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Solder Paste Residue Corrosivity Assessment: Bono Test

Céline Puechagut, Anne-Marie Laügt, Emmanuelle Guéné, Richard Anisko
Inventec Performance Chemicals
Bry sur Marne, France

Abstract

Lead free soldering with no clean solder pastes represent nowadays the most common process in electronic assembly. A solder paste is usually considered as no-clean if it passes all IPC J-STD-004 corrosion tests: copper mirror, copper panel corrosion test, Surface Insulation Resistance (SIR) and Elecrochemical Migration (ECM). Other SIR and ECM tests are described in Bellcore GR-78-CORE and JIS Z3197 standards.

Although SIR and ECM tests are recognized by all standards authorities to evaluate the solder paste residue corrosivity after reflow, a more selective method, the Bono test, has been developed and implemented in some French companies as a qualification criterion. It has been proven that compared to common corrosion tests, the Bono test better differentiates the nature of solder paste residues.

Introduction

In electronic assembly, boards have higher densities and narrower spacings between tracks and pads. Tracks can have a width down to one hundred ten (110) microns. Thus, dendritic growth can become a big issue. The purpose of the Bono test is to assess the corrosive nature of solder pastes and to quantify it by the corrosion factor (Fc). Over the duration of the test, a curve of data points is achieved that can be examined to give meaningful information. In addition to that, other visual parameters are taken into account: 1) whether or not mousebites (pitting) are present, and 2) the actual appearance of the residue (color, spread, etc.).

It has been proven that compared to common corrosion tests, the Bono test better differentiates the nature of solder paste residues. This can be attributed to many factors: the board design, the test conditions (temperature, humidity), and the applied bias.

In this paper, the methodology will be described: the material used (test board, stencil…), the specific test conditions (electrical measurements, power supply, applied bias during the test, and the climatic conditions), and the corrosion factor calculation. This paper will then focus on parameters like solder paste origin, solder paste chemistry (halogen or halogen-free), thermal profile (short and long profile), environment (air or nitrogen reflow), and conformal coating.

Bono Test Description

This method is based on an existing test which assesses the liquid soldering flux residue corrosivity after wave soldering. The test board has been modified to measure the solder paste residue corrosivity[1] (Figure 1) and is different from the one used in the SIR and ECM tests. It is composed of 10 electrolytic cells and is made of an FR4 epoxy substrate with a single copper layer, having a very thin anode between two cathodes.

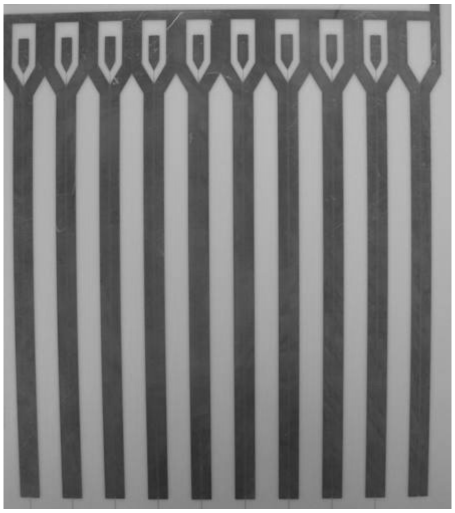
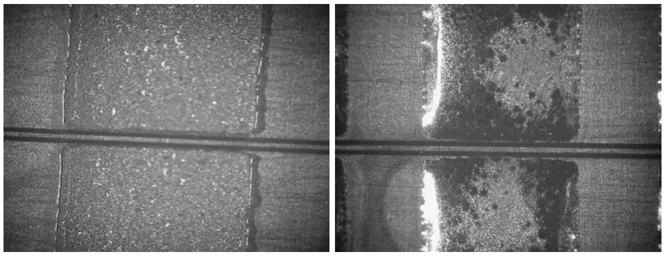


Figure 1: Bono Test Board

The solder paste is printed on cathodes through a 120µm thickness stencil and reflowed according to the desired profile[2] (Figure 2). The thermal profile used for the tests is described below (Figure 3).



2a) **2b)**

Figure 2: Solder Paste a) after printing and b) after reflow

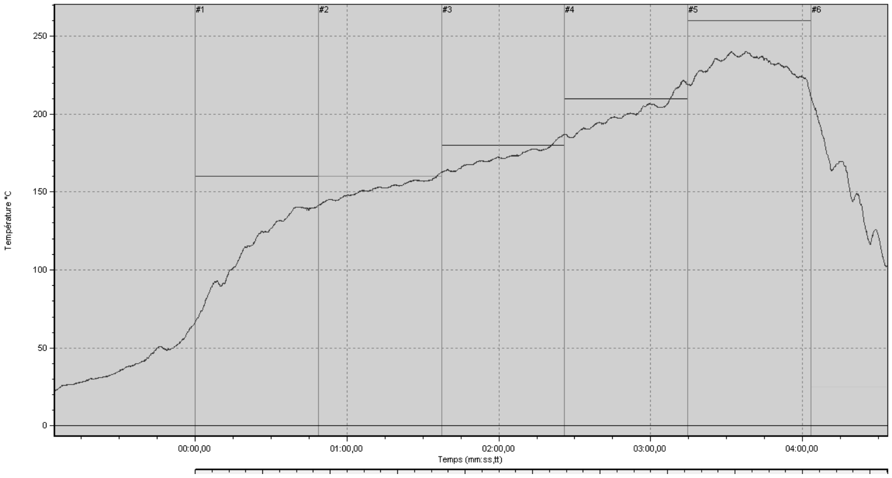


Figure 3: Thermal Profile for boards reflow (Profile 1)
Time above liquidus: 50sec; Peak Temperature: 240°C; Time from 25°C to 240°C: 270sec

Twenty-four (24) hours after reflow, the boards are submitted to ageing conditions; the samples must be then placed in a vertical position in the climatic chamber according to the temperature/humidity curve below (Figure 4). This is necessary to avoid any condensation on the test boards.

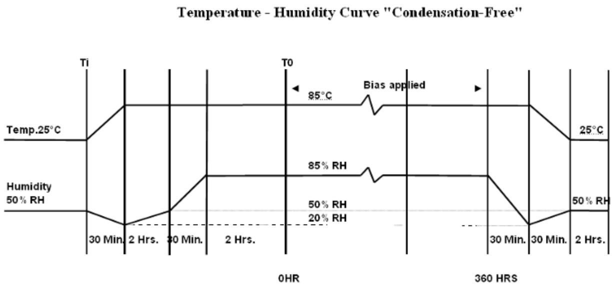


Figure 4: Temperature – Humidity Curve

The samples are conditioned for 16 hours 85°C/85% RH. Initial measurements (T0) are then taken. All measurements are made under temperature/humidity exposure, at a test potential of 12 VDC. The chamber is set at 85°C/85% RH for a total exposure time of 360 hours (15 days), with 20 VDC bias voltage applied to all samples. Resistance measurements of the anode are taken daily and the corrosion factor (Fc) is calculated according to the equation below:

$$\text{Fc} = \frac{R_d - R_0}{R_0} \text{ x } 100$$

where R_d is the resistance value at day "d" and R_0 is the resistance value at day "0". Fc is given in percentage (%).

SIR, ECM and Bono tests comparison

SIR and ECM tests lead to electrochemical migration which is defined as the growth of conductive metal filaments on a printed wiring board (PWB) under the influence of a DC voltage bias. Dendrites are formed by electro-deposition from a solution containing metal ions which are dissolved and re-deposited as a metal form[3].

The Bono test looks for electrochemical corrosion: The higher the amount of harmful residue, the greater the rate of attack on the metal in the circuit. The presence of an electrical potential greatly accelerates the corrosion process. At the anode, copper is dissolved forming mousebites[4]. These materials are only observed in the solder paste residue, which proves it is not a Canodic Anodic Filament (CAF) phenomena.

The corrosion factor value is representative of the corrosion effect and of the leakage current, caused by the flux residue.

The test conditions between SIR/ECM and Bono differ also from one test to another[5,6,7,8] (Table 1).

Table 1: SIR, ECM and Bono test conditions

Standard	Test Method	Temperature (°C)	Humidity (%RH)	Test Voltage (V)	Bias Voltage (V)	Test Duration (hrs)	Board
IPC J-STD-004B	IPC.TM.650, 2.6.3.3	85	85	-100	50	168	IPC B24
	IPC.TM.650, 2.6.3.7	40	93	Same as bias	25 V/mm	> 72	IPC B25A
	IPC.TM.650, 2.6.14.1	1) 40 2) 65 3) 85	1) 93 2) 88.5 3) 88.5	45-100	10	500	IPC B25A
Bellcore	SIR: 13.1.3	35	85	100	45-50	96	IPC B25A (D pattern)
	ECM: 13.1.4	65	85	45-100	10	500	IPC B25A (D pattern)
JIS Z 3197	SIR	A) 40 B) 85	A) 90 B) 85	100	0	168	IPC B25A (D pattern)
	ECM	A) 40 B) 85	A) 90 B) 85	100	45-50	1000	IPC B25A (D pattern)
BONO	Inventec: MO.SB.10029	85	85	12	20 V	360	Bono board

Three lead-free SnAgCu solder pastes have been selected for the SIR and Bono tests: Solder pastes A, B and C. All the pastes are no clean, lead-free pastes. Solder pastes A and C are halide/halogen free, Solder paste B is equivalent to solder paste C but halogens were added. Results are shown in the table below (Table 2).

Table 2: SIR, ECM and Bono Results

Standard	Test Method	Solder Paste A	Solder Paste B	Solder Paste C
IPC J-STD-004B	IPC.TM.650, 2.6.3.3	Pass > $1.10^{8}\Omega$, No dendrites	Pass > $1.10^{8}\Omega$, No dendrites	Pass > $1.10^{8}\Omega$, No dendrites
	IPC.TM.650, 2.6.3.7	Pass > $1.10^{8}\Omega$, No dendrites	Pass > $1.10^{8}\Omega$, No dendrites	Pass > $1.10^{8}\Omega$, No dendrites
	IPC.TM.650, 2.6.14.1 (2)	Pass No dendrites	Pass No dendrites	Pass No dendrites
Bellcore	SIR: 13.1.3	Pass > $2.10^{10}\Omega$, No dendrites	Pass > $2.10^{10}\Omega$, No dendrites	Pass > $2.10^{10}\Omega$, No dendrites
	ECM: 13.1.4	Pass No dendrites	Pass No dendrites	Pass No dendrites
JIS Z 3197	SIR A)	Pass > $1.10^{11}\Omega$, No dendrites	Pass > $1.10^{11}\Omega$, No dendrites	Pass > $1.10^{11}\Omega$, No dendrites
	ECM A)	Pass No dendrites	Pass No dendrites	Pass No dendrites
BONO	Inventec: MO.SB.10029 Fc after 15days	Fail Fc=8.1%, No Copper dissolution	Fail Fc=1.7%, Copper dissolution	Pass Fc=1.8%, No copper dissolution

Solder pastes A and B passed all the SIR and ECM tests but not the Bono test. Solder paste C passed all the tests. It showed that the Bono test better differentiates the nature of solder paste residues.

Bono Test: Solder Paste Influence

Three other no clean, lead-free pastes were tested in addition to the three solder pastes presented previously to assess their corrosive nature. The curve Time-Fc (Figure 5) shows the corrosion factor for each solder paste.

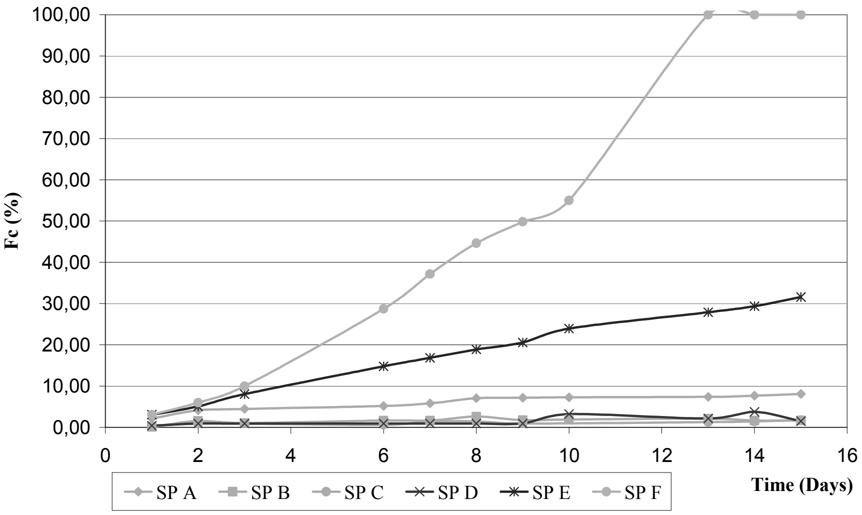
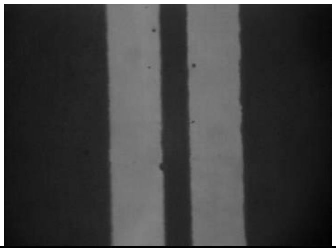
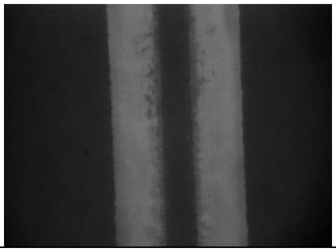
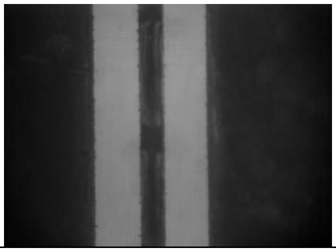
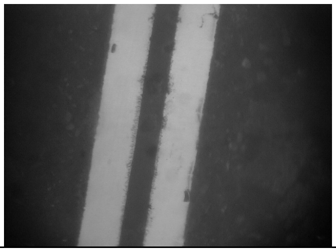
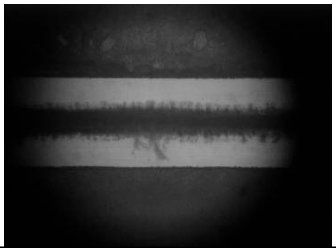


Figure 5: Solder Paste Influence

The curve of data points shows that solder pastes A, E, and F exhibit a very high Fc value, and the three other solder pastes have low Fc values. Moreover, a visual inspection has been conducted (Table 3) to observe 1) whether or not mousebites are present, and 2) the actual appearance of the residue (color, spread, etc.).

This experiment showed that 1) even if the Fc value is low, copper dissolution may appear (solder pastes B and D): since there are no short circuits between anodes and cathodes, the Fc value can be low; 2) a high Fc value does not necessarily lead to mousebites (solder paste A). Since the residue can be conductive, the leakage current can then be measured through the Fc value. Residue spreading could also be a root cause for high Fc values; 3) halogen in the solder paste flux caused mousebites (Solder paste B); 4) some no clean solder pastes lead to a very high level of corrosion (solder pastes E and F).

Table 3: Visual Inspection, Solder pastes from different origin

Solder Paste	Copper dissolution	Short circuit (over 9 tracks)	Residue Aspect
Solder Paste A	No 	No	Greenish Small residue spreading
Solder Paste B	Yes 	No	Brown No spreading
Solder Paste C	No 	No	Light brown No spreading
Solder Paste D	Yes 	No	Transparent No Spreading
Solder Paste E	Yes 	2	Greenish and minimal spreading
Solder Paste F	Yes 	All	Green-brown No Spreading

Bono Test: Reflow environment influence

In this experience, two solder pastes have been selected for reflow under nitrogen: solder paste A and C[9]. The results are given in Figure 6 and Table 4.

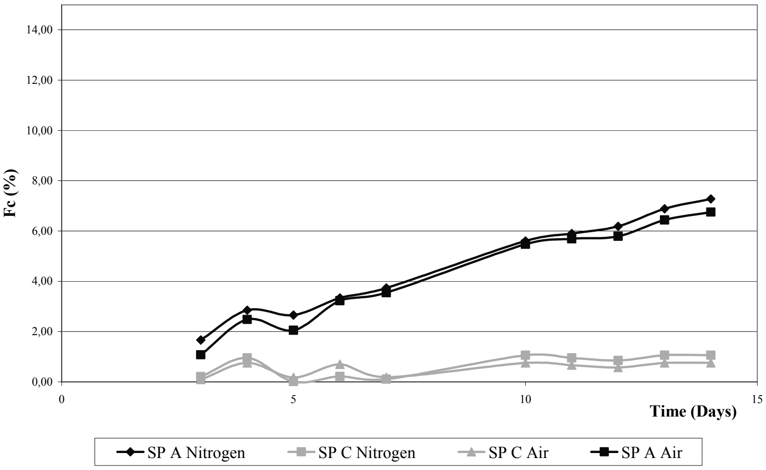
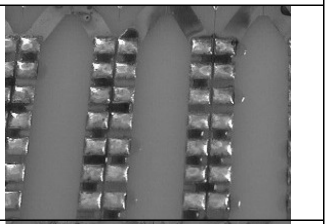
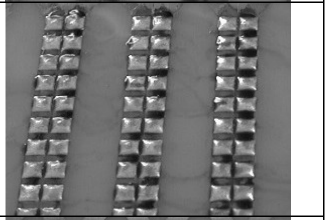
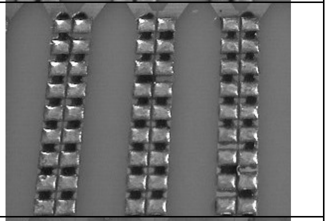
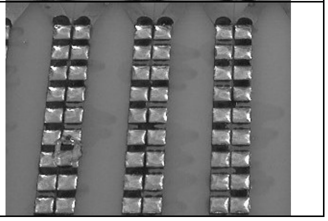


Figure 6: Bono test, Reflow under Nitrogen

Table 4: Visual Inspection, Reflow under Nitrogen

Solder Paste	Reflow Condition	Copper Dissolution	Short circuit (over 9 tracks)	Residue Aspect	Residue Picture
Solder Paste A	Air	No	No	Green Small residue spreading	
	Nitrogen	No	No	Light Green Residue spreading all over the boards	
Solder Paste C	Air	No	No	Light brown No spreading	
	Nitrogen	No	No	Light brown No spreading	

The first experiment (solder paste influence) seemed to show that the more the residue spreads, the higher the corrosion factor is. In spite of the fact that reflow under nitrogen leads to residue spreading, the corrosion factor is not affected compared to air reflow. In conclusion, residue spreading is only a cosmetic parameter which does not necessarily lead to a corrosion effect.

Bono Test: Thermal profile influence

In this experiment, a different profile is tested with solder pastes A and C. Profile 1 is the one described in Figure 3. Profile 2 is shorter, considered as easier and is described in Figure 7 in comparison with Profile 1.

After 15 days into the test, the boards were visually observed and no mousebites nor short circuits were detected. Residue spreading was similar to the previous experiment (minimal spreading for A and no spreading for C in air atmosphere). Fc value results are given in Figure 8.

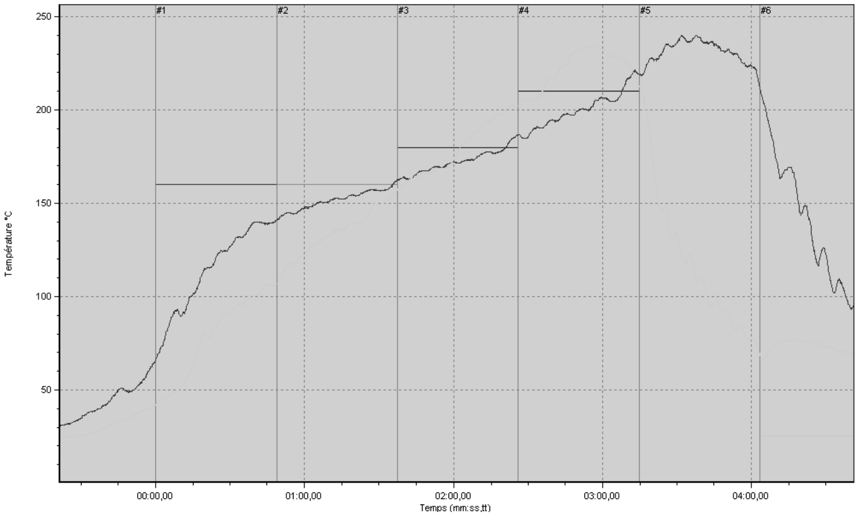


Figure 7: Profile 1 (red) and 2 (green) on the same graph

Profile 1: Time above liquidus: 50sec; Peak Temperature: 240°C; Time from 25°C to 240°C: 270sec

Profile 2: Time above liquidus: 35sec; Peak Temperature: 235°C; Time from 25°C to 240°C: 230sec

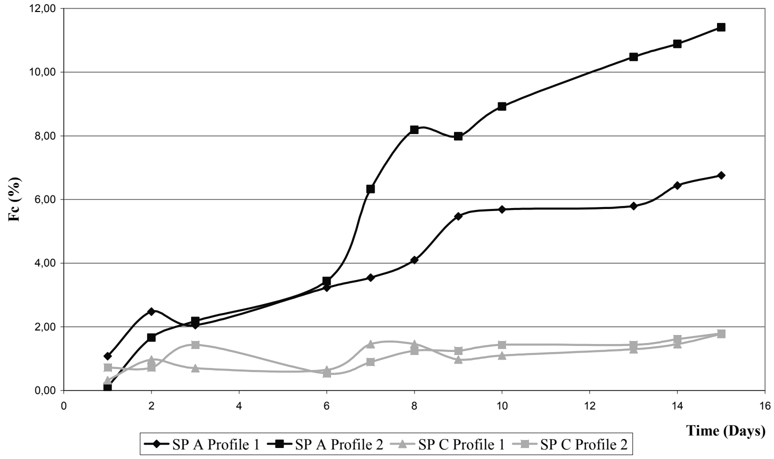


Figure 8: Thermal profile influence on solder paste

This experiment showed that the thermal profile seemed to have an influence on solder paste A but not on solder paste C. Solder paste C is not corrosive at all, regardless of the thermal profile used. Solder paste A is more corrosive if the thermal profile is shorter (Fc=6.7% for Profile 1 and 11.5% for Profile 2). This can be explained by the fact that some activators remained on the board after reflow due to the shorter thermal profile. Thus a higher corrosion factor is observed for solder paste A.

Bono Test: Conformal coating influence

To protect the boards from environmental conditions (temperature, humidity), conformal coating is sometimes required. The Bono test is a very good technique for assessing the compatibility between the solder paste and the conformal coating. Solder pastes A and C were once again selected and reflowed according to the profile 1; the conformal coating used for this study is a polyurethane (PU), cured according to its Product Data Sheet. The SIR tests (IPC TM 650 method 2.6.3.3) passed for both solder pastes: the SIR values were above $10^8\Omega$ and no dendritic growth was observed. However, the solder paste A with the PU conformal coating gave the lower SIR value (Figure 9).

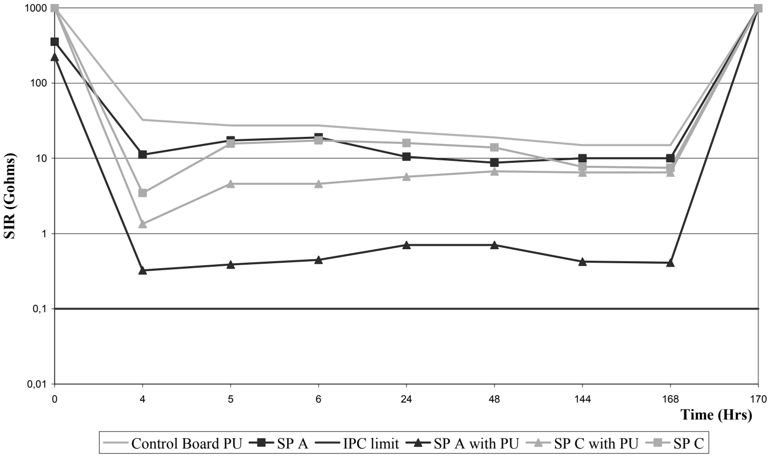


Figure 9: SIR results for solder pastes A and C with and without PU conformal coating

The Bono test was then applied to the same solder pastes. Both solder pastes exhibited a higher Fc value when the conformal coating was applied (Figure 10). The corrosion factor for solder paste A increased more than the one for solder paste C, meaning that the solder paste A residue and the PU conformal coating were not totally compatible, even though the IPC SIR test passed. No mousebites were observed in either case.

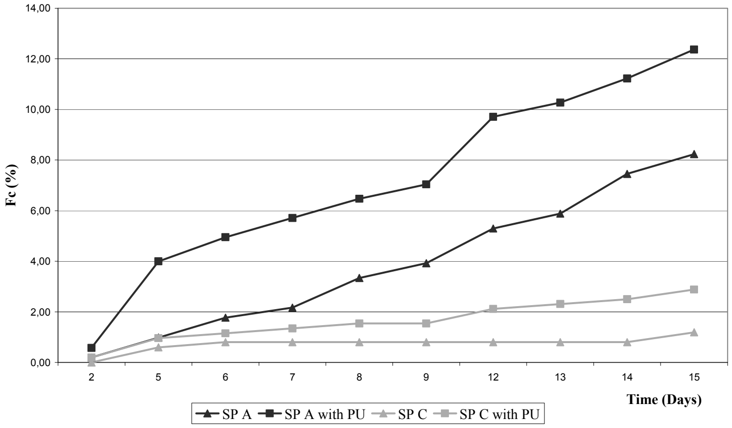


Figure 10: Bono results for pastes A and C with and without PU conformal coating

Test consistency

When comparing the four (4) experiments for solder paste A and solder paste C, it was showed that this method is consistent (Table 5).

Table 5: Fc values from the diverse experiments

Experiment #	1 Solder Paste influence	2 Reflow Environment	3 Thermal Profile	4 Conformal Coating
SP A - Fc Value (after 15 days) %	8.1	6.8	6.7	8.2
SP C - Fc Value (after 15 days) %	1.8	1	1.1	1.2

Conclusion

The Bono test differentiates the nature of solder paste residues better than other methods. Lead-free, no clean solder pastes have very different behaviours. Some can be very corrosive, as the Bono test proves even though common SIR and ECM tests fail to do so. Through the different experiments, it was shown that this method is consistent and repeatable.

Even if the Fc value is low, the start of dendrite creation may be seen (since there are no short circuits between anodes and cathodes, the Fc value can be low), and a high Fc value does not necessarily lead to mousebites. Residue spreading is only a cosmetic issue, and halogens in the solder paste flux can cause copper dissolution. The thermal profile will influence the solder paste residue corrosivity if the solder paste tends to be corrosive, however the reflow environment does not seem to have any influence. This test is also a good way to check the compatibility between solder pastes and conformal coatings, as it increases the difficulty to pass the test.

It should be noted that the Bono test procedure does not specify any real critical value above which a solder paste is considered to be corrosive. However, from the different experiments, a solder paste residue corrosivity assessment can be taken into account using the following guidelines: corrosivity does not exist in solder paste residue when the Fc value is under 2%(which can due to measurement precision), the solder paste residue corrosivity is acceptable when the Fc value is between 2 and 8%, and the solder paste residue starts to be corrosive when the Fc is above 8%.

In addition to characterizing solder paste residues, the Bono test can be performed for wave soldering fluxes, repair fluxes, and tacky fluxes using the same method and the same board.

Acknowledgments

The authors would like to thank Dr David Bono for his help in developing and implementing the test, which bears now his name.

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