Speaker is an invited presentation

A Technical Paper was not required for the 2014 APEXPO™ Technical Conference

APEX EXPO IPC
NEW IDEAS ... FOR NEW HORIZONS
MARCH 25-27, 2014
MANDALAY BAY RESORT AND CONVENTION CENTER
LAS VEGAS, NEVADA

An Experimental Approach to Characterising CAF

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NPL (National Physical Laboratory)

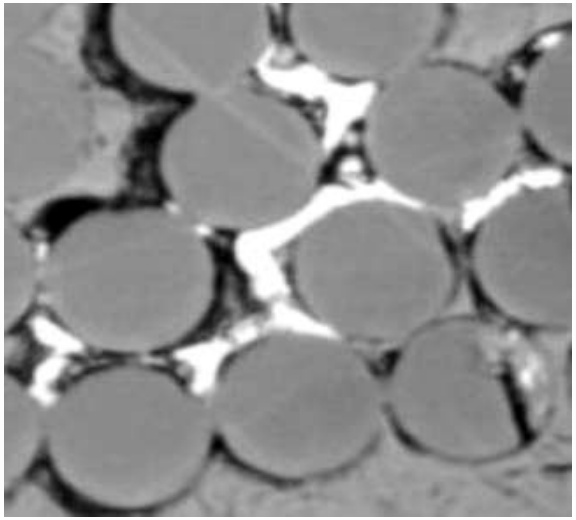
Acknowledgements

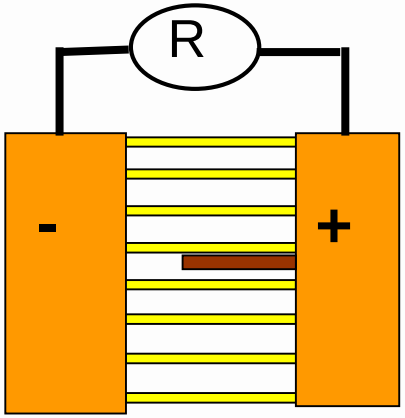
- Aero Engine Controls
- Bosch
- ESA
- GEN3 System
- Graphic
- IBM
- Isola
- Invotec
- MBDA
- Rolls Royce
- Texas Instruments
- TRW Auto

The National Measurement Office of the UK Department for Business, Innovation and Skills

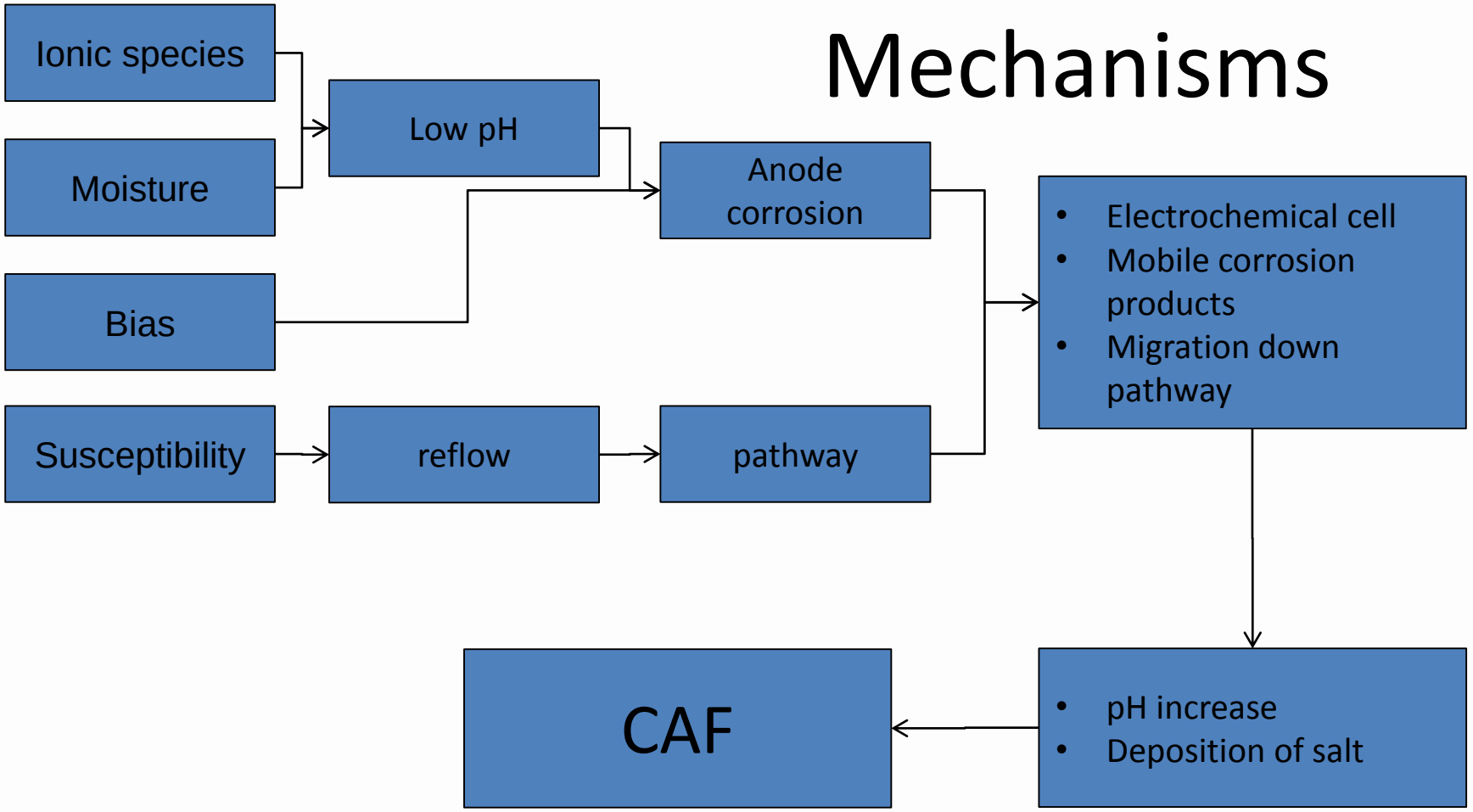
Conductive Anode Filament (CAF)

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

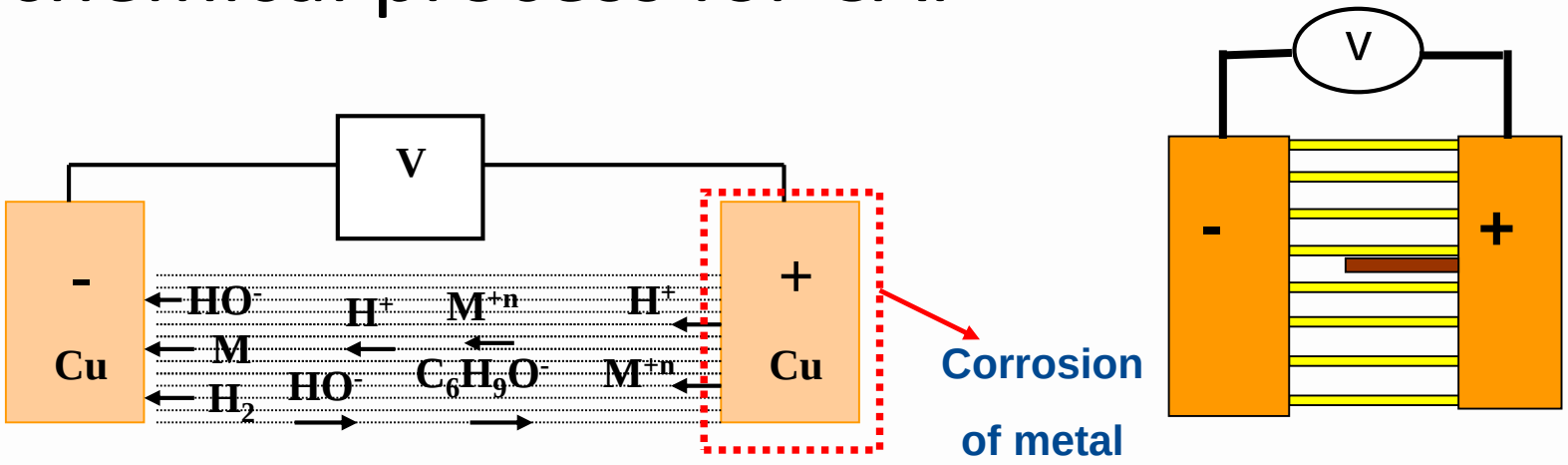




Mechanisms


Ionic species
Moisture
Bias
Susceptibility
Low pH
reflow
Anode corrosion
pathway
• Electrochemical cell
• Mobile corrosion products
• Migration down pathway
• pH increase
• Deposition of salt
CAF

Electrochemical process for CAF



Cathode

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

$H^+ + 2e \rightarrow H_2$

$O_2 + H_2O + 4e \rightarrow 4OH^-$

Anode

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

$2H_2O \rightarrow O_2 + H^+ + 4e$

$$Cu^{+2} + 2OH^- \rightarrow Cu(OH)_2\downarrow$$

$$Cu(OH)_2 \rightarrow CuO + H_2O$$

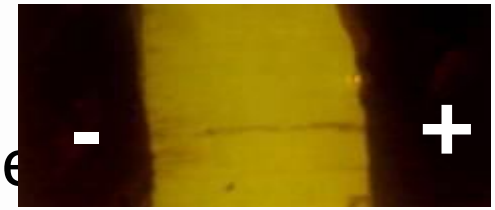
CuO: Black $CuCl_2$: Yellow brown $CuSO_4 5H_2O$: Blue

Conditions for CAF formation

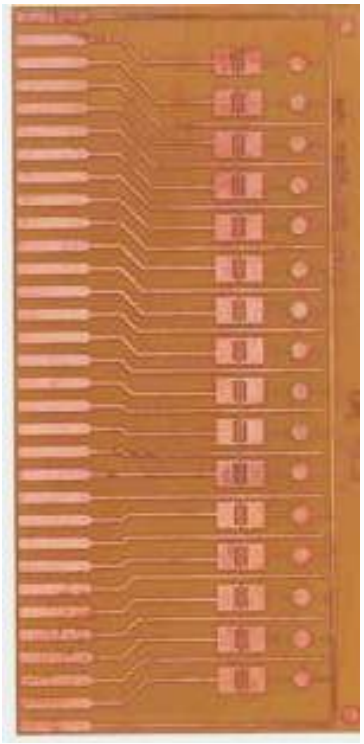
- Electrical charge carriers must be present to form electrochemical cell
  - Ionic species inside PCB, H^+ and OH^- from water
- Water must be present to dissolve the ionic material and sustain them in their mobile ionic state
  - Moisture, humidity
- Acid environment around conductors is needed to initiate Cu corrosion at anode.
  - Ionic contamination from resin, 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

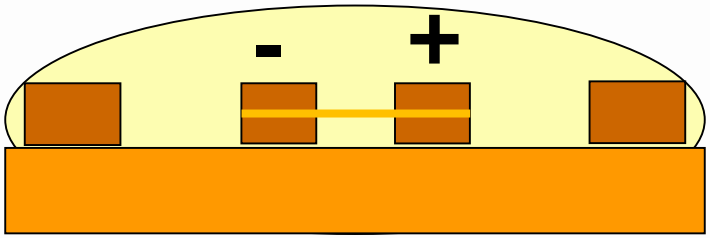
Simulated Test Vehicle (STV)

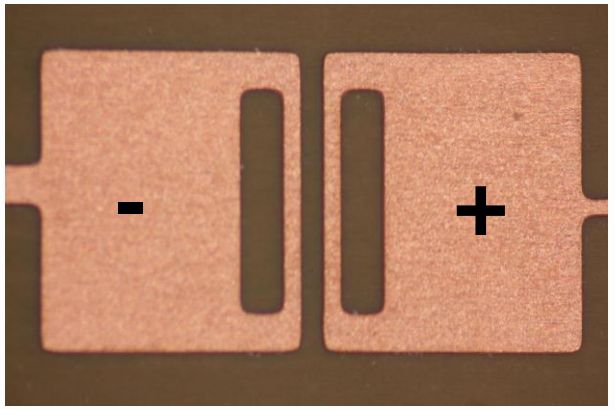
- Simulated Test Vehicle (STV1) was developed, which provides a controlled way to grow CAF.
- Enables the investigation of different variables separately.
- CAF formation:
  - Different resin systems and glass fibres
  - Reflow process
  - Desmear process: sample drilled
  - Glass bundle size
- CAF can be easily seen using microscope backlight



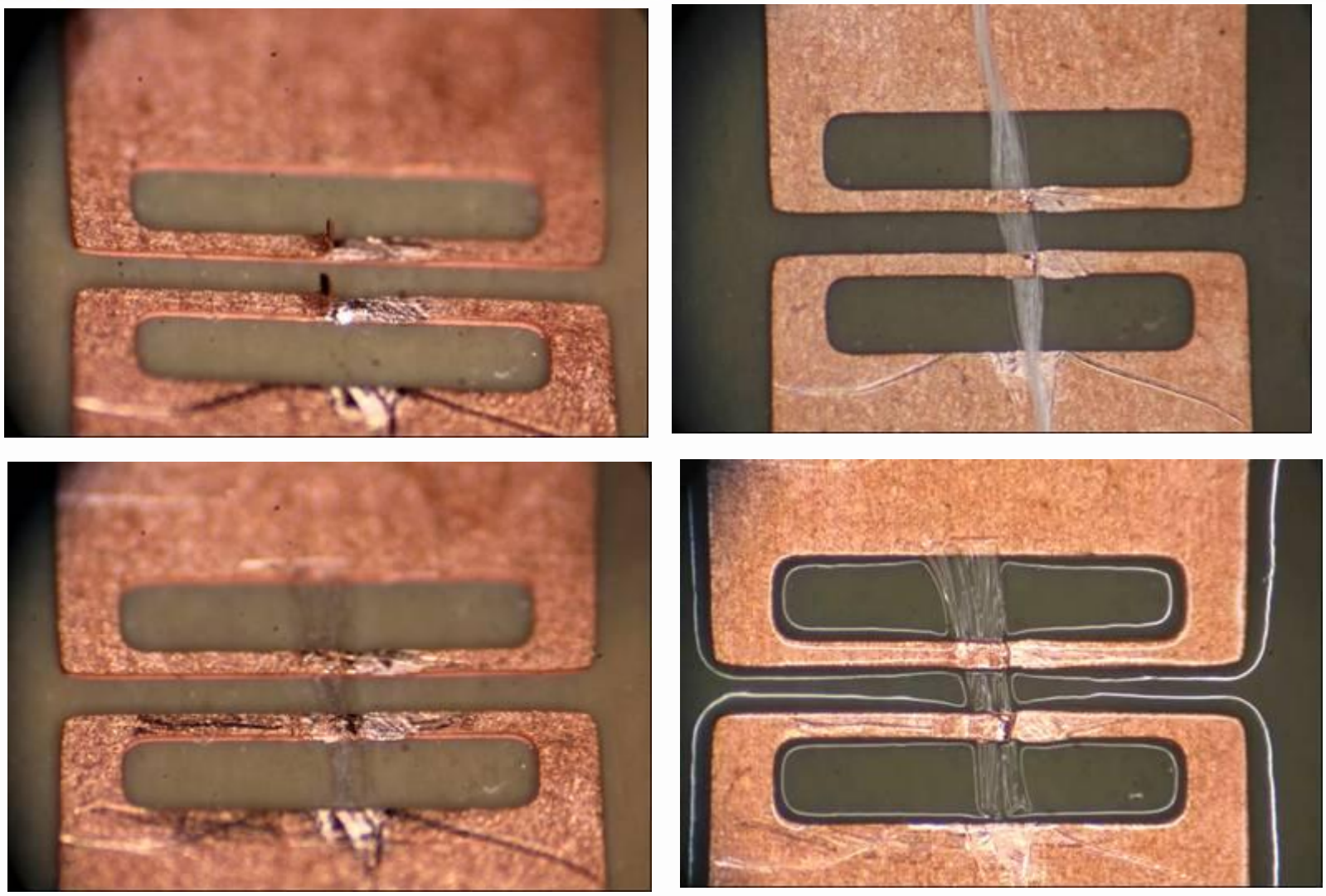
STV sample





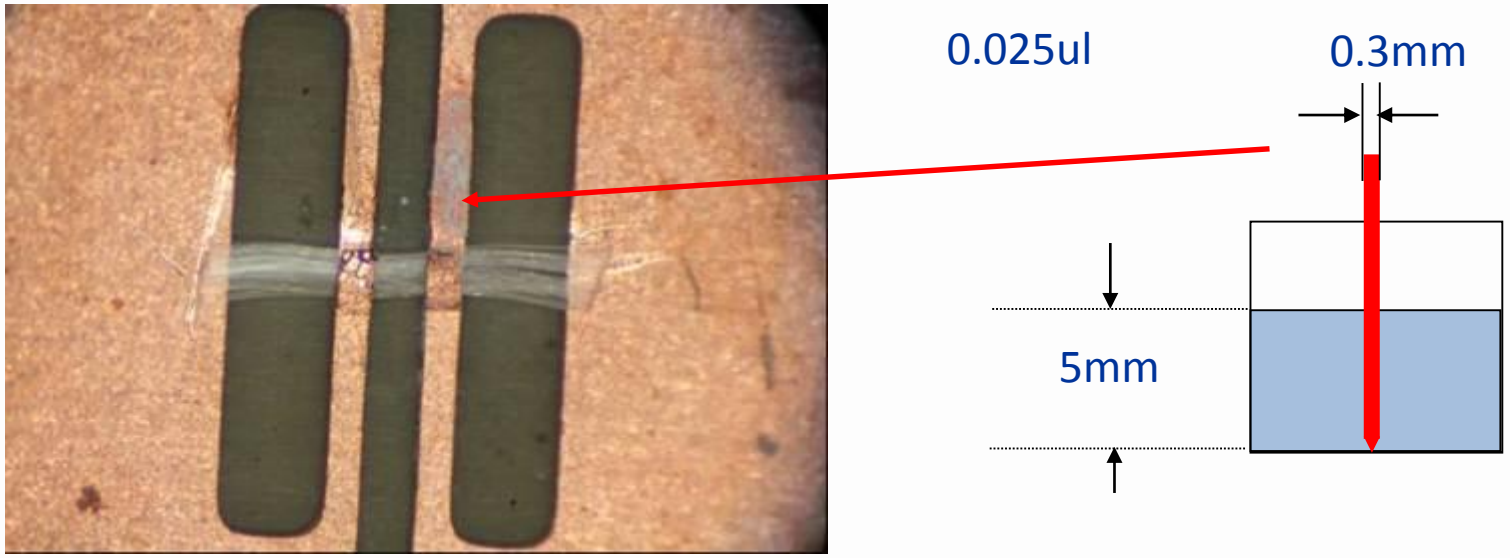


- Polyimide substrate with 2 oz Cu
- Resin powder dissolved in acetone
- Resin cured at 150°C for 60 minute



Test sample preparation

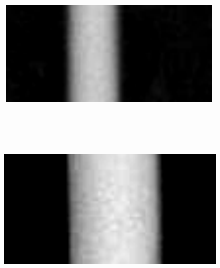
Different variables



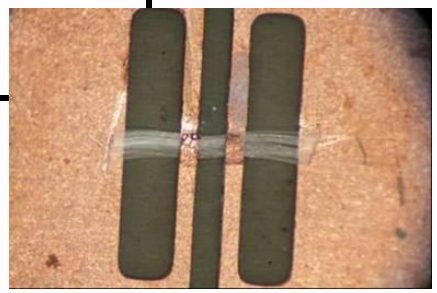
- Acid condition at anode (plating solution $CuSO_4$+H_2SO_4)
- Ionic contamination inside PCB (contaminated fibres)
- Pathway between two conductors (Reflow process)

Test different resins and glass fibres

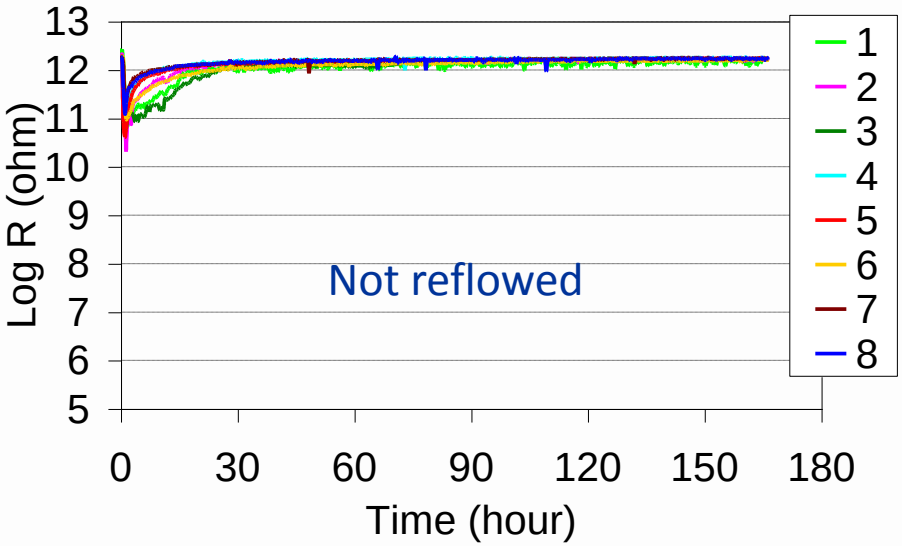
Resin	Glass fibres	Supplier
DICY Cured*	1080 finished	A
	7628 finished	
Phenolic cured	7628 finished	B
	7628 heat cleaned no finish	
	7628 loom state no finish	

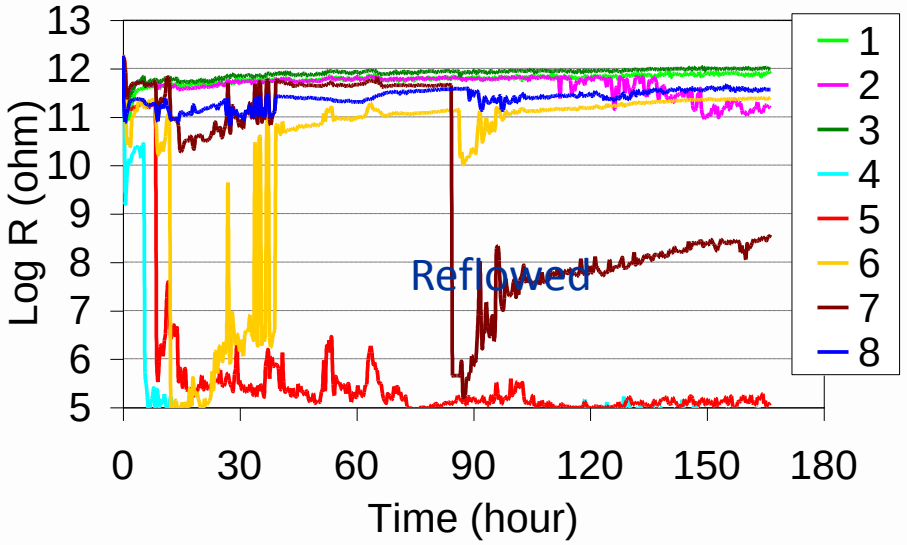


- Anode contamination (on / off)

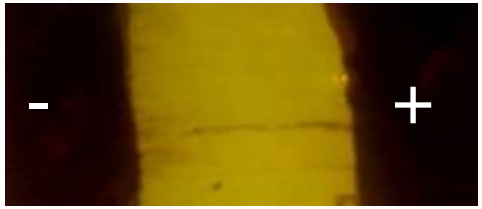


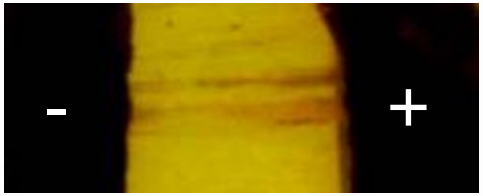
Phenolic cured resin - 7628 heat clean fibre

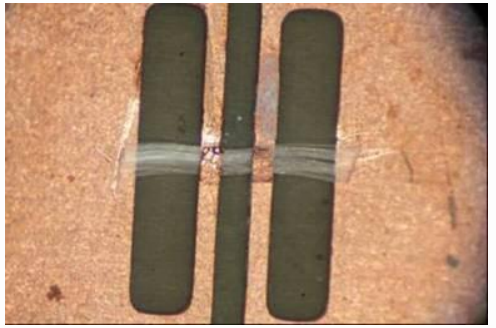




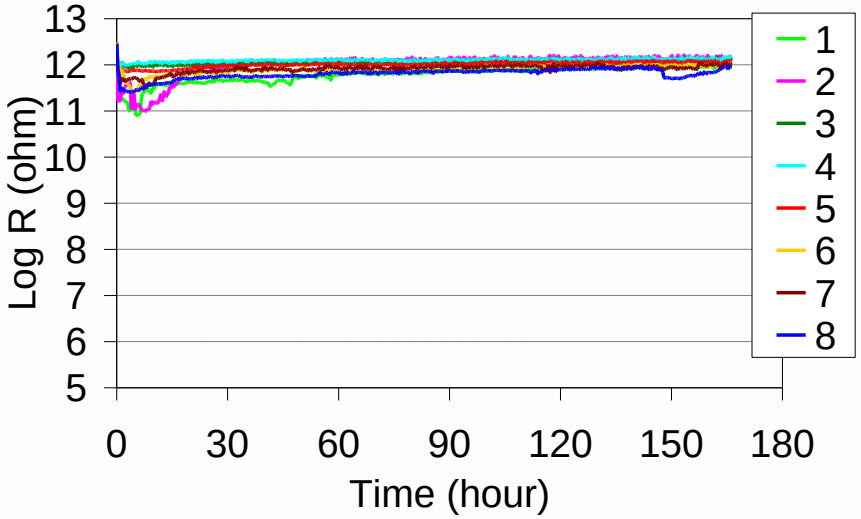
- Anode: no contamination
- Fibres: clean
- CAF formed on reflowed sample

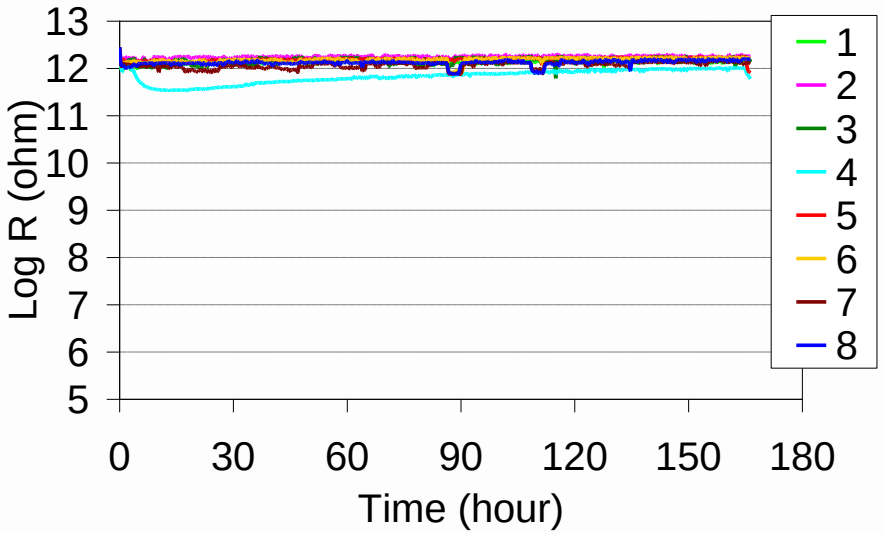


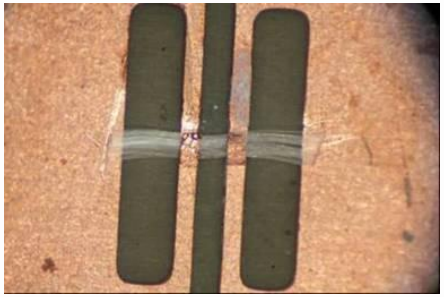




Phenolic cured resin - 1080 finished fibre







- Anode: 100% plating solution
- Fibres: clean
- No CAF formed on both reflowed and no reflowed samples

CAF propensity

Anode contamination	Glass fibres	Resin	CAF formation	
			No Reflow	Reflowed
100% plating solution	1080 finish (A)	DICY Cured	×	×
	7628 finish (A)			
	7628 finish (B)			
	7628 heat cleaned		✔	
	7628 loom state			
None	7628 heat cleaned			×
	7628 loom state			
	7628 heat cleaned		×	✔
	7628 loom state	Phenolic cured	✔	✔
100% plating solution	1080 finish (A)		×	×
	7628 finish (A)			
	7628 finish (B)			

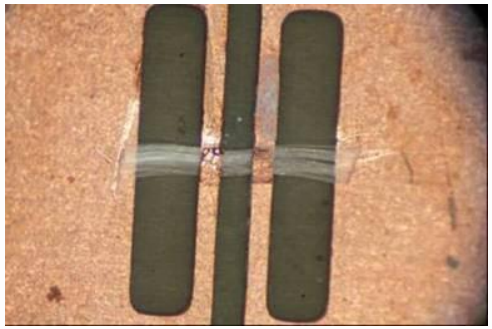
Different resins and glass fibres

- With anode contamination only:
  - There is CAF formation for heat cleaned and loom state fibres with both resins (DICY and phenolic cured).
  - There is no CAF formation for all finished fibres with both resins.

Finished glass fibre - DICY resin

Anode	Fibre	Reflow
100% plating solution	3% NaCl	✔
20% plating solution		×
20% plating solution		✔
100% plating solution		×
100% plating solution	1% NaCl	✔
100% plating solution		×
20% plating solution		✔
20% plating solution		×

- Anode contamination
- Fibre coated in NaCl
- Reflow & no reflow

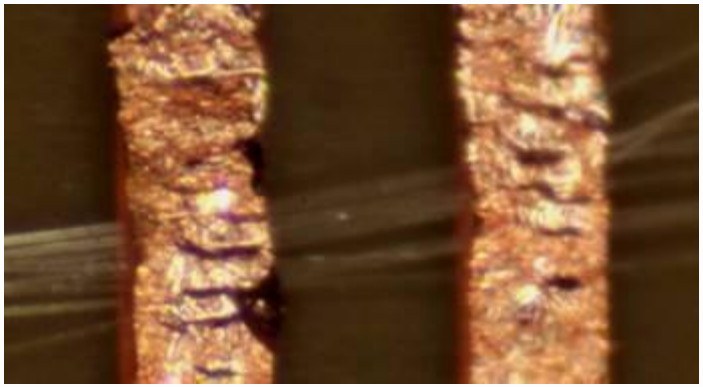


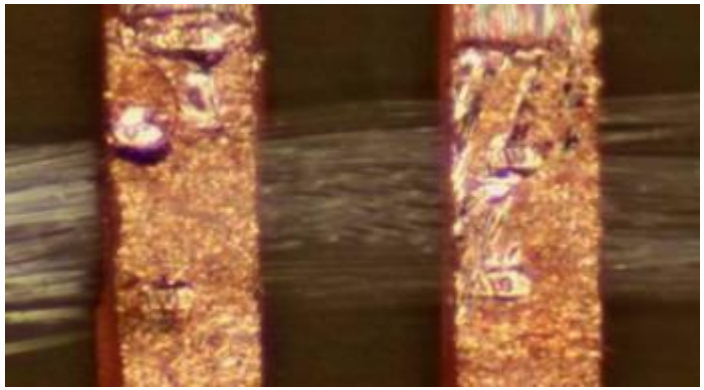
Conclusion for finished fibres

Anode	Fibre	Reflow	CAF formation
100% plating solution	3% NaCl	✔	✔
100% plating solution		×	×
20% plating solution		✔	✔
20% plating solution		×	×
100% plating solution	1% NaCl	✔	×
100% plating solution		×	×
20% plating solution		✔	×
20% plating solution		×	×

- Three factors must be met for CAF formation
  - Low pH at anode (Plating solution contamination)
  - Ionic contamination inside PCB (NaCl coated fibres)
  - Pathway between two conductors (Reflow process)

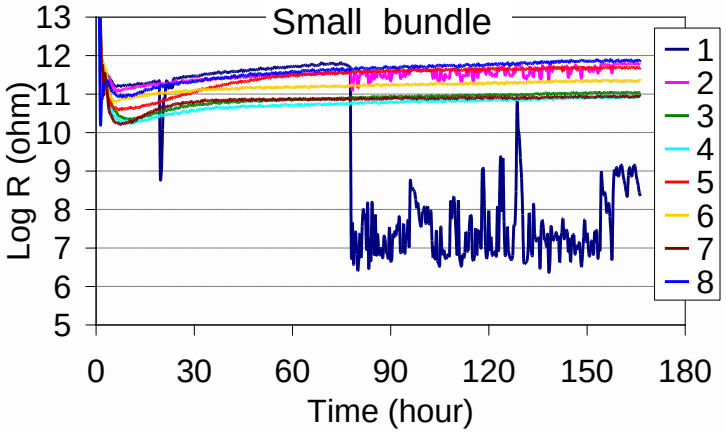
Different glass fibre bundle size

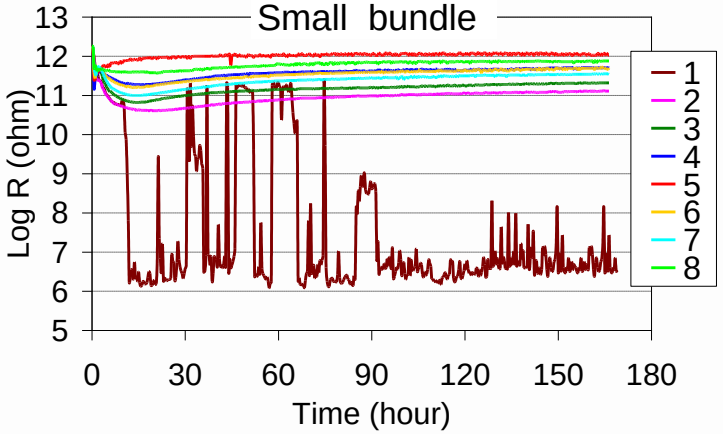


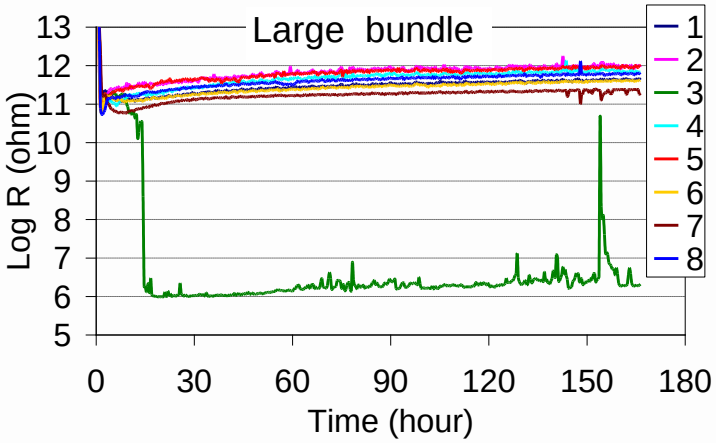


- Phenolic cured resin
- Anode: no contamination
- Fibres: Heat cleaned and loom state glass fibres
- Bundle size: small (~10) & large (30~50)
- Reflowed

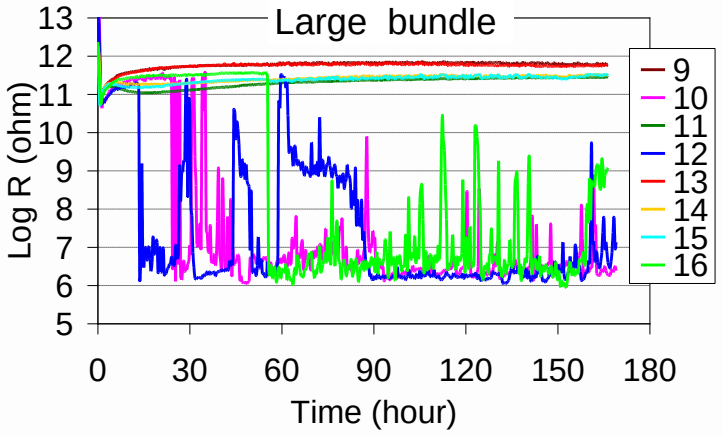
Phenolic cured resin





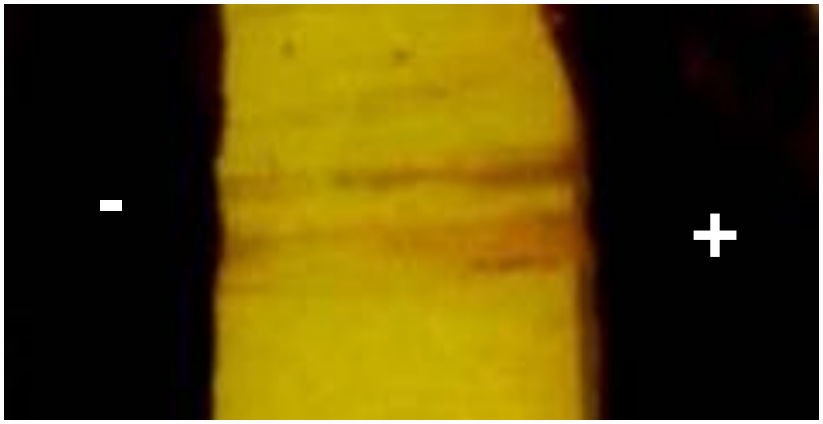


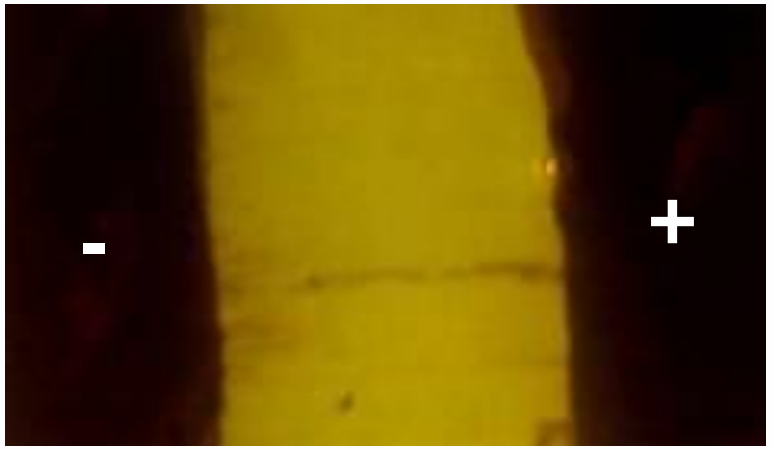
Heat cleaned fibre

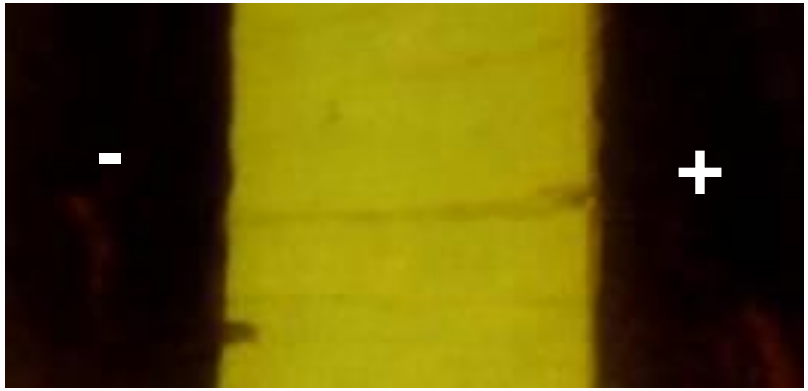


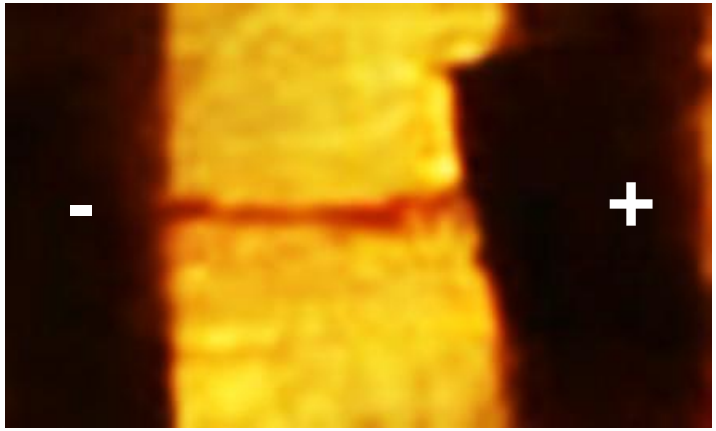
Loom state fibre

CAF formation

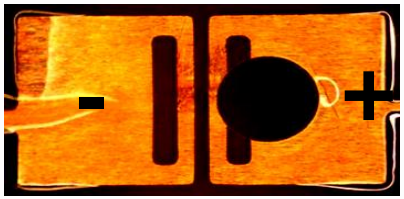


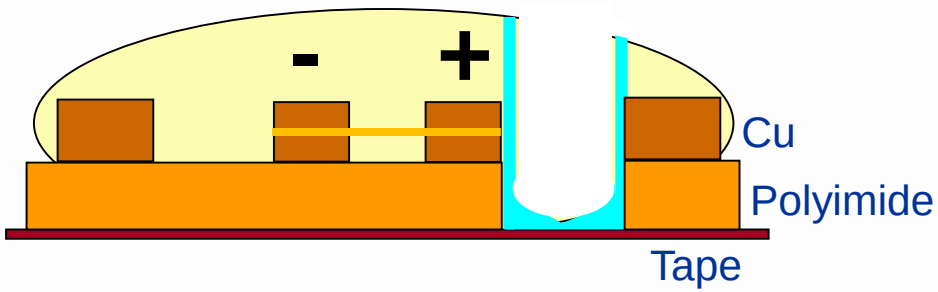


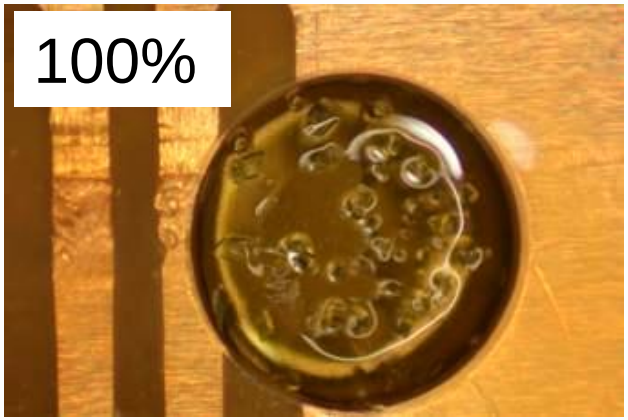


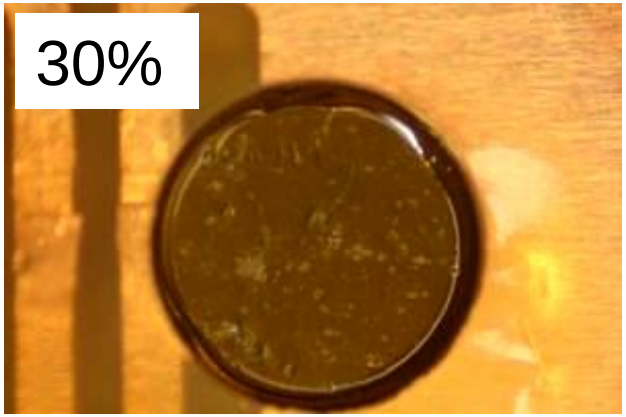


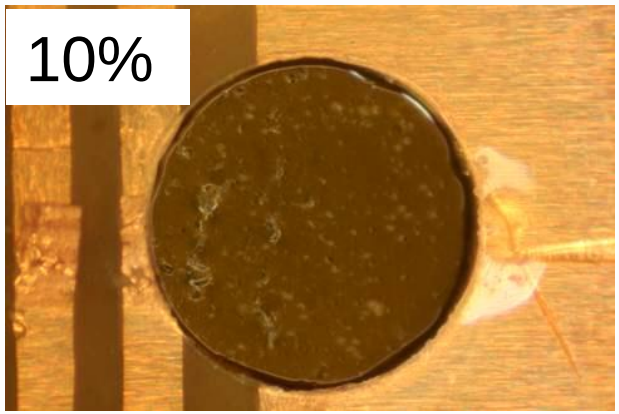
STV with drilled hole





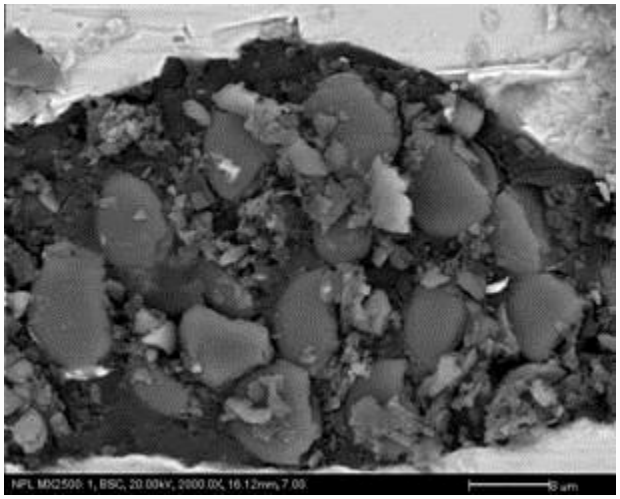




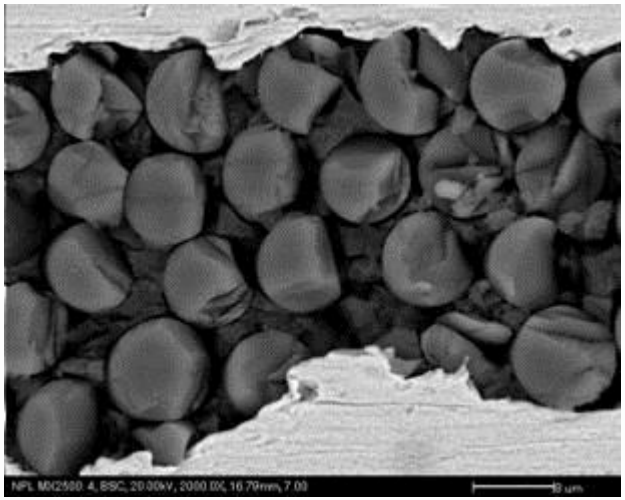


- STV placed on adhesive tape.
- Hole filled with 1µl different concentration plating solutions.
- Filling solution dried for 2 hours at room temperature before CAF testing.

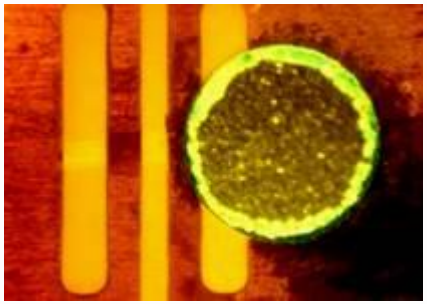
CAF formation – desmear process



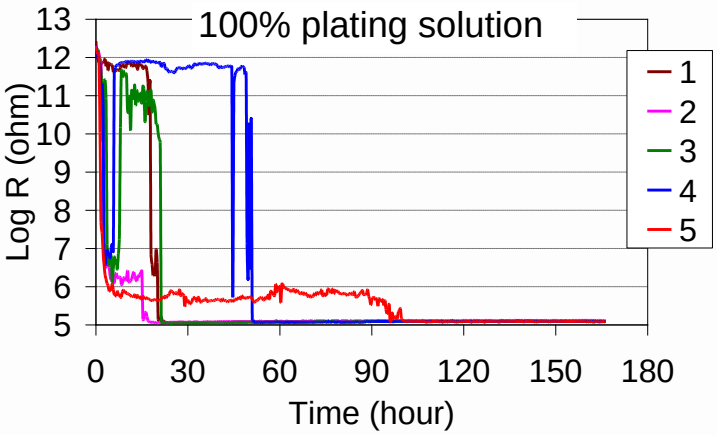
No-desmear

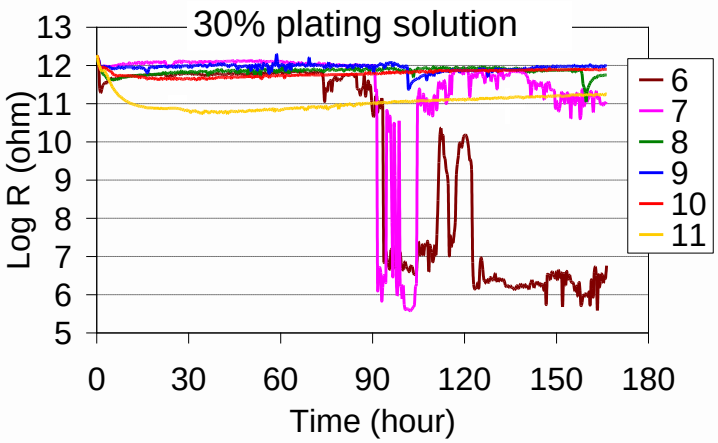


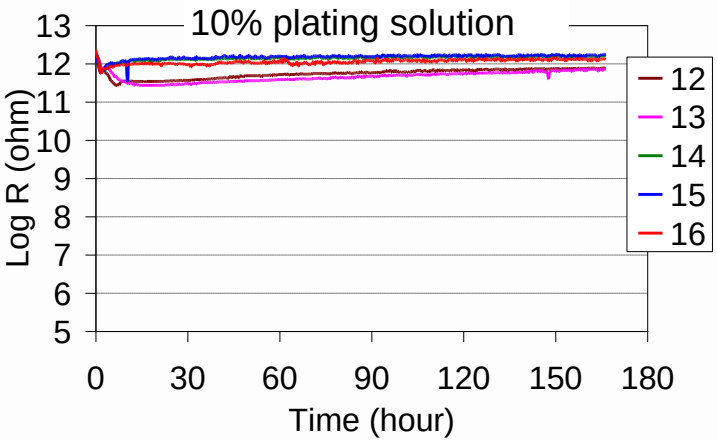
Desmeared



CAF formation without desmear

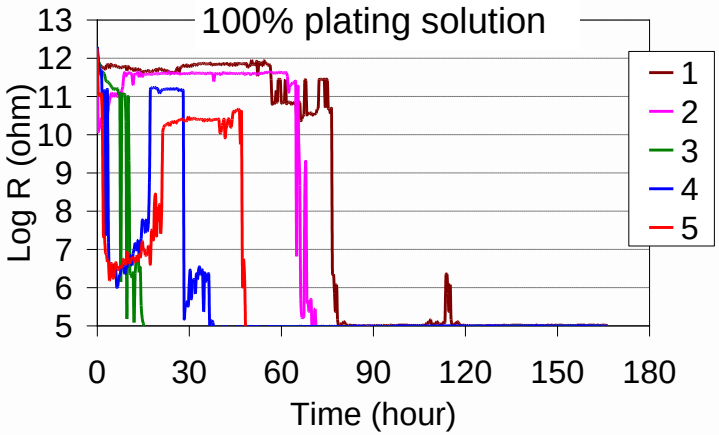


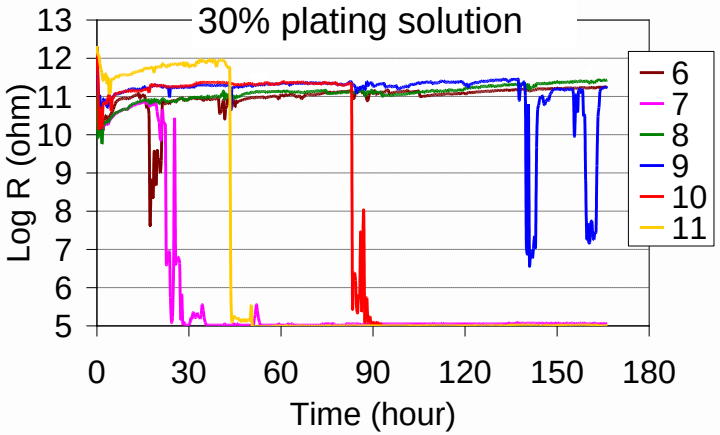


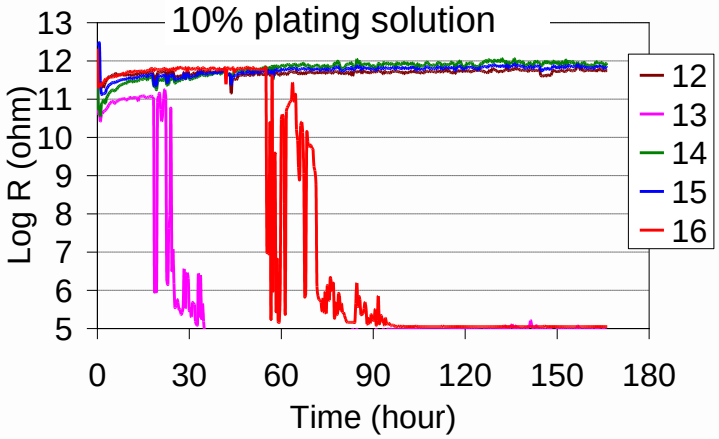


- Phenolic cured resin & 7628 finished glass fibre (B)
- More CAF formed with contamination increase

CAF formation with desmear

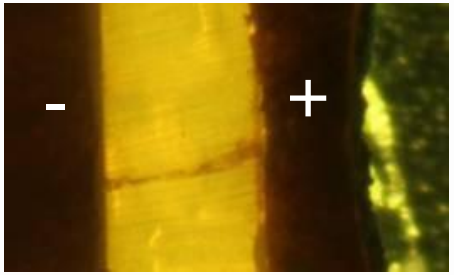


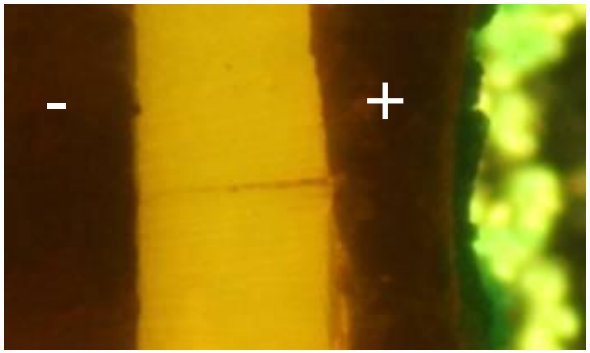


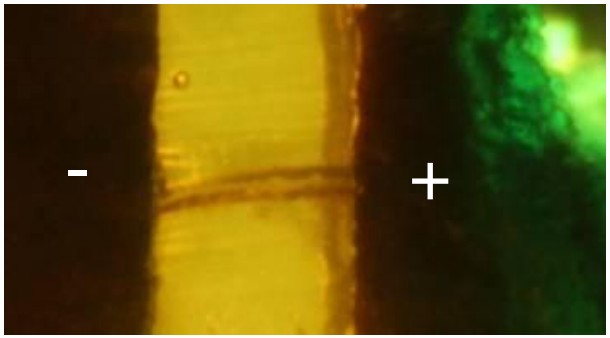


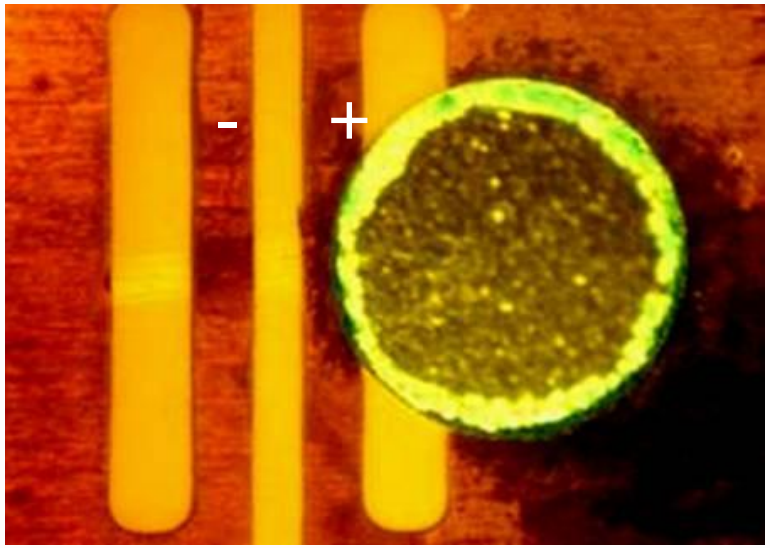
- Phenolic cured resin & 7628 finished glass fibre
- Desmear process increase CAF formation, but not significant.

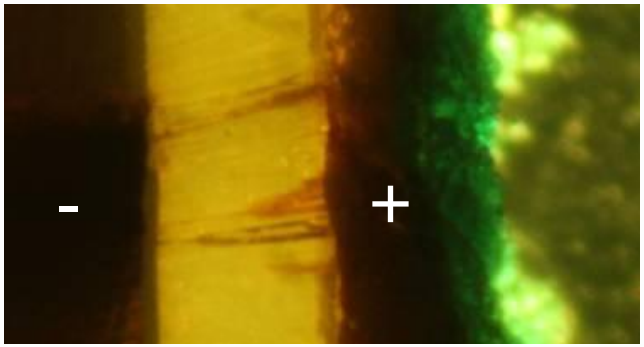
Examples of CAF growth in STV



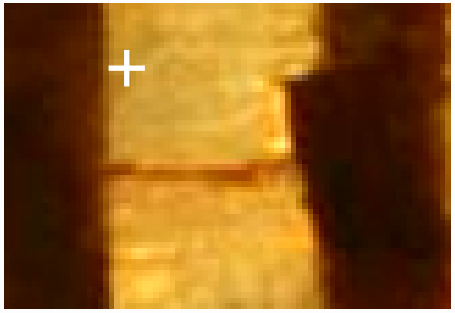


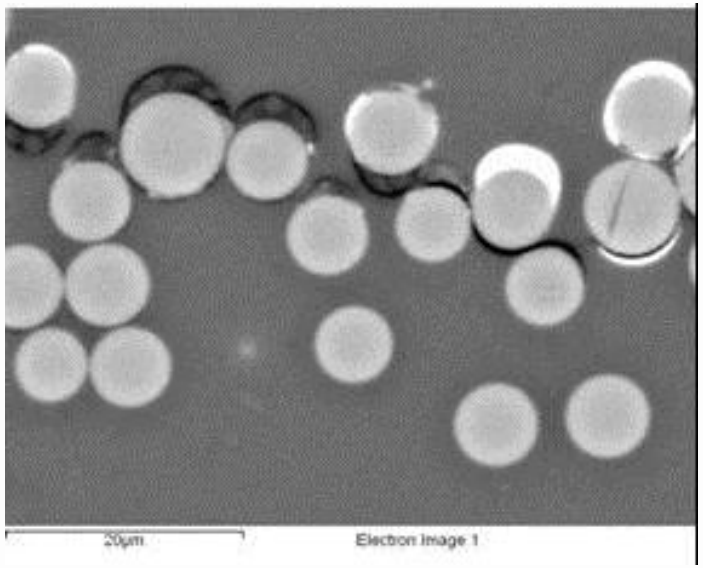


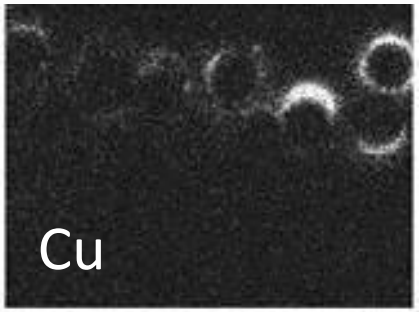


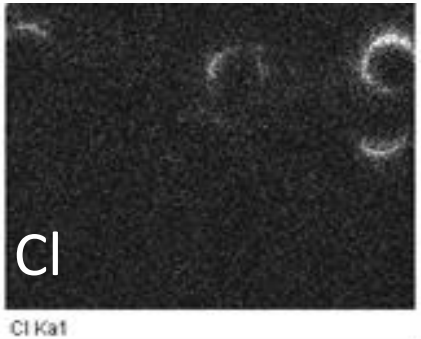


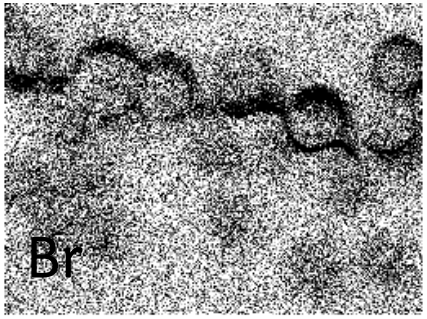
CAF formation

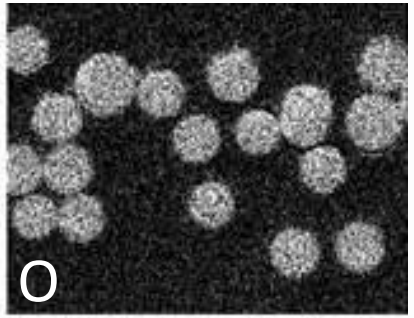












Conclusions

- STV has been successfully used to evaluate the effect of different resin systems, different glass fibres, desmear process, reflow process and glass fibre bundle size on CAF failure.
  - Heat cleaned and loom state fibres form CAF more easily than finished fibres. Loom state fibre has the highest propensity to form CAF compared with others.
  - Phenolic cured resin promote more CAF than DICY cured resin, this is probably because the DICY was removed when the resin was dissolved in acetone in our sample preparation.
  - Desmear process can increase CAF formation, but not significant.
  - Reflow process increase CAF formation significantly.
  - Large bundle size increase CAF formation, but not significant.