TAGUCHI EXPERIMENTAL DESIGN FOR CLEANING PWAS WITH BALL GRID ARRAYS

by

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Abstract

Ball grid arrays (BGAs), and other area array packages, are becoming more prominent as a way to increase component pin count while avoiding the manufacturing difficulties inherent in processing quad flat packs (QFPs). The JPL Electronic Packaging and Fabrication section is currently conducting process development in order to be able to effectively place BGAs on printed wiring boards (PWBs). Among the important processing steps is that of cleaning, which generally follows component placement anti solder reflow. Cleaning off detrimental residues left after the various processing steps, especially solder paste application and solder reflow, is necessary to avoid harmful contaminants remaining on the PWB surface. Cleaning printed wiring assemblies (PWAs) with BGA components mounted on the surface is problematic. Although these components typically have a standoff of 0.015 inch -0.025 inch, cleaning under such components is complicated by the hundreds of solder ball leads that such components have. Currently, a low flash point semi-aqueous material, in conjunction with a batch cleaning unit, is being used to clean PWAs. The approach taken at JPL was to investigate the use of (1) semi-aqueous materials having a high flash point and (2) aqueous cleaning involving a saponified, In order to optimize the experiment---that is, to maximize the information gained and to minimize the cost of conducting the investigation, the experiment was set up using Taguchi Design of Experiment (TDOE). The details of the approach and the final results are presented in the paper.

Key Words

Ball grid array, area array package, semi-aqueous cleaning, flash point, aqueous/saponified cleaning, design of experiment (DOE), Taguchi DOE (TDOE), quality characteristic, output characteristic, ionic contamination testing, ionic residue, rosin residue.

Introduction

The Electronic Packaging and Fabrication Section at the Jet F'repulsion Laboratory currently produces various types of surface mount PWAS. After the components are mounted on the PWB and reflowed to form a metallurgical interconnection, they are cleaned in a batch unit utilizing a semi-aqueous (SA) material. Cleaning off detrimental residues left after the various processing steps, especially solder paste application and solder reflow, is necessary

to avoid harmful contaminants remaining on the PWB surface. After cleaning, they are then rinsed in a separate batch unit utilizing a 45°/0 D.I. water/51 % isopropyl alcohol (IPA)/4% saponified (by volume) rinse mixture, Rinsing is performed until the resistivity of the rinse effluent rises above 1 MΩ-cm. However, because the SA material has a relatively low flash point (124°F), it is not heated.

Preliminary results suggested that perhaps this cleaning process was not adequate for surface mount PWAS having ball grid arrays. Hence, an investigation was undertaken to determine the effectiveness of alternative cleaning processes.

Current Cleaning Activity in JPL's SMT Lab

At present, PWAS with BGAs are being cleaned in JPL's SMT Lab in suitable batch cleaning equipment, Cleaning is currently being conducted in two separate stages:

1 Washing of the PWAS takes place in a batch unit utilizing a semi-aqueous (SA) cleaning agent with a flash point (F. P.) of 124°F. Since this semi-aqueous material is considered the baseline material, it is herein referred to as SA #0.

2 Rinsing is performed in a separate batch unit, utilizing a combination of isopropyl alcohol (I PA), D.I. water, and a saponified.

Because the SA material has a relatively low flash point, it is classified as a Class II combustible liquid (1 OO°F ≤ F. P.> 140 °F). by the National Fire Protection Association (NFPA). Although the interior atmosphere of the cleaning unit is inerted with nitrogen gas (N_2) during the purge and wash cycles to avoid possible combustion of the SA cleaning agent, the latter also is not heated, This is to further reduce the combustibility hazard.

Cleaning Investigation for BGA PWAS

To date, the cleaning system currently in place in the SMT Lab has come under increasing scrutiny in the case of PWAS with BGA components. Hence, it was considered prudent to investigate other cleaning options to position JPL's SMT Lab to accomplish this task.

It is well known that heating a cleaning agent enhances its effectiveness. One cleaning method suggesting itself was to use a SA cleaning agent, but one having a higher F.P. Two of these were considered in this investigation: semi-aqueous material No. 1 (SA #1) with a F.P. of 285°F and semi-aqueous material No. 2 (SA #2) with a F.P. of 210 °F. Both of these materials are classified as Class IIIB combustible liquids (F, P. >200°F) by the NFPA. Another method which was investigated was the use an aqueous system with a saponified. The saponified is necessary to remove rosin paste, the kind currently being used in the SMT Lab.

Approach: Taguchi Design of Experiments (TDOE)

In order to optimize the results of this investigation- that is, to maximize the information gained and to minimize the. cost of conducting the investigation, the experiment was approached with the intent of utilizing Taguchi Design of Experiments (TDOE). To best gain the answer to the BGA PWA cleaning question, the following three experiments, after a brainstorming session to decide which variables were the important ones, were considered:

Preliminary Processing Prior to Cleaning

Prior to conducting the cleaning experiments, all BGA PWAS were processed in JPL's SMT Lab using standard processes to apply solder paste, mount the components, and reflow the solder. For the latter, a quasi-in-line vapor phase reflow machine was used. All PWAS were visually inspected prior to cleaning and all anomalies noted, The time lapse between reflow and cleaning was kept constant for all PWAS. Cleaning was performed the day after the PWAS were reflowed.

Experiment #1

Dcf: Baseline information, conducted at JPL's SMT Lab.

Run the present cleaning system (pointed out above) at two (2) different wash times using the lPA/water/saponified rinse feature. Perform a separate run using water/saponifier rinse only, The matrix used for Experiment #1 is presented in Table 1. Note that this is not a Taguchi matrix.

Table 1: Matrix for Experiment #1

Run	Cleaning agent	Wash time rnin	iPA/HzO/Saponified rinse
1	SA #0	5	yes
2	SA #10	10	yes
3	SA #0	5	no-- tlzO/saponified only

Experiment #2

Def: SA cleaning agent investigation, conducted at the application facility of the company which produces the batch cleaning equipment. (Subsequent to this investigation, the cleaning division of the company at which the cleaning portion of this experiment was

performed was sold to another company.) A batch cleaning unit was used. Both SA agents were run in this batch unit. A separate batch rinse machine was used.

Experiment #2 consisted of three (3' factors at two (2) levels:

Controllable factors:

- Cleaning agent
- Wash time
- Temperature of cleaning agent during washing.

Fixed factors: PWA positioning in machine racks during cleaning, the cleaning machine, the rinsing cycle—water only, i.e., no IPA.

Use a Taguchi L4 matrix: The factors are the column headings; the runs of the experiment are the rows. See Table 2. That is, there are four (4) runs. For a full factorial experiment, there would be, of course, $2^3 = 8$ runs. The matrix for Experiment #2 is an L4 Taguchi matrix; it is presented in Table 2.

1 Cleaning agent #1= SA #1 (F.P.285°F);
cleaning agent #2 = SA #2 (F. P. ?1 0°F)
(Both semi-aqueous cleaning agents are marketed by the same company; however, different trade names are used)

2 Wash time #1= 10 rein; wash time #2 = 20 min.

3 Wash temperature #1=150°F; wash temperature #2 = 160°F.

Table 2: Taguchi L4 Matrix for Experiment #2

Run	Cleaning agent	Wash time min	Wash temperature c.F
1	SA #1	10	150
2	SA #/I	20	160
3	SA #2	10	160
4	SA #2	20	150

For all runs, the rinse time was held constant at 10 min. and employed H_2O only.

Experiment #3

Def: Aqueous/saponified cleaning agent investigation, conducted at the application facility of the company which produces the batch cleaning equipment. One batch aqueous unit was employed for the low pressure runs; a separate batch aqueous unit was employed for the high pressure runs.

Experiment #3 consisted of three (3) factors at two (2) levels:

Controllable factors:

- Cleaning agent
- Wash time
- Pressure during washing.

Fixed factors: PWA positioning in machine racks during cleaning, wash temperature (fixed by the cleaning agent chosen), saponified concentration (follow manufacturer's recommendation), the cleaning machine-- a suitable batch unit, the rinsing cycle- water only.

Use a Taguchi L4 matrix: The factors are the column headings; the runs of the experiment are the rows. There are four (4) runs. The matrix for Experiment #3 is an L4 Taguchi matrix; it is presented in Table 3.

Table 3: Taguchi L4 Matrix for Experiment #3

Run	Cleaning agent	Wash time min	Wash pressure psi
1	SP #1	10	?
2	SP #1	20	40
3	SP #2	10	40
4	SP #1?	?0	2

1 Cleaning agent #1= Saponified #1 (SP #I I);
cleaning agent ##2 = Saponified #2 (SP #2)
(Saponifies marketed by different companies under different trade names)

2 Wash time #1= 10 rein; wash time #2 = 20 min.

3 Pressure #1= 2 psi (60 gal/rein); pressure #2= 40 psi (35 gal/rein).

Quality Characteristic

To verify that adequate cleanliness was achieved, the following quality characteristic (also called output characteristic) was used:

- Ionic residue determined by ionic contamination testing using an Omega Meter® 600 SMD.

Determination of the output characteristic was conducted at the application facility of the company which produces the batch cleaning equipment.

Confirmation Experiments

After the three experiments above were performed, the results were analyzed. The standard Taguchi analysis of means (ANOM) technique was employed for analyzing Experiments #2–#3; Experiment #1 did not involve a Taguchi matrix. Based on the results, two (2) confirmation experiments were performed. One confirmation experiment was performed using the optimal (as determined by the ANOM analysis) semi-aqueous cleaning process, and a separate confirmation experiment was performed using the optimal (as determined by the ANOM analysis) aqueous/saponifier cleaning process.

The optimal semi-aqueous cleaning process as determined by ANOM analysis was:

- SA #1 at **20** min. at 150°F.

The optimal aqueous/saponifier cleaning process as determined by ANOM analysis was:

- SP #2 at 20 min. at 40 psi.

For each confirmation experiment, in addition to the ionic contamination testing (two PWAS per test), four additional PWAS were required for destructive physical examination: two (2) from the optimal semi-aqueous process and two (2) from the optimal aqueous/saponifier process. The components were removed from all four PWAs and a visual examination under 30x magnification was used to check for flux/paste residues. ?-he F'WAS were then subjected to Fourier Transform Infrared (FTIR) spectrophotometric analysis to determine the amount of remaining rosin residue.

Number and Type of PWAS Used in the Experiment

Two (2) PWAs per run were used.

Experiment #1: 3 runs x 2 PWAS per run = 6 PWAs

Experiment #2: 4 runs x 2 PWAS per run = 8 F'WAS

Experiment #3: 4 runs x 2 PWAS per run = 8 PWAs.

For Experiments #1--#3, a test PWA having four (4) BGAs reflow soldered to an FR-4 PWB was employed. This PWA was 4.0 inch x 5.5 inch. Two (2) of the BGAs were dummy plastic components having a full periphery of 396 (20x20-4) terminations. The other two (2) BGAs were dummy plastic components having a full periphery of 117 (1 1x1 1-4) terminations. After reflow, the standoff height was approximately 0.018 inch. See Figure 1 showing this particular F'WA.

Confirmation Experiment #/I: Optimal semi-aqueous process = 4 PWAs (2 PWAS for ionic contamination testing and 2 PWAS for component removal followed by first visual inspection and then FTIR analysis for rosin residue).

Confirmation Experiment #2: Optimal aqueous/saponified process = 4 PWAS (2 PWAs for ionic contamination testing anti 2 PWAS for component removal followed by first visual inspection and then FTIR analysis for **rosin** residue).

For the two Confirmation Experiments, a test PWA having five (5) BGAs reflow soldered to an FR-4 PWB was employed. This PWA was also 4.0 inch x 5.5 inch. Two (2) of the BGAs were dummy plastic components having a full periphery of 396 (20x20-4) terminations. Two (2) BGAs were dummy plastic components having a full periphery of 117 (1 1x1 1-4) terminal. ions. The fifth BGA was a ceramic BGA having a partial array and 352 terminations. After reflow, the standoff height was approximately 0.018 inch. Figure 2 depicts the soldered PWA with five BGAs; Figure 3 depicts the PWA after the components have been removed.

1 otal Number of PWAs used for all experiments = 30 PWAs.

Experimental Results

In Table 4, each number represents an arithmetic average of two independent determinations on the Omega Meter® 600 SMD. The quality characteristic measured was the ionic residue expressed in micrograms of NaCl or equivalent per square inch (µg NaCl or eq./in^2).

Table 4: Ionic Residue Results for Experiments #1–#3

Run	Experiment #1	Experiment #2	Experiment #3
1	**3.40**	**5.40**	**4.35**
2	**2.40**	4.25	**3,95**
3	**5.35**	**5.45**	**3.75**
4	N/A	4.20	3.85

In Table 5 (see below–following page), the results for the two confirmation experiments are presented. Again, as in Table 4, each number represents an arithmetic average of two independent determinations. In the case of the confirmation experiments, three quality characteristics were employed: (1) amount of ionic residue expressed in micrograms of NaCl or equivalent per square inch (μg NaCl or eq./in^2), (.2) a qualitative assessment of the amount of remaining rosin after the components were removed when the PWAS where examined at 30x magnification, and (3) amount of rosin residue expressed in micrograms of rosin per square inch (μg Rosin/in^2).

Conclusions

Two conclusions follow from the data presented above. The first is that the semi-aqueous batch cleaning is superior to batch aqueous/saponified cleaning. T here are two caveats to this conclusion. First, the saponified chosen, SP #2, was picked based on the lowest ionic residue results, and in fact it is presumed superior to SF' #1 in this regard. However, SP #2 may not be the better saponified with regards to effective removal of rosin. The second caveat is that the aqueous/saponified cleaning was performed in a batch unit. If the cleaning had been performed in an in-line machine with the potential for higher pressures, the cleaning results might well have been different.

T he second conclusion is that it may not be necessary to utilize a higher flash point semi-aqueous material; the original SA material (F. F). = 124°F) may be satisfactory. This needs to be investigated further.

Table 5: Results for the Two Confirmation Experiments

Confirmation Experiment	Ionic residue μg NaCl or eq./in^2	Visual examination after component removal	Rosin residue μg Rosin/in^2
Semi-aqueous (SA #1 at 20 min. at 150°F)	3.45	**2-3** small spots of flux/paste visible under each component	11.3
Aqueous/saponified (SP #2 at 20 min. at 40 psi)	3.95	Lots of flux/paste visible under each component- -app. 1-2 orders of magnitude more than the SA results	29-7.'4

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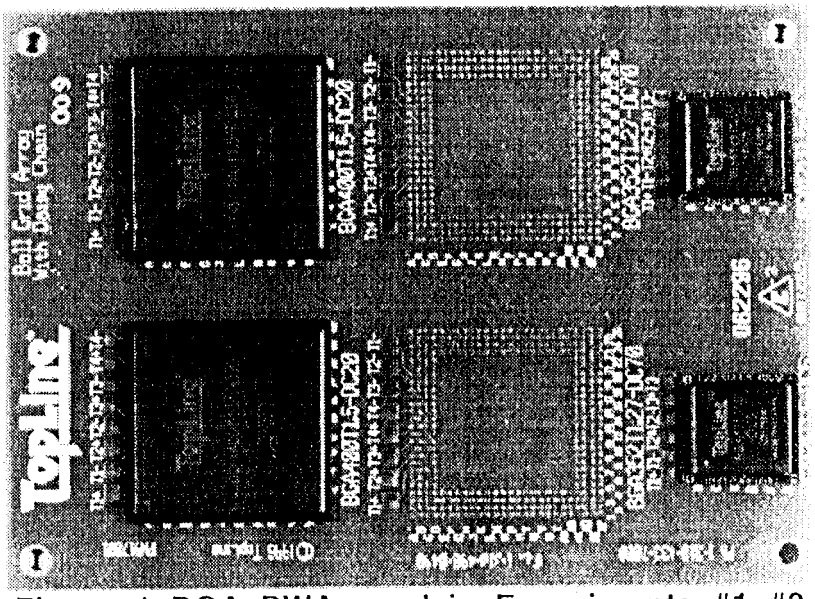

Figure 1 BGA PWA used in Experiments #1–#3

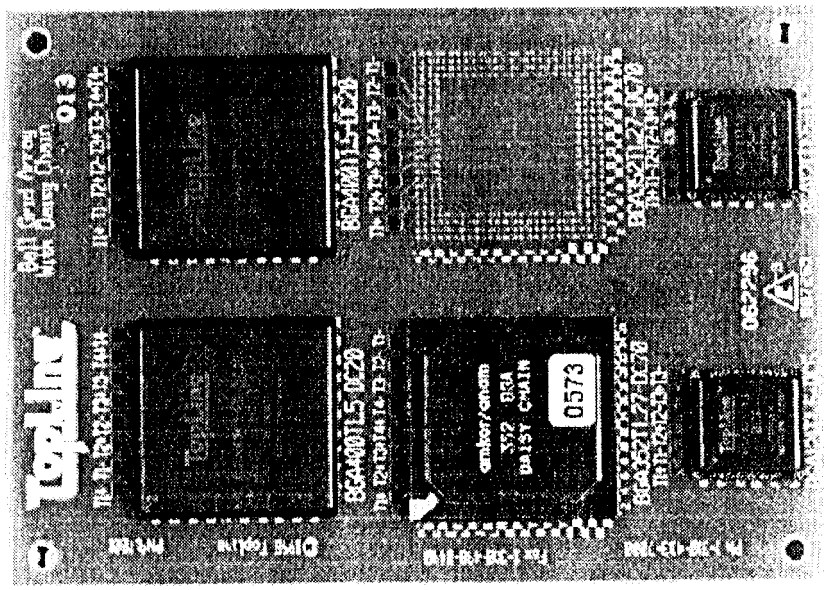

Figure 2 BGA PWA used in Confirmation Experiments

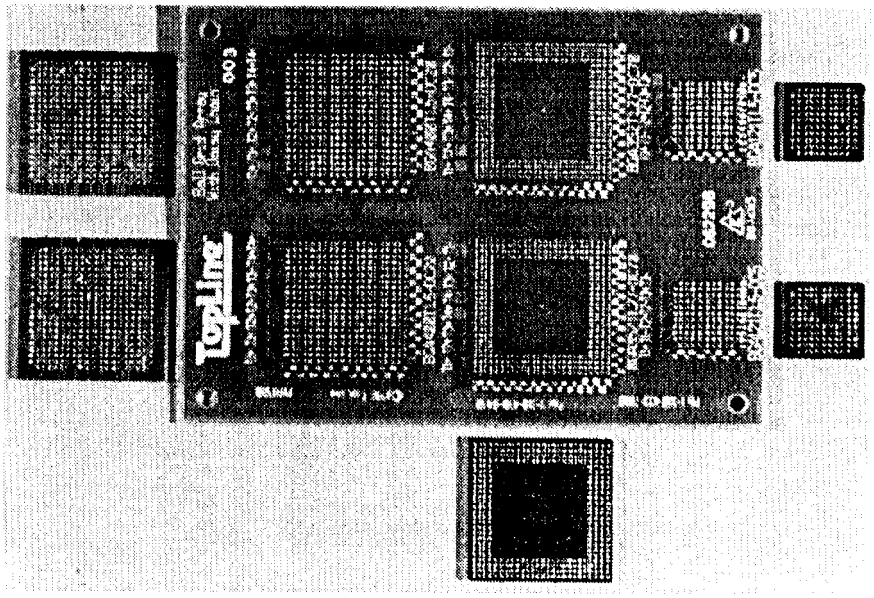

Figure 3 BGA PWA shown in Fig. 2 with components removed