CHEMICAL DATA VS. ELECTRICAL DATA IS ONE A BETTER RELIABILITY PREDICTOR?

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ABSTRACT
The goal of this study was to correlate IPC Chemical and Electrical CAF test results. The electrical testing utilized for the test coupons was found within the PCQR2 Database document. The chemical testing of the coupons utilized Ion Chromatography (IC) testing in accordance with IPC-TM-650, method 2.3.28.

INTRODUCTION
The electronics industry has long been faced with understanding, defining and developing techniques that allow manufacturers the ability to evaluate product reliability risks long before products are ever placed into service. There are myriad of tests available to examine a wide range of potential risk areas.

In this study, the focus was placed on two common methods used for evaluating electrochemical risks. Two questions were posed: 1) is either method a good reliability predictor for electrochemical events and 2) can the methods be correlated.

With conductor spacing and overall part sizes shrinking, the necessity for improved electrical / chemical tests (i.e. CAF, IC, etc) or different types of testing for the electronics industry is increasing.

CONDUCTIVE ANODIC FILAMENT OVERVIEW
IPC-TM-650, Method 2.6.25A, defines Conductive Anodic Filament (CAF) Formation as the growth of metallic conductive salt filaments by means of an electrochemical migration process involving the transport of conductive chemistries across a nonmetallic substrate under the influence of an applied electric field, thus producing Conductive Anodic Filaments. Conductive Anodic Filament (CAF) testing helps to determine the reliability of a printed circuit board (PCB) laminate material on a finished product.

ION CHROMATOGRAPHY OVERVIEW
Ion Chromatography (IC) is a technique that utilizes a stationary phase (a column) and a mobile phase (eluent) to separate ionic material from a liquid sample. Within the electronics industry this testing has been particularly useful for identifying problematic ionic contaminates left by the various materials, processes and handling practices used for the production of electronic devices.

Figure 1 show how the two phases interact to separate a mixture into individual ions. A sample is injected into the IC system and it mixes with an eluent to be transported through the column. The column contains a resin that allows ions to be trapped based on their attraction for the resin (affinity) and the size of the molecule. Ions that have a stronger attraction to the column resin reside in the column longer. Ions that have a larger molecular size take longer to travel through the resin.

The eluent maintains movement of the sample ions through the column. If you think of the eluent as a hammer, it maintains the forceful drive of each ion through the column to achieve complete elution (separation) of all ions. The interactions of the column resin with the eluent and sample mixture all play a part in separating individual ions out of the complex sample matrix.

This is a simplistic explanation for how separations of ions take place, but hopefully you get the idea of how this testing works.

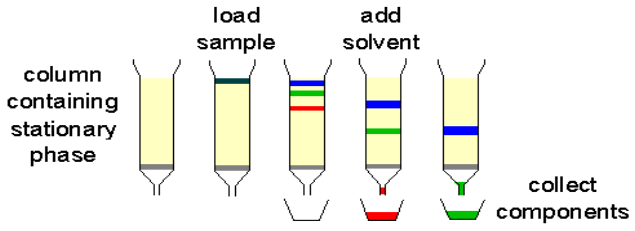


Figure 1: Ionic Separation of a Sample

PROBLEM STATEMENT

One of the challenges facing the electronics industry has been how best to determine product reliability. "How clean is clean enough?" is one of the common questions posed by manufacturers that have particular concerns over the "cleanliness" of their products. Currently there is no industry standard that defines what levels of ionic contaminates should be expected to delineate how long assembly products will last once they've been placed into service. Let's be clear on this point, there is "NO" industry "cleanliness" standard for printed board assemblies, period.

The basis for why there is no standard has been and remains to be that there are too many process and material variables to narrow a cleanliness definition to a one-size-fits-all. Additionally, there are too many board designs, end use applications and environments to narrow cleanliness concerns down to a single limit or set of limits. In other words, every assembly will have its own threshold for how much residue it can tolerate.

There are a number of cleanliness limits and guidelines circulating the industry, but the question is how accurate are those definitions in predicting reliability for all products?

In this study, we set out to understand if there was a relationship to predict and correlate between industry methods used for evaluating this aspect of reliability. We began by utilizing two common techniques to determine if either of them could 1) predict reliability reproducibly and 2) did the two techniques correlate.

The following is a discussion of the test results and what our interpretation is, based on the data generated to this point.

Though before commenting further, we should issue a disclaimer that more testing is needed to garner a larger statistical picture of residue variability and how it affects electrical performance. Our study is in no way conclusive and should not be viewed as definitive evidence of correlativity of the two methods. It does however reinforce the notion that there is a disconnect between the methods used for the establishment of reliability, particularly where cleanliness is concerned.

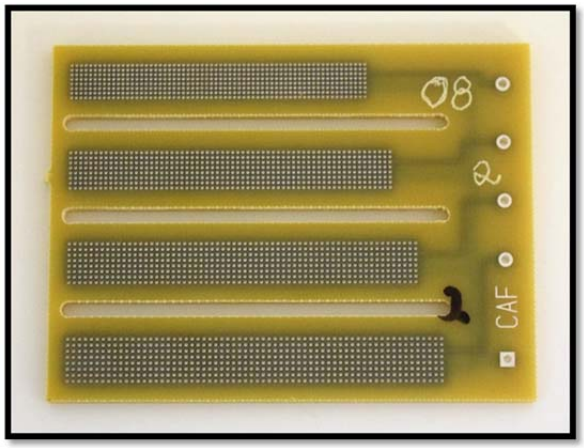
CAF EXPERIMENTAL OVERVIEW

The IPC-9151D (PCQR2) CAF coupons submitted for Ion Chromatography(IC) testing involved the following parameters:

- IPC-9151D (PCQR2): 75C / 85%RH and 48 volt bias
- IPC TM-650, 2.6.25: 65C / 88%RH
- IPC-9253 / IPC-9254 / PCQR2 - Wall-to-wall ranges from 10 to 25mil spacing
- 1.8 by 2.48 inch [4.57 by 6.30cm] fixed drilled hole size of 0.010 inch
- Fixed edge of via to edge of plane distance of 0.010 inch [0.25 mm/9.84mil] for this report
- Through hole only with 512 vias per net
- Record times (hours) to first, second and three consecutive failures. Record data every minute
- Real time failure detection at 10^7 ohm latch level
- No Soldermask

IC EXPERIMENTAL OVERVIEW

The methodology by which the test samples were evaluated was IPC-TM-650, method 2.3.28. This is method with a long history of use and it is the best technique currently published by an electronics industry standards body. The samples evaluated were IPC-9151D CAF coupons (See the following photograph).



Photograph 1: IPC-9151D CAF Coupon Sample

The sample coupons were analyzed both before CAF testing and again afterwards to baseline the starting cleanliness and determine what, if anything changed after testing. The samples were placed into ionically clean pouches with a small volume of 75% 2-propanol and 25% deionized water. The samples were then placed into a heated (80°C) circulating water bath for one hour. After the extraction process the samples were removed from the bath and allowed to return to ambient conditions. The mixture was then analyzed through ion chromatographs calibrated for anion, cation and weak organic acid ion species.

DATA COMMENTS AND OVERVIEW

With permission from IEC Electronics, we utilized their cleanliness limits for the purpose of having an actual set of corporate limits by which we could determine how clean the samples were before and after CAF testing. Additionally, we used IEC's green, yellow, and red street light criteria to show what levels were within acceptable (green) levels, which were marginal (yellow) and which were failed (red).

The samples evaluated prior to CAF testing showed levels of formate and calcium that exceeded IEC's defined limits (See Tables 1 – 4). In theory, if these values were correct, we would predict that the test samples would have some sort of issue during the CAF test.

Post-CAF testing, the samples were again evaluated and an interesting change showed up. The CAF coupons now had higher levels of organic acids and all groups, but the P3 group had lower levels of formate. Likewise, the levels of calcium had dropped considerably on all of the groups.

After comparing the CAF data to the IC results, the basic conclusion that can be reached at this point is that reliability was not predicted by the IC test. Groups P1, P3 and O21 failed to meet IEC's cleanliness requirements prior to and after CAF testing. Theorizing that the IEC's levels were accurate, we would have expected all three groups to experience some issue. However, that was not the case as all three groups (P1, P3 and O21) passed CAF testing.

There were five remaining groups (P5, P10, O8, O28 and O30) that failed CAF testing. For this discussion, we won't address P10 since there were no post-CAF IC samples. For the remaining samples, the IC data appears to support IEC's limits and their ability to predict reliability. The problem is that the limits failed to accurately predict the outcome for CAF testing in all cases, despite each test group having equivalent levels of contamination before and after testing. Likewise, CAF testing failed to prove out IEC's cleanliness limits by yielding different outcomes despite the ionic contamination levels being similar before and after testing.

There are other inferences that could be drawn from the data. But for now, the initial data indications suggest that current methodologies have a limited ability to predict, with certainty product reliability pertaining to cleanliness. Certainly more work is needed in this arena with a larger DOE.

CONCLUSIONS

1. There currently are no Pass / Fail cleanliness criteria exist for the IPC ion chromatography method. Criteria used for this study was based on customer suggested levels.

2. The Current Pass / Fail criteria for CAF testing per PCQR2 are $10^7\Omega$ latch level.

3. Per industry customer cleanliness criteria, the following groups failed chemical testing: * All, except P10 because there were no samples available after CAF testing

4. Per PCQR2 criteria the following groups failed electrical testing: * P5, P10, 08, 028 and 030

5. Neither method is a better CAF reliability predictor.

RECOMMENDATIONS

1. Remove soldered connectors from CAF coupons to eliminate extraneous residues from flux, cleaning steps and / or handling and. utilize press-fit connectors as a fix.

2. Improve cleanliness data by reducing the size of the coupon to get more focused extraction. This should improve precision and accuracy of the chemical test.

3. Develop a CAF Coupon Generator specific to PCB geometries on panel assembly verses current reduced pitch windowed approach.

4. Develop better pass / fail limits based on a larger data sampling and honing the testing methodologies (i.e. improve understanding of spatial relations and impacts to limits).

TABLES 1 – 4: DEFINITIONS:

Green = Contaminate levels fell below the customer's requirements.

Yellow = Contaminate levels were at the customer's defined limits.

Red = Contaminate levels exceeded the customer's requirements.

All values reported in the following tables are reported in micrograms per square inch ($\mu g/in^2$).

Table 1. IC Data before CAF – Anions:

Sample Description	Fluoride F^-	Chloride Cl^-	Bromide Br^-	Nitrite NO_2^-	Nitrate NO_3^-	Phosphate PO_4^{3-}	Sulfate SO_4^{2-}	Organic Acids (SMT)	Organic Acids (PTH Clean)	Organic Acids (PTH No clean)	Acetate	Citrate	Formate	MSA
IEC Anion Limits	**1**	**3**	**5**	**3**	**3**	**3**	**3**	**25**	**0**	**150**	**3**	**2**	**1**	**0**
Mean P1 Group	0.00	1.20	3.40	0.00	0.37	0.00	0.60	0.00	0.00	0.00	0.00	0.00	**1.63**	0.00
Mean P3 Group	0.00	2.57	3.25	0.00	0.20	0.00	0.65	0.00	0.00	0.00	0.00	0.00	**2.13**	0.00
Mean P5 Group	0.00	1.15	0.00	0.00	0.29	0.00	0.13	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00
Mean P10 Group	0.00	1.50	0.79	0.00	0.21	0.00	0.43	0.00	0.00	0.00	0.00	0.00	**1.06**	0.00
Mean O8 Group	0.00	2.68	1.03	0.00	0.30	0.00	0.74	0.00	0.00	0.00	0.00	0.00	**0.49**	0.00
Mean O21 Group	0.00	1.62	0.52	0.00	0.10	0.00	0.47	0.00	0.00	0.00	0.00	0.00	**0.96**	0.00
Mean O28 Group	0.00	1.97	5.45	0.00	0.49	0.00	1.22	0.00	0.00	0.00	0.00	0.00	**2.75**	0.00
Mean O30 Group	0.00	0.00	1.46	11.23	0.00	0.31	0.00	0.48	0.00	0.00	0.00	0.00	**0.00**	1.88

Table 2. IC Data before CAF – Cations:

Sample Description	Lithium Li^+	Sodium Na^+	Ammonium NH_4^+	Potassium K^+	Magnesium Mg^{2+}	Calcium Ca^{2+}
IEC Cation Limits	**0**	**2**	**2**	**2**	**0**	**0**
Mean P1 Group	0.00	1.02	0.00	0.98	0.00	1.62
Mean P3 Group	0.00	1.47	0.00	1.62	0.00	1.40
Mean P5 Group	0.00	0.54	0.00	1.47	0.00	0.55
Mean P10 Group	0.00	0.73	0.00	0.82	0.00	0.99
Mean O8 Group	0.00	1.48	0.00	2.34	0.00	0.49
Mean O21 Group	0.00	1.12	0.00	0.33	0.00	0.99
Mean O28 Group	0.00	0.98	0.57	1.32	0.00	0.60
Mean O30 Group	0.00	0.63	1.08	0.83	0.00	1.46

Table 3. IC Data after CAF – Anions:

Sample Description	Fluoride F^-	Chloride Cl^-	Bromide Br^-	Nitrite NO_2^-	Nitrate NO_3^-	Phosphate PO_4^{3-}	Sulfate SO_4^{2-}	Organic Acids (SMT)	Organic Acids (PTH Clean)	Organic Acids (PTH No clean)	Acetate	Citrate	Formate	MSA
IEC Anion Limits	**1**	**3**	**5**	**3**	**3**	**3**	**3**	**25**	**0**	**150**	**3**	**2**	**1**	**0**
Mean P1 Group	0.00	0.74	0.00	0.00	0.14	0.00	0.40	0.00	**0.42**	0.00	0.00	0.00	0.27	0.00
Mean P3 Group	0.00	0.98	0.48	0.00	0.12	0.00	0.36	0.00	**1.24**	0.00	0.00	0.00	**1.35**	0.00
Mean P5 Group	0.00	0.62	0.32	0.00	0.20	0.00	0.50	0.00	**0.64**	0.00	0.00	0.00	0.42	0.00
Mean O8 Group	0.00	0.68	0.13	0.00	0.00	0.00	0.35	0.00	**0.93**	0.00	0.00	0.00	0.00	0.00
Mean O21 Group	0.00	0.67	0.82	0.00	0.00	0.00	0.65	0.00	**0.60**	0.00	0.00	0.00	0.00	0.00
Mean O28 Group	0.00	0.43	3.61	0.00	0.00	0.00	0.96	0.00	**1.17**	0.00	0.00	0.00	0.49	0.00
Mean O30 Group	0.00	0.65	0.58	0.00	0.00	0.00	0.42	0.00	**0.35**	0.00	0.00	0.00	0.00	0.00

Table 4. IC Data after CAF – Cations:

Sample Description	Lithium Li^+	Sodium Na^+	Ammonium NH_4^+	Potassium K^+	Magnesium Mg^{2+}	Calcium Ca^{2+}
IEC Cation Limits	**0**	**2**	**2**	**2**	**0**	**0**
Mean P1 Group	0.00	0.70	0.00	0.14	0.00	0.00
Mean P3 Group	0.00	0.42	0.00	0.16	0.00	0.06
Mean P5 Group	0.00	0.46	0.00	0.33	0.00	0.26
Mean 08 Group	0.00	0.89	0.15	0.45	0.17	0.00
Mean 021 Group	0.00	0.77	0.00	0.16	0.00	0.00
Mean 028 Group	0.00	0.56	0.33	0.61	0.00	0.00
Mean 030 Group	0.00	0.49	0.00	0.18	0.00	0.23