Evaluating solder-paste defects

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An important part of a chemically compatible process is the solder system, which should be evaluated thoroughly to either maintain or improve it. A solder system may be defined as collection of chemicals that have flux such as solder paste, wave solder flux and most rework materials. For the purpose of this evaluation, researchers considered the bar and wire solder for the wave solder system to strictly be a commodity and not a part of the system evaluation.

A Six Sigma program was used to perform the solder-system evaluation analysis. Over the last three years, General Electric Co. has used the Six Sigma program to evaluate and introduce processes. The statistical tools and methods used in the program fit the type of analysis required for a solder-system evaluation.

At the beginning of the solder-system evaluation, process engineers decided that any system approved must be at least as good as the company's existing system, regardless of price. The goal, therefore, was to evaluate many suppliers on variable criteria wherein General Electric engineers would approve all systems that performed better than their current system.

Which manufacturers to evaluate?

The first step in the evaluation was to determine what type of solder paste was required. Available boards have fine (<0.508mm) pitch, intrusive reflow (pin in paste), double-sided reflow and glue dot. By examining the company process and working with several solder-paste manufacturers, it was determined that a no-clean, low residue, pin testable, 90 percent metal content solder paste was needed. Determining these needs in advance shortened the time and effort involved in requesting a quote. Simply requesting a quote for XX grams of solder paste/year probably made suppliers quote different products. Specifically determining the solder paste required was the best way to compare similar products from different manufacturers.

The next thing done was to determine which suppliers should be allowed to compete in the evaluation. This began by including what were considered to be the major manufacturers. The company's existing system was used as a baseline to which the other products were compared. Manufacturers who would provide paste, flux and rework materials were preferred in the evaluation. However, if two companies were willing to work together–for example, one supplies the flux and the other supplies the paste–to provide certification of their interactions, they were evaluated.

After determining the suppliers to be evaluated, a request for quote (RFQ) was prepared. At this point, the General Electric purchasing department was informed and they made the proper commercial modifications to the RFQ. It was required for the quotes to be returned to the purchasing department within 10 days. This requirement was actually a test. Any supplier who missed this date was eliminated from the evaluation.

Because of the number of manufacturers allowed to quote, it was necessary to reduce the list based on the criteria of response time and cost. On the day after the quote due date, one manufacturer was eliminated because its cost was very high. Another manufacturer was also eliminated for not responding within the allotted time. In the end, what remained were five candidate manufacturers and each company's baseline system to evaluate.

Selecting test vehicle

For this evaluation, it was decided that a production board is used without any plans of destructive tests. To use a production board for the evaluation, the information provided by solder-paste manufacturers had to be relied upon. The company's most diverse board regularly processed in production was used. This board uses fine-pitch devices and intrusive reflow. It also uses double-sided solder paste that allowed designers to reduce the total number of experiment runs by testing some variables on the topside and some on the bottom.

For the purpose of this evaluation, a statistically valid design of experiment (DoE) was performed. First, the variables were selected by which the solder pastes were to be evaluated–the smaller the number of variables, the smaller the number of experiment runs. Additionally, the following four variables were selected: Hold time after print; hold time after placement; different lots of solder paste; and reflow atmosphere.

For each of the four variables, high and low values were carefully selected. The high and low values for each of the hold times were two and zero hours respectively. The high and low value for the solder paste lots were simply two different lots of solder paste from the different manufacturers. The high and low values for the reflow atmosphere were nitrogen and air.

The DoE was made to evaluate two of the variables when running the bottom side and two of the variables when running the topside. It was also set up to run in the order that was most time efficient because constantly changing solder pastes and cleaning the stencil was not efficient. The board used had a lot size of 30.

To better understand the evaluation, the following matrix was implemented:

Bottom-side procedure

- Print boards 1 through 7 using manufacturing Lot A.

	Beads		Balls		Bridges		Insufficient		Residue		Open		Luster		Wetting		Lot diff.		ICT false fail.		Print observation		Dislodged comp.		Total
Paste No.	**5**		**5**		**8**		**6**		**3**		**0**		**3**		**4**		**4**		**9**		**3**		**0**		
1	*3*	10	*200*	0	*1*	8	*1*	9	*4.4*	3.2	*0*	10	*2.3*	7.3	*2.0*	8.0	*1*	8	*56*	0	*7*	7	*0*	10	285
2	*28*	*7*	*10*	10	*1*	8	*0*	10	*3.0*	6.0	*0*	10	*2.0*	8.0	*1.4*	9.2	*1*	8	*1*	9	*9*	9	*0*	10	428
3	*61*	4	*30*	9	*0*	10	*8*	6	*3.8*	4.3	*0*	10	*4.0*	3.9	*2.2*	*7.7*	*0*	10	*0*	10	*1*	1	*0*	10	369
4	*20*	8	*32*	8	*0*	10	*4*	8	*3.0*	6.0	*0*	10	*3.0*	6.0	*3.0*	5.9	*0*	10	*1*	9	*4*	4	*0*	10	401
5	*95*	0	*2*	10	*0*	10	*0*	10	*3.7*	*4.7*	*0*	10	*1.8*	8.5	*1.6*	8.8	*1*	8	*22*	6	*7*	*7*	*0*	10	372
6	*5*	10	*15*	9	*0*	10	*0*	10	*3.6*	4.8	*0*	10	*3.3*	5.5	*1.3*	9.4	*2*	6	*3*	9	*8*	8	*0*	10	432
7	*58*	4	*40*	8	*5*	0	*128*	0	*1.6*	*8.7*	*0*	10	*3.0*	6.0	*2.3*	*7.5*	*1*	8	*12*	*7*	*7*	7	*0*	10	250

- *Italized* values are a summary of inspection results. Values have been determined by taking mean, median or sum of raw data. Method of summarizing is dependent on frequency and normality of raw data.
- Normalized values are located in column to the right of the summarized values.
- **Bold** values are the weighting applied to each defect mode.
- Total is calculated by summing the products of each defect mode weight and its normalized defect result.

Table 1: The matrix used to run the evaluation boards are divided into bottom- and top-side procedures.

- Hold two hours after print.
- Place components.
- Hold two hours after placement.
- Turn boards upside-down for 10 minutes.
- Count number and type of components that are dislodged.
- Replace fallen components.
- Reflow boards in air.

Topside procedure

- Print boards 1 through 7 using manufacturing Lot A.
- Place components.
- Reflow boards in air.

Take note that this matrix was repeated for every solder paste.

Running the boards

The entire experiment was designed before beginning the actual run. The designed experiment was sent to all of the paste manufacturers before beginning the evaluation. Included with the procedure were the profiles of the company's reflow oven and screen printer. The purpose of sending this information to the paste manufacturers was to ensure that the experiment was not biased for the benefit of the current system.

When the evaluation commenced, the boards were run using the company's standard process. When changing from one solder-paste manufacturer to another, the stencil and squeegee blades were cleaned thoroughly. Also, an automatic stencil cleaner was used to avoid an additional variable due to the cleaning ability of individuals.

After placing the components on the bottom side, the board was held upside-down for 10 minutes. This procedure measured the green strength of the paste. No components were dislodged by this step. Test was not stringent enough to differentiate the green strength of the different solder pastes.

While running this type of experiment, remember that you are evaluating solder pastes, not optimizing the process. It is advised that you do not tweak the process. These adjustments will bias your results and introduce variables for which you did not plan.

Recording results and defects

Next, the visual defects to record were selected: solder beads, solder balls, solder bridges, insufficient solder; opens, luster, and wetting and residue. Following this, a spreadsheet was created to record all the defects on every board. Every board was inspected thoroughly. Of course, all inspectors should be calibrated to minimize the differences in the results among them.

An important criterion in the process is the pin testability of an in-circuit tester (ICT). For this purpose, all of the false failures were recorded while testing the boards. False failures are defined as failures that do not repeat when retested. All ICT pins were replaced when boards that used different pastes were processed so that any buildup of flux residue would not bias the remaining tests. Actual board failures were recorded at the tester and component failures that were not related to soldering were eliminated.

The results of the visual and tester inspections for each board were recorded into a spreadsheet. The mean, median or total for each defect mode with each paste was calculated in detail. For a very low-occurring defect such as solder bridging, a sum method was used. For more common defects, such as beads and balls, a mean or a median was implemented to summarize the defect. We used the mean when data were statistically normal and the median when data were not statistically normal. After which, the summarized values were converted to normalized values from 0 to 10. A summarized value having a high score is not good; however, in normalized values, a high score is good. Take note that the goal of this value normalization is only to create a comparison tool.

Part of the DoE was the comparison of two manufacturing lots. All the raw data were analyzed using analysis of variance (ANOVA) to determine any statistical difference in the two lots from each manufacturer. The ANOVA was performed for all defect modes. The normalized score was based on the number of defect modes when a statistical difference occurred between the two manufacturing lots.

The defect "print observation" is simply the company's opinion of how the paste looked when it was printed. Since there were significant differences that occurred in the consistency of the pastes, it is all right to know that the company did not penalize a paste if it had a different consistency than what was expected. However, pastes that did not roll well were penalized.

For the purpose of determining the exact values, a weighted value was given to each defect mode. For example, pin testability is of great concern to the evaluation process while cosmetic issues are a lot less, so they are given values of 9 and 3, respectively. Each of these values was multiplied by the individual paste's normalized value for that defect. These products were added together to give the final paste score.

The solder-paste manufacturer the company has always used is Paste #2. Only Paste #6 scored higher. This result was a confirmation that the company has been using a very good solder paste. But, because this evaluation is not an exact science, the company also considered Paste #4 for the final evaluation.

Final evaluation

Since the goal of this evaluation is to maintain or improve the company's existing solder system, the next step is to perform a similar evaluation on the wave solder flux and rework material. Here, the entire system is evaluated and not just the paste. Once the wave solder flux and rework material have both been evaluated, a total score is developed using the method similar to the one used for the solder paste. Again, these total scores will be normalized, and weighted values will be given to the three materials. A final score for the entire solder system will be compiled, and a thorough, final evaluation will be performed on all manufacturers that score higher than the company's current system.

The final approval will be an extensive evaluation over a long period of time and will include third-party, independent testing of the soldering system reactions. These tests will be performed to verify the chemical interaction certification that was initially provided. After the final system evaluation, successful solder-system manufacturers are presented to the company's purchasing department as fully approved suppliers.

	Bottom Side		Top Side	
Run (Boards)	**Variable 1** (Hold after print)	**Variable 2** (Hold after place)	**Variable 3** (Paste lot)	**Variable 4** (Reflow atmosphere)
A (1-7)	**High** (2 hours)	**High** (2 hours)	**Low** (lot #1)	**Low** (Air)
B (8-14)	**Low** (0 hours)	**High** (2 hours)	**Low** (lot #1)	**High** (Nitrogen)
C (15-21)	**High** (2 hours)	**Low** (0 hours)	**High** (lot #2)	**Low** (Air)
D (22-30)	**Low** (0 hours)	**Low** (0 hours)	**High** (lot #2)	**High** (Nitrogen)

Table 2: Tabulated results for the visual and in-circuit test inspection yield qualified solder-system manufacturers.

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