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Influence of Salt Residues on BGA Head in Pillow (Hip)

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Abstract

The oxide layers are known as wetting inhibitors in component and PCB metallizations. The oxide acts as barrier that prevent the tin diffusion from happening. Besides, in corrosion studies, the role of salt residues -with Cl ion- on some metals is known as being promoters of oxidation or corrosion. On the other hand, most of corrosion studies with tin metallization are focused mainly on the corrosion resistance of tin alloys, but little has been done respecting to the influence of salts on tin metallization wetting. In this paper, a series of experiments was carried over to know the influence of specifically NaCl on BGA wetting given Head in Pillow (HiP) as result. The aging of components was done following the procedure of J-STD 002C in which the components are exposed to a low amount of steam water for several hours. As a procedure modification, NaCl was added to the water that forms steam in several concentrations. The results show the more time of steam exposition, the more HiPs are obtained. Additionally, the higher concentration of NaCl in the water, the more HiPs are formed. As a conclusion, NaCl presence could inhibit tin wetting when the proper conditions of energy and environment exist. One interesting fact is during the analysis of BGAs with SEM/EDX; the presence of NaCl was not detected on the solder/BGA ball interface but was found on its edges. This finding would be explained because solder flux tries to remove the contaminants of the interface putting them around the Ball/solder interface. Besides, the oxygen concentration on BGA balls analyzed by SEM increased little or none at all showing the oxide increase cannot be detected by this type of analysis. Because of that, TOF SIMS analysis was carried over showing an increase of oxide on tin surface.

Introduction

In the electronics industry, Surface Mounting Technology (SMT) has allowed the assembly miniaturization making the products smaller and more productive[1]. Inside of this type of technology, the component packages have played an important role creating or having hundreds of electrical connections to the active components (Transistors, Memories, Microcontrollers, etc) in a reduced area. One of the most popular component packages is BGA (Ball Grid Array), see Figure 1. The BGAs are electronic components in which the solder joints are ball-shaped and found underneath of component body. Because the component surface is used to create hundreds of solder joints, BGA may have a large number of connections giving flexibility to designers. This is very useful to exchange a lot of information (digital and analog) plus other necessary connections (Power, clock, reset, etc); therefore, many Microprocessors use BGA package as the main one to reduce their size.

However, the connections are underneath the component or substrate body so it is difficult to inspect them visually (with a microscope) that is the main inspection used in SMT; Because of this, a faulty connection is very difficult to catch or detect, for example, a nonwetting solder joint using visual inspection only. One specific type of defect that has become more prevalent on Ball Grid Arrays is Head-on-Pillow (HoP) or Head in Pillow (Hip)[2].

Head in Pillow is a BGA solder joint defect in which the solder paste wets the pad but does not fully wet the ball, see Figure 2. The solder ball physically touches the solder paste deposit but there is not a metallurgical joint. The improper electrical connection situation becomes more severe because many of these type of connections would be electrically intermittent. This is due to a lack of solderability between the ball surface and solder paste alloy due to oxidation, contamination or a mechanisms that prevents the solder alloy to form a joint with the solder balls. One of the main possible causes is excessive oxidation even though the excess oxidation has mainly been attributed to external control problems of solder paste handling or reflow profile.

The Head-in-Pillow defects have become more prevalent since BGA components started to use lead-free alloys because higher temperatures are used and fluxes are more sensitivity to oxide thicknesses. The growing use of lead-free soldering in electronics manufacturing has increased defects that require proper identification and troubleshooting. Besides, a warpage effect can increase the probability of failure, when the solder reaches the liquid phase during soldering, the balls and solder paste deposits are separated physically. Consequently, there would not be sufficient fluxing activity left to break down the oxide layer when the solder ball and solder paste deposits touches again, resulting in possible HiP defects [3].

However, we have found cases in which reflow profile agrees with the recommendations of the solder paste supplier, and/or you have a proper management of solder paste, but you can have still problems with HiP . One of the possible causes of Head-in-Pillow not investigated deeply is the presence of contaminants that could alter the solderability of the solder balls. In a recent study, we found that the presence of chlorine could inhibit the solderability of the tin metallization (SOD 123) [4]. In this report, we investigated how the chlorine presence would alter the BGA solder ball solderability .

The tool used to perform these tests is the Design of Experiments (DOE). The DOE is defined as a set of tests in which changes in parameters that control a system or process are made in order to analyze, observe and identify the impact on the output variable or process responses. All phenomena, which can be observed and have features susceptible that would be measured, exhibit a variable behavior and we can analyze with a DOE. The design is the part that can be controlled by the experimenter, and its factor and level structure is the base of the experiments.

Some of the main parts of a DOE are the Factors (Each variable that can potentially influence the outcome of an experiment, for example: temperature, time, pressure), Interactions (Effect produced by the action of a factor, modified by changes in other factors), Levels (Discrete values taken by a factor in all experiments), Main Effects (Variations in the response of the system, attributable to the change in the level of a factor), and Answers (Values of the variable being optimized for example: performance of a chemical reaction, stability of an emulsion).

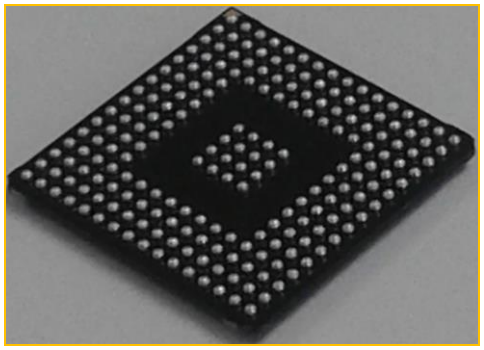


Figure 1. An example of Ball Grid Array (BGA)

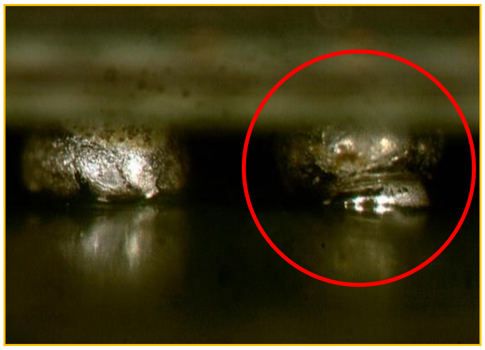


Figure 2. Head In Pillow Defect in a BGA connection (See the red circle)

In the next section, several DOEs are carried over to show the influence of Chlorine on the solderability of BGA solder balls. For that, the procedure to age components is according to J-STD 002, in which the metallizations are set over a small steam flow for several hours (The most recommended are 8 hrs although 16 hrs can also be used) to simulate aging or storage time. The modification is to add Cl in form of salt (NaCl or similar ones) to the steaming water and the purpose is to verify how the aging conditions would be altered with the presence of additional elements or contaminants. The suggested hypothesis is Cl presence on BGA balls before any electrical test or long storage time would diminish the wetting capacity of the BGA balls. In order to speed up storage time, the next specific procedure is followed: Components are put over steam (approx 89°C) in similar conditions described in J-STD 002 but NaCl is added to the steaming water. Steam will give the energy that is given by electrical tests or storage conditions to alter BGA ball wetting. A series of DOEs was performed to analyze the solderability.

I. DOE 1. Creating HiPs

I.1. Objective

In this DOE, a study was conducted to verify the influence of various elements including Cl on BGA solderability. The aim was to show the influence of Cl presence (in form of salts) on BGA soldering and if Head in Pillow can be created in the SMT process. The form to add Cl is using the aging steam procedure similar to J-STD 002 but using tap water with NaCl added at 10%.

I.2. Description

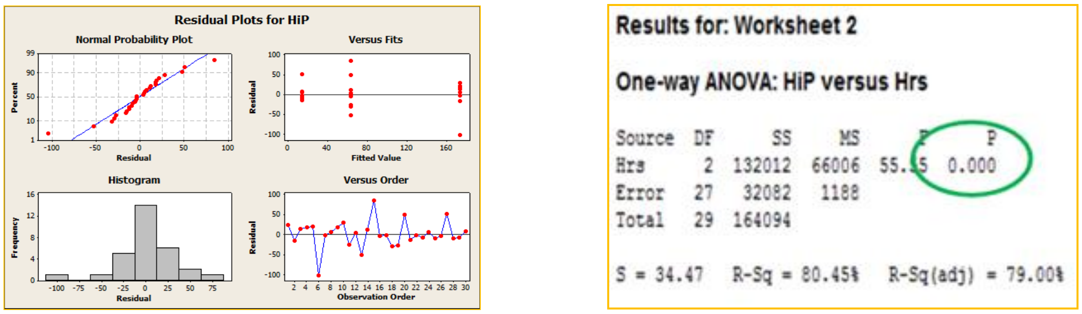
Table 1 shows the factor to study which is time and its levels are 3: 4, 8, 16 hrs. The constants are: Stencil, LF Profile, SMT Line, and Lead Free solder paste. The variations are component coplanarity (BGA), Pick and Place Position, Reflow oven variability. The experimental unit is a BGA with 208 solder balls and 1mm pitch. The DOE is one way Anova.

Table 1. Cl presence (in form of NaCl Salt) on BGA-SMT process

Factors	Levels	Output	Constant	Noisy Variable	Instrument of Verification	Experimental Unit	Type
Time	**3 (Steam + NaCl) 4, 8, 16 hrs**	**BGA HiP**	**Stencil**	**Component coplanarity**	**Visual by Expert detaching components**	**BGA 208 1 mm pitch**	**One Way Anova**
			Current Profile	**Pick and Place Position**			
			SMT Production Line	**Reflow Variability**			
			LF Solder Paste				

I.3. Results

In residual plot analyses, see Figure 3(a), we can see there are some outliers, but we would consider these have low influence. The model would give good correlation, although the variances are influenced due to the final value, see top-right graph in Figure 3(a). The p-value is lower than 0.05, see Figure 3(b). This means the time under the salt containing steam has influence on BGA HiP.



Results for: Worksheet 2

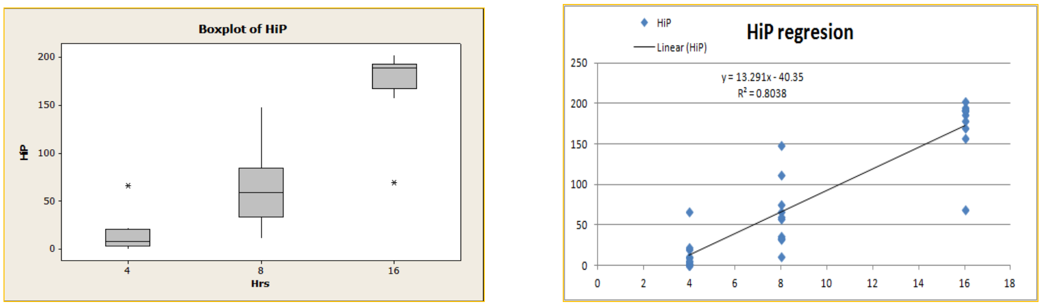
One-way ANOVA: HiP versus Hrs

```
Source  DF      SS     MS      F      P
Hrs      2  132012  66006  55.[illegible]5  0.000
Error   27   32082   1188
Total   29  164094

S = 34.47   R-Sq = 80.45%   R-Sq(adj) = 79.00%
```

(a) (b)

Figure 3. (a) Residual Plot Analysis, (b) Result for DOE 1 Anova: HiP versus steaming hour

In the box plot, Figure 4(a), the results of HiP created per component versus time are shown. The more time, the more HiPs are created up to making the entire component not solderable. Because there is a clear relationship between HiP and time, a linear regression is proposed, see Figure 4(b). The linear regression has a R^2 of 0.80 which is an acceptable correlation.



(a) (b)

Figure 4. (a) Box-Plot Graph: The results of HiP number versus time, (b) Linear regression with a R^2 of 0.80 (good correlation)

I.4. HiP Images

The images in Figure 5 show the HiPs resulted in DOE 1. The images, Figure 5(a), are the test at a time of 4 hours and did not have many defects of HiP. The Figures 5(b) are the components with a steam time of 8 hours, and more defects are seen. Finally, Figure 5(c) are the components at 16 hours of steam. These components got misplaced due to the number of HiPs. According to the results and comparisons, we can consider that the longer the time, the more defects.

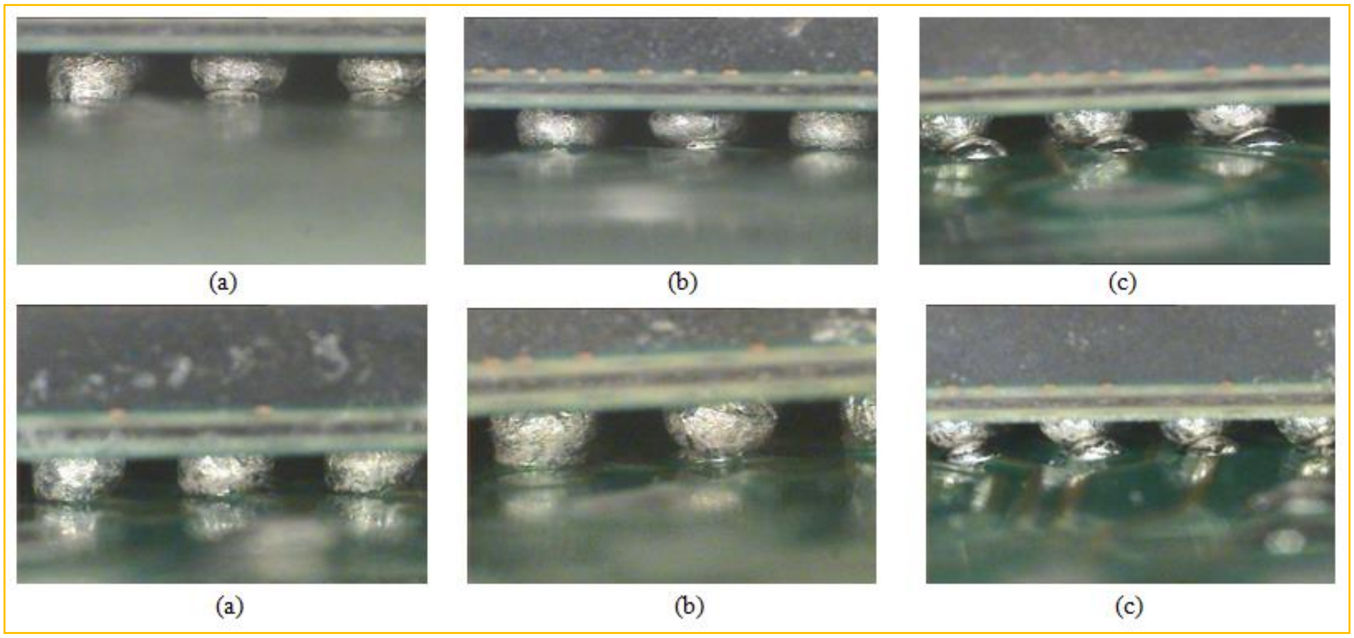
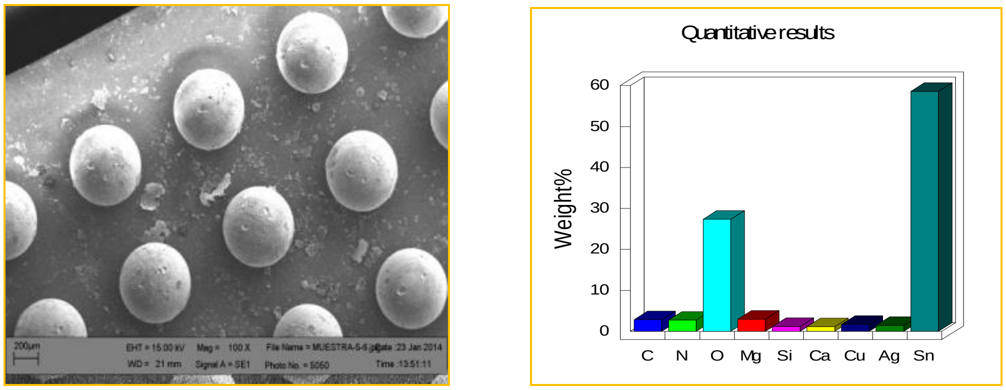


Figure 5. DOE 1 Results: (a) Components at 4 hrs of steam, (b) Components at 8 hrs of steam, and (c) Components at 16 hrs of steam, the components are misplaced due to number of HiPs

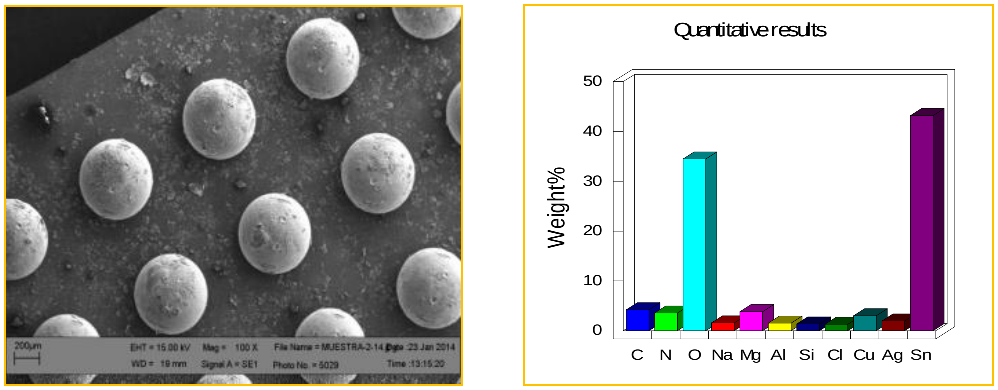
I.5. SEM/EDX Analysis

In the analysis of SEM/EDX, components have the presence of several elements on the surface. Figure 6 shows the results for the components at 16 hrs steam. Several elements are found (Mg, Ca, Al) beside Na and Cl. It is interesting to mention the solder balls have specific spots of the elements. Only components with 16 hrs of steam show more uniform distribution of the elements on the surface.



(A)

(a) 16hrs in 10% NaCl in tap water-Sample 1-



(B)

(b) 16hrs in 10% NaCl in tap water-Sample 2-

Figure 6. SEM Images of components at 16 hrs of steam, Samples 1 and 2 (A and B), EDX results (a and b)

II. DOE 2. Influence of NaCl Concentration

II.1. Objective

In DOE 2, the experiments were created to analyze only influence of NaCl. The difference between the DOE1 and DOE 2 is NaCl concentration is reduced to 0.1% and we changed the tap water into DI water. This is because the investigation should look to verify the influence of only NaCl and not other possible contaminants that tap water would have. The procedure to add chlorine is similar to DOE 1.

II.2. Description

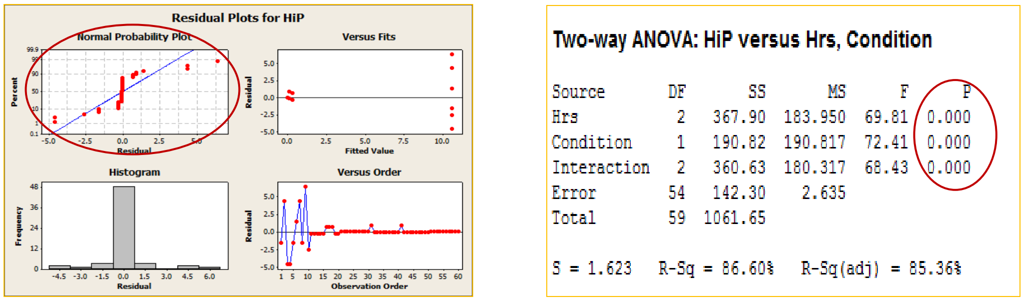
The following DOE, see Table 2, has two factors to study in the experimental design: the water condition and time. The first factor has two levels: 2 levels (0.1% NaCl and only DI Water), and the second factor has 3 levels (4, 8, and 16 hrs). The variations are similar to DOE 1: component coplanarity (BGA), Pick and Place Position, Reflow oven variability. The experimental unit is a BGA with 208 solder balls and 1mm pitch. The DOE, therefore, is 2X3 way ANOVA.

Table 2. Cl presence (in the form of NaCl salt) on BGA soldering condition

Factors	Levels	Output	Constant	Noisy Variable	Instrument of Verification	Experimental Unit	Type
Water Conditions	**3 (0.1% NaCl, DI Water)**	**BGA HiP**	**Stencil**	**Component coplanarity**	**Visual by Expert detaching components**	**BGA 208 1 mm pitch**	**2 x 3**
			Current Profile	**Pick and Place Position**			
Time	**3 (4, 8, 16 hrs)**		**SMT Production Line**	**Reflow Variability**			
			LF Solder Paste				

II.3. Results

In residual plot analyses, see Figure 7(a), the normal distribution has a big deviation (See the left-upper graph). There are several outliers because there were results of zero HiP. The model would give good correlation although the variances are influenced due to the final values, see top-right graph in Figure 3(a). The p-values are lower than 0.05, see Figure 7(b); therefore, both conditions (Water condition and Exposure Time) and their interaction have statistical influence on BGA HiPs.



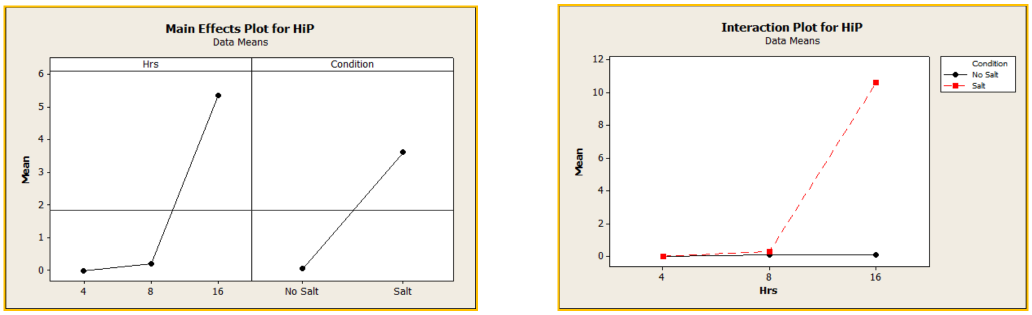
```
Two-way ANOVA: HiP versus Hrs, Condition

Source       DF      SS       MS      F      P
Hrs           2  367.90  183.950  69.81  0.000
Condition     1  190.82  190.817  72.41  0.000
Interaction   2  360.63  180.317  68.43  0.000
Error        54  142.30    2.635
Total        59 1061.65

S = 1.623   R-Sq = 86.60%   R-Sq(adj) = 85.36%
```

(a)   (b)

Figure 7. (a) Residual Plot Analyses, (b) ANOVA Table, the p-values are below 0.05 so factors are statistically significant

With respect to the analysis of results, the Main Effect Plots, see Figure 7(a), show the more time the more HiPs are created. The highest result is at 16 hrs. With respect to water conditions, the salt presence creates more HiPs. The interaction plot shows that presence of salt speed up more HiPs after 8 hrs of exposure, see Figure 8(b). When water has no salt, HiPs are not created.

To verify the HiP distribution per level, a box plot is shown. The tendency is similar to the DOE 1 but the number of HiPs are much lower. This can be explained because the concentration of NaCl is lower in the experiments (10% + tap water to 0.1 % in DI water).



(a)   (b)

Figure 8. (a) Main Effects Plot show the more time, the more HiP, (b) Interaction Plot shows that presence of salt brings about HiP

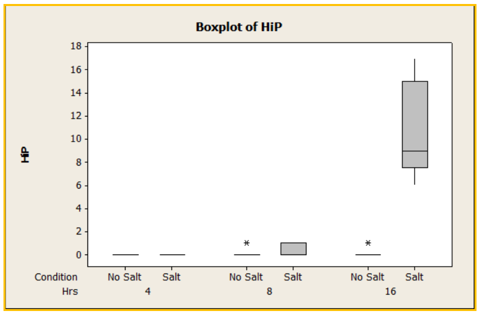
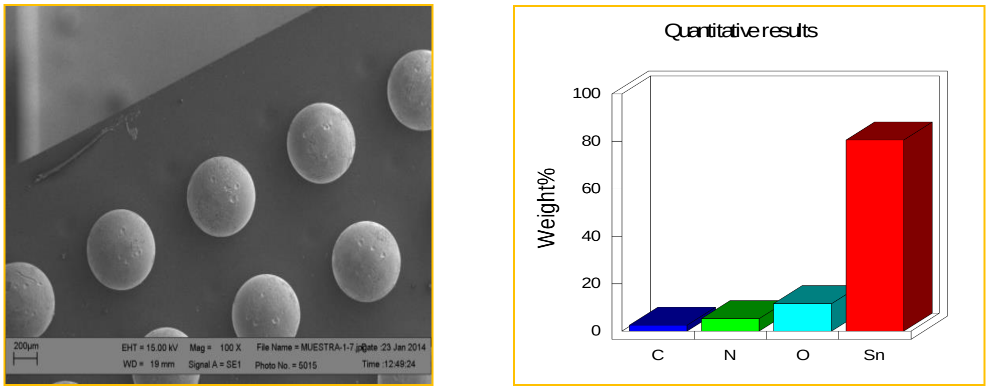


Figure 9. The Boxplot shows that HiP defects are lower than those shown in the DOE 1

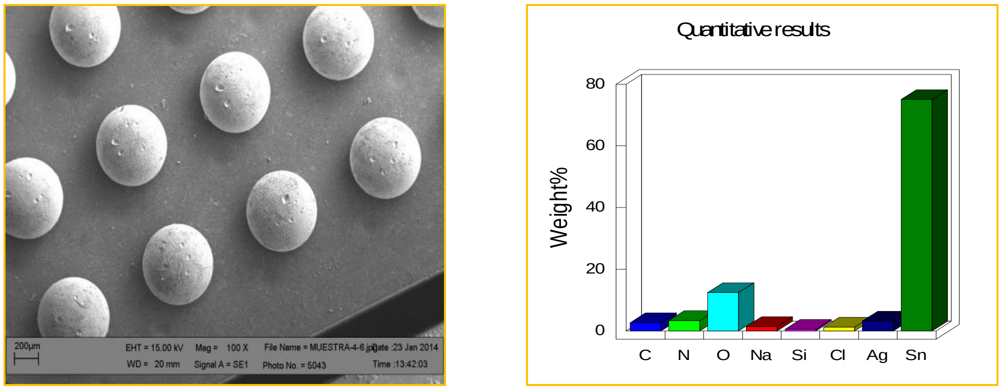
II.4. SEM Analysis

Several components were analyzed before soldering with SEM/EDX. The results are in Figure 10. The BGA images are in “raw” material after steaming. The EDX results are from specific areas where salt was detected and not general analysis. SEM images do not see the presence of NaCl presence until it is too high a value. This means analyzing images is not so reliable as expected to detect Cl presence because the NaCl presence exist but the detection is too low as would expect. However, we can get HiPs with low amount of NaCl under experiment conditions. In case of EDX analysis, Cl presence (in the form of salt) is dispersed and not uniformly distributed over the solder ball surfaces. The analysis had to be done checking specific points where Cl (NaCl) presence is detected. This means NaCl is accumulated in specific spots. In case of components steamed with only DI water, no Cl or Na presence was detected.



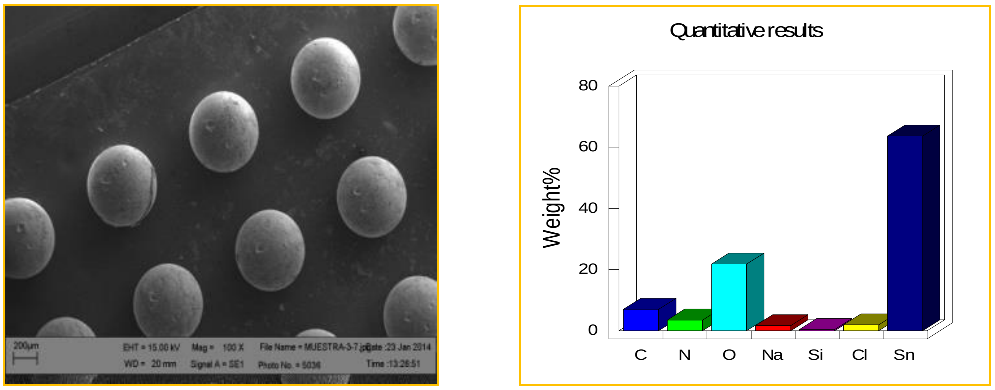
(A)

(a) 16 hrs in DI water



(B)

(b) 16hrs in 1% NaCl in DI water



(C)

(c) 16hrs in 5% NaCl in DI water

Figure 10. DOE 2. SEM Analysis Influence of NaCl in several conditions

III. DOE 3. Influence of Cl with different concentrations

III.1. Objective

In DOE 3, an analysis was made to determine the influence of chlorine on BGAs under five different concentrations and using three different times. The purpose was to cover the range of concentrations between DOE 1 and DOE 2.

III.2. Description

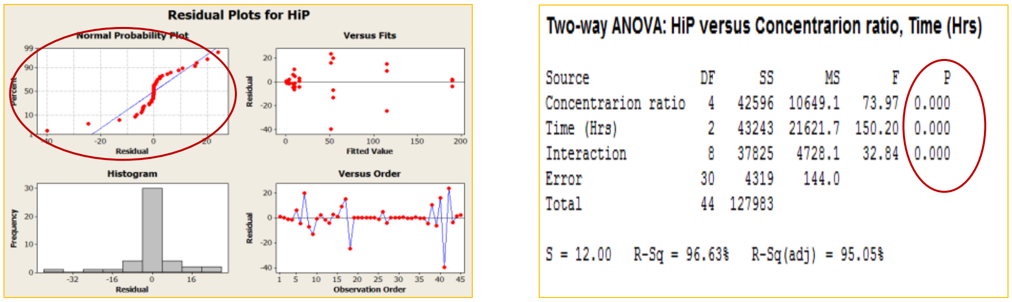
The DOE 3, see Table 3, has two factors to study: Concentration and Time. The concentration range includes 0, 001, 010, 0.050, and 0.10 % NaCl in DI water. The times are similar to ones in the DOEs done previously: 4, 8, and 16 hrs. The variations are similar: component coplanarity (BGA), Pick and Place Position, Reflow oven variability. The experimental unit is a BGA with 208 solder balls and 1mm pitch. The DOE is 5X3 way ANOVA.

Table 3. Cl presence (in form of the form of NaCl salt) on BGA /SMT process with factors of concentration and time

Factors	Levels	Output	Constant	Variable	Instrument of Verification	Experimental Unit	Type
Water Conditions	5 (0.000, 0.001, 0.010, 0.050, 0.100) NaCl)	BGA HiP	Stencil	Component coplanarity	Visual by Expert detaching components	BGA 208 1 mm pitch	5 x 3
			Current Profile	Pick and Place Position			
Time	3 (4, 8, 16 hrs)		SMT Production Line	Reflow Variability			
			LF Solder Paste				

III.3. Results

The results presented in the residual plot analyses, see Figure 11(a), show the normal distribution has a small deviation and correlation (see top left graph). The p-value are below 0, see Figure 11(b); therefore, both conditions (Concentration and Exposure Time) and their interaction have statistical influence on BGA HiPs, and the error are accepted.



Two-way ANOVA: HiP versus Concentrarion ratio, Time (Hrs)

```
Source             DF      SS       MS       F      P
Concentrarion ratio  4   42596  10649.1   73.97  0.000
Time (Hrs)          2   43243  21621.7  150.20  0.000
Interaction         8   37825   4728.1   32.84  0.000
Error              30    4319    144.0
Total              44  127983

S = 12.00   R-Sq = 96.63%   R-Sq(adj) = 95.05%
```

(a) (b)

Figure 11. (a) Residual Plot Analysis, (b) ANOVA: HiP versus Concentration, the p-values are below 0

The Main Effects plot for HiP, see Figure 12, shows the relationship between the concentration and type of defects HiP. On the left side shows the relationship between HiP and time. It is observed that the higher concentration the greater HiP defects, and with a more prolonged time the greater is HiP . This is also seen in Figure 13, with the plot for HiP Interactions.

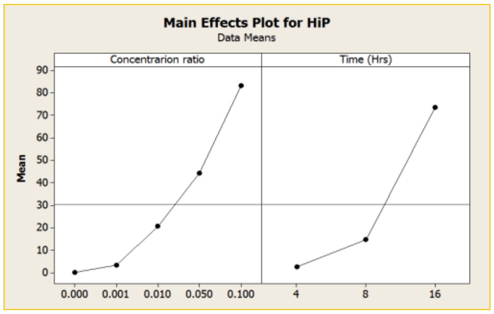


Figure 12. Main Effects plot for HiP versus concentration and time

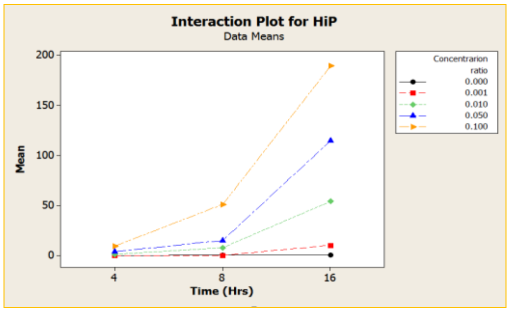
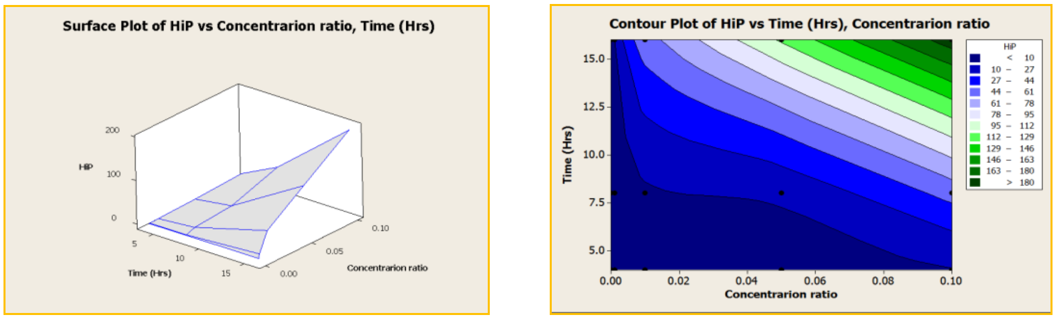


Figure 13. The Interaction plot for HiP in DOE 3

Figure 14(a) graph displays the Surface plot of Hip, and (b) is the 2D graph for visual. It indicates the number of HiP regarding the type of concentration and time.



(a) (b)

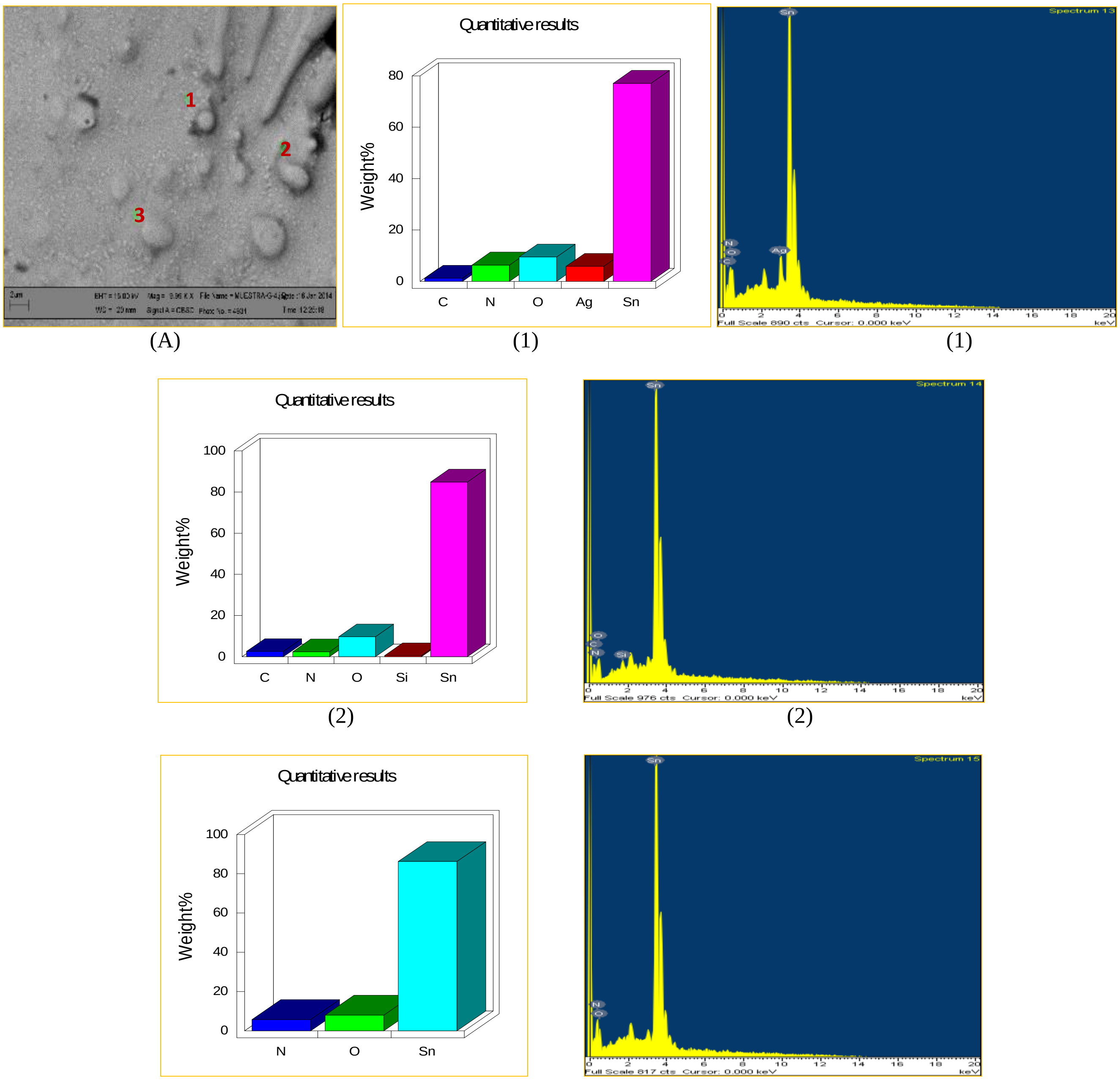
Figure 14. (a) Surface plot, (b) Contour plot of HiP versus time (Hrs)

III.4. SEM Analyses

The next sections present the DOE 3 results of SEM/EDX Analyses. The Section 4.1 are samples prepared with DI water at 16 hrs of steam. Sections from 4.2 to 4.4 show images and EDX results of components steamed with deionized water and different percentages of NaCl. The images are the punctual areas and the general areas analyses. This is to point out the differences in obtaining the general analysis of big areas from small specific areas.

III.4.1. Sample Evaporated

The next sample analyzed in SEM / EDX, were steamed for 16 hrs with deionized water.

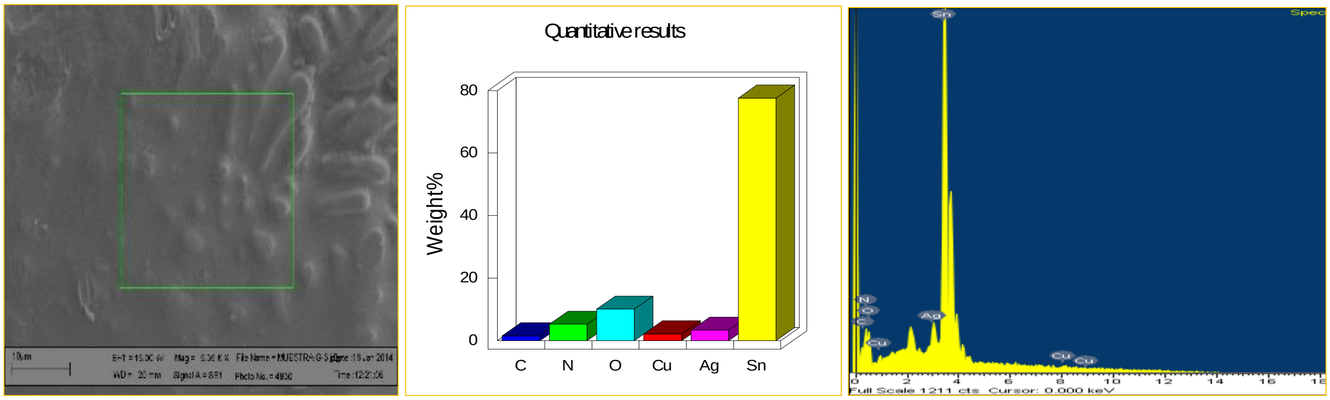


(A) (1) (1)

(2) (2)

(3) (3)

Figure 15. (A) shows three red numbers representing the punctual areas. (1) corresponds to the analyzed point 1, (2) to the analyzed point 2, and (3) to the analyzed point 3. The sample comes from 16 hrs test and DI water



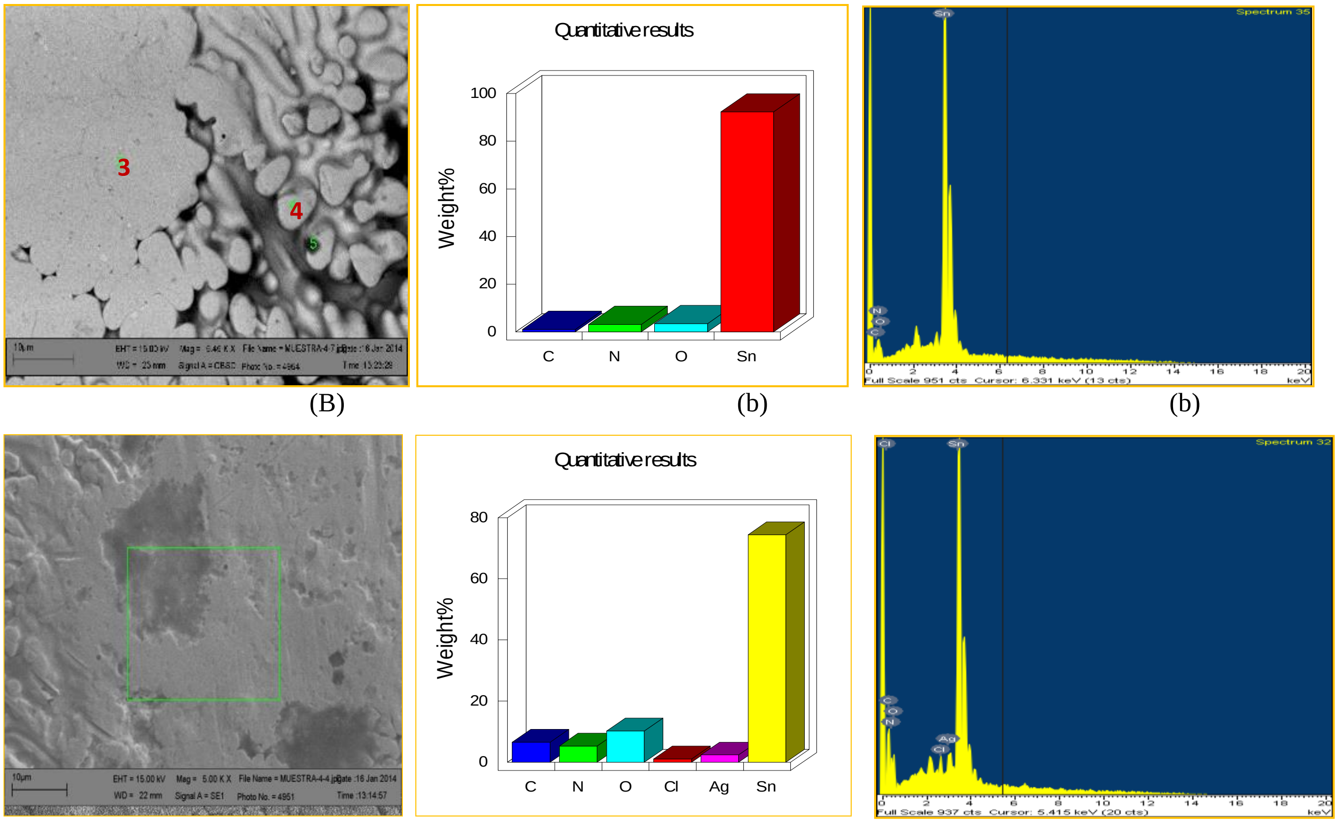
(A) (a) (a)

Figure 16. (A) is a general SEM Analysis. Sample comes from 16 hrs and DI water

The BGA sample has no NaCl presence. Point 1, 2 and 3, Figure 15, contain only tin, nitrogen and silver. The surface, Figure 16, has similar elements to the analyzed specific points.

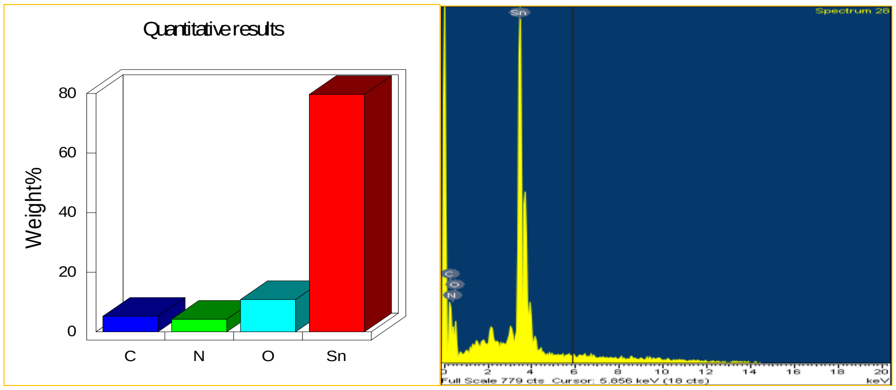
III.4.2. 0.5% NaCl Test - BGA

In this case, the results show a small concentration of chloride on the surface of the tin, see Figure 17; however, the presence of these chlorides is not evenly distributed across the surface of the ball but is found at specific points around the same; these points are located randomly.



(B) (b) (b)

(C) (c) (c)

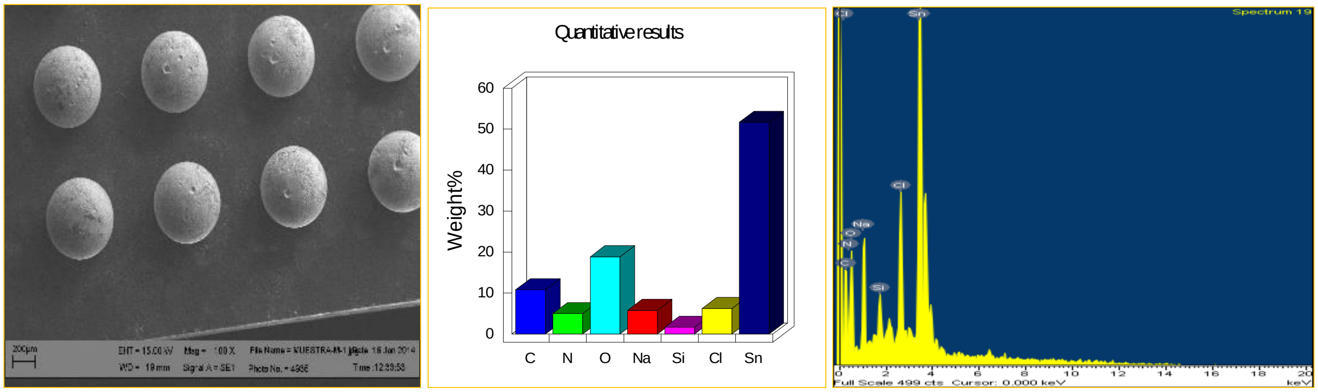


(a) (a)

Figure 17. The Images (B) and (C) are analyses of the sample with deionized water and 0.5% NaCl for 4 hrs

III.4.3. 1% NaCl Test - BGA

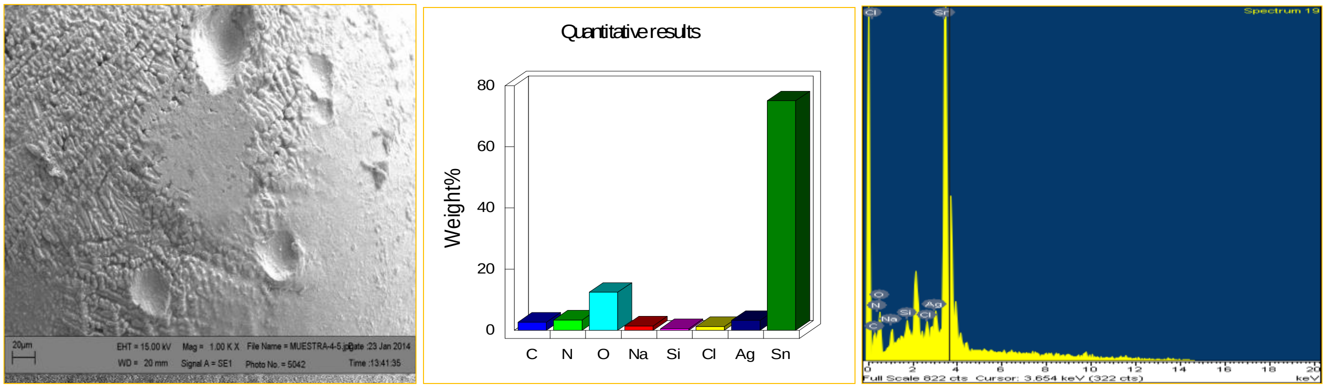
In Figure 18, the sample of analysis comes from deionized water and 1% NaCl at 4 hrs of steam. The samples are more contaminated with NaCl than BGA in Section III.4.2. The results show higher sodium chloride concentrations at specific points around the ball.



(A) (a) (a)

Figure 18. (A) Results SEM Analysis (NaCl),
Sample deionized water at 4 hrs

Although the component is exposed to a longer time, see Figure 19, than the component shown in the figure above, the sodium chloride concentrations are not substantially increased but the specific points with sodium chloride increases its presence in number.

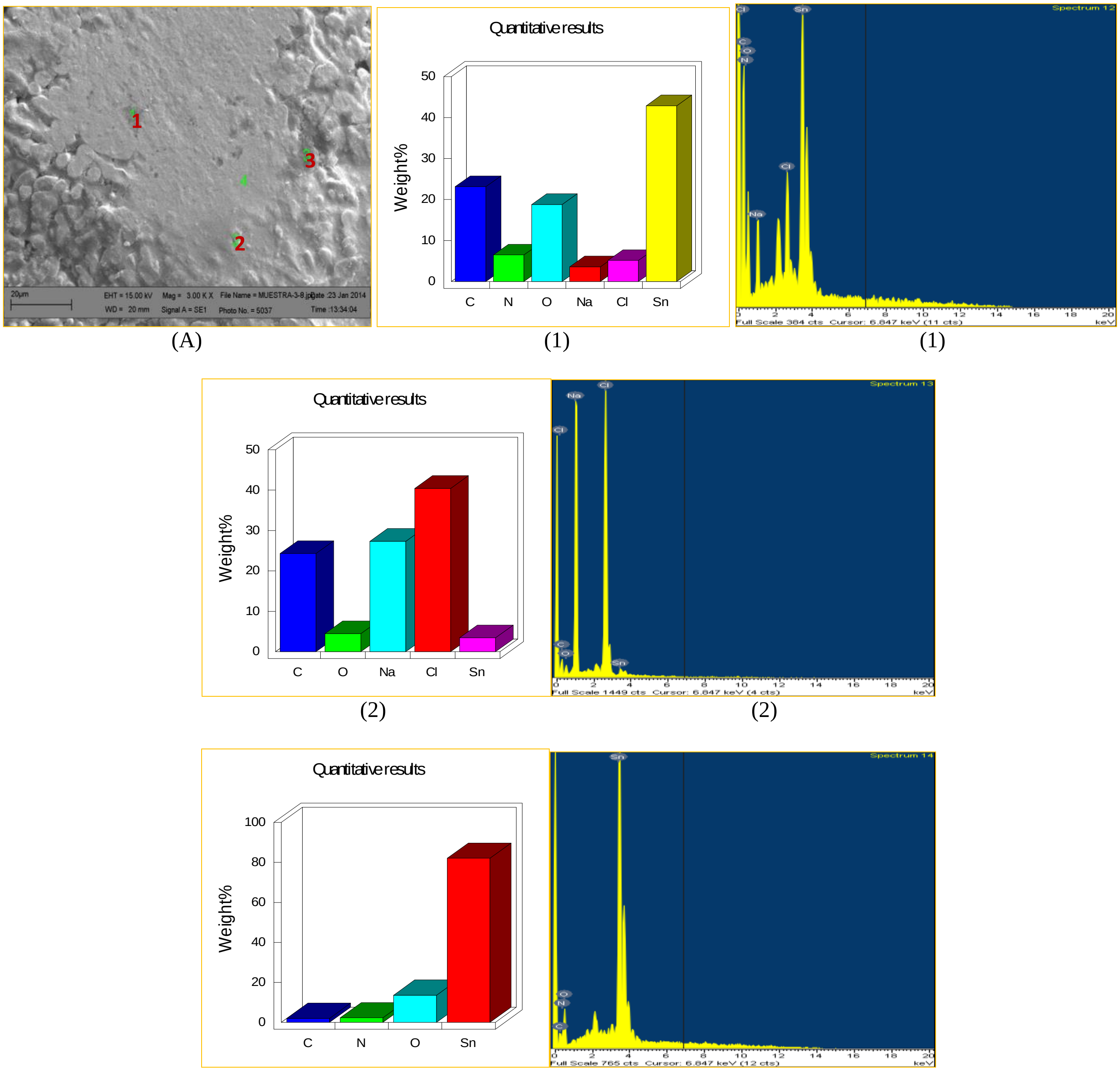


(A) (a) (a)

Figure 19. (A) Results of test-deionized water at 1% for 16 hrs. The sample presents disperse areas with NaCl

III.4.4. 5% NaCl Test - BGA

The results, Figure 20, show similar behavior to the previous sample, in which stains on the surface area increase. These areas are those containing a higher concentration of sodium chloride but do not cover the entire area of the ball but certain regions.

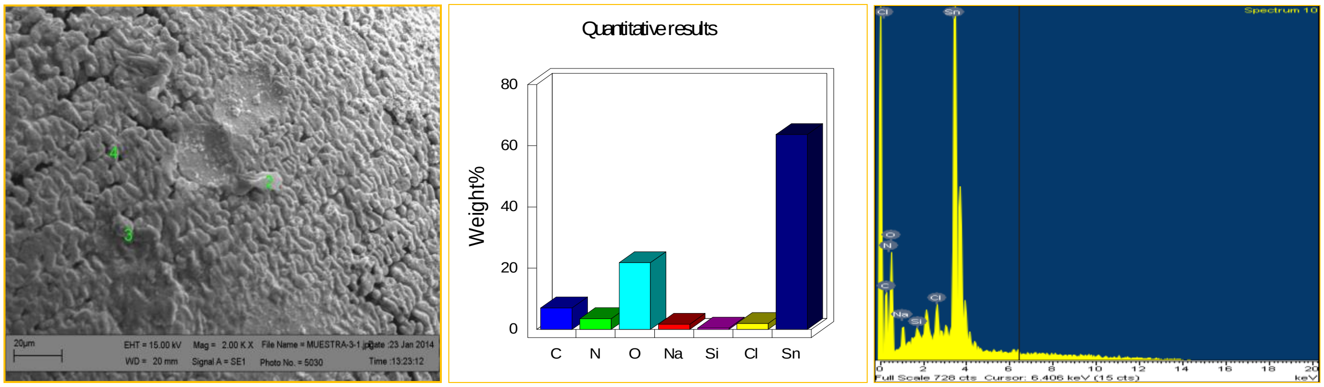


(A) (1) (1)

(2) (2)

(3) (3)

Figure 20. (A) Presents analysis showing three analyzed points.
The analysis was performed with deionized water at 5% (NaCl) for 16 hrs

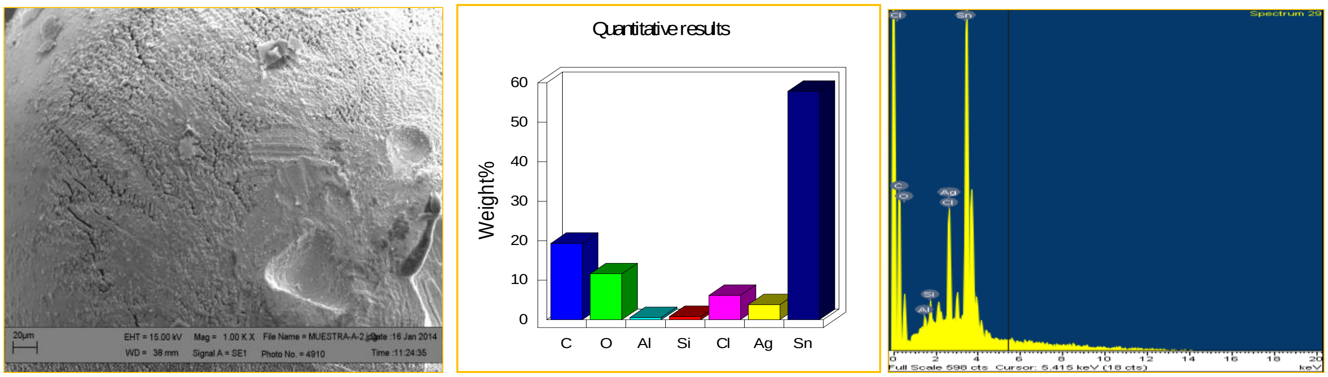


(A) (a) (a)

Figure 21. (A) is a general Analysis SEM. The sample was steamed with deionized water at 5% (NaCl) for 16 hrs

III.4.5. 10% NaCl Test - BGA

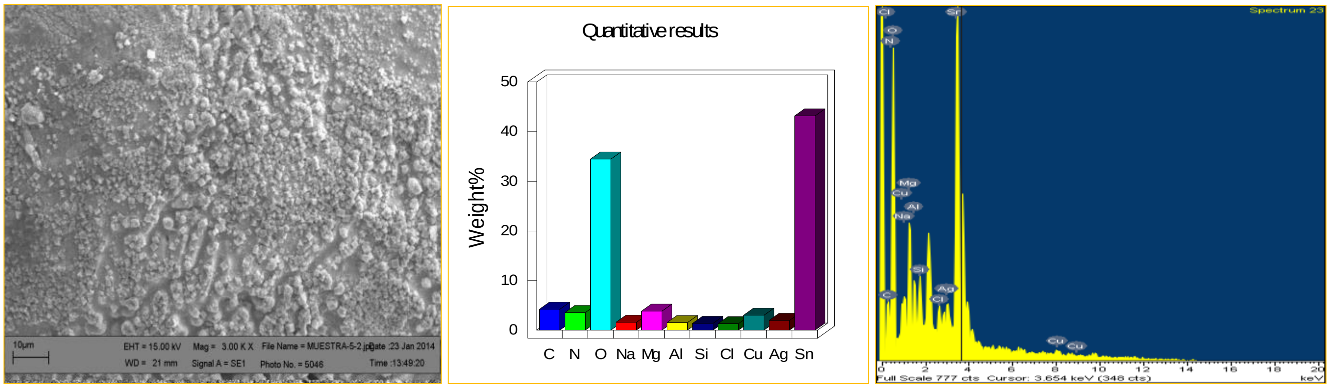
This sample, Figure 22, presents spots in larger surface areas. Additionally the presence of NaCl looks very marked in the component body. This case would be inadmissible in normal production, further the level of defects created with this NaCl concentration is very high.



(A) (a) (a)

Figure 22. (A) is a general analysis with SEM. Test in tap water at 10% (NaCl) for 4 hrs. The sample presents Cl and a high percentage of Oxygen

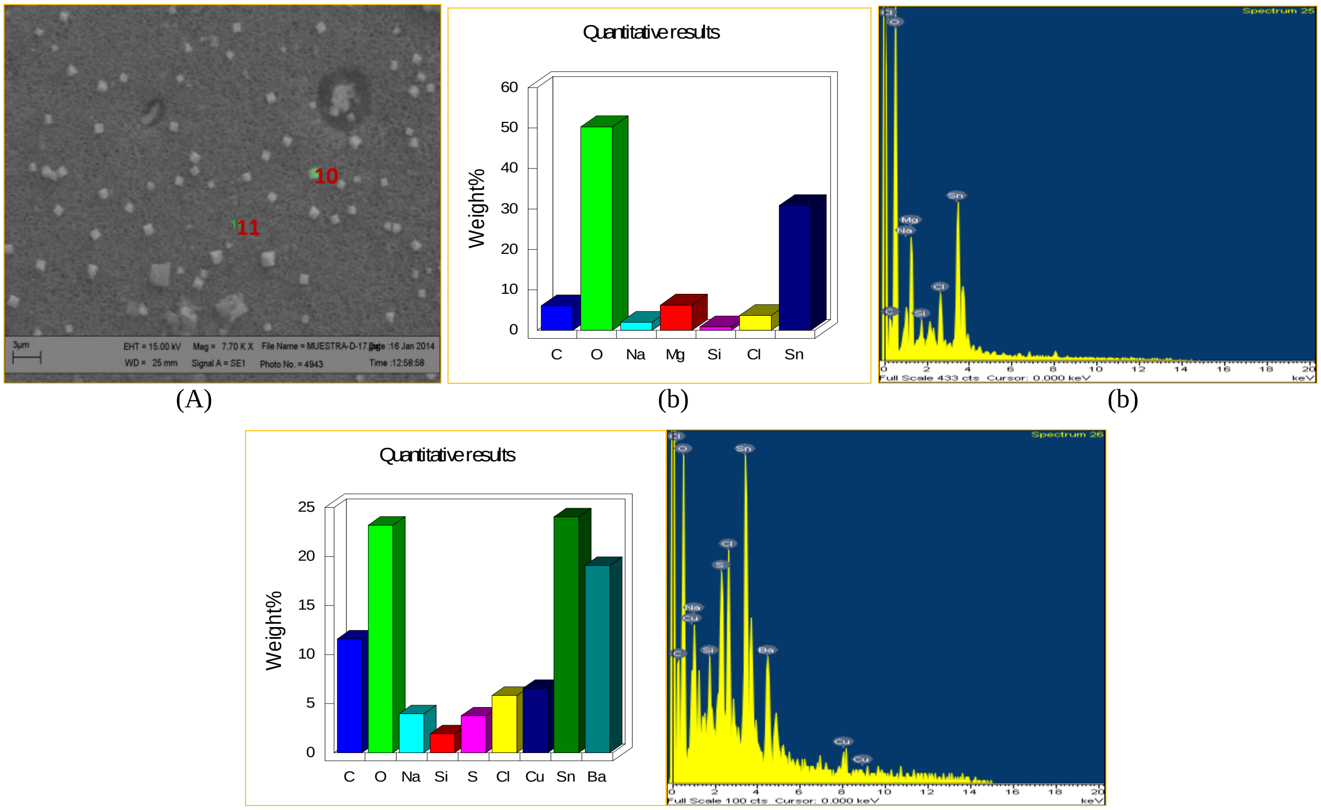
The analysis of this sample presents a large concentration on the surface of the ball in several chemical elements not only NaCl. See Figure 22 (A). These elements are Aluminum and Magnesium which also decrease the solderability of the balls.



(A) (a) (a)

Figure 23. (A) Sample in tap water at 10% for 16 hrs. Aluminum and Magnesium are present elements, which can affect the solderability

The SEM analysis shows contamination of NaCl in the BGA body in this case, see Figure 24. The contamination is in the form of small squares..



(A) (b) (b)

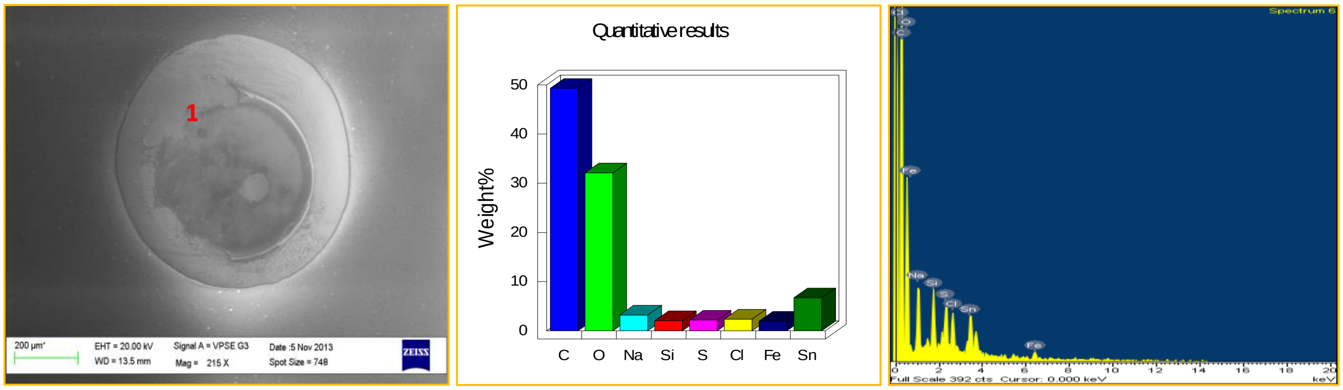
(c) (c)

Figure 24. (A) General analysis body component (b) corresponds at point 10, and (c) at point 11

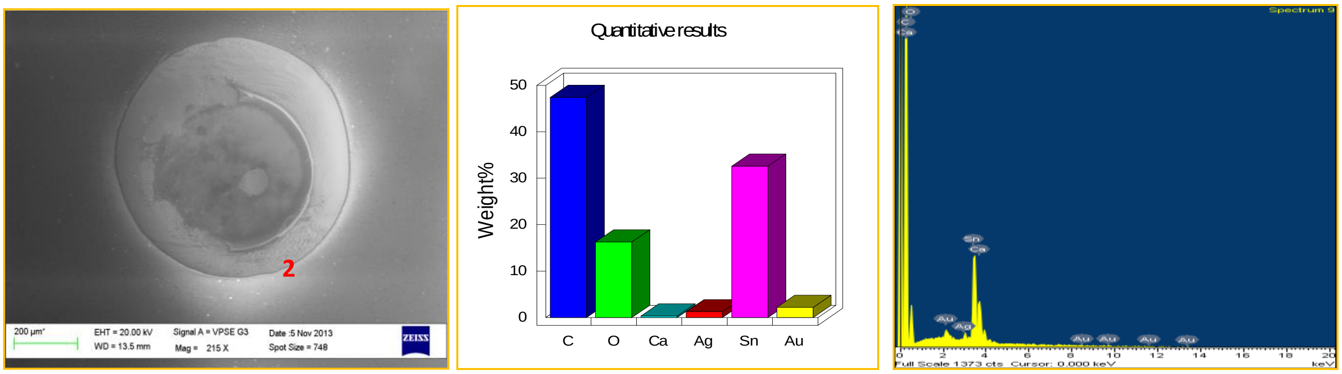
IV. Reject Analysis

The next analysis points out an actual HiP rejection from production lines. The analysis shows that in some areas Cl concentrations are present and in other areas do not show similar to cases analyzed above. Cl concentrations are found around the component in specific areas. Although the reject would be related to other possible causes, it is interesting to mention the relationship between the experiments and this real case.

Ball 1: HiP defect



(A) (a) (a)

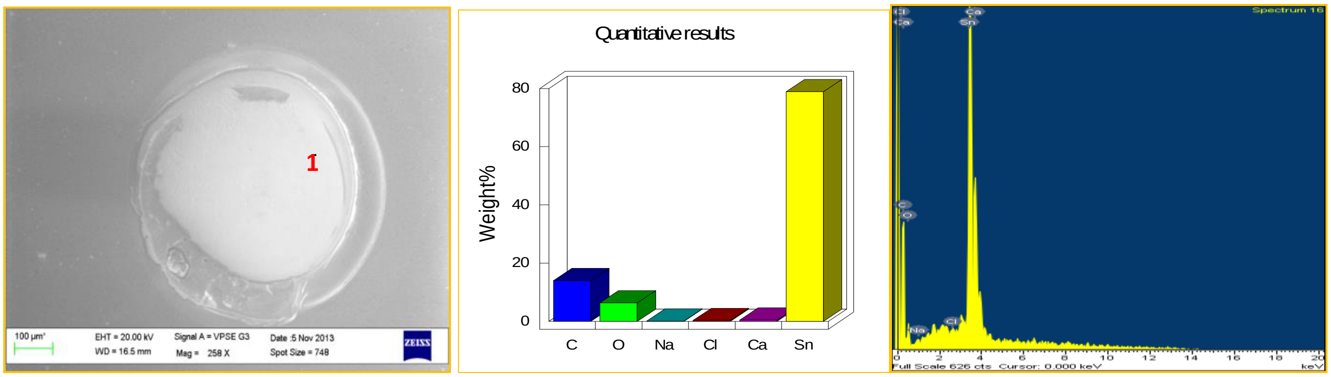


(B) (b) (b)

Figure 25. (A) The analysis of analyzed point 1 presents Cl; (B) is the analyzed point 2 which does not show Cl in a real HiP

IV.1. Pad Analysis

The following images show HiP SEM/EDX Analysis made on the pad. There are only small residues of NaCl left on the surface.



(A) (a) (a)

Figure 26. (A) There is NaCl presence on the pad

Conclusions

The presence of NaCl under some determined conditions can make wetting decrease in BGA solder balls. In this paper, 3 DOEs were presented together with their results. For the first DOE, the presence of foreign elements such as Na, Cl, Mg and Ca decrease substantially the wetting of solder balls. Several HiPs were created. In the second DOE, we reduced the amount of foreign material and were selective using only NaCl to contaminate the solder balls. The results showed HiPs are still created. An interesting fact is analyzing the solder balls with SEM/EDX, the concentrations of NaCl on the solder ball surfaces is not uniform but distributed randomly. Besides, the solder balls with low concentration of NaCl still created BGA HiPs. In the final DOE, we completed it with more and intermediate NaCl concentrations. The results completed a range of created HiPs from components with only one HiPs to components with most balls having HiPs. The main conclusion is that there is a direct relationship between NaCl amount on the metallization component and non-wetting issues. Of course, only NaCl presence is not enough but also energy and time are required to create the issues.

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