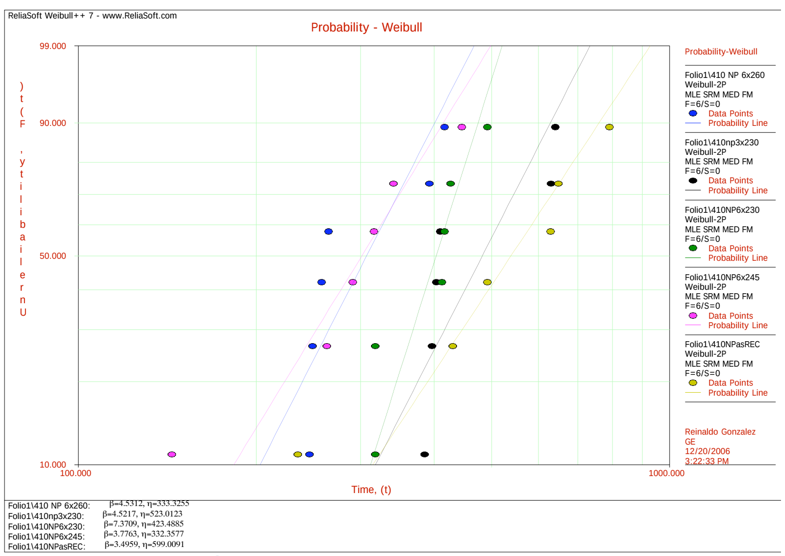


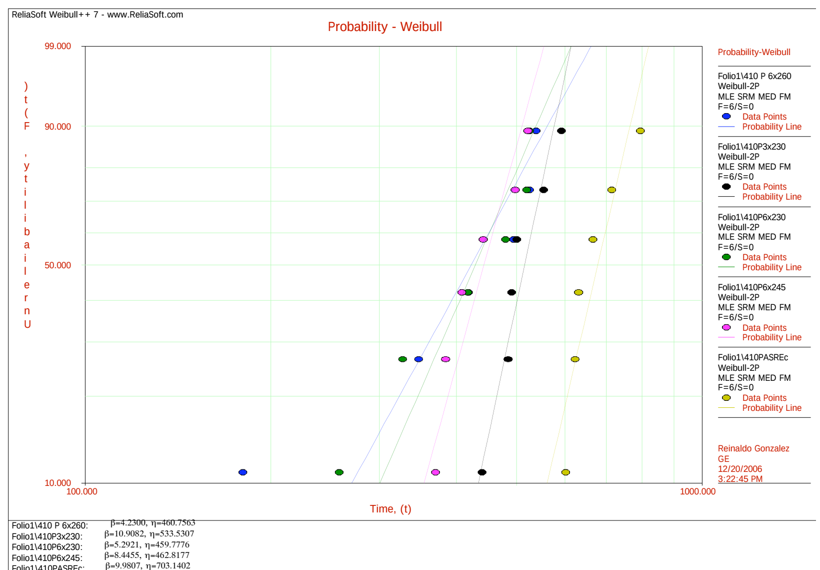
IST Testing Results – Design Effect (NFP vs. No NFP)



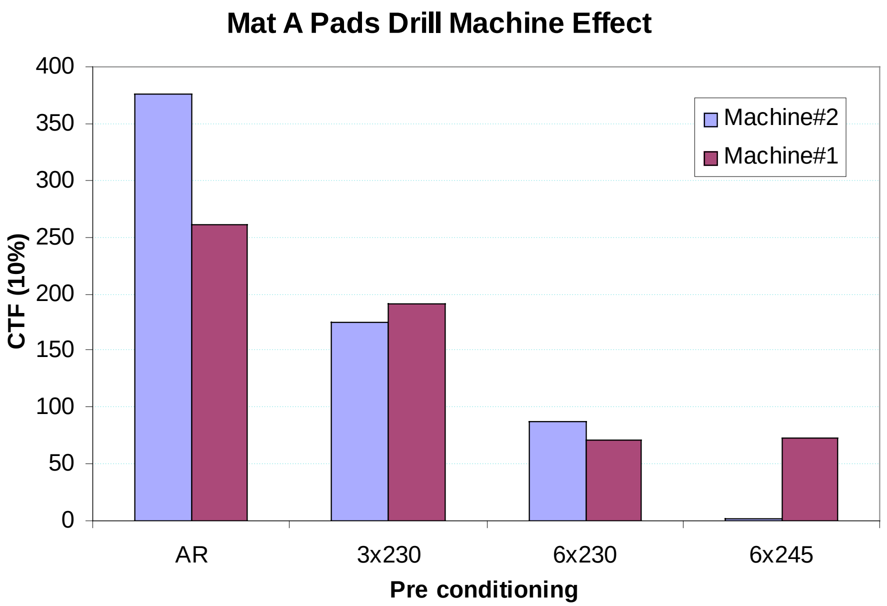
Summary

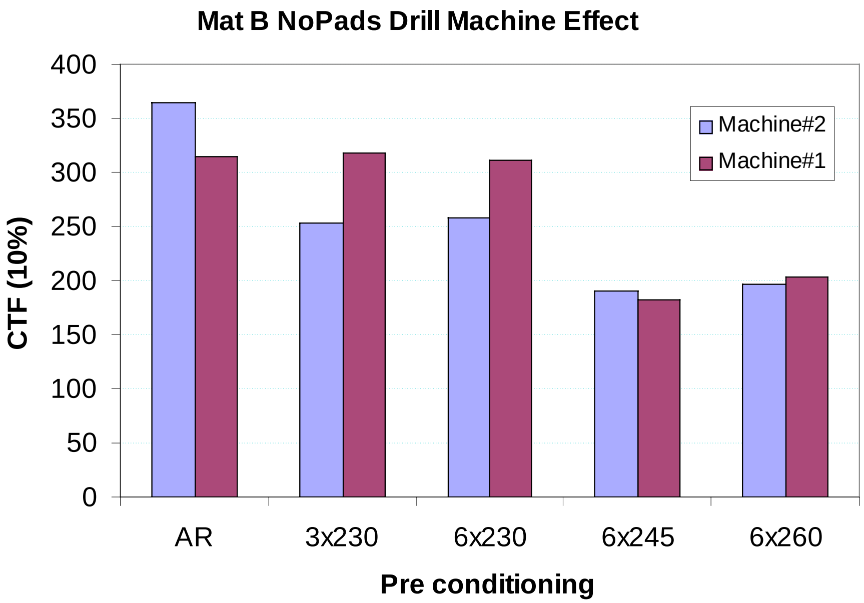
- Material B with NFP slightly superior to Material B without NFP, higher CTF (10%) .





IST Testing Results – Process Effect (Drill #1 vs. Drill #2)





Summary

- Effect of Drill Machine is not pronounced
- Drill #1 is slightly superior to Drill #2, not a very significant factor

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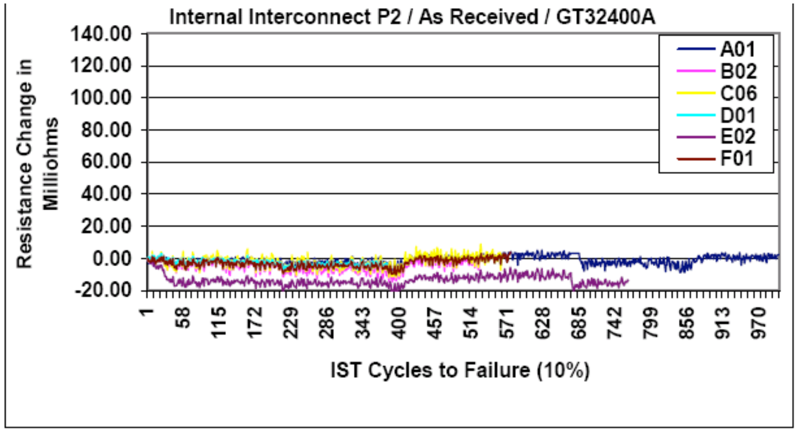
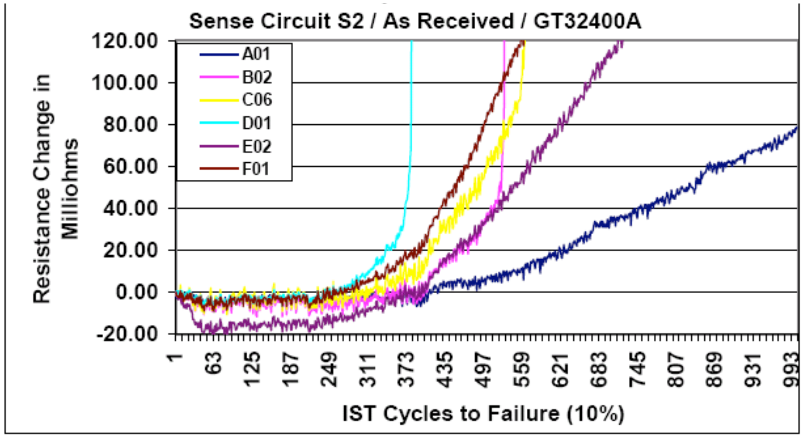
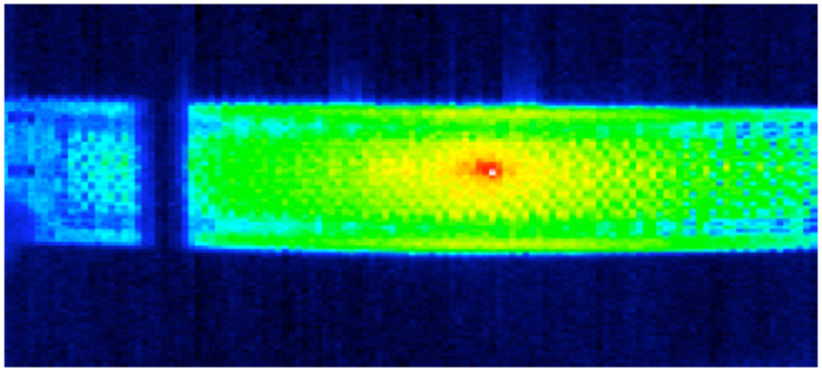
IST Testing: Examples of Resistance Graphs, Thermal Imaging for Failures





Thermal Image of a Typical Failure Site
Photo 1



IST Results: Failure Modes

Microscopic examination of cross sections revealed five failure modes. The modes included crazing, metal fatigue, barrel cracks, corner cracks, and material break down. There was evidence of "stress relieving" delamination from the crazing.

	A/P	B/P	A/P	C/NP	B/NP	B/P	B/NP	C/NP
IST	79	370	4	1000	224	180	246	895
PreCon	6 X 230	6 X 245C	6 X 245C	6 X 245C	6 X 260C	6 X 260C	6 X260C	6 X260C
Activity	10.0%	10.0%	10.0%	2.4%	10.0%	10.0%	10.0%	10.0%
Cu Thick	.001"	.001"	.001"	.0009"	.0012"	.0011"	.0011"	.0011"
Barrel C	X	X	X					
Metal F		X		X	X	X	X	X
Corner C						X		
Delam	No	Crazing	Break Dn	Crazing	Crazing	Crazing	Crazing	No

<u>Conclusions</u>

- Material A – dominant failure mode was barrel cracking
- Material B, C – dominant failure mode was metal fatigue – indication of via wear-out
- Corner cracks were observed on Material B one cross-section
- Crazing was evident in Materials B & C, may have stress-relieved via and prolonged CTF data.

IST Failure Modes: Metal Fatigue

Metal Fatigue – Some of the cracks observed in these sections would be classified as metal fatigue. Metal fatigue cracks usually transverse the copper at a 20 to 50 degree angle. A metal fatigue crack will typically propagate between copper crystals; cracks are frequently closed at ambient temperatures. This type of failure mode is consistent with slowly accumulating resistance that accelerates over time.

Material C, NFP Included, no failure at 1000 cycles

Photo 2

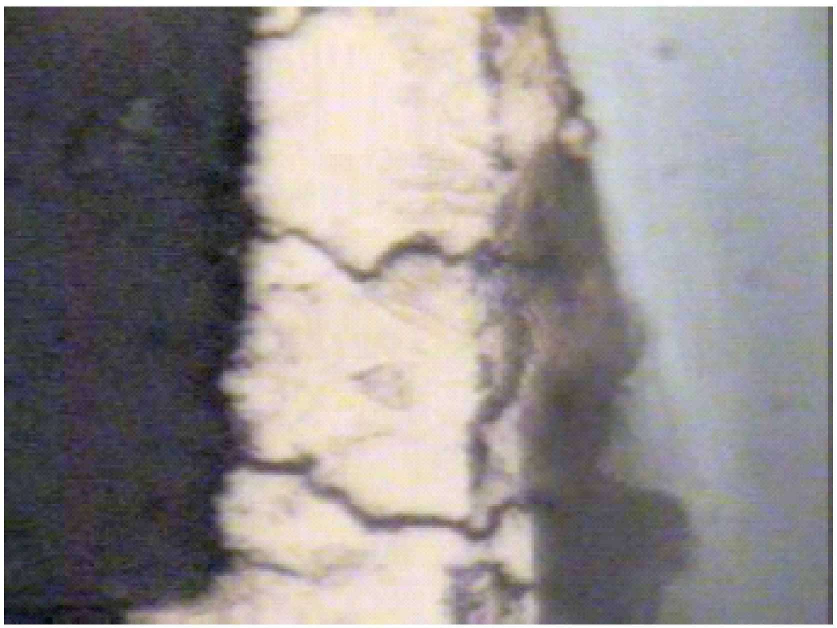
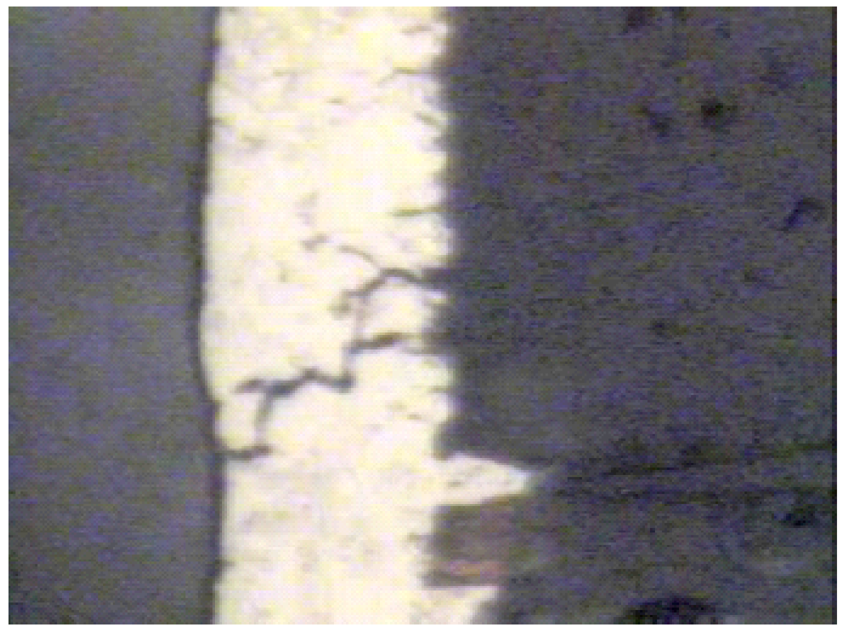


Photo 3



IST Failure Modes: Barrel Cracks

Barrel Cracks –Barrel cracks are typically at right angles to the plane of the drilled holes; the crack runs through copper crystals and the crack is open, or gaping, at ambient temperature. The gaping crack imparts a degree of hysteresis in the coupon. In the cooling phase of the thermal cycle the resistance does not turn to the original measurements. A reluctance to return to the original condition is called hysteresis. Barrel cracks are observed in coupon with reduced IST cycles to failure.

Material A, NFP Included, failure at 79 cycles

Photo 4

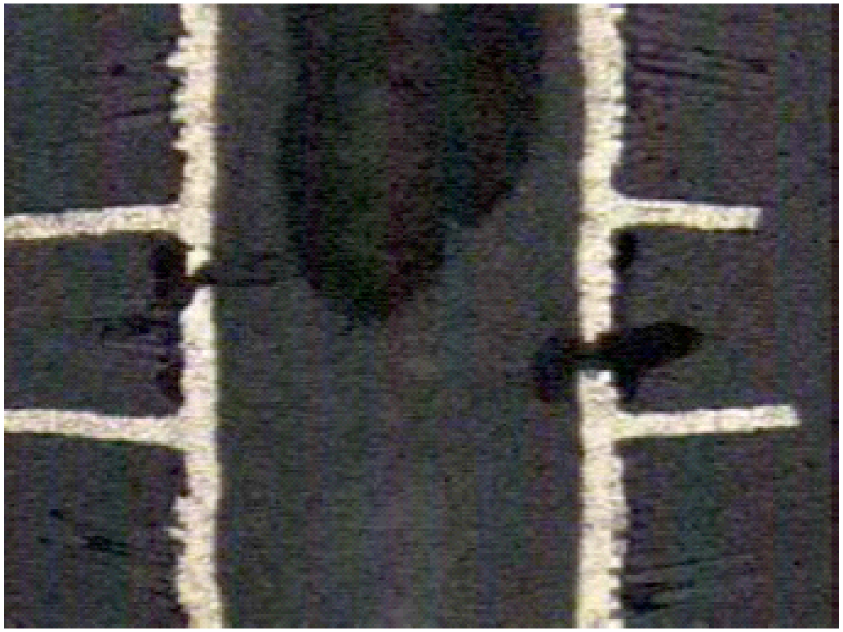


Photo 5

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IST Failure Modes: Copper Elongation

Copper Elongation – There are times when the Z-axis expansion is aggressive enough to produce an area thinning copper at the edges of a gaping crack. It appears that the copper is elongated prior to a rupture. This condition is seen when copper is being stress to its' limit by the Z-axis expansion of the dielectric during thermal excursions. The failure is usually abrupt in one or two cycles after onset.

Material A, NFP Included, failure at 4 cycles

Photo 6

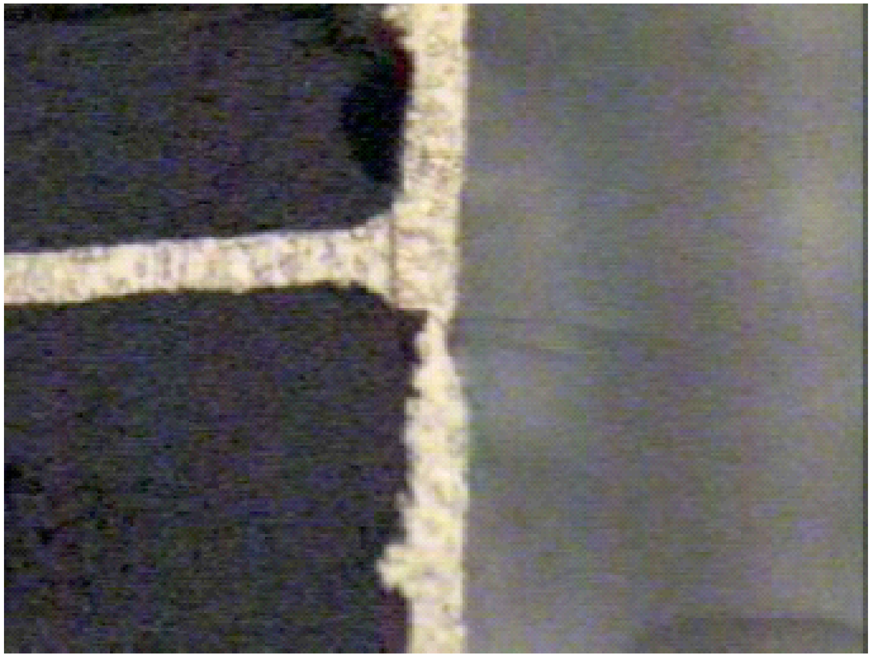

Photo 7

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IST Failure Modes: Corner Cracks

Corner Cracks and Pad Rotation– Corner cracks may be a result of pad rotation due to Z-axis expansion. The expansion of the dielectric material puts strain on the corner of the PTH producing a fracture line the proceeds up the face of the surface foil and then across the plated copper at a 45-degree angle. Relatively small cracks can cause a 10% increase in resistance. With the advent of lead free assembly failure modes are shifting from barrel cracks to corner cracks. Corner crack failures can be "wear-out" type failures where the copper at the corner is fatigued over time due to pad rotation from repeated Z-axis expansion associated with thermal cycling. Corner cracks are seen in many of the coupons preconditioned to 6 X 260C.

Material B, NFP Included, failure at 180 cycles

Photo 8

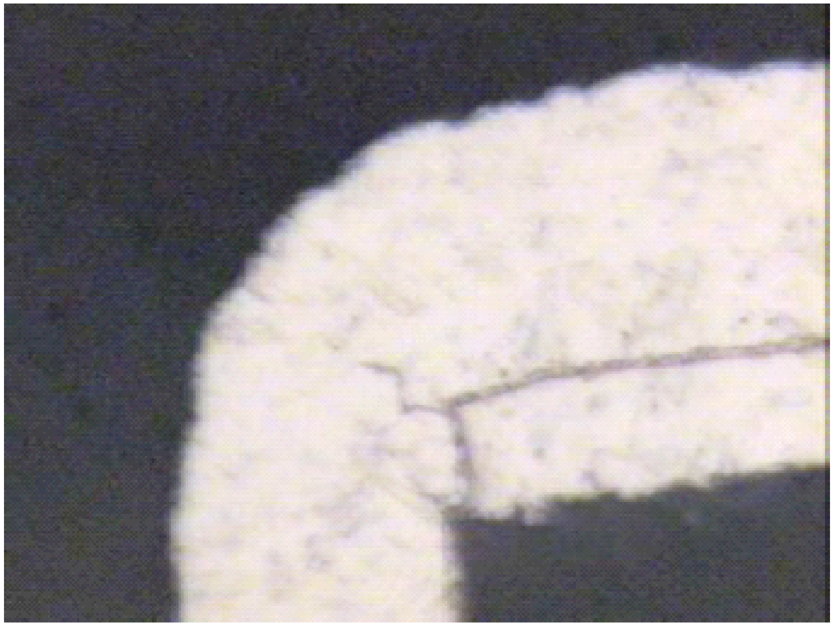
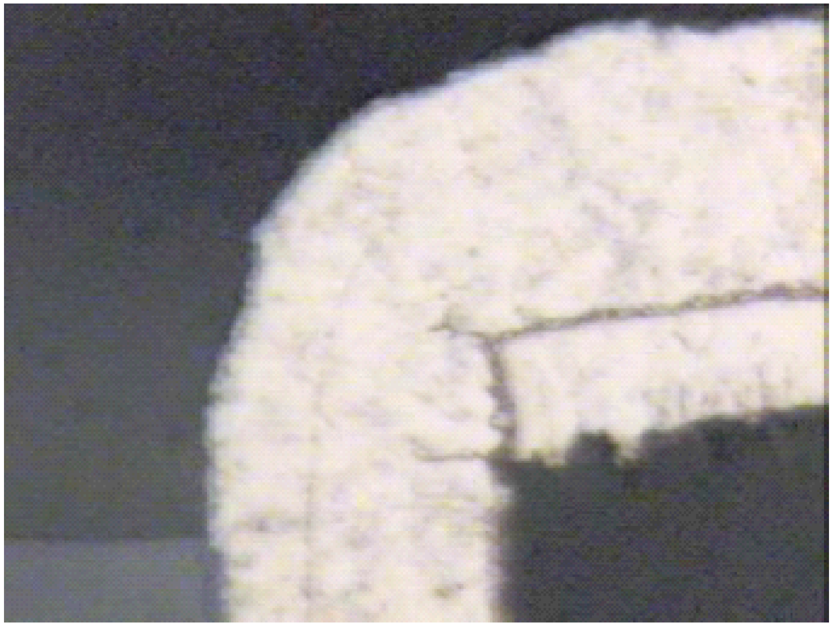


Photo 9

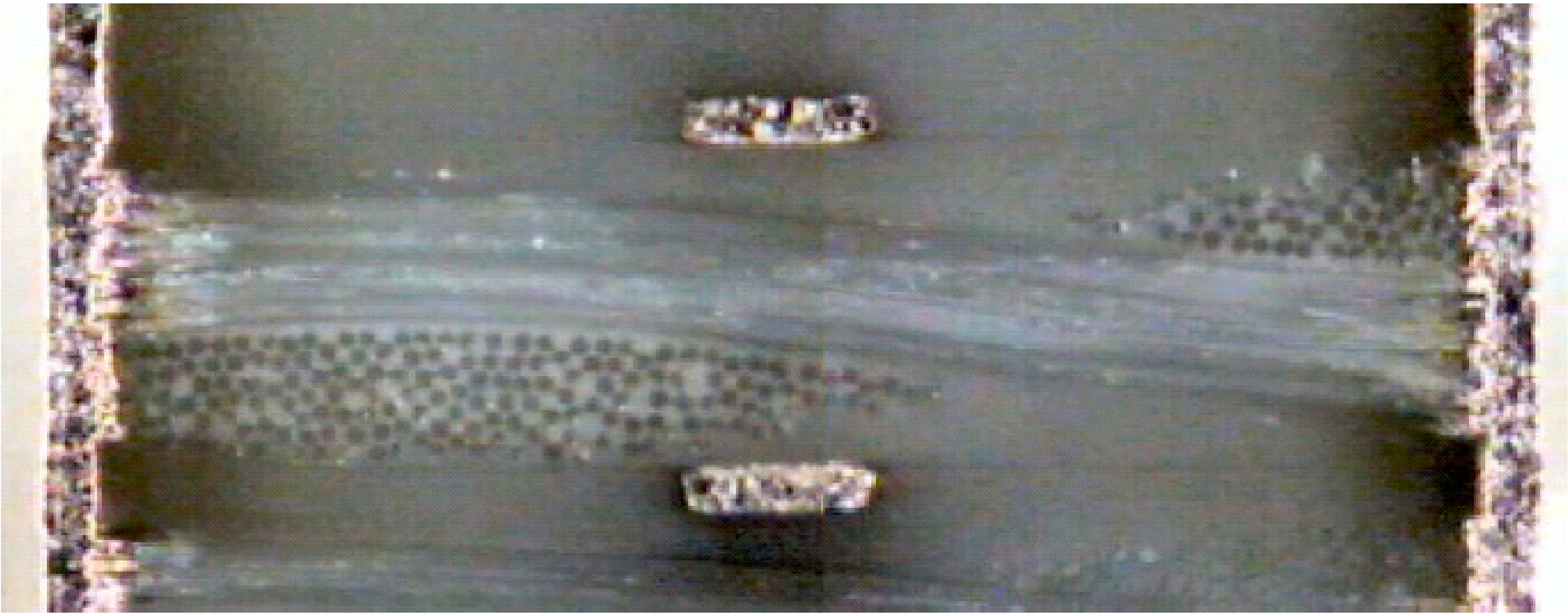


IST Failure Modes: Crazing

Crazing - Fine cracks in the bond between the glass fibers and the dialectic produce a condition described as crazing. This condition is rejectable to IPC-A-600 if the crazing bridge the space between two conductors. In this study we believe that the presents of a significant amount of crazing has stress relieved the PTH and artificially extended IST cycles to failure.

Material B, NFP Included, 6x260C, failure at 246 cycles

Dark Field Microscopy
Photo 12



IST Results: Material Analysis

Comments

- Material A: Failed cyclic TMA during preconditioning cycle, shows Material A not ideal for lead-free applications.
- Material B & C: Within acceptable TMA and DMA limits
- Material C had highest Tg and lastest longest during cyclic TMA testing

	Material A	Material B	Material C
TMA			
Tg α C	164C	158C	169C
Tg β C	164C	154C	171C
△ Tg	0C	-4C	2C
CTE α ppm/C	49 ppm/C	62 ppm/C	43ppm/C
CTE β ppm/C	196 ppm/C	238 ppm/C	107ppm/C
Cyclic T 260 (mod)	Cycle 6	38 min.	54 min.
DMA			
Storage 50C MPa	17375 MPa	16714 MPa	21525 MPa
Storage 220C MPa	1973 MPa	2827 MPa	5220 MPa
Storage Tg C	172C	165C	169 C
Loss Tg C	184C	182C	185 C
Tan △Tg C	186C	189C	198 C

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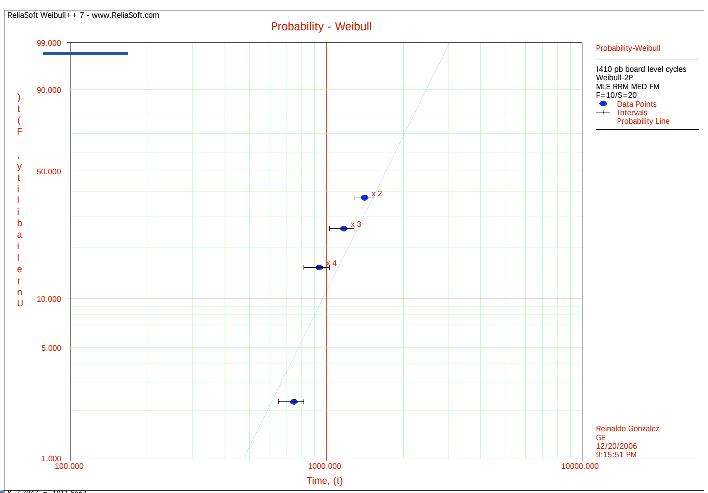
Thermal Cycling Results – Comparison To IST Results

Test	Temp range (C)	Range mean (C)	Weibull Beta	63.5% CTF	10% CTF	Aspect ratio
IST	125	87.5	4.5	523	317	9:1
TC	165	42.5	3.3	1911	967	7:1

Comparison to IST results

- Data presented as reference, IST performed on FAB and T/C performed on fully assembled board.
- Data indicated Beta's are almost equal for both IST and TC
- Data indicates that T/C produced significantly greater CTF, greater life.

Weibull: T/C for Material B, half NFP



Comments

- Thermal Cycling of Fully Assembled Boards – another method to obtain end of life reliability data
- Temp Cycle: -40 To 125 C, 15 minute dwell, 30C/min. ramp rate
- Results are with Material B with half NFP (every other layer)
- Failure mode is via cracking

Conclusions

1. Material C performed much better than either Material A or Material B for all pre-conditioning cycles.
2. Material B outperformed Material A for all pre-conditioning cycles.
3. NFP (non-functional pads) increased CTF on average for Material B.
   1) This may be a result of the NFP adding mechanical structure to the BGA via region, allowing for less thermal expansion and greater CTF.
4. The drill machine had little to no influence on CTF for the same material and design.
5. At the lead-free preconditioning temperature, separation of the glass fiber bundles was observed in most of the materials tested. This separation may have stress-relieved the via region, and may have also prolonged CTF results. An understanding of this phenomenon and the other failure modes is critical to developing a robust lead-free fab.