Presented at IPC Printed Circuits Expo®
SMEMA Council APEX®
Designers Summit 04

Development of Assembly and Rework Processes for Large and Complex PCBs Using Lead-Free Solder

David A. Geiger, Jin Yu and Dr. Dongkai Shangguan
FLEXTRONICS
San Jose, CA

Abstract
The continued functional densification and integration in networking products is driving the need to study large form factor printed circuit boards that use high I/O packages (either ceramics column grid arrays, CCGA, or plastic ball grid array, PBGA). As of today, there has been limited work on understanding the impact of lead-free soldering on these large and complex assemblies. This paper will look at larger packages (up to 52.5mm square with 2577 I/O) in combination with lead-free soldering. Assembly processes such as solder paste printing and reflow soldering will be studied and the results presented. The rework of these component types will be evaluated and the key issues for developing a successful rework process will be discussed.

Key words: CCGA

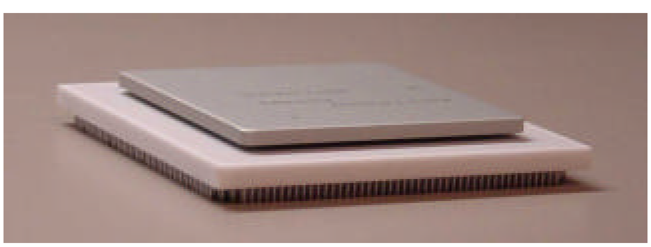
Introduction
As lead-free soldering moves towards wide implementation, it is anticipated that lead-free soldering may be needed for certain large and complex boards with large, high I/O, and high thermal mass components, such as CCGAs. The current CCGAs with Sn-Pb columns are expected to be used in the near future with lead-free solders under certain circumstances, while CCGAs with lead-free columns continue to be developed and evaluated.

Results of investigation on the important process parameters for soldering CCGAs with Sn-Pb solder have been reported previously. In this work, certain critical aspects of soldering CCGAs with lead-free solder are investigated, including solder paste printing, component pick and place, reflow and rework. While the self-alignment study was specific for CCGAs with Sn-Pb columns with lead-free solder paste, the thermal studies for reflow and rework are more generally applicable to high thermal mass components, perhaps regardless of the metallurgy of the solder columns.

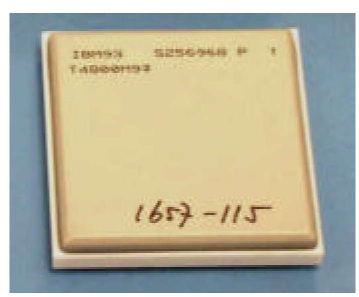
Component Selection
Two types of CCGA components with daisy chains were selected (Figure 1). One component, CCGA2577, is of the largest ceramic body of 52.5mmx52.5mm and attached with a flat open lid, and the other one has a very thick ceramic substrate of 3.75mm and attached with a closed lid. These components were selected for this investigation because of the process challenges during reflow due to their large thermal mass.

Large ball grid array (BGA) package with 45mm x 45mm body size and 1900 I/Os, and large quad flat pack (QFP) packages with 40mmx 40mm body size, as well as fine pitch QFP with 0.40mm pitch and 28mm x 28mm size, were also included on this test vehicle. Details of these components are listed in Table 1.

Small components, such as 0402 and 0201, were also included on the test vehicle adjacent to the CCGA's and BGA's.



(a) CCGA2577



(b) CCGA1657

Figure 1 – Pictures of Ceramic Column Array Components

Table 1 – Features of CCGA, BGA and QFP Components Used

Item	Part Name	I/O	Pitch	Body Size	Ball Matrix	Ball Alignment	Qty Per Board
1	CCGA 2577	2577	1.00mm	52.5 X 52.5mm	51 X 51	FULL GRID	10
2	CCGA 1657	1657	1.00mm	42.5 X 42.5mm	41 X 41	FULL GRID	2
3	PBGA 1936	1936	1.00mm	45 X 45mm	44 X 44	FULL GRID	3
4	QFP 304	304	0.50mm	40 X 40 X 3.8mm			8
5	QFP 256	256	0.40mm	28 X 28mm			5

Test Vehicle Design

A test vehicle (Figure 2) with 18”x20” outside dimension and 0.125” thickness, with over 62,611 mechanical drills, was developed, using Ni/Au surface finish.

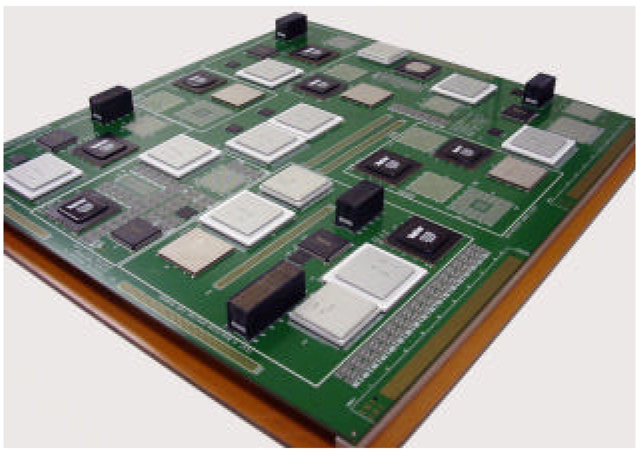


Figure 2 – Picture of the Test Vehicle

Results and Discussion

Printing Process

The printing process was investigated for the lead-free solder paste (Sn-3.9Ag-0.6Cu). A DOE was run to determine the best printing parameters to be used. The squeegee pressure, the printing speed and the separation speed are the parameters that were varied in the process. Twelve combinations were run with three samples for each combination. A 0.150mm (6 mil) thick stencil was used for the experiment and the volume deposited was collected for CCGA2577 and the 0.5mm CSP. The standard deviation of the solder paste volume was used as the response factor. Table 2 shows the printing results based on the standard deviation percentage. The data show that the best results were obtained when the squeegee pressure was set to medium, the printing speed is set to low and the separation speed is set to high. The printing process was not seen to be different from the Sn/Pb printing process.

Table 2 – Printing Results

Rank	Setting	% Std Dev of Average
1	MLH	7.8%
2	HML	8.5%
3	HLM	8.6%
4	HMH	9.4%
5	LML	9.7%
6	LHM	10.0%
7	MHL	10.2%
8	LLM	10.2%
9	MHH	10.3%
10	MMM	10.8%
11	LMH	11.8%
12	MLL	12.3%

Placement Process

For pick and place, the main concern using the lead free solder is the ability for the parts to be able to self-align (or self-center) to the pads. For this test, a PBGA1517 (with Sn/Pb solder balls) and CCGA2577 (with high Pb columns) were used. The parts were then placed 25%, 50% and 75% off from the center of the pad, and then reflowed in air in a lead-free profile using the lead-free solder paste. The parts were inspected before and after reflow using x-ray and visual inspection.

The PBGA device was able to self-center as it normally does, even if it was placed 75% off the center of the pad. Pictures can be seen in Figure 3 for the placement of the CCGA devices. The CCGA devices could only be placed up to 25% off the pad and be able to self-align to the pad. At 50% off-pad and above, it was seen that the columns tended to touch the solder paste deposit on the neighboring pad and then the column would try to align to the neighboring pad, causing a short to form.

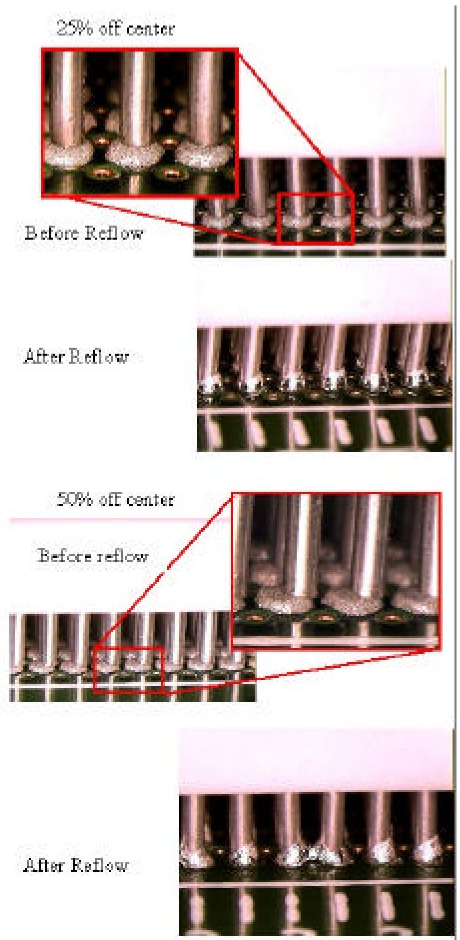


Figure 3 – Self-Alignment of CCGA Devices

Reflow Profile

A nine-zone convection reflow oven was used to create the reflow profiles in air for this test vehicle. The best reflow profile was created that would most closely match the minimum peak temperature requirement for the lead-free solder and at the same time maintain as low a delta T as possible across the board.

Thermal couples were placed on the board at six different locations (Table 3). The actual reflow profile can be seen in Figure 4. Once the profile was set up, it was run multiple times to check the stability of the profile. Cp and Cpk were then calculated for this oven. The minimum reflow peak temperature was set to 235°C with a tolerance of ±5°C. Based on this criterion, the Cp and Cpk for the oven was 3.6 and 3.2 respectively (Table 4). This shows that the oven is more than capable of maintaining its profile in a normal process.

Table 3 – Thermocouple Locations

Thermal Couple Locations	
TC1	Center PBGA1517
TC2	Center CCGA2577
TC3	Center of CCGA2577 + BGA1600 (bot)
TC4	Board Surface
TC5	Center CCGA1657
TC6	Top of CCGA2577

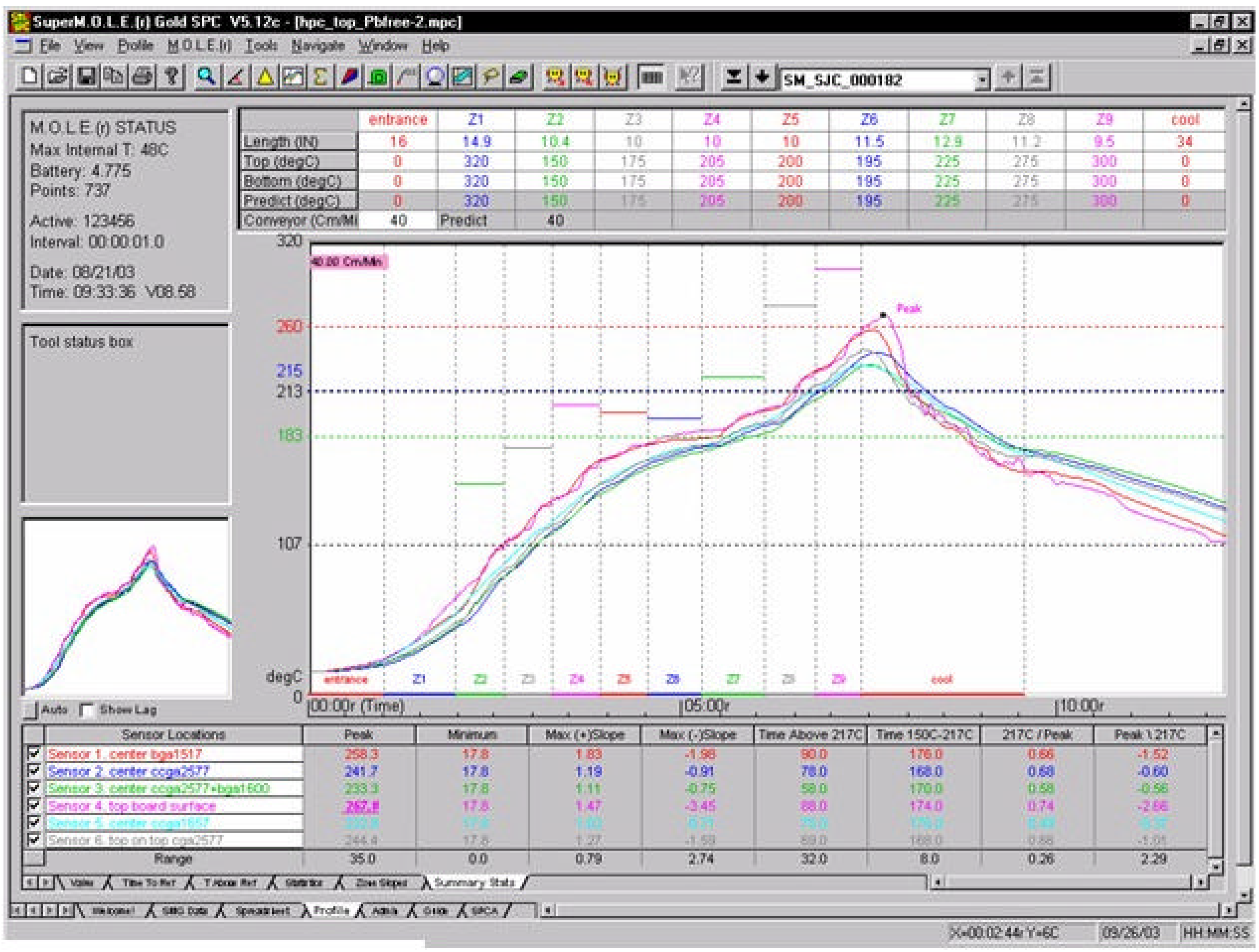


Figure 4 – Lead-Free Reflow Profile

Table 4 – Reflow Oven Capability

Large Form Factor Board

	Location	Peak Temperature					Range	Cp	Cpk (minimum peak temperature)
		Run 1	Run 2	Run 3	Run 4	Run 5			
Thermocouple #1	Center BGA1517	258.9	259.4	258.9	258.3	258.9	1.1	4.3	
Thermocouple #2	Center CCGA2577	242.2	241.7	241.7	241.1	242.2	1.1	3.7	
Thermocouple #3	Center of CCGA2577 with PBGA1600 on Bottom	235.0	234.4	234.4	233.9	235.0	1.1	3.6	***3.2***
Thermocouple #4	Board Surface	263.9	263.9	264.4	265.0	263.9	1.1	3.4	
Thermocouple #5	Center CCGA1657	240.6	240.0	240.0	239.4	240.6	1.2	3.3	
Thermocouple #6	Top of CCGA2577	246.7	246.1	245.6	245.0	246.7	1.7	2.3	

Tolerance = +/- 5 deg C

The largest delta T (35°C) was seen between the center of the CCGA1657 and the board surface, whereas for the CCGA2577, the delta T was only 27°C. To explain why the smaller CCGA1657 (42.5mm square) gave a larger delta T than the larger CCGA2577 (52.5mm square), a closer look at the package construction was needed. Figure 5 shows the key differences between the parts. It turns out that the CCGA1657 is thicker than the CCGA2577. The 1657 CCGA has a 3.7mm thick ceramic substrate and a 3.0mm thick lid, and the lid is also directly attached to the ceramic substrate. In comparison, the 2577 CCGA device has a 2.8mm thick substrate and a 2.5mm thick lid, and this lid is attached directly to the die and leaves some air space open under the lid. It is believed that the differences in heat transfer due to these structural differences are responsible for the difference in delta T between CCGA1657 and CCGA2577.

CCGA1657

Component weight = 42.5grams
Ceramic thickness = 3.7mm
Lid thickness = 3.0mm
(Lid is sealed to substrate)

CCGA2577

Component weight = 51.3grams
Ceramic thickness = 2.8mm
Lid thickness = 2.5mm
(Lid is attached to the die)

Figure 5 – CCGA Comparisons

Rework

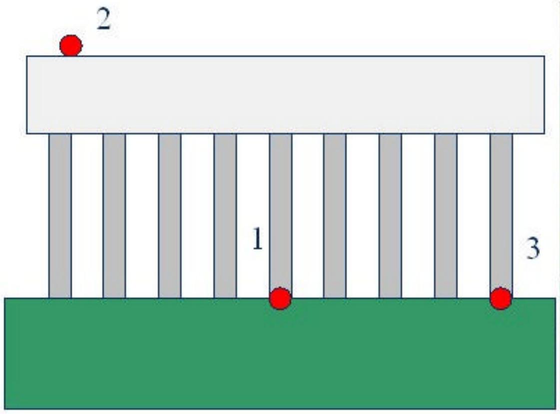
The last area investigated is the ability of the rework equipment to be able to process lead-free solders for the large CCGA packages. The rework equipment has a convection bottom side heater and a topside nozzle for localized heat. A board was thermocoupled at eight locations (Table 5) and was then run through multiple profiles with peak temperatures on the coldest spot ranging from 185°C up to 240°C. The board was brought up to 150°C using the bottom-side heater only prior to engaging the topside heaters. The results were then plotted onto a chart and analyzed.

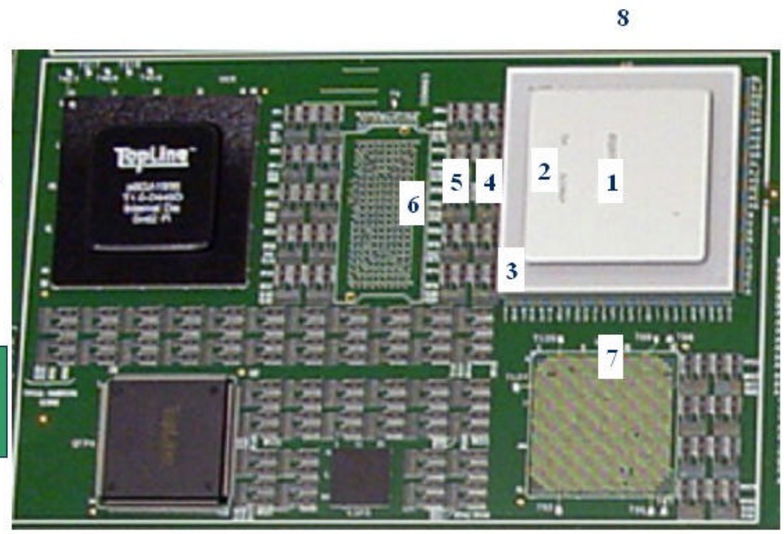
As can be seen from Figure 6, each thermocouple location increases in peak temperature slightly differently from other locations as the top heater setting is increased. This helps explain why it can be harder to create a proper profile for large components. For example, for a lead-free replacement profile, for every degree of topside heater increase, the top of the CCGA will increase about 0.766°C while the center of the CCGA device will change about 0.666°C. So for every 10°C change in the topside heater, one can expect a 1°C increase in the delta T between the center solder joint and the top of the component.

On this rework station, a delta T of about 17°C was seen between the center solder joint and the outside corner solder joint of the CCGA package.

Overall, this particular rework equipment is capable of creating a suitable profile in order to remove and replace a large CCGA device for lead-free process.

Table 5 – Rework Profile Locations and Results





Thermcouple Location	Peak Temperature Trial 1 (185)	Trial 2 (200)	Trial 3 (210)	Trial 4 (220)	Trial 5 (230)	Trial 6 (240)
1 Bot center of CCGA	**182**	**197**	**213**	**223**	**227**	**239**
2 Top of component	201	222	236	248	253	268
3 Bot left edge	175	190	202	212	215	222
4 Left ctr edge (10mil)	166	182	185	193	195	199
5 Left ctr edge (50mil)	160	175	181	227	248	261
6 Left ctr edge (500mil)	152	164	169	173	177	202
7 Lower edge (500mil)	127	147	168	144	171	179
8 Upper edge (500mil)	150	164	169	173	175	181

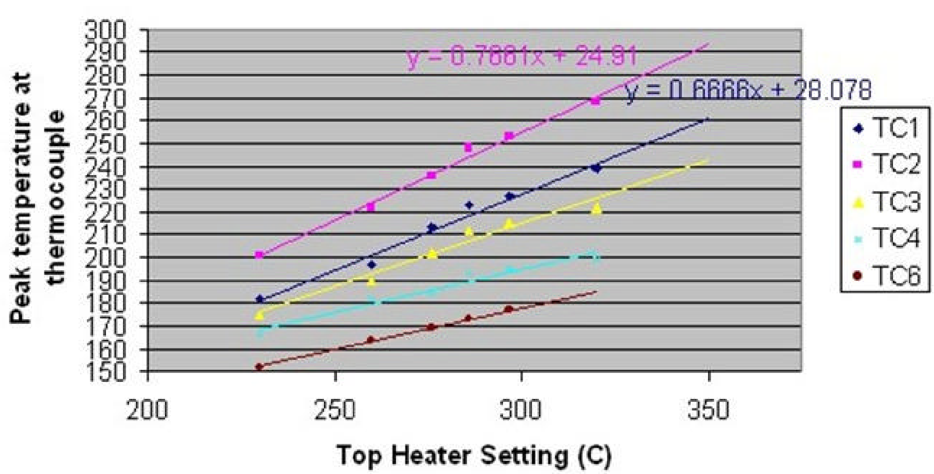


Figure 6 - Rework Profile Analysis

Summary

It has been shown that a lead-free process is possible for the large CCGA components. The solder paste printing and component pick and place for the lead-free process are considered being the same as the tin-lead process. With the lead-free solder, the CCGA devices could self-align to the pad while placed up to 25% off the pad.

The main concerns are with the thermal profiling for reflow and rework, and the impact of the temperature on the surrounding components. A large delta in temperature is seen with the CCGA, but for the largest/newest CCGA component, the delta T is lower than an older version of a smaller device. This will help alleviate some of the potential thermal issues that may be encountered. An existing rework station was demonstrated to be able to remove and replace the CCGA components for a lead-free process. Further work is ongoing to investigate lead-free CCGA with lead-free soldering processes.

References

1. M. Cole, I. DeSousa, M. Interrante, L. Jimarez, J. Jozwiak, M. June, G. Martin, C. Milkovich, J. Ross, M. Shannon, “The New Millennium for CCGA beyond 2000 I/O”, *Journal of SMT, Vol 15, Issue 1, 2002*.
2. M. Wang, D. Shangguan, D. Geiger, T. Castello, and S. Yi, "Assembly and Rework Process Investigation on New Ceramic Column Grid Array Packages", *Proceedings of SMTA 2002, Chicago, IL.*
3. M. Wang, A. Lewis and S. Yi, “Challenges and Solutions in Rework Process”, *SMTA 2000, Chicago, IL.*