TIN FLAKES/SPLASHES IN SMT

Jose M. Servin, Miguel Dominguez, Tabata Nöthel, Indira Vazquez,
Pedro Juarez, Ivan Roman
Continental
Cuautla, Morelos, Mexico
jose.servin@continental-corporation.com, miguel.dominguez@continental-corporation.com

ABSTRACT
During the quality revisions, an increasing of electrical shorts reported in several testers was noticed. Initially, it was found than more of the 80% of the shorts corresponding to thin metal flakes/splashes. Due to the fact, the non-conformity increasing coincided to a new solder paste introduction, an analysis of the solder residues found in several processes was made, including printing, pick and place, reflow, and rework. Scanning Electron Microscopy with X-Ray Microanalysis (SEM/EDS) shows the flakes were made of pure tin. The residues were characterized and ruled out according to them. The other possible source of the metal flakes was component metallization. However, because the product has several components with tin metallization, an analysis of flake positions was done to delimit the possible component. In order to prove the D2PAK component was producing these flakes, several experiments were made to reproduce the issue in lab test and reflow with different conditions. It was found that the tin metallization was detached and flying out during the reflow melting time. This was the reason that this issue only happened in lead-free products and not leaded ones because only when metallization is melted, the flakes were expelled out. The root cause of this metallization detachment was the cleaning state of the base metal before tin deposition because tin metallization existed but it was not proper adhered. A possible oxide layer prevented tin from getting a good attachment. After removing the suspicious lots and improving component quality, this type of short disappeared from the quality charts. Additionally, sometime later, similar issue appeared in another product. Tin flakes causing shorts. Using the last experience, it was quickly analyzed and a SOIC component was the possible source of the issue. Similar actions were made to eliminate the issue.

Key words: Short, Flakes, Burrs, Tin Short

INTRODUCTION
Among the several non-conformities that would appear in a SMT lines, shorts are between the two most common. The other one is insufficient solder. Short or Electrical Short can be defined as foreign electrical material that establishes an electrical conductive path that is not allowed or specified by design. Foreign means that is put there on purpose. This causes the system or assembly doesn't function properly and causes a severe or irreversible damages.

The most common short in SMT assemblies is due to solder excess between two leads or PCB pads. See Figure 1. This mainly happens in solder printing due to several factors, such as, solder excess, solder slump, assembly misalignment in printing, stencil damage, etc.

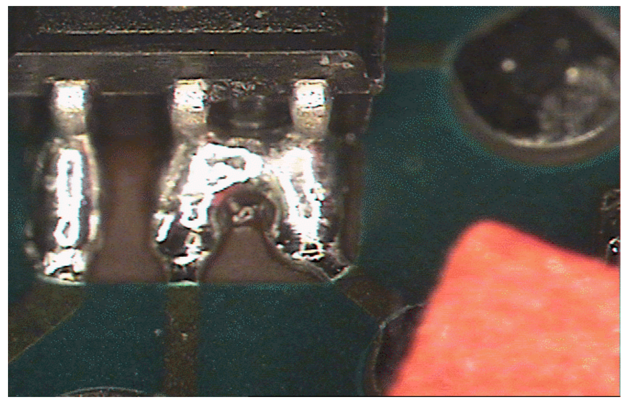

Figure 1. Typical Short in SMT Lines

However, in special cases, we can face situation in which the possible cause of the short is not related to solder excess or solder short. These cases are interesting to investigate because these need more effort to control and reduce in amount.

INITIAL SITUATION
During a specific time period, the shorts reported in back-end testers increased out of the goal. The tester was an ICT which can detect this non-conformity. An immediate action was required according to our internal quality system, see Figure 2.

However, the increased of ppm's coincided to an improved quality characteristic to the solder paste. This is important to mention because this fact would mislead to the idea that both events would be related.

An investigation started and the first step is to investigate what type of shorts are and why other testers before ICT would catch them.

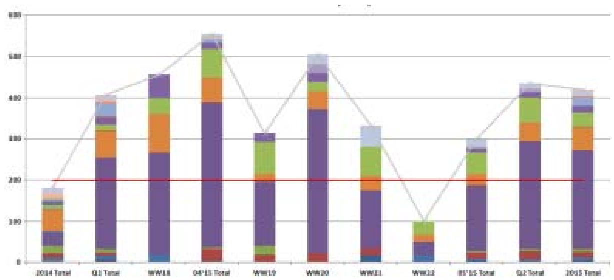

Figure 2. Increasing of short issues in our indicator, see the purple part of the columns.

PROCESS ANALYSIS

The first analysis was to collect in all the images of shorts that were reported in BE lines and separate them according to the shape or form characteristics (2 weeks). Based on the observation, the next classification was proposed:

- Burrs: Metallic burrs, flakes or threads that provoke any electrical short. These commonly are shine and silver colored.
- Type 1: Classic SMT short made by solder excess, see Image 1.
- Other: Other metallic short that is not shinning or metallic colored.

A Pareto Diagram was done and the percentages of each can be seen in the Figure 3.

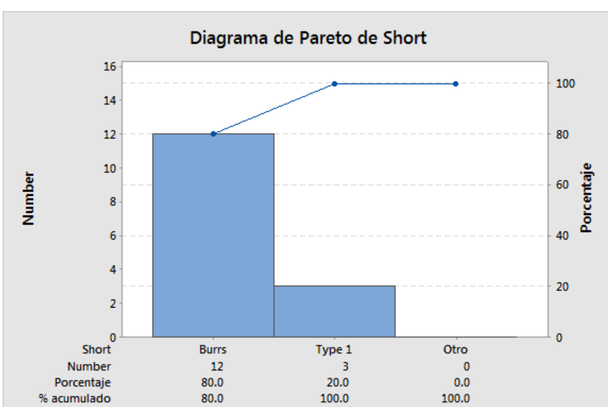

Figure 3. Pareto of short types

80% of the shorts were related to the burrs, see Figures 4 and 5. This type of short looks not related to solder paste because they don't like as solder excess but a better and deeper investigation was needed.

Figure 4. Example of a burr (1)

Figure 5. Example of a burr (2)

In order to find the root case, a Cause-Effect Tree (CET) was proposed and done from an initial brainstorming, Figure 6. In this methodology, one put the effects on the left of the causes. Two important modifications are done, first, the brainstorming is only to find the first causes, as scientific approach, and no energy is spend to name further causes. Second, in order to advance, every first cause has to be proved or disprove with objective facts, not only by guessing or logical views.

Following the effect-cause chart, several sources of metallic burrs, or particles are pointed to. If we apply the procedure correctly, every possible cause has to be proved with objective proof; otherwise they cannot be discarded.

In the next sections, the proofs for every possible cause are tested or evaluated.

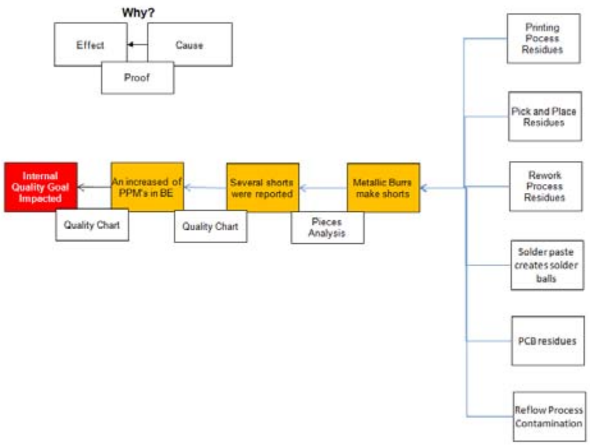

Figure 6. Initial Cause-Effect Tree (CET).

The Scanning Electronic Microscopy (SEM) Analysis shows that the burrs are made of tin mainly with some traces of C, N, and O.

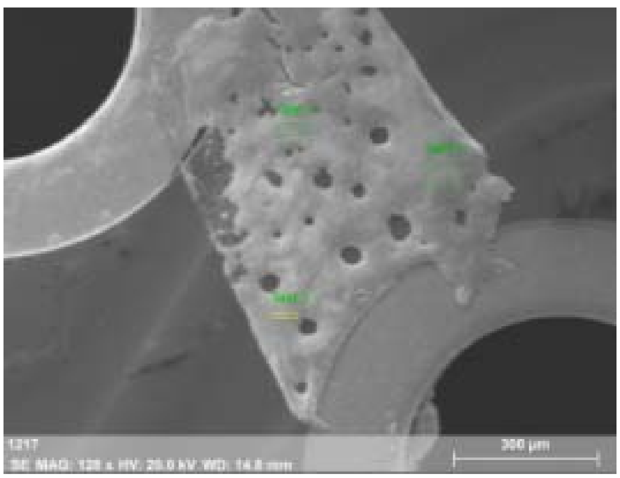

Figure 7. Burr SEM Image

Small amount of Si, Na and Cl are present as traces in some burrs, see Table 1. In the next analyses, these types of burrs have to be found.

Table 1. Burr EDS Analysis

Mass percent (%)

Spectrum	C	N	O	Si	Cu	Sn
Test 1	5.21	1.12	3.58	-	-	90.09
Test 2	4.18	1.94	3.00	-	-	90.88
Test 3	18.90	-	11.64	1.68	0.75	67.03
Mean value:	9.43	1.53	6.07	1.68	0.75	82.67
Sigma:	8.22	0.57	4.83	0.00	0.00	13.55
Sigma mean:	4.74	0.33	2.79	0.00	0.00	7.82

The next steps are to determine the possible sources of these flakes. For that, an analysis by every possible process or material (i.e. solder paste) was done. Remember, a solder paste quality improvement was done in similar time when the burrs had an increase.

A) PRINTING PROCESS

A deep scanning for possible source of metallic burrs was done. Residues from stencil and printing machine were taken, see Figure 8 and 9.

Figure 8. Printing Machine Residues

Figure 9. Stencil Residues

These residues are common to find in printing process. In order to verify how they are after reflow, the solder residues were reflowed to observe the type of shape or form that would be formed. See Figure 10 to observe the residues before reflow (set on purpose there), and Figure 11 to observe them after.

The residues after reflow are melted forming solder balls. The ball formation is because flux is still active and cleans the oxides to coalesce the solder particles all together. However, because some flux is dry and not so active, the small tiny solder balls cannot melt together and keep dry.

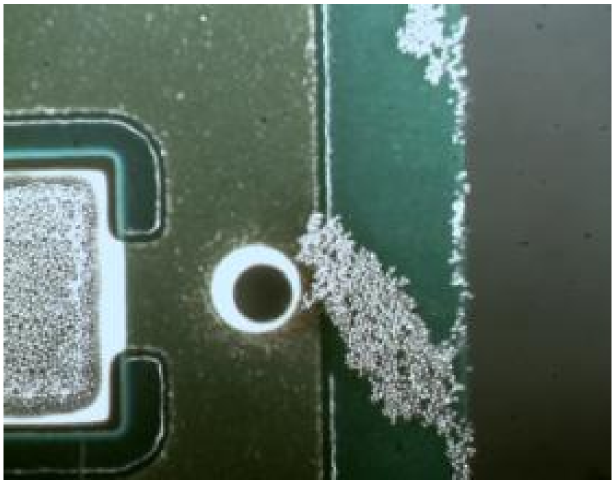

Figure 10. Residues before reflow

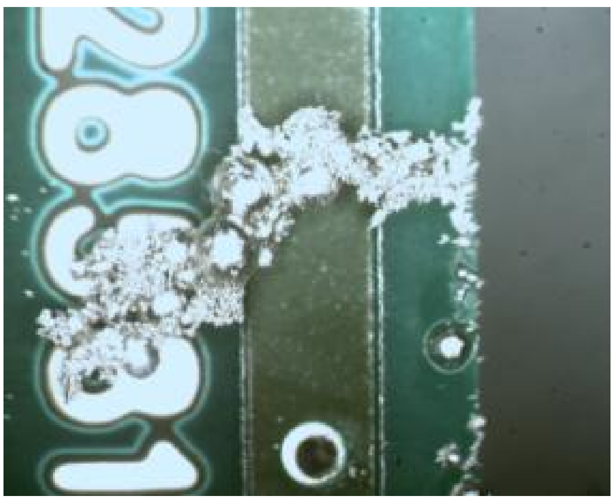

Figure 11. Residues after reflow

Some residues are too dry, and solder residues are not completely coalesced after reflow. Many tinny balls keep their forms.

Figure 12. Dry Residues before reflow

Figure 13. Dry Residues after reflow

The SEM analysis shows the solder paste residues form solder balls of different sizes. When solder paste is dried, the balls are the same size as the powder (too small). When they coalesced, there is a flux residue around them.

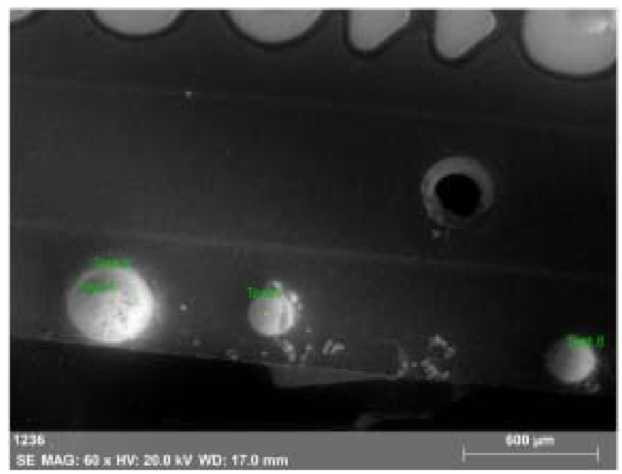

Figure 14. SEM of reflowed solder paste residues

Of course, EDX results show similar composition of solder residues with the solder paste alloy (Sn, Ag, and Cu), see Table 2.

Table 2. Solder ball EDS Analysis

Spectrum	C	N	O	Si	S	Cu	Ag	Sn	Ba
Test 5	27.73	12.87	16.65	0.86	-	-	2.93	38.95	-
Test 6	50.17	2.26	21.19	1.15	0.88	-	0.59	22.04	1.71
Test 7	39.78	-	17.95	1.67	0.98	0.66	1.76	33.89	3.30
Test 8	-	-	-	-	-	-	-	-	-

Therefore, solder residues are either dry solder tinny balls or flux-wetted balls but not metallic flakes. This cause is ruled out.

B) PICK AND PLACE PROCESS

During verification inside of the Pick and Place (P&P) equipment, some solder residues were found, see Figure 15. Solder residues were found in one reel of the pick and place machine due to the clamping. When PCB with solder paste is hold by the pick and place conveyor, the reel removed some solder paste from the PCB. A pad that is not used by the product (because no component is set on it) had solder paste deposition and was slightly close to one edge. Due to this, solder paste was removed by clamping. The correction was done in the stencil avoiding solder paste deposition on that pad.

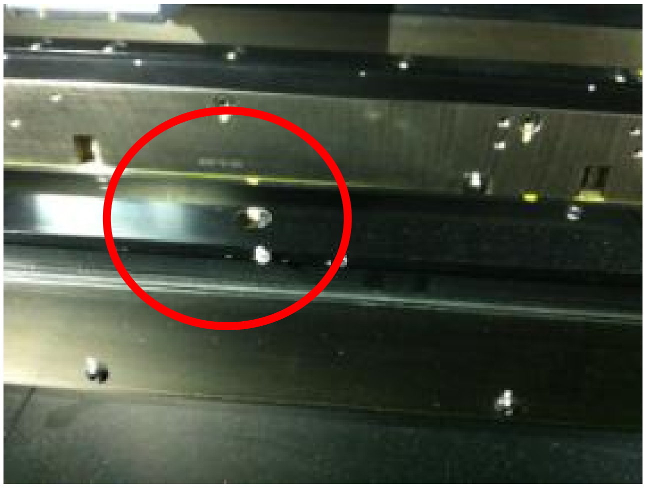

Figure 15. Solder residues in Pick and Place Equipment

However, in order to continue with the analyses, the solder paste residue found in P&P was reflowed, see Figures 16 and 17.

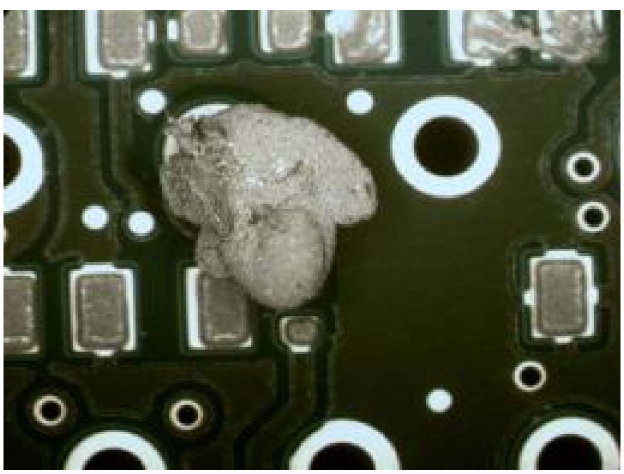

Figure 16. Pick and Place residues before reflow

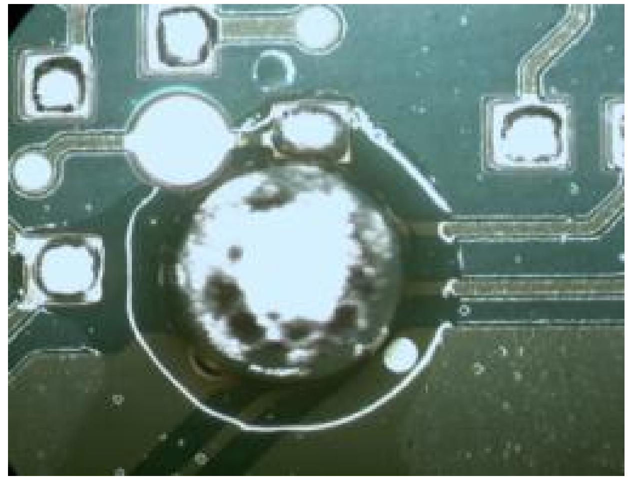

Figure 17. Pick and Place residues after reflow

Solder residues formed a big ball with a lot of flux around it. The form and size don't correspond to the metallic flakes, so this cause was ruled out.

C) REWORK PROCESS.

In some products, rework is allowed, although special controls exist to avoid any contamination, an analysis of the residues was carried over. See Figure 18.

The particles created during rework are big and with volume, and not are flat or shaped-irregular. They are not flakes. In some case, the solder residues from rework are similar to solder webs but not flake shape again.

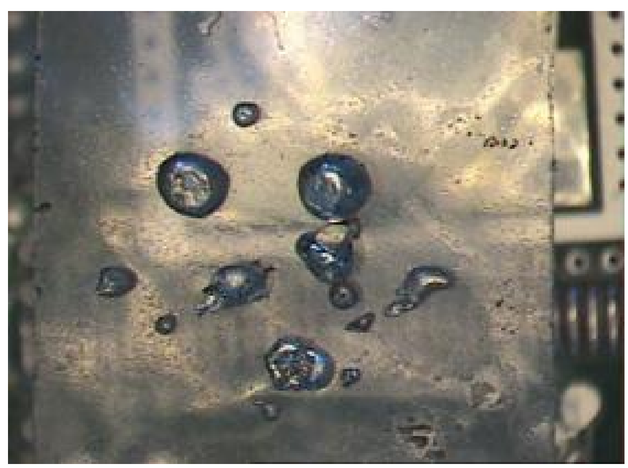

Figure 18. Rework residues from the iron tip sponge

The residues from rework are without clear flux excess. Their edges are rounded or the residues are like solder ball. An example is shown in Figure 19.

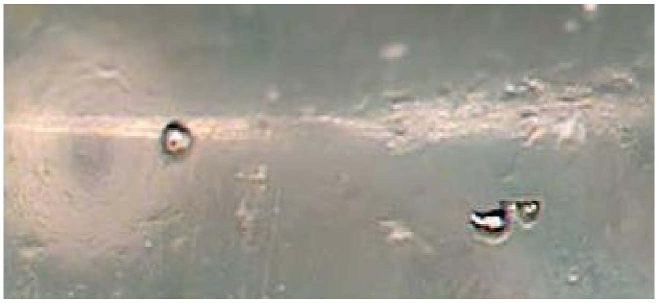

Figure 19. Typical Rework residues

The SEM analysis confirms the rounded shape of the rework residues and adding another finding: the rework solder residues contains silver that comes from the solder wire that has the similar composition as the alloy in the solder paste and this is seen clearly in EDX Analysis, see Table 3.

Table 3. Rework solder residues EDS Analysis

Spectrum	C	O	Mg	Ag	Sn
Test 1	3.72	4.80	-	3.00	88.48
Test 2	4.64	5.91	-	1.82	87.63

D) SOLDER PASTE

To determine if solder paste can form solder balls during reflow; an experiment was designed and carried over.

- Solder paste was printed on ceramic slides.
- A copper pipe of 1 in diameter was cut half. One half was set over the ceramic slide to catch any solder ball jumping from the solder depositions
- The slides and half pipe were set on a hot plate at 232°C
- After solder paste was reflowed, the copper pipe was checked to observe any residue.

Below you will see how the experiment was set. In Figure 20, the ceramic slide, half copper pipe, and the hot plate are observed. In the Figure 21, the half copper pipe and the ceramic slide are observed.

Figure 20. Solder paste analysis for ball forming

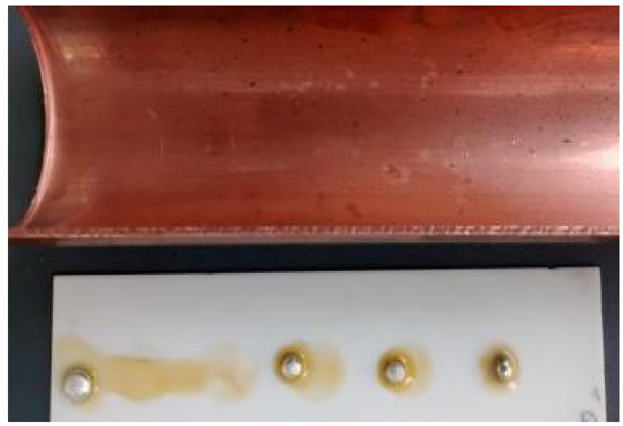

Figure 21. Results of the experiment to verify the contribution of solder ball/splashing from the solder paste

The residues adhered on the copper found can be divided into two groups: flux and solder balls. The flux residues can be in Figure 22 and is only flux splashing and not causing any issue. The solder balls of similar size to solder powder are shown in the Figure 23 and are too small to cause any issue. They are not similar to the problematic metallic burrs. This cause is ruled out too.

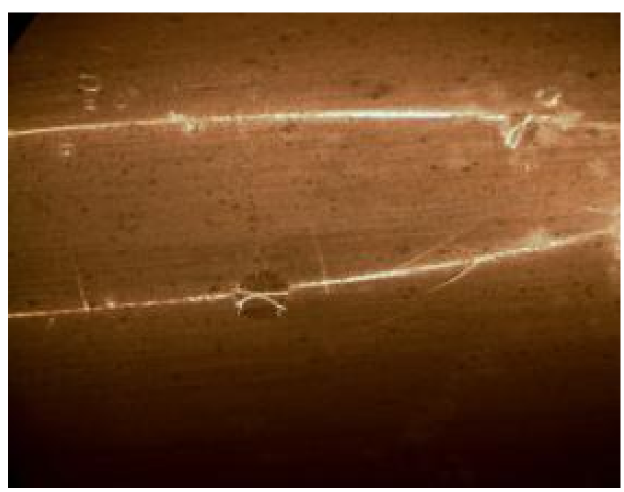

Figure 22. Flux splashes

Figure 23. Tinny solder balls found on the copper pipe

E) PCB ANALYSIS.

Another possible cause of metallic burrs is the PCB. The metallization used on PCB's with issues was Immersion Tin. The metallization has low thickness (1.1 um approximate). This metallization is low probable to be the cause of the flakes although some residues would exist made of tin. On the other hand, possible explosions due to trapped air would make solder paste on thermal vias make solder balls or burrs. In order to prove if the PCB's can create this type of burrs, 100 PCB's with printed solder were reflowed and inspected. The PCB's come from the models with more short issues. A small DOE with one factor and two levels was proposed.

Table 4. DOE setting

Factors	Levels	Repetitions
PCB models Production Line	2 (A & B) 2 (a & b)	25

The results show, see Figure 24, the PCBs contain a few tiny and small burrs in all combinations. None of the PCBs contained large or significant particles to make a short circuit. Some contaminations such as solder resist residues were found, but none of importance for the purpose of the test. No relationship between Burr and Production line of PCB were found.

Figure 24. Results from PCB DOE

F) REFLOW OVEN.

The reflow oven from the line where most of the PCB with issues was found was inspected to find residues before the weekly maintenance.

It is interesting that several types of residues were found. Because of that, completely the oven was inspected were PCB go through. Some residues were even found on the top side of the heating zone (This means the top hot plates). An example of this is shown in Figure 25.

Figure 25. The solder balls found inside of the oven in the peak zone show dark color due to the high temperatures.

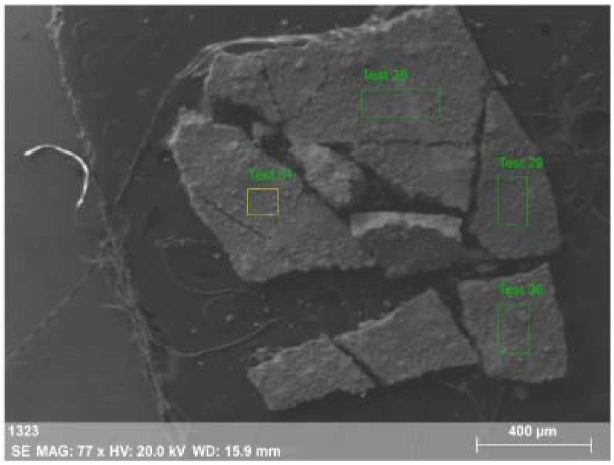

Figure 26. Crust found on the bottom plate of the reflow oven

On the bottom and top plates, several solder crust were found. In the Figure 26, you see an example. It is formed of tin mainly as EDX results show, see Table 6. But there are traces of Si and Al, elements found in the oven hot plates.

Table 6. Crust EDX Analysis

Spectrum	C	N	O	Al	Si	Sn
Test 28	14.86	3.47	30.96	-	0.54	50.17
Test 29	21.56	-	29.30	-	0.21	48.94
Test 30	16.02	-	29.99	0.30	-	53.69
Test 31	18.26	-	29.06	0.18	0.23	52.27

On the conveyors, also some crusts were found. The element analysis by EDX shows the presence of Sn, Al, and S. Al and S were in higher concentration than in crust found in the bottom plates.

The conclusion of the findings is the solder flakes are produced recurrently inside of the oven. These are found in the peak zone of the temperature profiles, found in the last zones of the oven.

The accumulation of these flakes is higher on the conveyor, close to PCB way, but also they can be found on the top and bottom hot plates.

These crust or flakes are formed of tin, similar to one that provoke short.

Another observation is the crust tin is reacting to the aluminum of the conveyor and oven plates forming a new alloy (tin-aluminum) due to the high temperatures in the zone. An issue found is the new alloy can be easily detached from the surface and it is deteriorating the oven.

Continuing with the CET analysis, see Figure 27, we found the most probable burrs that have made shorts coming from inside of the reflow oven. However, the oven itself cannot make the burrs.

Modifying the profile was discarded due to the fact we don't know where the burrs come from.

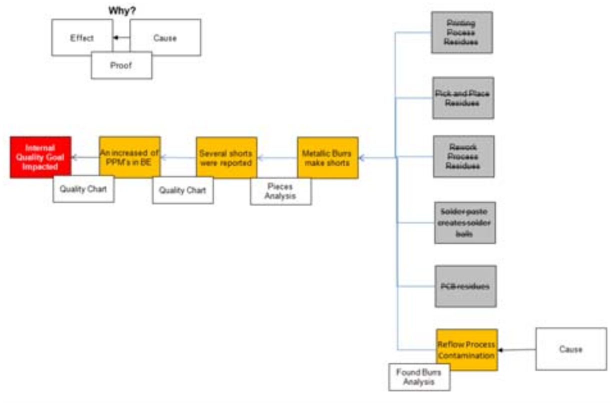

Figure 27. CET with new cause

In order to find the main cause of the burrs, the location of the burrs on PCB will be analyzed.

In Figure 28, the location of burrs causing shorts is shown. As we found, one component is in the center of the possible affecting area. This component is a D2PAK power transistor.

The possible problematic component was also reported by another plant in Europe with similar issues. They located the component based on a similar analysis of locations.

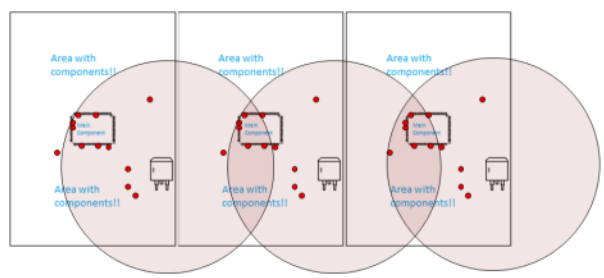

Figure 28. Analyzing what possible source of burrs is

The analysis of the possible problematic component unveiled, that the tin surface of several parts after reflow showed a detached metallization. This means the tin metallization is lost in these areas, see Figure 29 and Table 7. However, in order to prove, some reproduction tests were proposed and made.

Figure 29. Component SEM Analysis (After reflow)

Table 7. Component EDX Analysis

Mass percent (%)

Spectrum	C	N	O	Al	Si	Ca	Cu	Sn
Test 10	6.85	3.07	8.57	-	2.00	-	-	79.51
Test 11	10.00	-	4.82	-	1.71	-	35.52	47.96
Test 12	7.93	0.46	9.33	-	1.98	-	-	80.30
Test 13	37.96	-	41.76	0.82	19.01	0.46	-	-

In order to reproduce the issue, two tests were proposed. The first one is to pass the component alone through the reflow, and observe and analyze the possible burr generation.

The second was to do a similar test as test 1 but using a hot air pistol. This is to avoid the idea the oven itself was contaminating the results of experiment or Test 1.

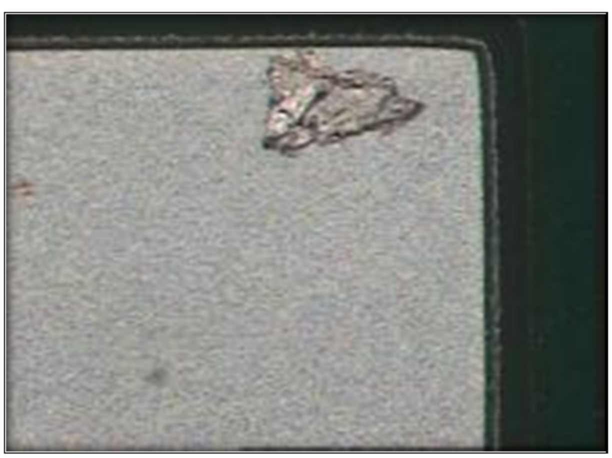

Figure 30. Results of Test 1

The results of the Test 1 show the presence of several metallic burrs around the components. The Figure 30 comes from the test 1. This means the component was losing metallization and was expelling metallic burrs around it.

For the second test, a hot air pistols was used. The components were set on aluminum paper and hold with aluminum tape. A copper pipe divided half was used to catch any possible material detaching or jumping in the test. A thermocouple was used in order to monitor and control the reflow temperatures. The heating time was similar to the reflow profiles. You see the arrangement in the below image.

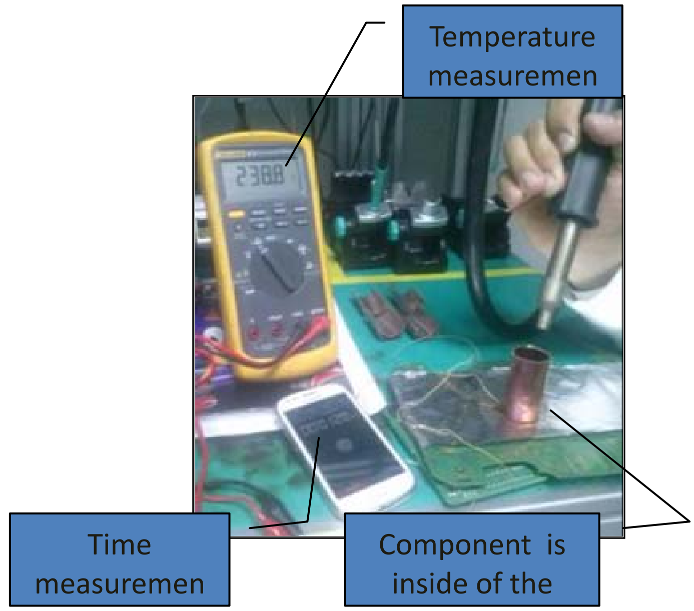

Figure 31. Arrangement of Test 2

Several metallic burrs were also found in the second test. Most of them were found close to the component on the aluminum tape, but some also were found on the copper pipe surfaces.

Two examples of these burrs are in Figures 31 and 33.

Figure 32. Metallic Flake on the Al tape

Figure 33. Metallic Flake on the Copper pipe

The particle analyses from the last two tests have shown similar results. The particles or flakes are made of tin, almost pure tin with some amount of oxygen and carbon, highly similar to one found in the shorts, see Table 8.

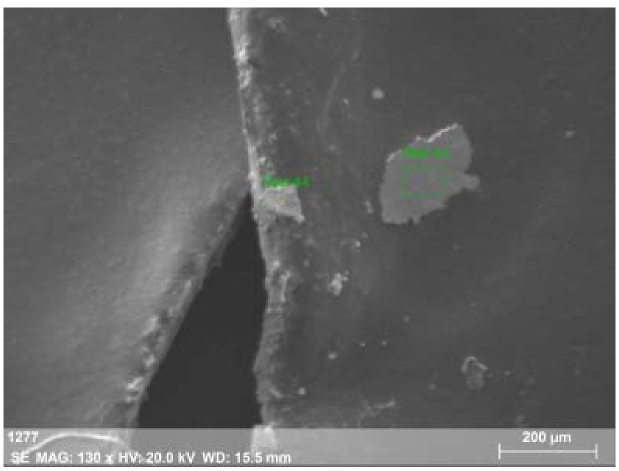

Figure 34. SEM Metallic Flake from Test 2

Table 8. Tin Flake EDX Analysis

Mass percent (%)

Spectrum	C	N	O	Sn
Test 43	8.13	4.71	-	87.17
Test 44	3.24	0.75	2.70	93.30

The source of the flakes is the D2PAK component metallization. In order to reduce the non-conformities a containment action was set: the suspicious date code was removed.

A complaining was delivered to the supplier in order to get the root cause of these flakes and the CET was modified to add the possible root cause, see Figure 34.

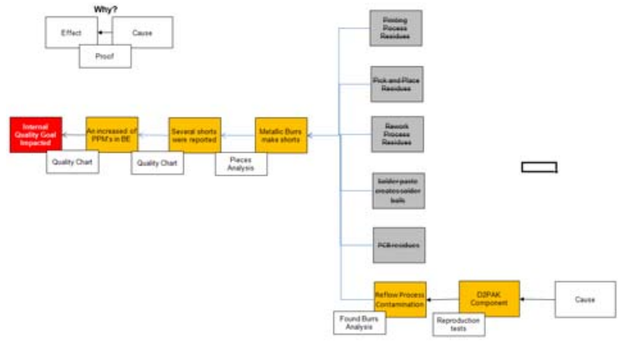

Figure 34. CET with new causes, version 3

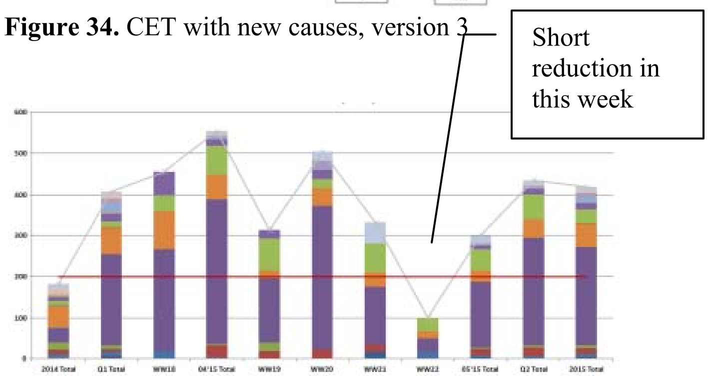

Figure 36. Reduction of the shorts after the containment action. The purple part is the short index.

After not using the affected date codes, there was a strong reduction of shorts. The containment action was useful but the root cause was unknown yet, see Figure 36.

ROOT CAUSE

After several discussions and experiments with the component supplier, it was found the activation surface process was the one with more influence on the issue.

The activation process prepared the surface before the tin electroless process. If this process is not done correctly or is less efficient, a possible oxidation or contamination exists between base metal and metallization. Consequently, the metallization is poorly attached. See Figure 37.

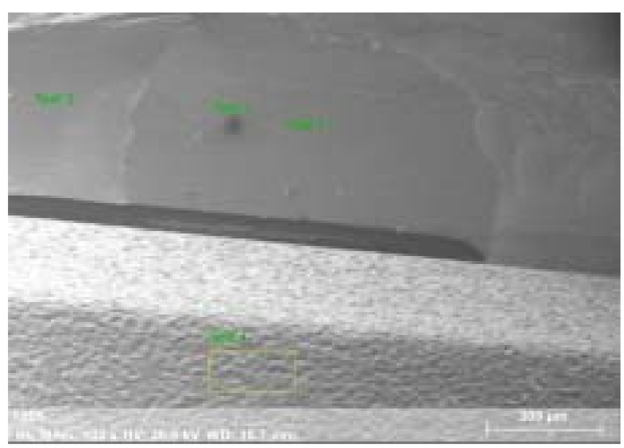

Figure 37. Detachment metallization due to poor activation surface

In order to improve, a better activation process was selected by the supplier. This improves the quality indicator in the plant. This helped to reduce the presence of this type of burrs in the shorts.

Although the root cause was found, other possible sources of contamination were found. Our quality system indicates we need to also set actions to these findings. For that, in order to diminish the possible incidence of these sources, other actions were done, such as improvement of printing cleaning cycle, improvement of stencil design, and keep training level in rework .

CONCLUSIONS

- The shorts that are well known in SMT process can have different causes from solder excess.
- In this article, a different source of shorts was found and shown.
- The Cause-Effect Tree tool was used and developed for solving the issue.
- A complete analysis of the process was carried out in order to determine the source of the metallic burrs.
- Other possible sources of burrs were found and actions were taken.
- The main cause of the shorts was the detachment of the tin metallization of a component.
- The activation process on the component manufacturing was the root cause of the issue and the action to improve it was done.
- Other actions to other possible contamination sources were done also.

REFERENCES

[1] IPC, IPC-J-STD 004A, Requirements for soldering fluxes, January 2004

[2] IPC, IPC-J-STD 005, Requirements for soldering pastes, January 1995

[3] IPC, IPC-J-STD 001D, Requirements for soldered and electrical and electronic assemblies, February 2005

[4] JIS, JIS Z-3284, Solder paste, 1994

[5] IPC, IPC A 610E, Acceptability of Electronics Assembly, April 2010