IEC TR 61189-5-506

Edition 1.0 2019-06

TECHNICAL REPORT

colour inside

Test methods for electrical materials, printed boards and other interconnection structures and assemblies –
Part 5-506: General test methods for materials and assemblies – An intercomparison evaluation to implement the use of fine-pitch test structures for surface insulation resistance (SIR) testing of solder fluxes in accordance with IEC 61189-5-501

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FOREWORD

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IEC/TR 61189-5-506, which is a technical report, has been prepared by IEC technical committee 91: Electronics assembly technology.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
91/1500/DTR	91/1530A/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61189 series, published under the general title *Test methods for electrical materials, printed boards and other interconnection structures and assemblies*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This document addresses the development of IEC 61189-5-501 and the introduction of a fine-pitch test pattern. The introduction of this pattern is needed to meet the need for IEC 61189-5-501 to reflect current assembly technology. This document describes an intercomparison that tests a new test pattern and benchmarks it to existing test patterns. The work validates the introduction of the new fine-pitch test pattern.

It is well known that structures at fine pitches with flux residues are more susceptible to corrosion issues and electrochemical migration (ECM) problems. Characterization of flux residues in terms of ECM are commonly characterized using SIR testing. A key parameter of the SIR test is the comb pattern used and gap between the electrodes. The current B24 and B25 with their 500-µm and 318-µm gap patterns are not representative of fine pitches. It has been proposed to use a 200-µm gap pattern, and this document describes an intercomparison that validates the introduction of the 200-µm gap pattern.

This document describes an exercise that used a new test board that included the B24 and B25 patterns with an additional 200-µm pattern, with each pattern duplicated, giving six patterns in all on each test board. This work was motivated by an update to IEC 61189-5-501. A protocol for the testing was developed that took a standardised test rosin flux and defined the flux loading and thermal conditioning. Seven laboratories took part from five countries. The test boards were prepared centrally and then tested in the seven laboratories, and the results analysed to validate the usage of the 200-µm pattern. The document describes the intercomparison and the data analysis.

TEST METHODS FOR ELECTRICAL MATERIALS, PRINTED BOARDS AND OTHER INTERCONNECTION STRUCTURES AND ASSEMBLIES –

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1 Scope

This Technical Report is an intercomparison supporting the development of IEC 61189-5-501 in relation to the SIR method. This document sets out to validate the introduction of a new 200-µm gap SIR pattern, and was benched marked against existing SIR gap patterns of 318 µm and 500 µm.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Test board concept for intercomparison

4.1 The need for a fine-pitch SIR pattern

The pursuit of higher quality and reliability leads to the requirement of proving that electronic assemblies are not susceptible to electrochemical failure. Such robustness will lead to proven lifetime performance in the field. Electrochemical failure can occur at the surface or sub-surface, and in this paper we focus on surface failure phenomena and its characterisation. Electrochemical failure needs three factors to be present simultaneously for a failure to occur: a continuous water film, an applied electric filed, and soluble ionic material. Under condensing conditions, a macroscopic water film will form and in most instances an uncoated assembly will fail instantly. But for high humidity conditions, an invisible sub-micron water film will form that will support low levels of conduction, and certainly no fast dramatic loss of isolation. Applied electric fields can cause electrochemical failure, from 25V/mm and upwards, by driving ions down an electric field. Ionic material is needed as pure water has very high resistivity, hence dissolved ions increase conductivity and polarization at electrodes resulting in corrosion at anodes. Sources of contamination can appear on the surface of the assembly from the manufacturing process or the environment. If the contamination is water soluble and dissociates to form ionic species, these ions migrate under an electric field.

It is of course of interest as to what ionic materials are present, but more importantly, the question is what will be the impact of these residues or contamination. The industry many years ago developed the basis of the “Surface Insulation Resistance” test, which applies an electrical bias across an interdigitated comb in a damp heat environment at elevated temperatures and measures the resistance stability. This test is a simulation of what will happen in the field, and hence the outcome is relevant to that performance. The IPC TM650 2.6.3.3, 2.6.3.6 and 2.6.3.7 describe the SIR test for various applications, providing various test geometries and voltage conditions. The B24 has a 500-µm gap in the comb pattern, and this is typically a lot greater than the minimum distances found on high-density circuit assemblies, where the gap can easily be down to 200 µm and below. The B24 was proposed circa 1990 and reflected the needs of those days, and of course since then there has been a move to finer pitches. At finer gaps, the electrochemical behaviour can accelerate and is sensitive to the applied electric field (see NPL work from 2000). In this work, it was shown for certain residues that as the test voltage dropped, so did the measured resistance, hence the electrochemical pathway did not behave in a simple ohmic manner. A conclusion of this work was that the gap in the SIR pattern and the applied voltage should be representative of the intended use environment. Hence, within IPC 2.6.3.7 there is a recommendation to use a 200-µm pattern with a 25V/mm field strength. No SIR pattern is given there. However, within the IPC-B-52 there are 200-µm SIR patterns used, specifically below the QFP devices.

Therefore, there is a strong interest in using the 200-µm SIR pattern but there is not a dedicated test coupon available. This paper sets out to demonstrate the interoperability of using different SIR patterns and hence demonstrate that the 200-µm pattern can be used with confidence. Most SIR patterns are approximately 25 mm × 25 mm, and as the pitch of the interdigitated comb decreases, the so-called number of squares increases. As the number of squares increases, the resistance will drop. Hence, if we consider the case where there is a fixed resistance for any square, as the number of squares increases, the overall measured resistance of the pattern will decrease, since these squares are in parallel. Any comparison shall therefore take into account the number of squares in the SIR pattern.

The electrochemical behaviour in the SIR test is known to be pitch-sensitive, and as the pitch reduces, the incidence of dendrites increases, even when the field strength is held constant. The potential for this catastrophic failure is the motivation for this intercomparison, but it is not something we wish to occur here. Rather, we are attempting to demonstrate that under intermediate SIR values (10^8 Ω and above), the patterns behave in an identical way, allowing for differences in the number of squares. Hence a test regime will be invoked that causes this behaviour and allows a straightforward comparison between the various pitches in this study.

In this study, we have taken a 200-µm gap pattern in common use, and originally defined in a joint European project. This pattern will be compared with two SIR patterns in common use today, the IPC B24 and a pattern from the B25, with 400 µm/500 µm and 318 µm/318 µm track and gap, respectively. A board was designed that included these three SIR patterns, duplicating each pattern, and named TB144.

To validate the introduction of this new test-pattern, an intercomparison exercise was undertaken, with seven laboratories taking part, from Denmark, Germany, Japan, the UK, and the USA. The laboratories were: Alpha Assembly Solutions, Gen 3 Systems, Hytek, National Physical Laboratory (NPL), Nihon Genma MFG. CO. Ltd, Robert Bosch GmbH Automotive Electronics, and Rockwell Collins[1].

4.2 Test board design

This round robin sets out to establish the justification for using a finer-pitch pattern. The test PCB has three SIR pitch patterns, two current designs (IPC B24 and a pattern from the B25, with 400 µm/500 µm and 318 µm/318 µm track and gap, respectively), and a finer-pitch pattern with a 400 µm/200 µm track and gap pattern. A board was designed and this board currently has the name TB144, and is shown below.

1 This information is given for the convenience of the users of this document and does not constitute an endorsement by IEC of the laboratories named.

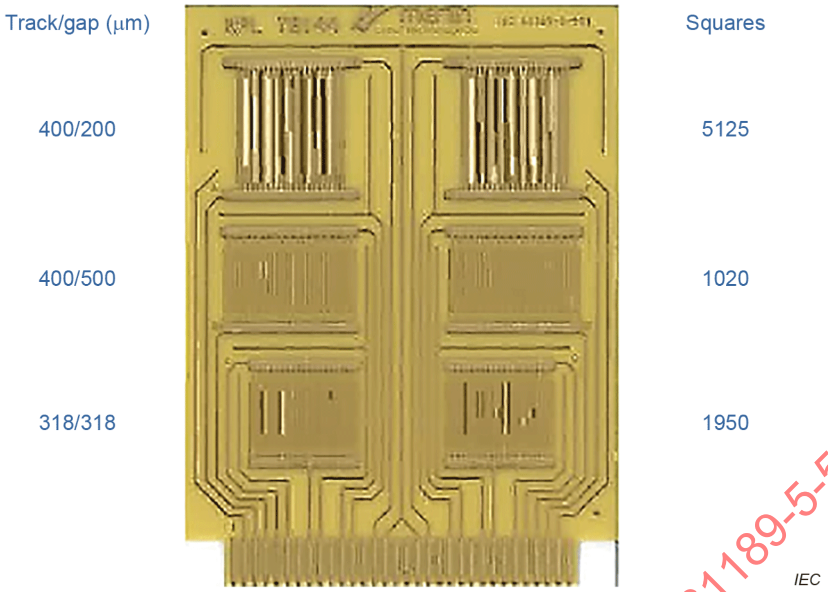

Figure 1 – TB144

In Figure 1, the number of squares is also given, and as can be seen, the number of squares for the 400 µm/200 µm pattern are significantly higher. It can also be seen that there are only small differences in overall size between the patterns. All test patterns have the same applied voltage and, in this work, was set to 20 V. This meant that the electric field strength was different for the three SIR patterns, as occurs on products. The impact of these changes are shown in Table 1. The intercomparison will establish the relative performance of the new pattern, prior to its inclusion in a new standard.

Table 1 – SIR pattern information

	B24	**B25**	**New**
Track/Gap (µm)	400/500	318/318	400/200
Number of squares	1 020	1 950	5 125
Resistance (Ω)[a]	1,00E+08	5,23+07	1,99+07
Field Strength (V/mm)[b]	40,0	62,9	100,0

[a] The 10^8 Ω is an example value for the pattern and the two following values assume the same resistance per square, and calculated the drop in resistance caused by the increase in the number of squares.

[b] The field strength is calculated using an applied bias of 20 V.

4.3 Test board fluxing

All six patterns were dosed with the same density of an activated rosin flux and tested under two climatic conditions, 40 °C/93 % RH, and 85 °C/85 % RH. All test boards were cleaned and then fluxed at NPL by a single operator and shipped to the test house 2 weeks before commencement of the testing.

Each test house, after completing the analysis and inspection, returned the data to the coordinator, NPL, for analysis.

1) The project provided test boards, sourced from a single PCB fabricator. The PCBs were made from 152 g/m^2 (0,5 oz/ft^2) Cu and EM-827 high Tg laminate.
2) The flux used is given in Table 2.

Table 2 – Flux to be used for SIR evaluation test

Constituent[a]	Composition by mass fraction (%)
Colophony	25 ± 0,5
Diethylammonium hydrochloride (CAS No. 660-68-4)	0,39 ± 0,01
2-propanol (Isopropyl alcohol) (CAS No. 67-63-0) or ethyl alcohol (CAS No. 64-17-5) as an alternative	74,61 ± 0,5
Mass of chlorine of solids[b]	0,5

[a] See IEC 60068-2-20:2008, Annex B for specification.

[b] Expressed as free chlorine based on the colophony content.

5 Test procedure for intercomparison

5.1 Sample preparation

a) There were three test PCBs for each test condition.

b) Samples were tested in the cleaned state. Samples were cleaned in an ionic contamination tester containing 75 % propan-2-ol, 25 % deionized water for 15 min.

c) In addition, at least one un-fluxed cleaned control coupon was tested.

d) A permanent and non-contaminating identification of test samples was undertaken using a vibrating scribe.

e) The test samples were visually inspected for any obvious defects. If there was any doubt about the overall quality of any test sample, the test sample was discarded. The samples introduced into the chamber are given in Table 3.

Table 3 – Samples for SIR evaluation testing

Sample group	Flux	Number of coupons
A = 85/85	Yes	3
B = 85/85	No	1
C= 40/93	Yes	3
D = 40/93	No	1

f) During the remainder of the sample preparation, the test samples were only handled by the edges only, or by using non-contaminating rubber gloves.

g) If boards were stored before treatment, they were stored in contamination-free bags or containers and closed bags (not heat sealed).

h) Fluxed samples were coated using the following procedure.

   1) A micro-pipette was used to spread the flux uniformly to coat each of the 4 test patterns with 5 µl/cm^2 of the liquid flux, and avoiding the flux spreading to outside the pattern (the flux loading was verified by NPL prior to the intercomparison).

   2) Flux-coated samples were dried by placing them in a heated fan-assisted box oven at 100 °C ± 1 °C for 5 min. The boards were placed on an aluminium plate at 100 °C, which was already in the oven. The aluminium plate should be at least 20 mm bigger than the board in both length directions, and at least 2 mm thick.

   3) NPL prepared all the fluxed boards for all partners to avoid the variation on flux sample preparation.

   4) When the fluxed samples were received by the partners, the samples were tested within four weeks to avoid time effect on flux residues.

5.2 Preparation of samples for humidity chamber

The samples were again visually inspected and any defective combs with bridging of conductors were discarded. Then one of either system connection method a) or b) was used.

a) *Connector system – High-resistance measurement verification:* The connector arrangement is shown in Figure 2. Before connecting test samples to the measurement system, each cable assembly was connected to the resistor verification coupon inside the humidity chamber at ambient conditions and a measurement taken. Any cable that did not read within the tolerance value of the total measurement system (±5 % up to 10^{10} Ω, ±10 % between 10^{10} to 10^{11} Ω, and ±20 % above 10^{11} Ω) was reworked or replaced. A TB144 board with six 10^{11} Ω resistors soldered on each test pattern was sent to each participant to check their SIR measurement systems and connectors before the round robin test. Five measurements were performed at ambient condition at 20 V ± 0,1 V DC with a 6-min interval for each pattern, and the results were noted.

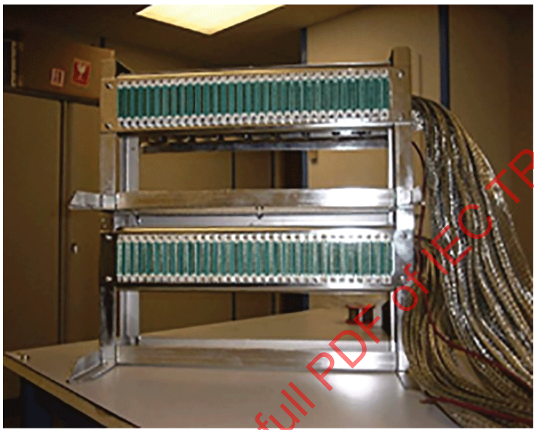

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Figure 2 – Connector arrangement

b) *Hand Soldering Cables to the PCB:* To hand solder cables, use a low-residue no-clean flux to solder Teflon-insulated wires to the connection tabs of the PCB. For this round robin work, hand soldering is not recommended.

5.3 Placement of samples inside the humidity chamber

The samples were placed in an environmental chamber in a vertical position in such a way that the air flow is parallel to the direction of the board in the chamber as shown in Figure 3. The chamber was set to one of the following conditions dependent upon the type of flux under test. The environment chambers were in validated calibration condition, and using DI water for the chamber.

a) For conditions A and B, the temperature was set to 85 °C ± 2 °C and humidity at 20 % RH; allow the chamber to stabilize at this temperature for 3 h.

b) For conditions C and D, the chamber temperature was set to 40 °C ± 2 °C and humidity to 20 % RH and allow the chamber to stabilize at this temperature for 3 h.

c) The humidity was slowly ramped up to 85 % RH ± 2 % or 90 % RH ± 2 % over a minimum period of 15 min. The samples were allowed to come to equilibrium for at least 1 h before applying the bias voltage to begin the test.

d) The 20 V ± 0,1V DC was connected to the sample test points.

Figure 3 – Sample orientation in test chamber

5.4 Resistance measurements

Four measurements with 6-min intervals at ambient condition (~25 °C/50 % RH) were taken before the chamber started to benchmark starting conditions. Measurements were then made with test samples in the chamber under the test conditions of temperature and humidity at 20-min intervals for 168 h.

5.5 Evaluation of results

a) The insulation resistance values of each comb pattern were noted. Any reason for deleting values (scratches, condensation, bridged conductors, outlying points, etc.) were noted.

b) All samples were photographed and evaluated within 1 day of test completion. If suspected, it was determined whether dendritic growth had occurred owing to condensation within the chamber.

c) All SIR results were recorded in an Excel file and sent to NPL for analysis.

d) A complete test report by each partner was sent to NPL.

5.6 Additional information

The participants were reminded that if condensation occurred on the test samples in the environmental chamber while the samples were under voltage, dendritic growth will occur. This can be caused by a lack of sufficient control of the humidification of the oven. Water spotting may also be observed in some ovens where the air flow in the chamber is from back to front. In this case, water condensation on the cooler oven window can be blown around the oven as micro-droplets which deposit on test samples and cause dendritic growth if the spots bridge the distance between two electrified conductors. Both of these conditions shall be clearly reported.

It was also advised not to use a test chamber that had been previously used with any salt tests or any heavily contaminated samples, which may affect SIR results. If a chamber was suspected of being contaminated, it was advised to wipe it clean using a 50/50 mixture of IPA and DI water to ensure the chamber was in a clean condition for testing.

6 Results

The results of testing the 10^{11} Ω checkerboard for each participant are presented in Figure 4.

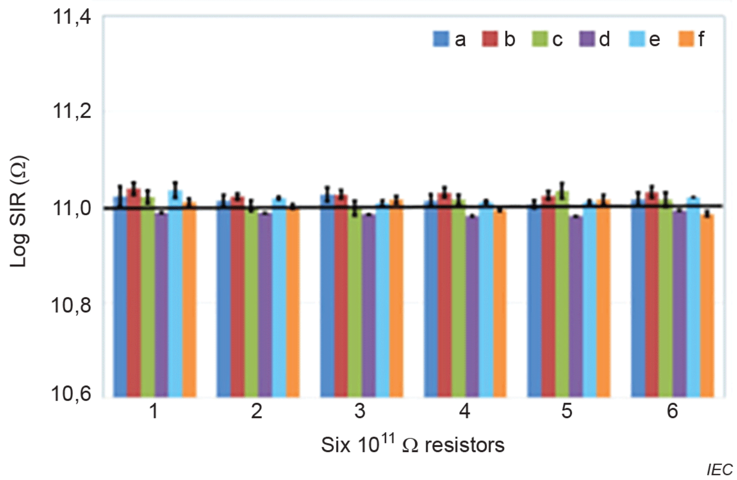

Figure 4 – Participants' (a to f) resistance measurements for the six test patterns on the checkerboard

For each participant, the average log SIR value for each test pattern from 5 measurements on 4 different measurement channels (20 measurements in total) is shown in Figure 4. The resistance results from all participants are within 0,2 % of the nominal value (10^{11} Ω). This shows that, for all participants, the resistance performance is well within the specification required by the standards.

The seven participants' results are presented below, starting with participant A. The three results shown in each graph, are an average of results from 2 identical SIR patterns per PCB and of 3 PCB test samples, 6 measurements in total for the fluxed coupons.

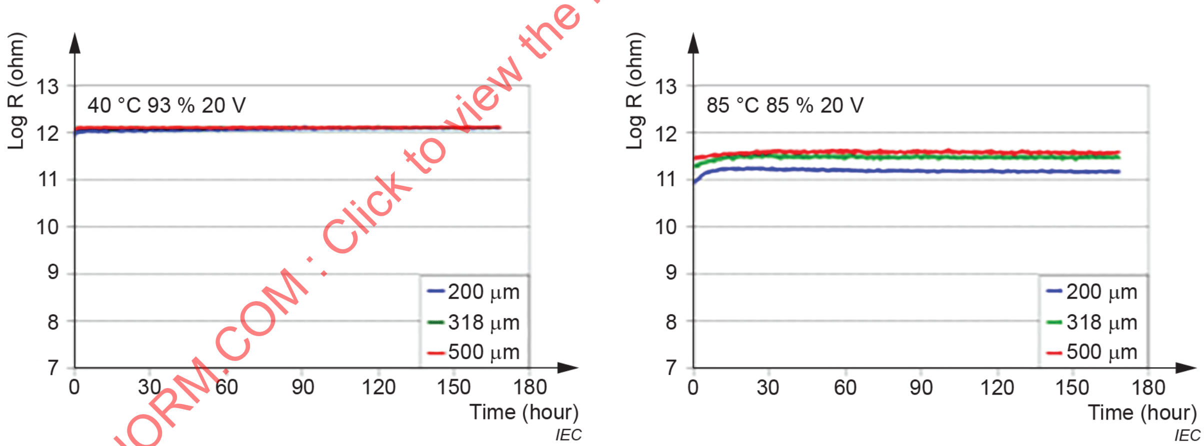

Figure 5 – Participant A control boards

Figure 5 shows the measurements for participant A of the control boards. Figure 7, Figure 9, Figure 11, Figure 13, Figure 15, and Figure 17 show the measurements for participants B, C, D, E, F and G, respectively.

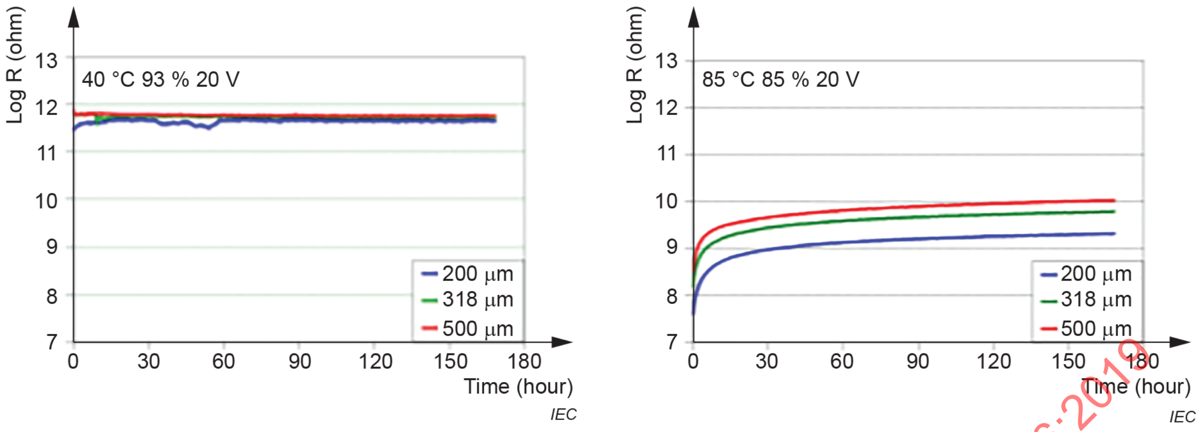

Figure 6 – Participant A flux loaded boards

Figure 6 shows the measurements for participant A of the fluxed boards. Figure 8, Figure 10, Figure 12, Figure 14, Figure 16, and Figure 18 show the measurements for participants B, C, D, E, F and G, respectively.

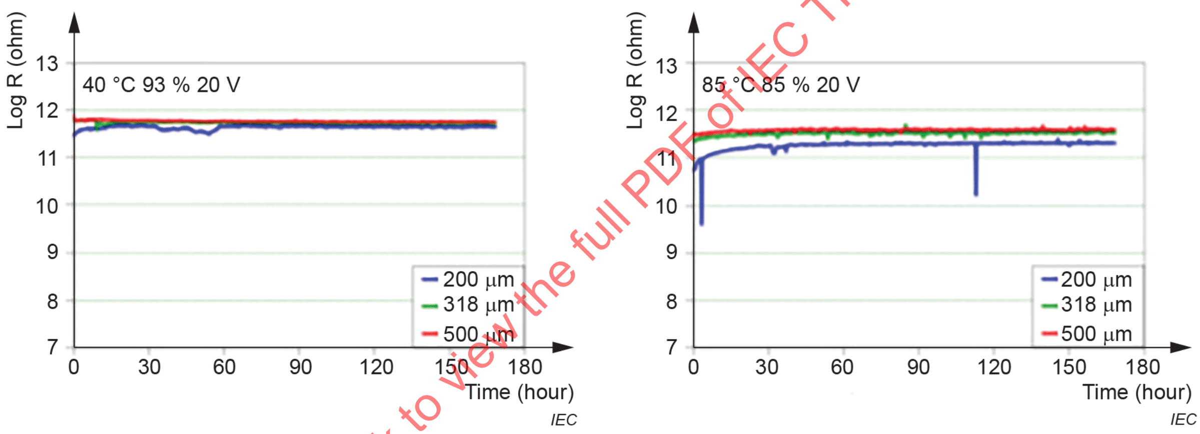

Figure 7 – Participant B control boards

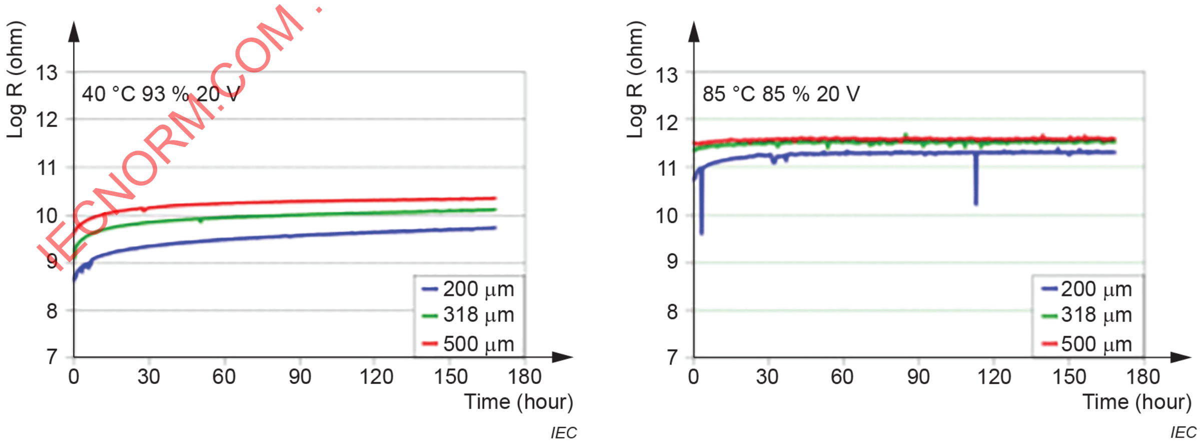

Figure 8 – Participant B flux loaded boards

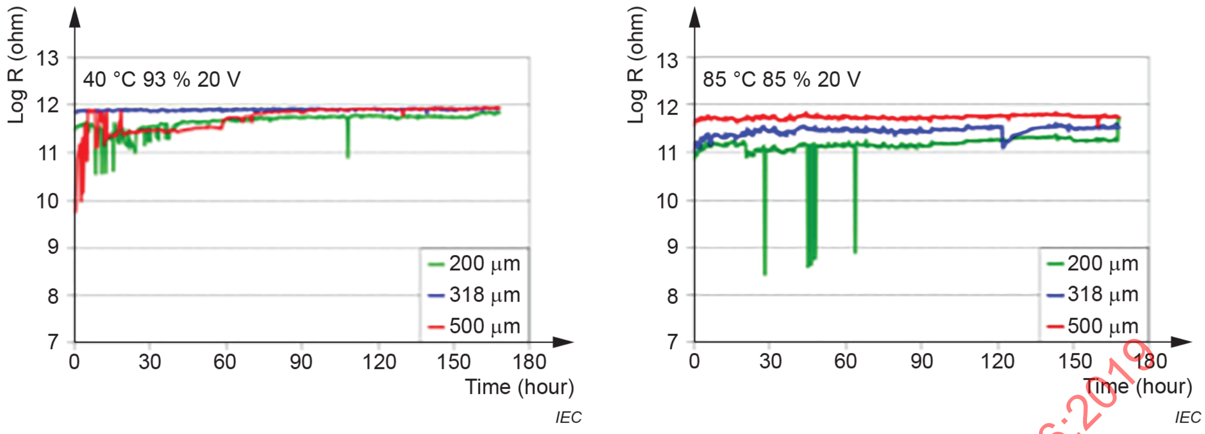

Figure 9 – Participant C control boards

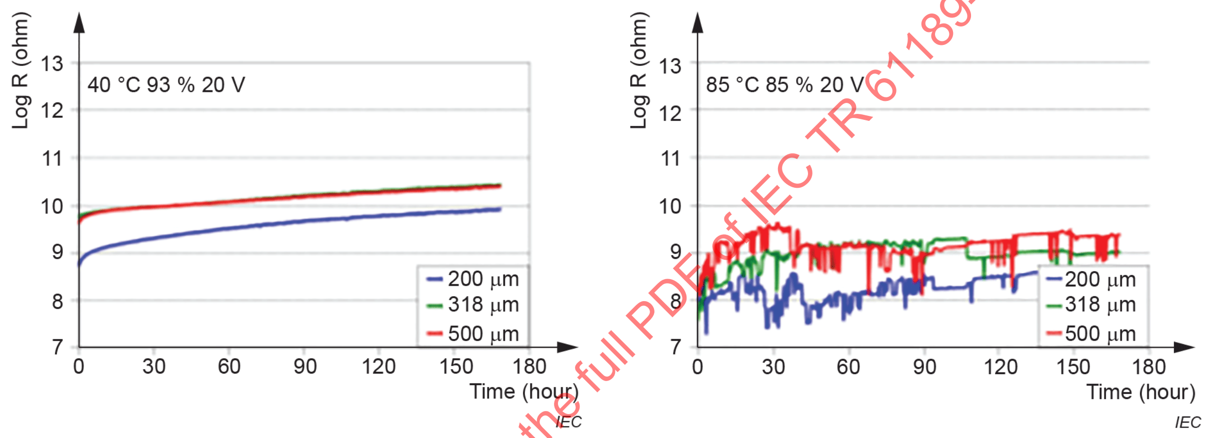

Figure 10 – Participant C flux loaded boards

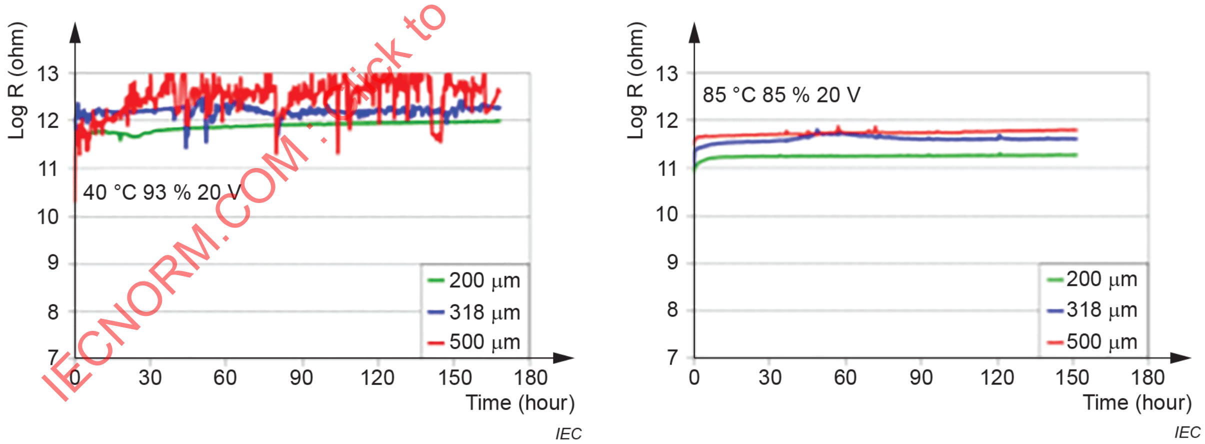

Figure 11 – Participant D control boards

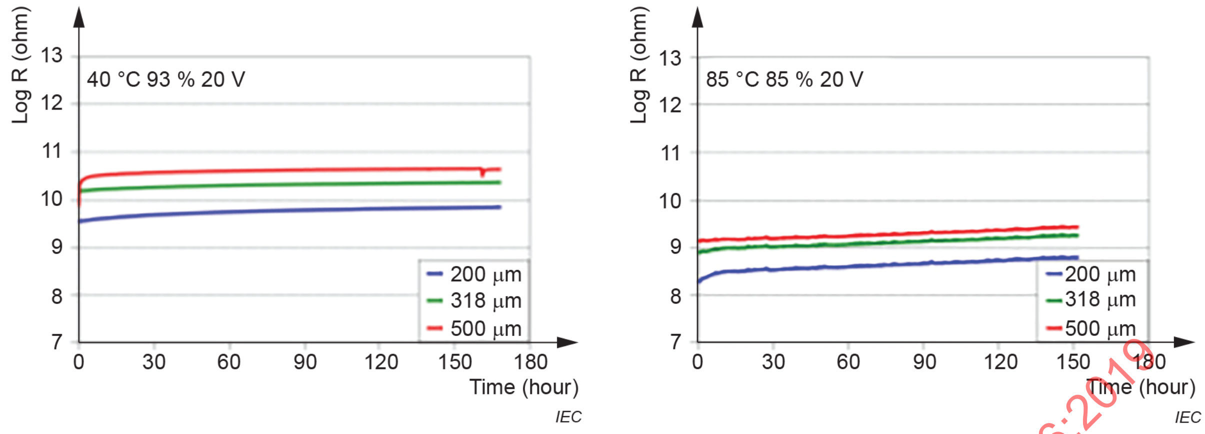

Figure 12 – Participant D flux loaded boards

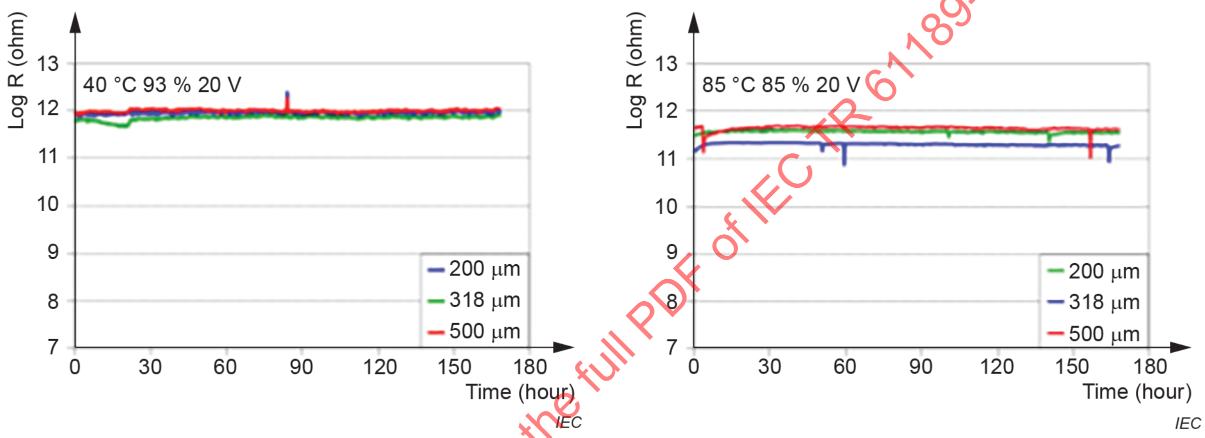

Figure 13 – Participant E control boards

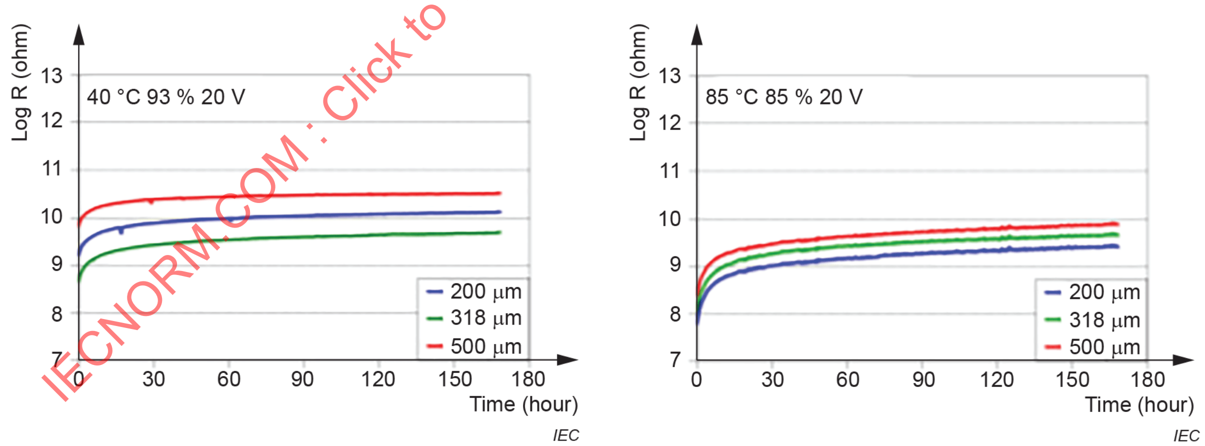

Figure 14 – Participant E flux loaded boards

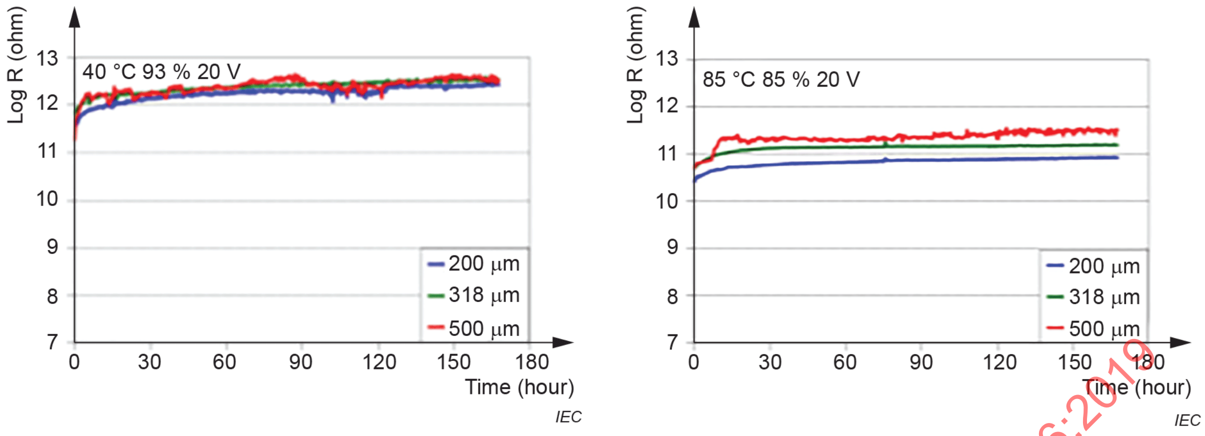

Figure 15 – Participant F control boards

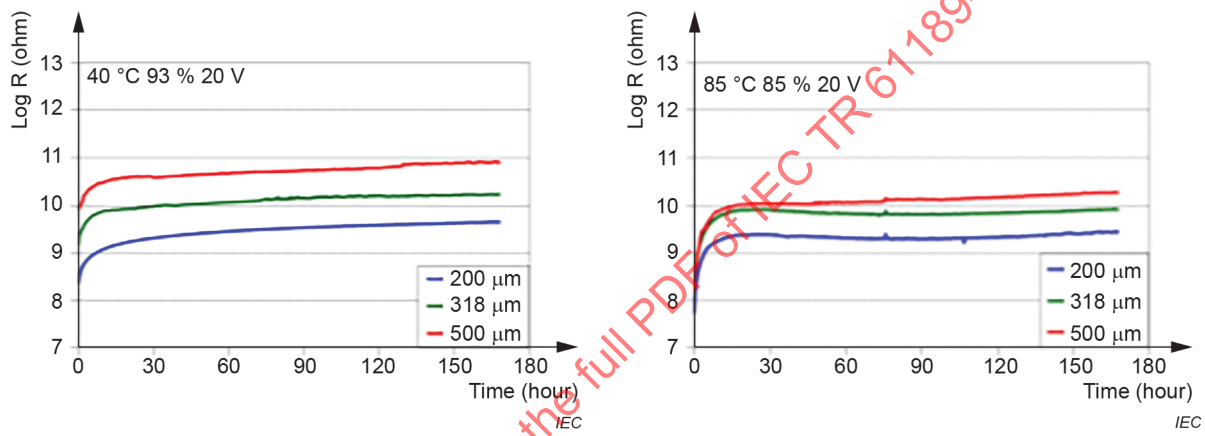

Figure 16 – Participant F flux loaded boards

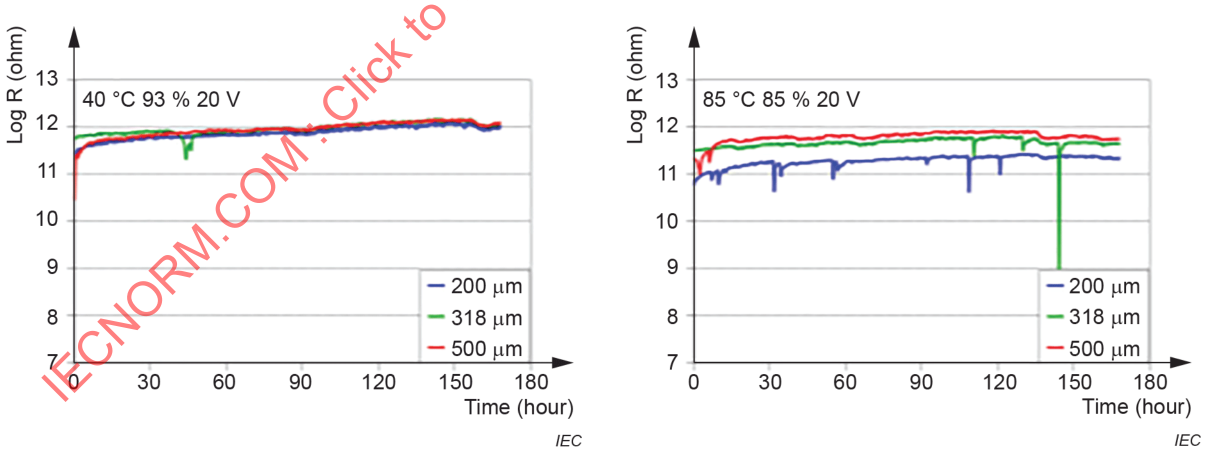

Figure 17 – Participant G control boards

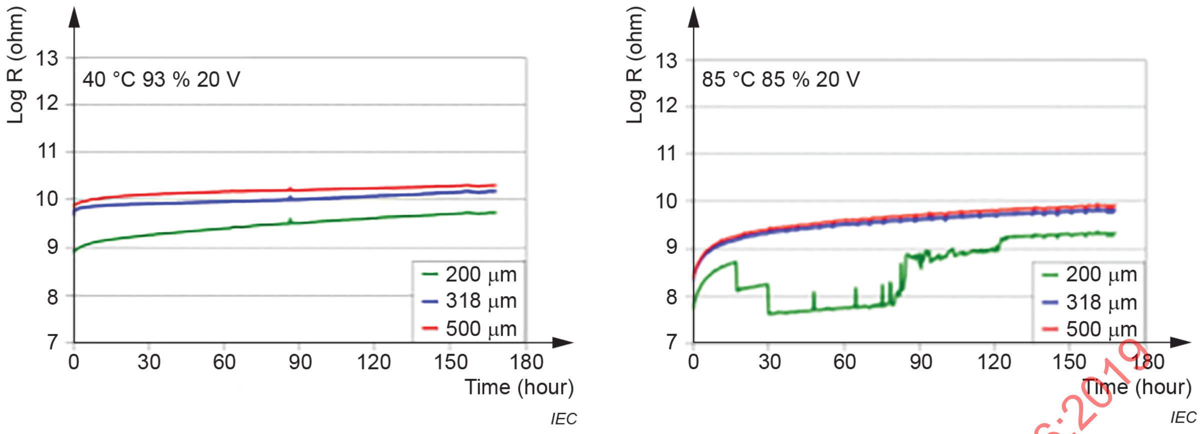

Figure 18 – Participant G flux loaded boards

Overall, these detailed results show that the quality of these experiments is very high. We can see some issues on some participants' data, and in four specific cases, a result from an individual pattern has been removed, and we make a general observation on participant C. Results have been removed because of: fibres, dendrites, water droplets leading to corrosion, and general corrosion. These results are anomalous and not consistent with the flux loading applied at NPL. These observations are shown in the following results.

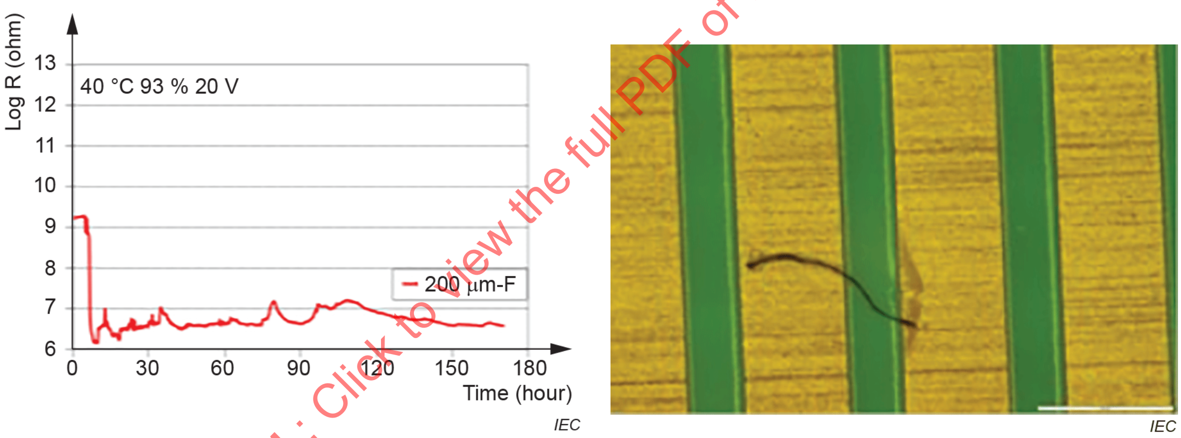

Figure 19 – Participant D, and evidence of a fibre and the effect on the SIR

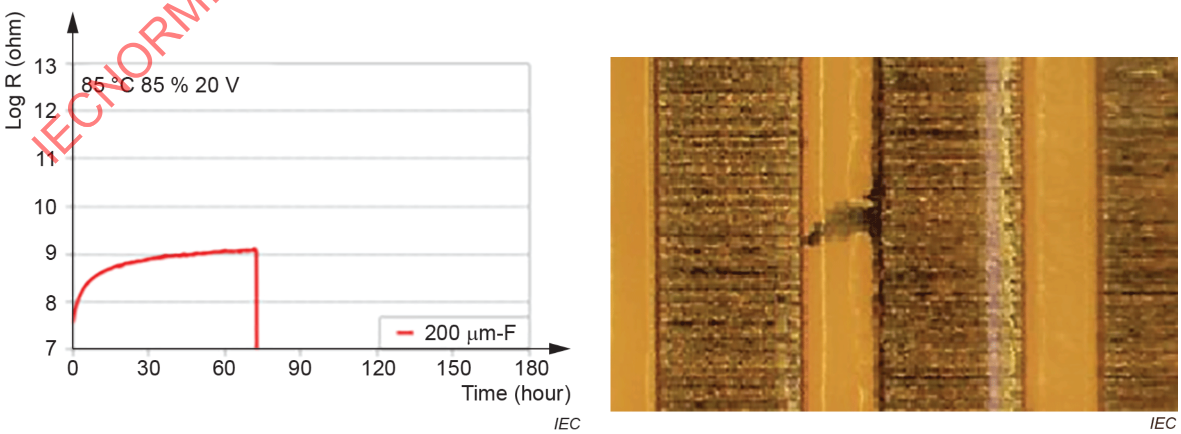

Figure 20 – Participant E and evidence of corrosion shorting across the gap

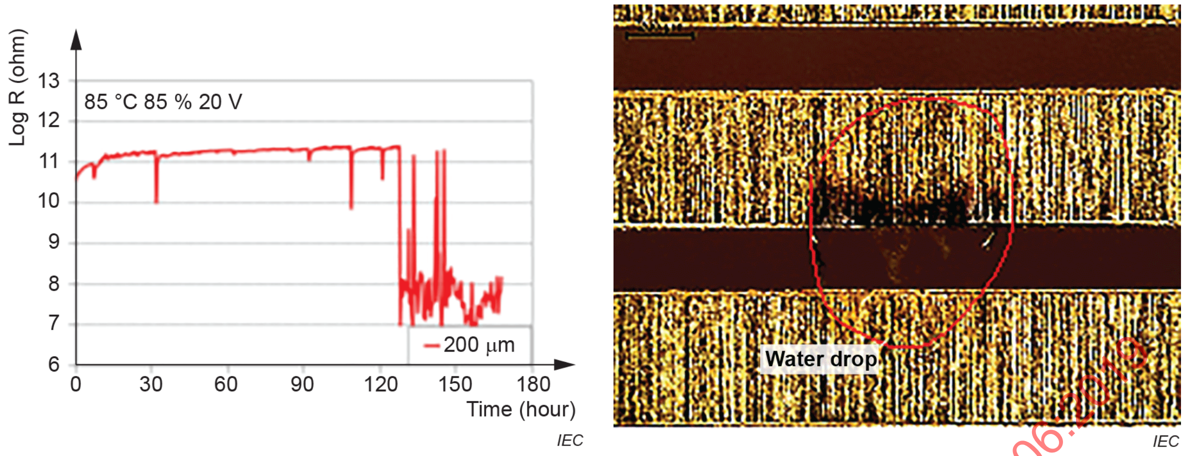

Figure 21 – Participant G and evidence of a water droplet and the resulting drop in SIR and dendrite like failure

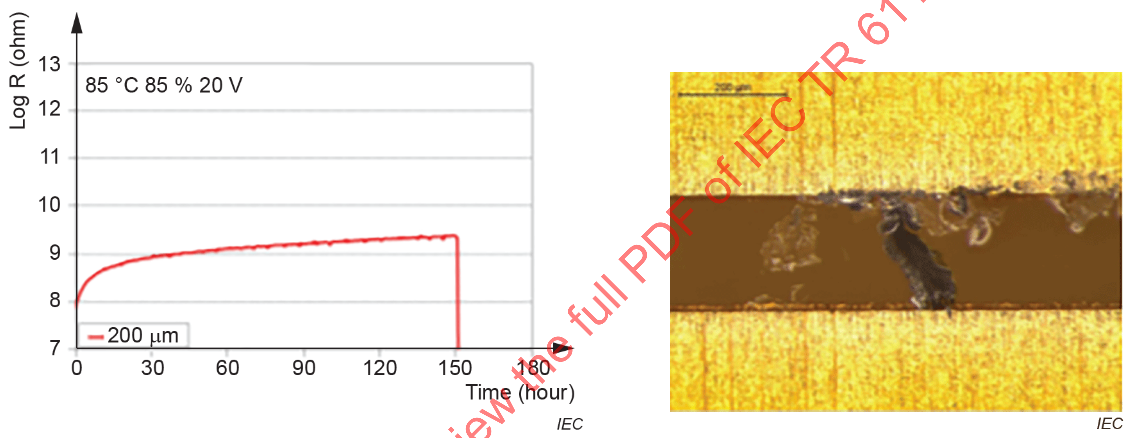

Figure 22 – Participant G and a corrosion defect probably from a flux residue

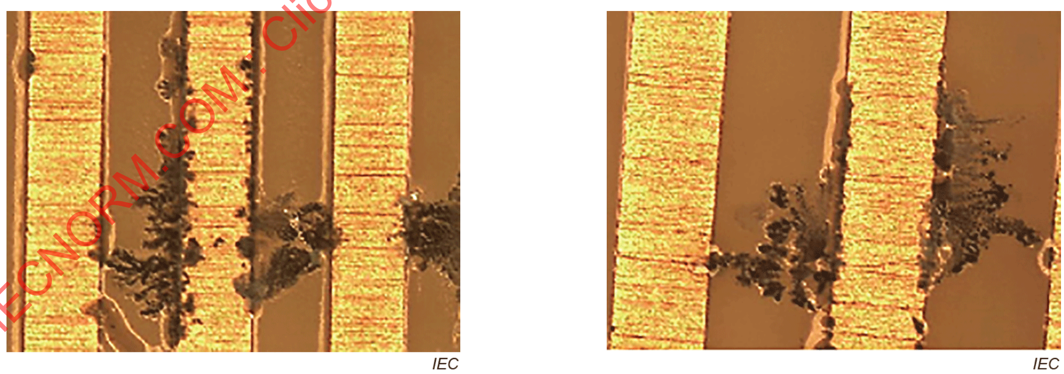

Figure 23 – Participant C dendrites and corrosions formed on all SIR patterns of all fluxed samples tested at 85°C/85%

Figures 19 to 23 show the defects and the basis for the justification for the removal of specific pattern results. The results from participant C reveal problems with dendrites and general corrosion at 85 °C/85 % RH, but we have not removed any data from the analysis.

The SIR results in Figures 5 to 18 show that overall there are distinct trends between the different SIR patterns for all participants. There are downwards ticks but this behaviour is independent of the pattern type. Hence, an average of the final 20 data points for each result is calculated and a single resistance value is given for each pattern participant combination. These results are shown in the next two figures.

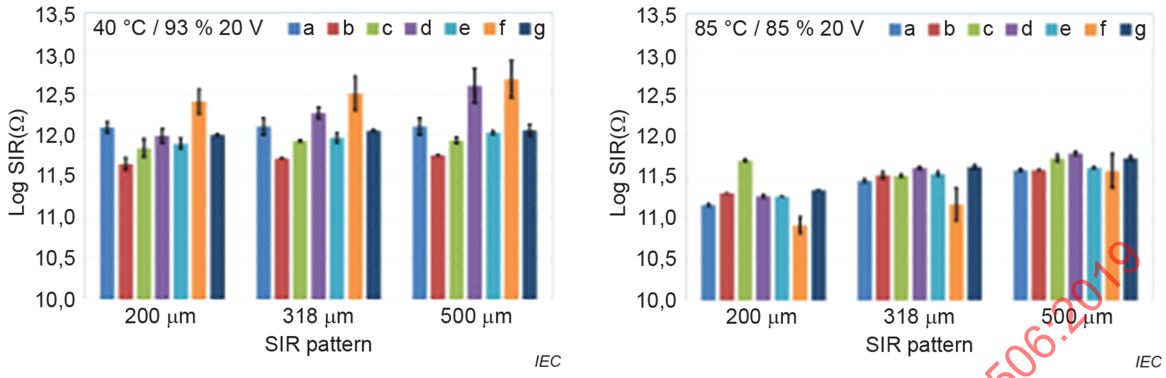

Figure 24 – The average final SIR value for the control boards

These results in Figure 24 show more variation than with the resistors in Figure 4. Clearly, the measurement repeatability for the resistors is superior. For these results, this can be attributed to the variability in the conduction layer, the thin water film. This film thickness is very sensitive to the exact temperature and humidity condition at the coupon surface. Furthermore, small differences in surface energy and surface structure of the coupon will affect the adsorption and conduction in the water film, with further contamination adding to the differences in conduction. This is more evident at 40 °C/93 % RH, particularly since the current level of ~20 pA leads to a greater electrical noise sensitivity, more than for the 85 °C/85 % RH results. In Figure 25, the fluxed condition shows between the 200-µm, 318-µm and 500-µm gap patterns, following the effect of the number of squares. The reproducibility at 40 °C/93 % RH is similar to the control results in Figure 24, but the 85 °C/85 % RH results seem more divergent. This cursory observation is strongly influenced by the low results seen for participant C, noted above.

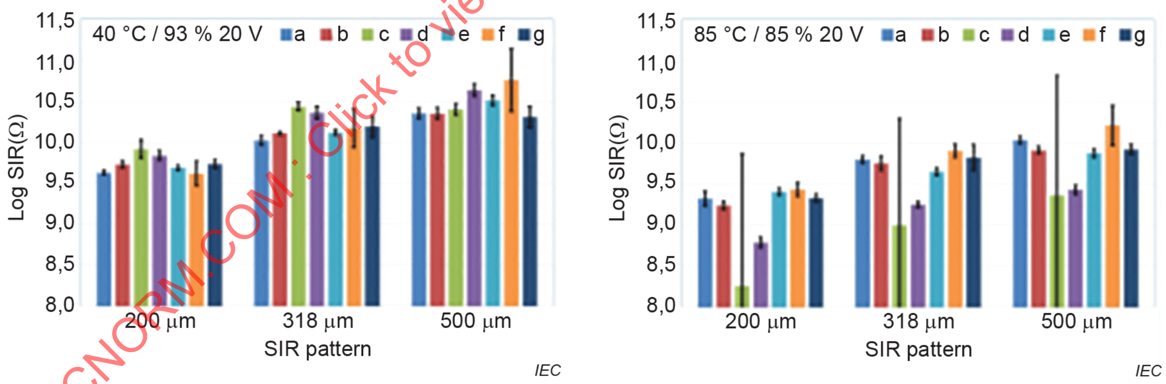

Figure 25 – The average final SIR value for the flux loaded boards

The data is rearranged in Figure 26, and plotted per participant, and now the effect of pattern pitch becomes very apparent for each participant. A similar relationship for the patterns is seen for both environmental conditions for each participant.