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How to Avoid Conductive Anodic Filaments (CAF)

Ling Zou

16 November 2015

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How Good Are Conformal Coatings at Preventing Sn Whisker Failures?
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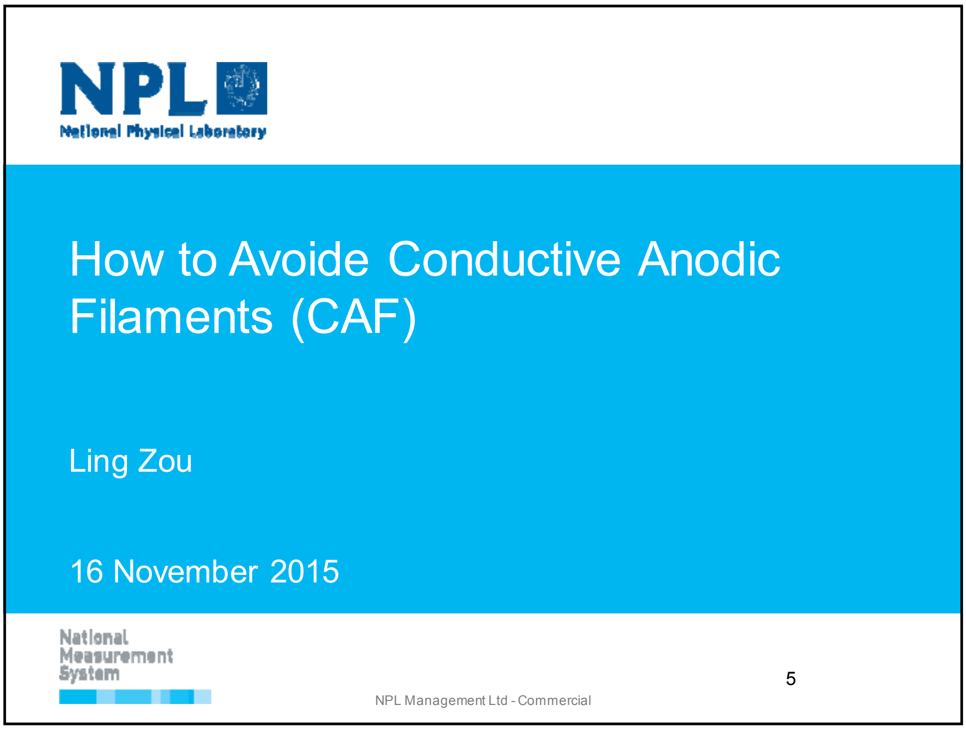

How to Avoide Conductive Anodic Filaments (CAF)

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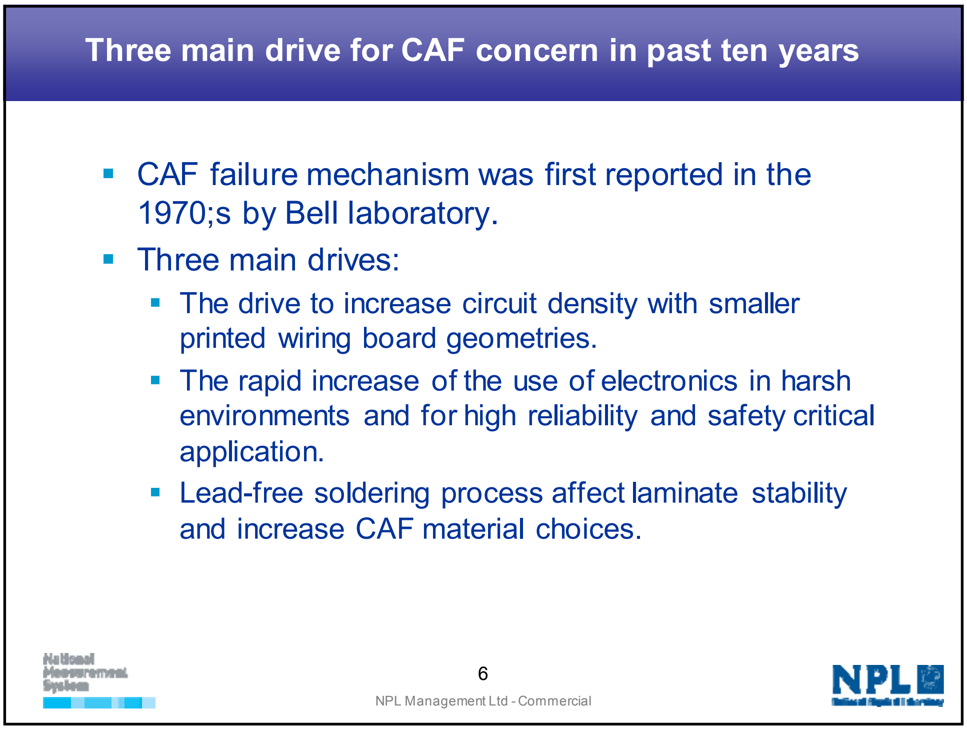
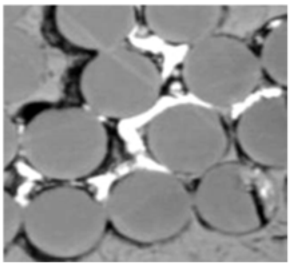


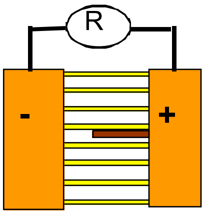
Three main drive for CAF concern in past ten years

- CAF failure mechanism was first reported in the 1970;s by Bell laboratory.
- Three main drives:
  - The drive to increase circuit density with smaller printed wiring board geometries.
  - The rapid increase of the use of electronics in harsh environments and for high reliability and safety critical application.
  - Lead-free soldering process affect laminate stability and increase CAF material choices.

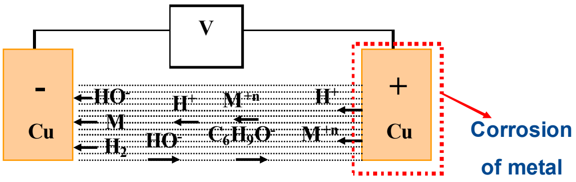
Conductive Anode Filament (CAF)

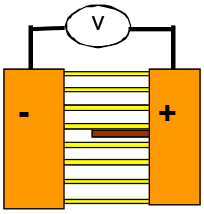
- CAF formation inside the PCB is an important failure mode for electronic circuit. It is a electrochemical process, and initially caused by anodic Cu corrosion.
- CAF is Cu corrosion products grow along the glass/resin interface from anode to cathode





Electrochemical process for CAF





Cathode

$\mathrm{Cu^{+n} + ne \rightarrow Cu}$

$\mathrm{H^+ + 2e \rightarrow H_2}$

$\mathrm{O_2 + H_2O + 4e \rightarrow 4OH^-}$

Anode

$\mathrm{Cu \rightarrow Cu^{+n} + ne}$

$\mathrm{2H_2O \rightarrow O_2 + H^+ + 4e}$

$\mathrm{Cu^{+2} + 2OH^- \rightarrow Cu\,(OH)_2}\downarrow$ $\mathrm{Cu\,(OH)_2 \rightarrow Cu\,O + H_2O}$

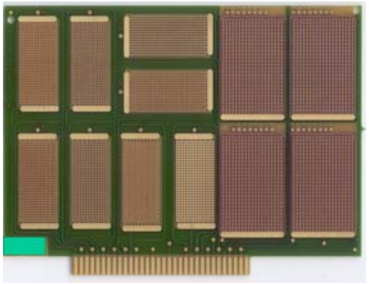
CuO: Black CuCl$_2$: Yellow brown CuSO$_4$ 5H$_2$O : Blue

- The Cu salt or **Cu (OH)$_2$ can be deposited at high pH**

Conditions for CAF formation

- Electrical charge carriers must be present to form Electrochemical cell
  - Ionic species inside PCB, H^+ and OH^- from water
- Water must be present to dissolve the ionic material and sustain them in their mobile ionic state
  - Moisture, humidity
- Acid environment around conductors is needed to initiate Cu corrosion at anode.
  - Acid contaminations from glass fibre surface, fluxes from assembly process or/and acid residues from plating process
- Pathway is needed for Ions to move
  - Delamination between glass fibre and resin due to reflow
- Bias acts as driving force for ion transport
  - Circuits need to be powered up in service

CAF measurement



- Test PCBs at high temperature and humidity (85°C/85% RH) condition with bias (50V) for 500 -1000 hours.
- Monitor Insulation Resistance (IR) continually.

Industry partners joint project

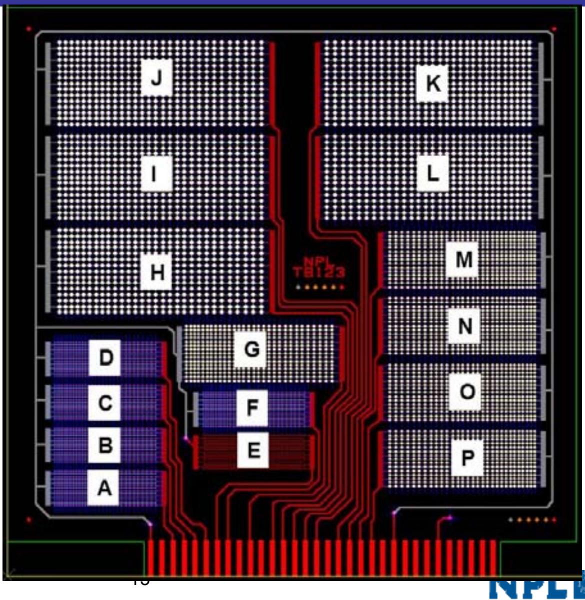
- Aero Engine Controls
- MBDA
- Isola
- Rolls Royce
- Invotec
- Graphic
- IBM
- TRW Auto
- GEN3 System
- Bosch
- Texas Instruments

CAF TB123 Test board design

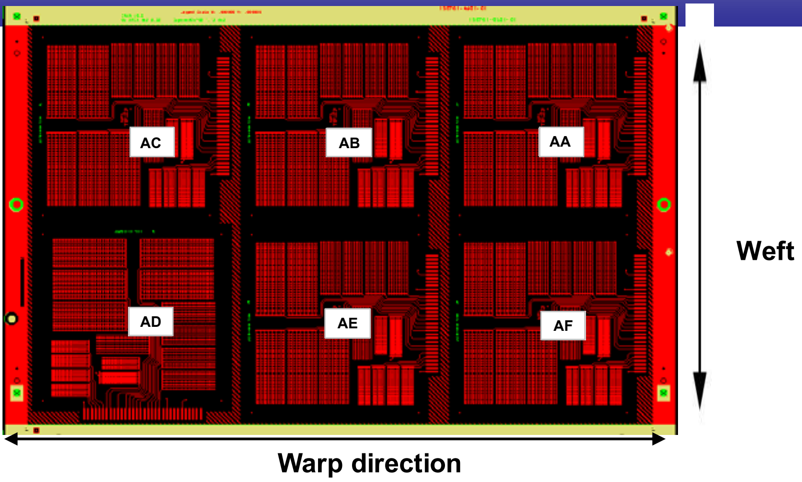
- Panel matrix for test board NPLB123
- Variables
  - Two PCB houses (X & Y)
  - 7628, 106, 1080 and 1067 glass styles
  - Switch between desmear process (X to Y etc.)
  - Switch between electroless process (X to Y etc.)
  - Standard and high desmear (X & Y)
  - Electroless and direct metallisation (X & Y)
  - 3 via sizes/pitches
    - 250µm drill Ø 300 µm wall to wall (X & Y)
    - 500µm drill Ø 400 µm wall to wall (X & Y)
    - 800µm drill Ø 550 µm wall to wall (X & Y)
  - Best glass finish (370HR Best)
  - Standard, high hit (1000-2000) drills & regrind drills (x3)

CAF TB123

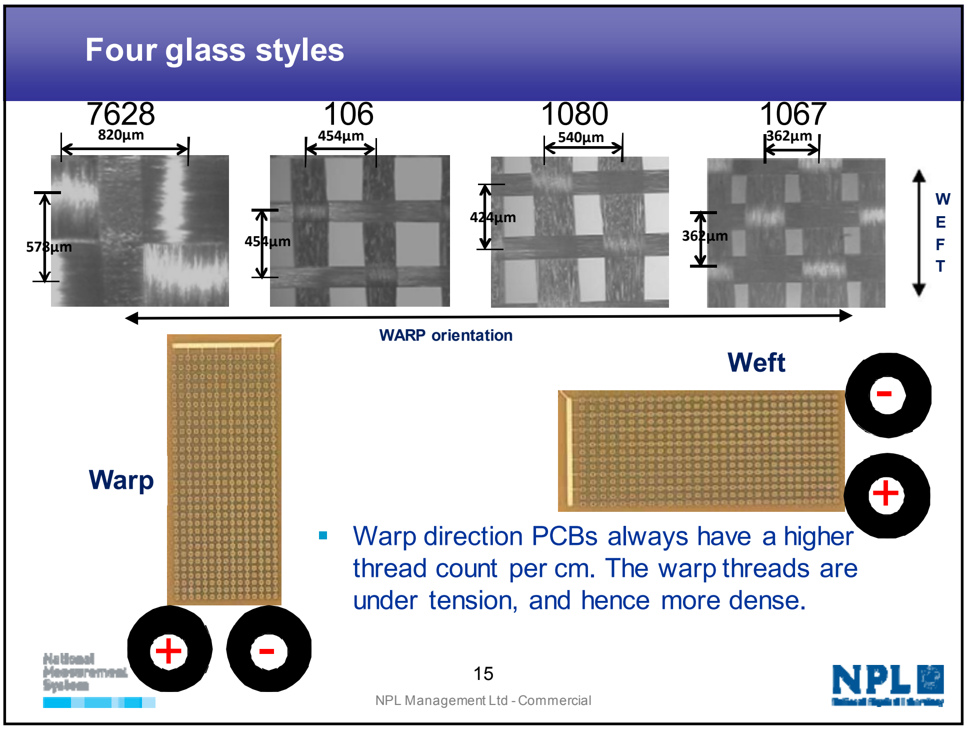
- 16 Patterns:
  - 5 x 250µm Ø 300 µm wall to wall
  - 5 x 500µm Ø 400 µm wall to wall
  - 5 x 800µm Ø 550 µm wall to wall
  - 1x SIR control
- Each Pattern has 450 holes & 420 CAF opportunities
- 30 holes in staggered in x Pitch varied by 0.541 mm corresponds to 1080 Fabric fill pitch
- 6 boards per panel (Horizontal or vertical)



TB123 Panel Layout

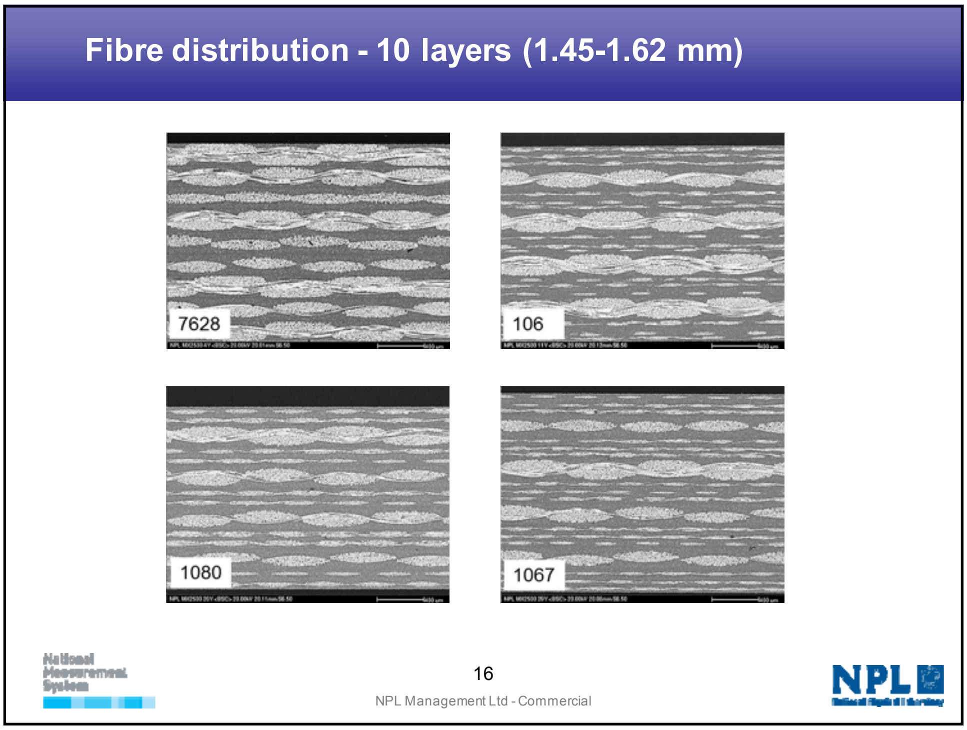


- For each panel, there were 6 PCBs, AA, AB, AC, AD, AE, and AF.
- Warp direction: AA, AB, AC, AE and AF (CAF formed along warp fibres)
- Weft direction: AD (CAF formed along weft fibres)



Four glass styles

- Warp direction PCBs always have a higher thread count per cm. The warp threads are under tension, and hence more dense.



Fibre distribution - 10 layers (1.45-1.62 mm)

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PCB panel matrix – 7628 glass fibre

Panel No.	Code	Glass/ Resin	Initial process	Desmear	Electroless	Post process	Drill
1	X electroless	7628	X	X standard	X standard	X	P1
2	Y electroless	7628	Y	Y standard	Y standard	Y	P1
3	X Y electroless	7628	X	X standard	Y standard	X	P1
4	Y X electroless	7628	Y	Y standard	X standard	Y	P1
5	X Y desmear	7628	X	Y standard	X standard	X	P1
6	Y X desmear	7628	Y	X standard	Y standard	Y	P1
7	X direct metallisation	7628	X	X standard	X direct metallisation	X	P1
8	Y direct metallisation	7628	Y	Y standard	Y direct metallisation	Y	P1
9	X high desmear	7628	X	X high desmear	X standard	X	P1

PCB panel matrix – 106 glass fibre

Panel No.	Code	Glass/ Resin	Initial process	Desmear	Electroless	Post process	Drill
10	X electroless	106	X	X standard	X standard	X	P1
11	Y electroless	106	Y	Y standard	Y standard	Y	P1
12	X Y electroless	106	X	X standard	Y standard	X	P1
13	Y X electroless	106	Y	Y standard	X standard	Y	P1
14	X Y desmear	106	X	Y standard	X standard	X	P1
15	Y X desmear	106	Y	X standard	Y standard	Y	P1
16	X direct metallisation	106	X	X standard	X direct metallisation	X	P1
17	Y direct metallisation	106	Y	Y standard	Y direct metallisation	Y	P1
18	X high desmear	106	X	X high desmear	X standard	X	P1
37	X high hits drill	106	X	X standard	X standard	X	Reused drills (1000-2000 hits)
38	Y 3 regrind	106	Y	Y standard	Y standard	Y	3x Regrind
39	X 3 regrind	106	X	X standard	X standard	X	3x Regrind
40	Y high hits drill	106	Y	Y standard	Y standard	Y	Reused drills (1000-2000 hits)

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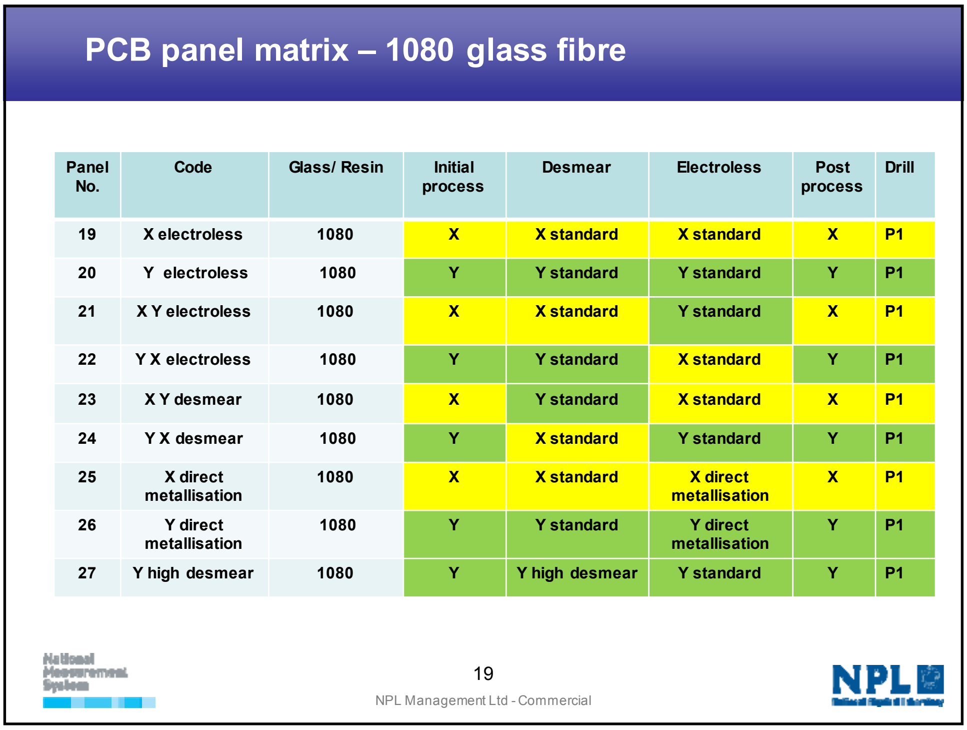
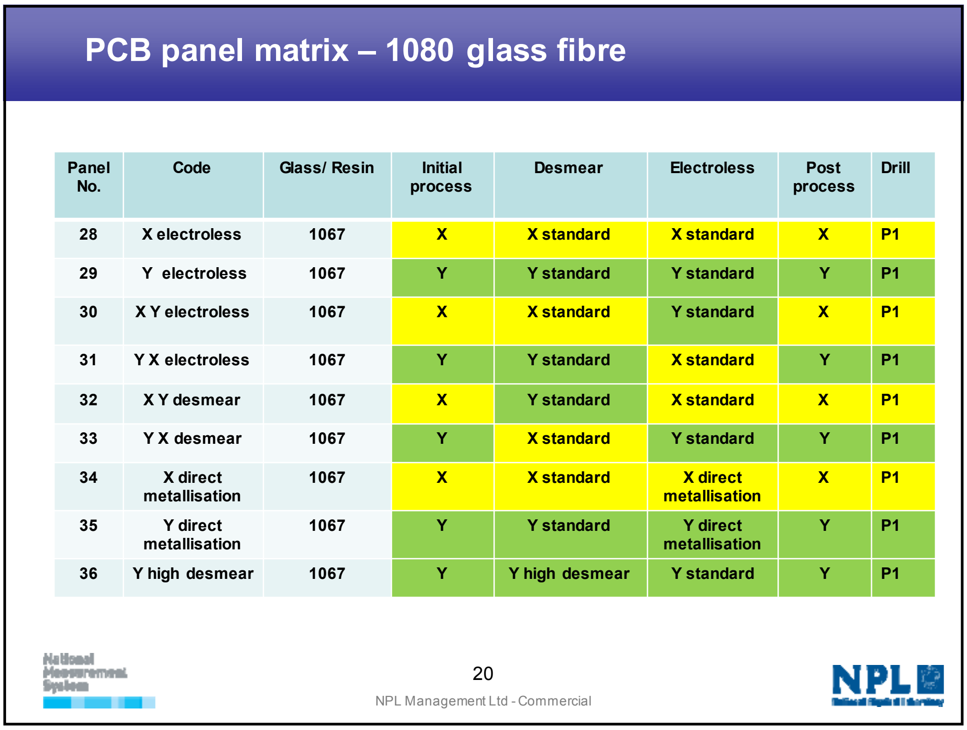


PCB panel matrix – 1080 glass fibre

Panel No.	Code	Glass/ Resin	Initial process	Desmear	Electroless	Post process	Drill
19	X electroless	1080	X	X standard	X standard	X	P1
20	Y electroless	1080	Y	Y standard	Y standard	Y	P1
21	X Y electroless	1080	X	X standard	Y standard	X	P1
22	Y X electroless	1080	Y	Y standard	X standard	Y	P1
23	X Y desmear	1080	X	Y standard	X standard	X	P1
24	Y X desmear	1080	Y	X standard	Y standard	Y	P1
25	X direct metallisation	1080	X	X standard	X direct metallisation	X	P1
26	Y direct metallisation	1080	Y	Y standard	Y direct metallisation	Y	P1
27	Y high desmear	1080	Y	Y high desmear	Y standard	Y	P1



PCB panel matrix – 1080 glass fibre

Panel No.	Code	Glass/ Resin	Initial process	Desmear	Electroless	Post process	Drill
28	X electroless	1067	X	X standard	X standard	X	P1
29	Y electroless	1067	Y	Y standard	Y standard	Y	P1
30	X Y electroless	1067	X	X standard	Y standard	X	P1
31	Y X electroless	1067	Y	Y standard	X standard	Y	P1
32	X Y desmear	1067	X	Y standard	X standard	X	P1
33	Y X desmear	1067	Y	X standard	Y standard	Y	P1
34	X direct metallisation	1067	X	X standard	X direct metallisation	X	P1
35	Y direct metallisation	1067	Y	Y standard	Y direct metallisation	Y	P1
36	Y high desmear	1067	Y	Y high desmear	Y standard	Y	P1

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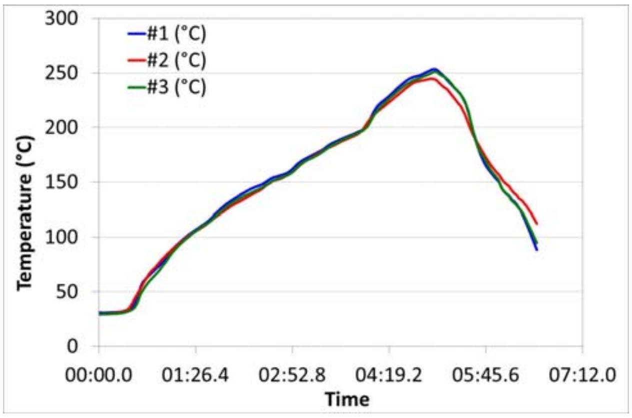
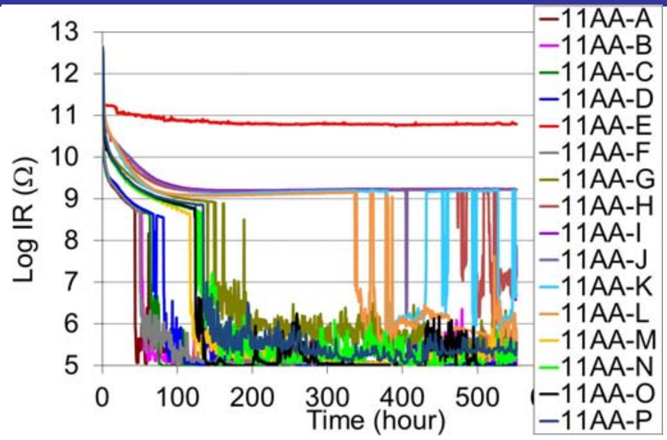
CAF testing for the PCBs to investigate

- 10 same pitch patterns (1 PCB or 2 PCBs) were tested for each combination.
- Test condition: 85° C/85%RH.
- Effect of reflow cycles on CAF.
- Effect of test voltage on CAF.
- Effect of distance between hole wall on CAF
- Effect of different process, desmear, electroless and direct metallisation from two companies (X and Y) on CAF.
- Effect of high desmear on CAF
- Effect of drilling on CAF
- Effect of materials on CAF
- Effect of PCB orientation on CAF

Reflow profile

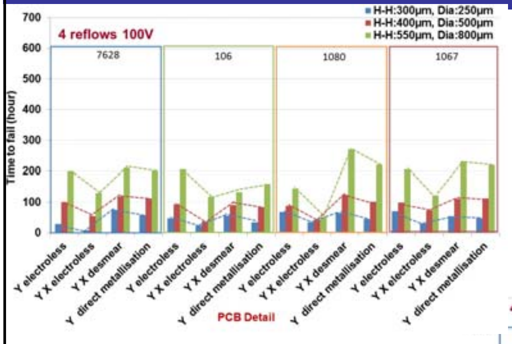


Example of IR results

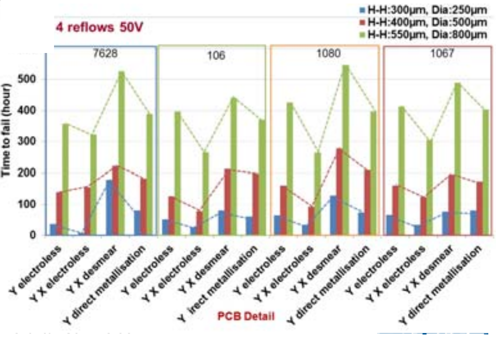


- Time to Failure (TTF): Time at IR first drop below $10^8\Omega$
- Average TTF from 10 same pitch patterns (2 PCBs).

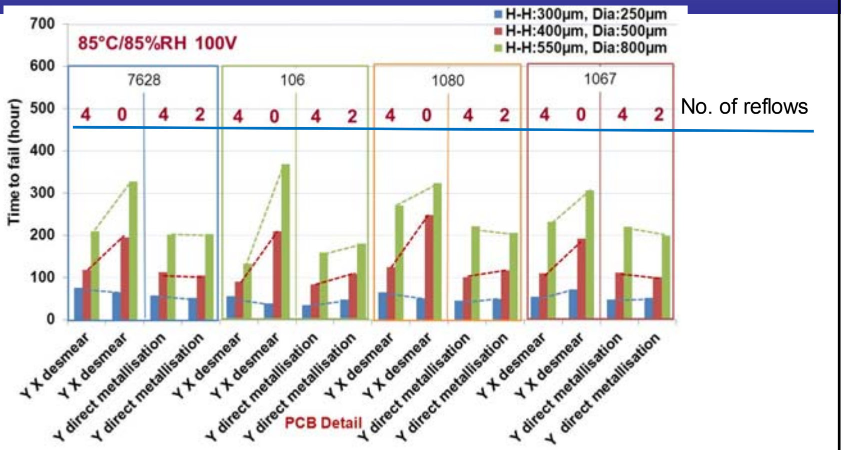
Effect of test voltage on CAF



- In general, an increase in test voltage, reduced the TTF, and was more significant on coarse pitch than on fine pitch.
- 50V bias discriminated TTF better for different pitches

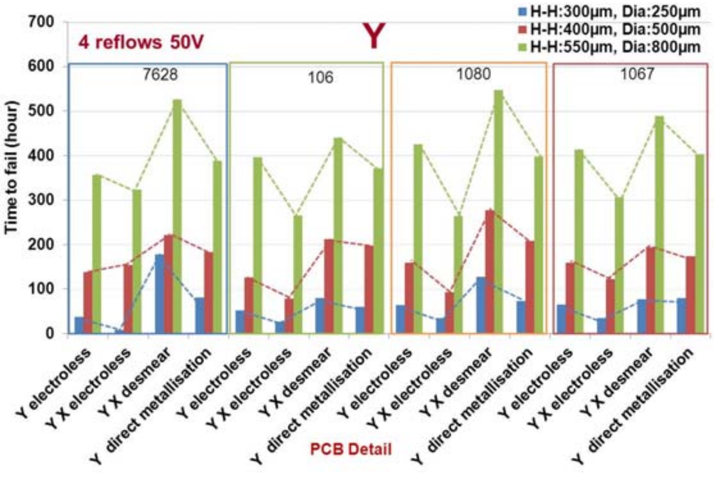


Effect of different reflow cycles on CAF



- There were significant differences in TTF between 0 reflow and 4 reflows for samples of middle and large pitch patterns, but not for small pitch patterns.
- There were no notable differences in TTF between 2 and 4 reflows on all pitch patterns.

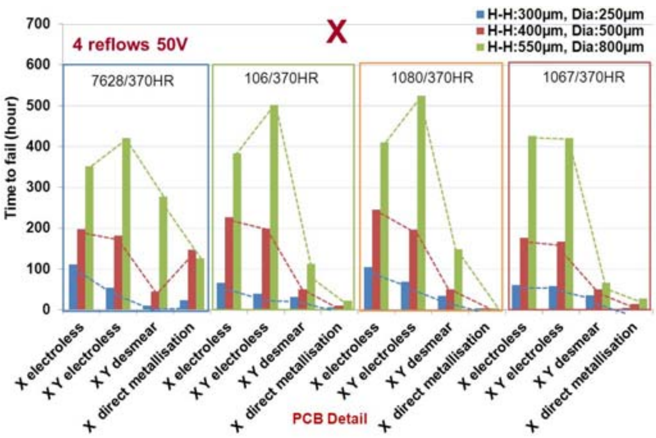
Effect of different processes and materials on CAF- Y



Different processes and materials from Y

- The trend in TTF from different processes is very similar between different materials and different pitches
- Y X electroless samples failed more rapidly than others, and Y X desmear gave the best results.
- This indicates that X electroless process more easier to promote CAF than Y electroless process, and X desmear process give better CAF results than Y desmear process.
- There was no significant difference on TTH between electroless and direct-metallisation process.

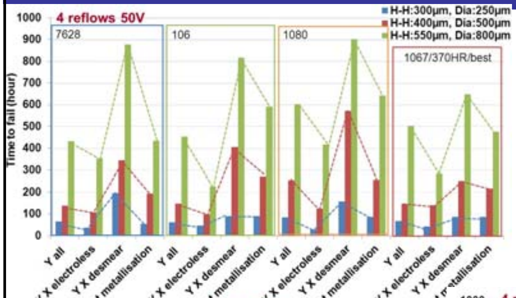
Effect of different processes and materials on CAF - X



Different processes and materials from X

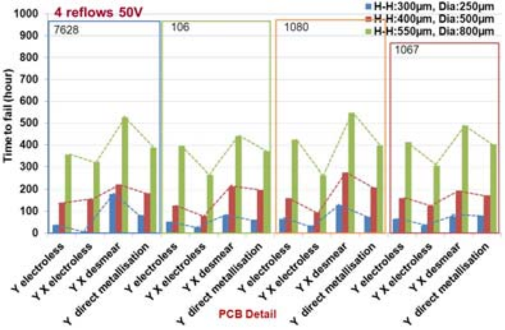
- The trend in TTF is very similar between different materials, but not with different pitches
- Generally XY electroless samples gave the best results, and XY desmear samples failed much earlier.
- The IR dropped immediately after testing for almost all samples with X direct metallisation process. The source of this behaviour is not known.
- The results from both X and Y agreed each other. X desmear process is better than Y, and Y electroless process is better than X.

Effect of PCB orientation on CAF -Y

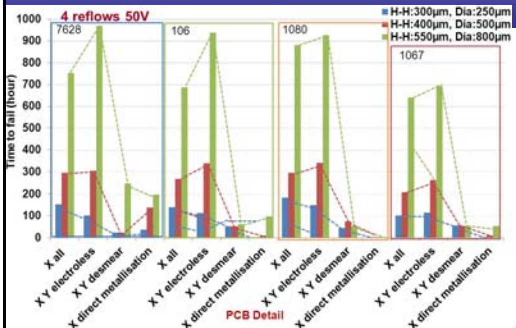


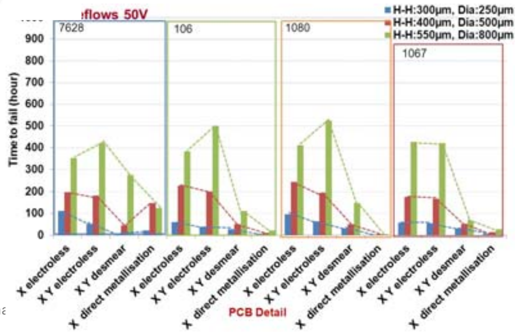
- TFTs on warp direction PCBs were much lower than that on weft PCBs, as warp PCBs had more and dense fibres running between two opposite charged vias

- However the trend from different processes and materials was the same between weft and warp direction PCBs.

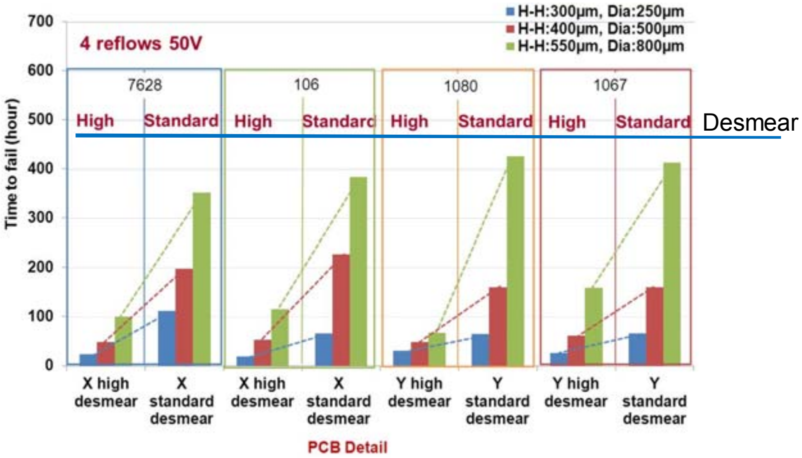


Effect of PCB orientation on CAF - X





Effect of desmear on CAF



- High desmear process from both companies significantly reduced TTF. This implies that desmear process is critical in CAF failures, and needs to be controlled.

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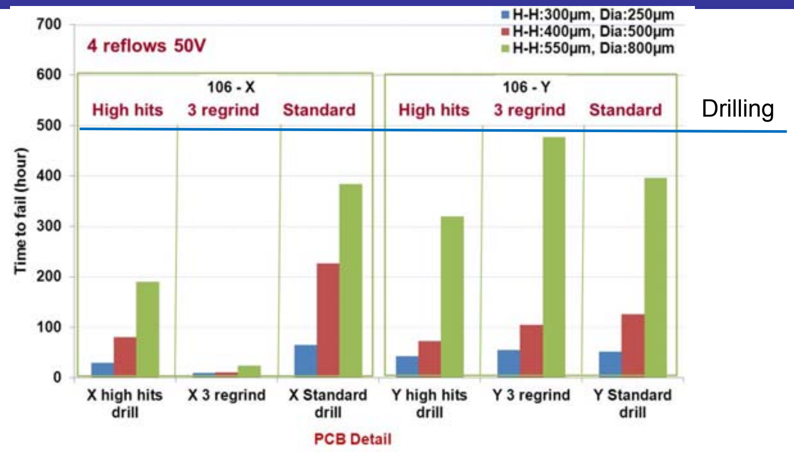
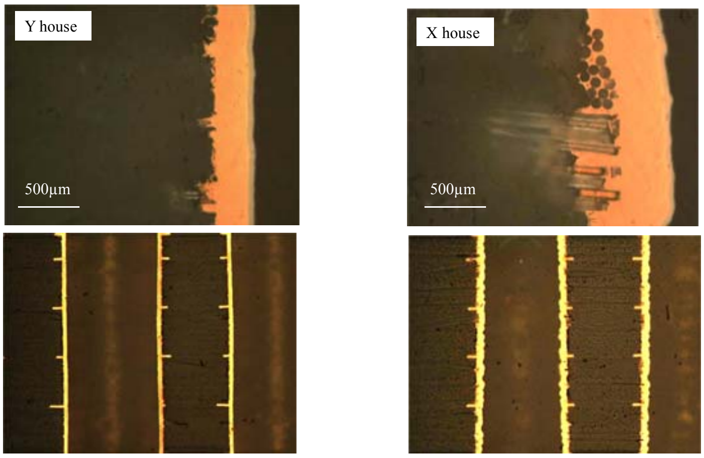
Effect of drill condition on CAF



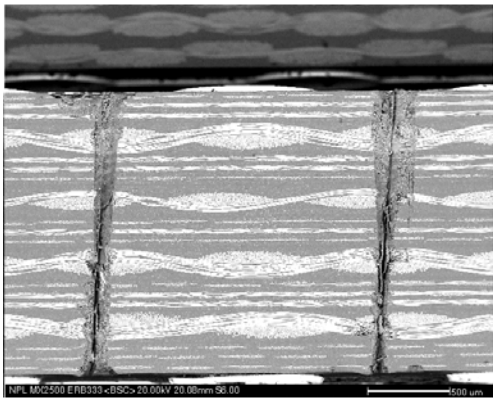
- The effect of high hit and regrind drills on CAF is different from X and Y. For X, the samples failed immediately using regrind, and high hit drills reduced TTF significantly. For Y samples, the TTF on samples using regrind drill were very similar with standard drill, but high hit drill reduced TTF.

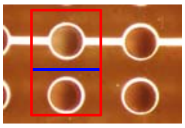
Wicking for regrind drill from – X & Y

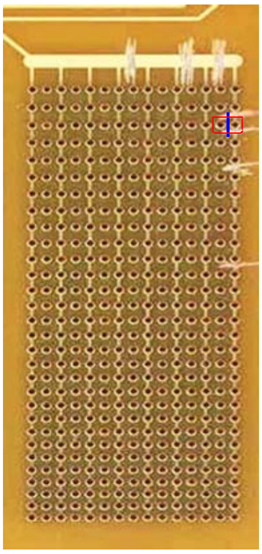


- Significant difference on TTF between X and Y from regrind drill can be seen to affect wicking.

Locating CAF between two via

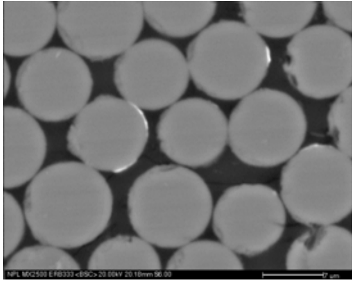


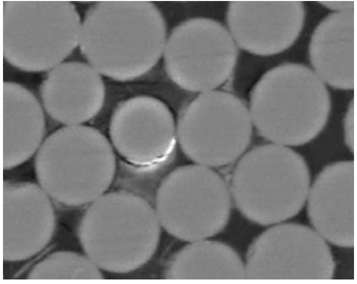


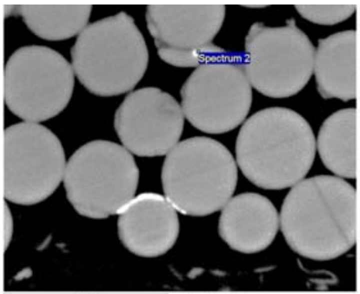


- Each Pattern has 450 holes & 420 CAF opportunities.

CAF found in core







- CAFs were physically seen in three of ten short samples, and they all appeared in 7628 core rather than in the laminate. This explains four different glass style samples demonstrated the same CAF performance, as they had the same 7628 core.

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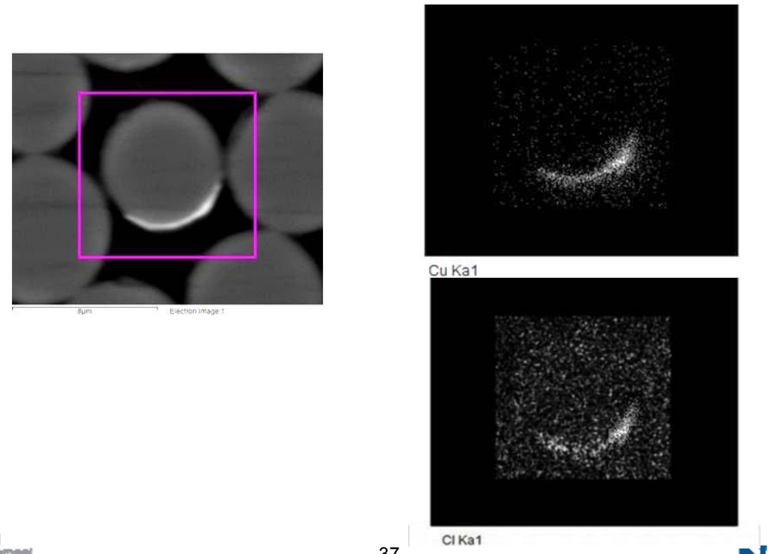
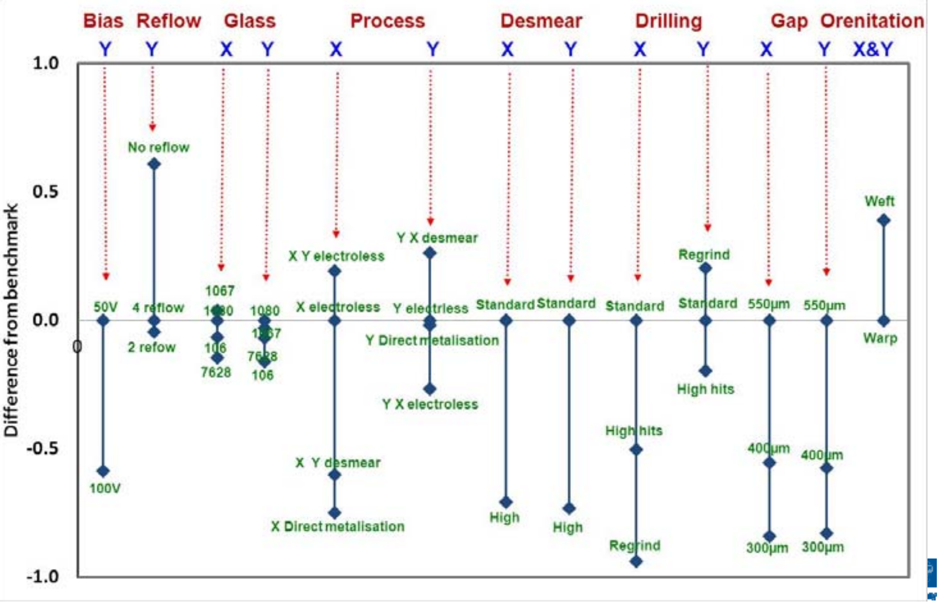
Element map for CAF



Results normalisation

- In order to investigate the strength of particular variables effect on CAF, the TTF data were analysed in the following procedure:
- Group data (A) to different sets (a, b, c) and average the TTF data for each set in which all other materials and processing parameters are identical, except for the key variable A (TTFAa, TTFAb, TTFAc).
- For each group the key parameter can be normalised against the benchmark set chosen (Ab), Aa = (TTFAa-TTFAb)/TTFAb.

Summary



Conclusions

- Test voltage significantly affected CAF performance on the tested samples
  - Increased voltage caused a shorter time to failure, but did not change the trends between different processes
    - 50V test voltage discriminated CAF performance better than 100V for different pitch patterns.
- There were significant differences in TTF between 0 and 4 reflows, but there were no notable differences between 2 and 4 reflows.
- There was no significant difference on CAF performance from different materials from both X &Y, since CAF failures were only found in the 7628 materials. The four different materials have the same 7628 core.

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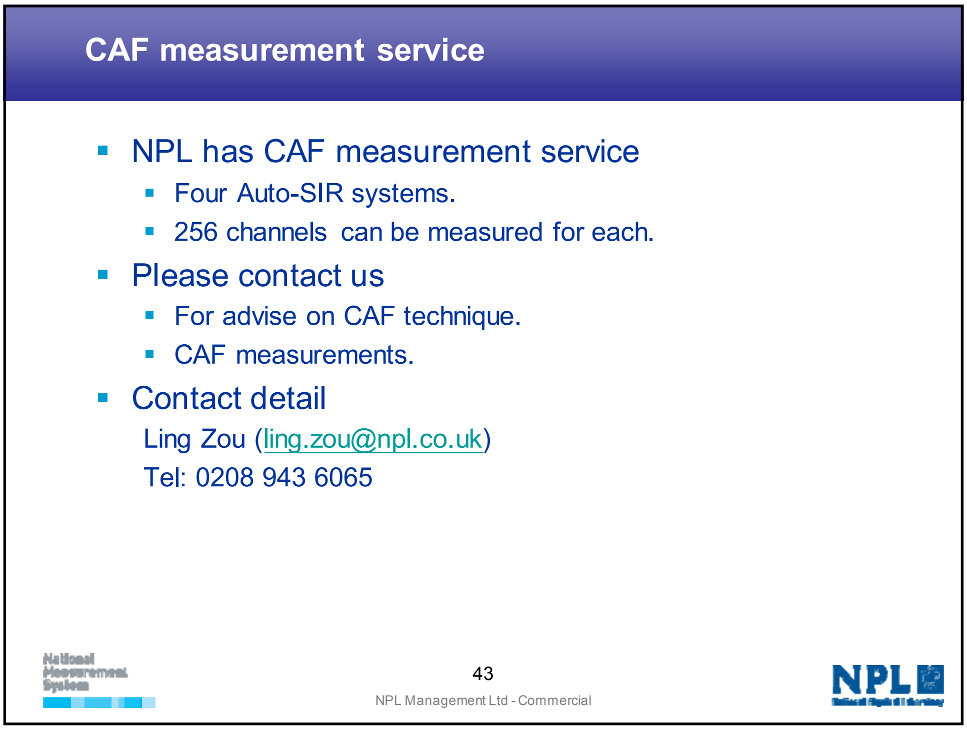
Conclusions

- PCB process has significant effect on CAF rather than the materials.
  - X desmear process was better than Y, and Y electroless process was better than X.
  - There was no notable difference on CAF performance between electroless and direct metallisation processes from Y, but for X their direct metallisation gave worse CAF performance than the electroless.
  - A high level of desmear significantly reduce TTF for both X and Y.
  - High hit drills reduced TTF significantly for both X and Y. For X, regrind drill failed immediately after testing, but for Y regrind drills gave similar CAF performance as the standard drill.
- Increasing via pitch increased TTF significantly. For the smallest pitch patterns, CAF performance was not sensitive to other variables

CAF formation - different glass fibre bundle size

- PCB orientation has significant effect on CAF performance
  - Weft orientation has high TTF than warp orientation
- Locating CAF is difficult, and only three CAF were found, and only in the core.



CAF measurement service

- NPL has CAF measurement service
  - Four Auto-SIR systems.
  - 256 channels can be measured for each.
- Please contact us
  - For advise on CAF technique.
  - CAF measurements.
- Contact detail

  Ling Zou (ling.zou@npl.co.uk)
  Tel: 0208 943 6065

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Measuring Coating Protection Performance under Condensing Conditions
Presented by Dr Chris Hunt NPL
Monday 30 November 2015 (14:30 hrs UK time)

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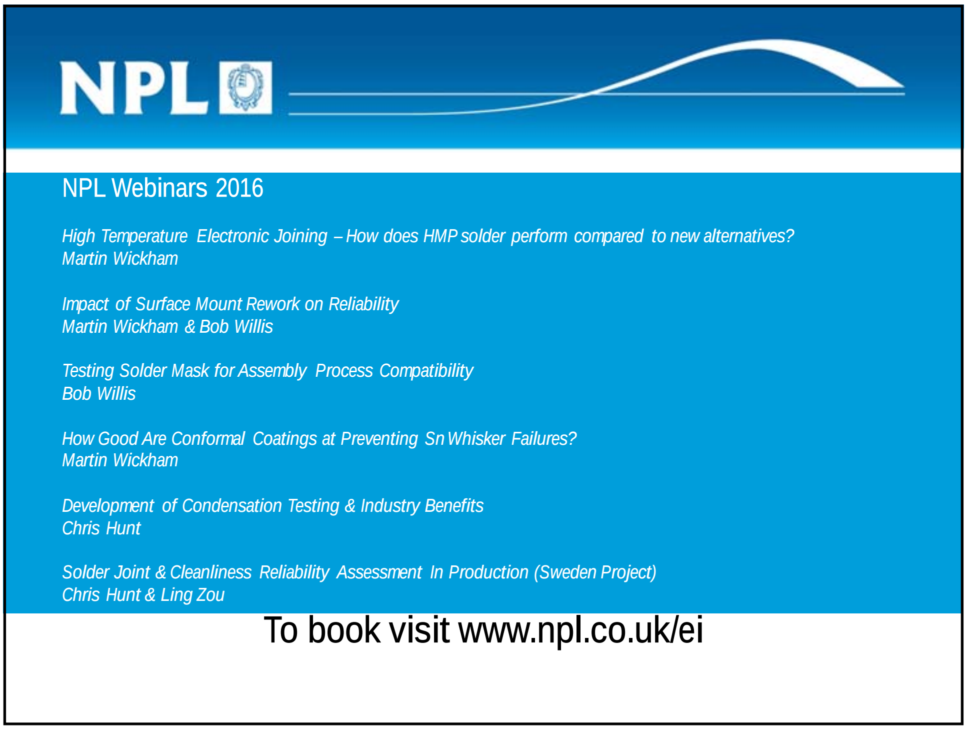

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