Universal®
AUTOMATION IN ELECTRONIC ASSEMBLY

Process Parameters Optimization For Mass Reflow Of 0201 Components

Abstract

The research summarized in this paper will help to address some of the issues associated with solder paste mass reflow assembly of 0201 components. Attachment pad design, stencil design, component to component spacing, component orientation, flux type, and solder paste reflow atmosphere were the major variables researched during the project. The two major responses from the experimentation were assembly yield and assembly quality. Assembly yield defects, such as tombstones (open solder joints), solder bridges, and solder balls (beads) were used to determine the assembly yield. Solder joint shape, solder appearance, and solder volume (unacceptable low, acceptable or unacceptable high) responses were used to determine the quality of the assembly process. The combination of flux type and reflow environment were found to have the largest impact in the number of assembly defects produced. Boards assembled with no-clean solder paste and reflowed in an air atmosphere exhibited the best yields with the highest tolerance for attachment pad dimension variation. Conversely, assembly processes using no-clean solder paste with a Nitrogen reflow atmosphere generated the largest number of assembly defects and was found to be the most sensitive to changes in the attachment pad design.

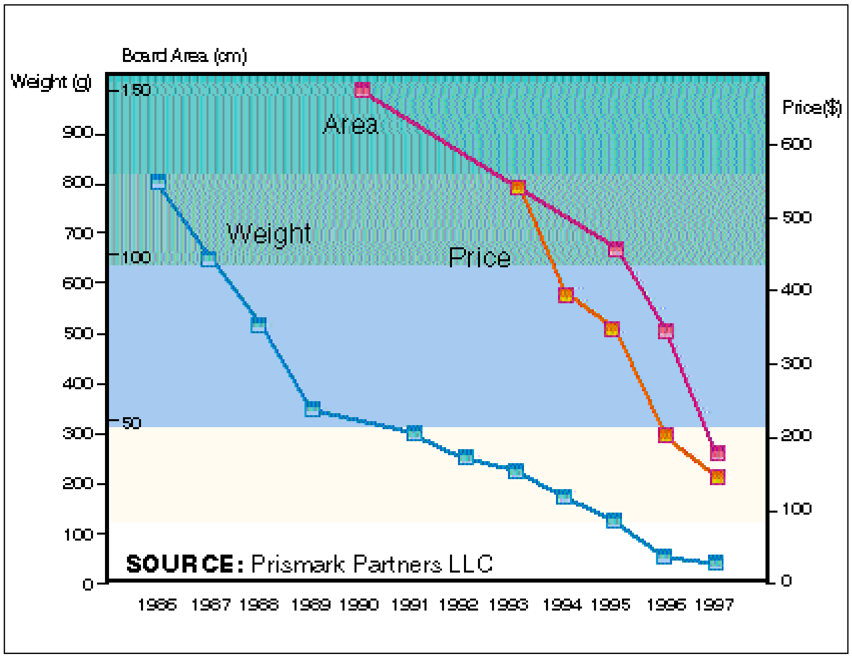

Figure 1 - Mobile Phone Evolution

Introduction

The need to reduce the size and weight of electronic products is continuing as Surface Mount Technology matures further. Size reduction in both active and passive components coupled with improved printed circuit board technology is producing smaller, lighter weight, and higher performing end products. Extensive research and development continues to reduce the size of active packages. Passive components have also been reduced in size to enable designers to use smaller printed circuit boards to perform a given task. The use of 0603 and 0402 components have been prevalent for a number of years. These component sizes can be run in high volume applications at very high yields. More recently, 0201 components have been implemented in high density applications. The 0201 component is approximately one-quarter the size of a 0402 component and this could reduce the assembly process robustness and yield. This paper presents the results of an ongoing study designed to determine the impact that specific assembly and board design parameters have on assembly yield of these components in a mass reflow senario.

A full factorial experimental design of 27 different attachment pad designs (3 levels each for distance between pads, pad width, and pad length) were used to determine the optimum attachment pad design. Five different stencil aperture designs were tested for each attachment pad design. No-clean and water-soluble flux chemistries were tested in both air and Nitrogen reflow environments. Component to component spacing was tested at four different levels at both zero and ninety degree component orientations. Stencil thickness, stencil fabrication, attachment pad metallurgy, solder mask type, screen printer process settings, component placement system, thermal profile, and reflow system were major parameters that were fixed during the research project.

Market Drivers and Attributes for 0201 Components

Continued miniaturization of consumer electronics is shrinking component size from 1210 and 1206 in the 1980's down to 0402 and 0201 in the late 1990's. The main driver is the demand for higher performance in smaller packages at the lowest cost. *Figure 1* shows the mobile phone evolution in regards to phone weight, size and cost.

Figure 2 - Component Size Comparison

0201 components are 75% smaller than 0402's in both volume and weight. 0201 components also consume 66% less board area than 0402's. These components can produce significant reductions in size, weight and volume for hand held and portable consumer electronic products. *Figure 2* shows the size comparison of 1206, 0805, 0603, 0402, and 0201 components.

At high frequencies 0201 Capacitor's perform better than 0402 for low Equivalent Series Resistance (ESR) and low impedance. A reduction in the dielectric layer thickness and an increase in the layer count allows the 0201 capacitance ranges to be in line with 0402 devices. The capacitance range of 0201 capacitors cover up to approximately 80% of high frequency modules demands.

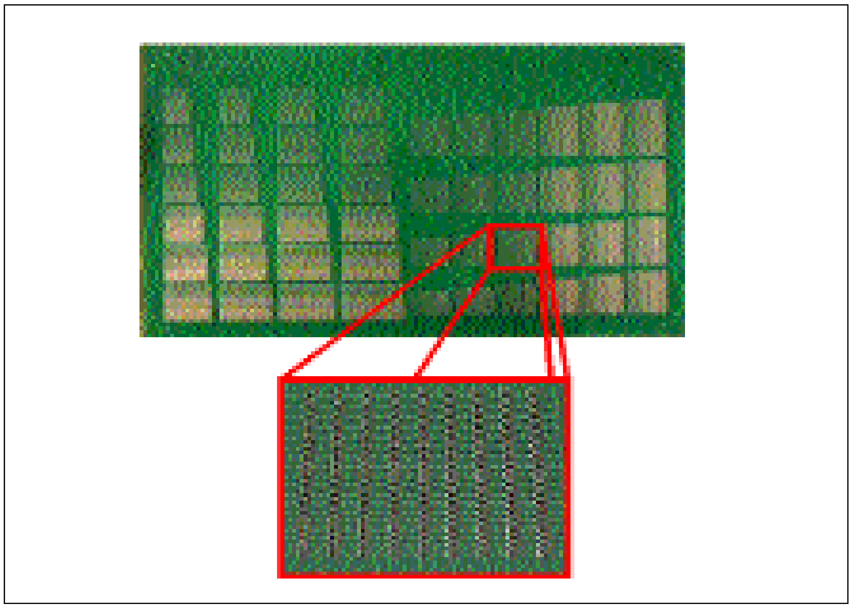

Figure 3 - Photograph of 0201 Test Vehicle

Experiment Materials and Assembly Equipment

A test board with both 0201 and 0402 components was designed for the experiment. *Figure 3* is a photograph of the 0201 test vehicle.

The printed circuit board was a single sided panel that measured 7.5" wide by 12.5" long. The board thickness was a standard 0.062". Attachment pad metallurgy was bare Copper covered by Entek Plus (OSP). Half ounce Copper was used for all traces and attachment pads. Taiyo PRS4000 solder mask was used. Three different attachment pad widths, lengths, and spacing between pads were tested for both the 0201 and 0402 components in a full factorial design, giving a total of 27 different attachment pad designs for both the 0201 and 0402 components. Each pad design was replicated 120 times within a single row. Each row was designated by a three letter code based on the attachment pad dimensions from *Table 1*. Table 1 lists the 0201 attachment pad dimensions for all three 0201 levels.

Table 1 - Attachment Pad Dimension Matrix for 0201 Components

0201 Pads Designs

Pad Width = W	A = 0. 012"	B = 0.015"	C = 0.018"
Pad Length = L	D = 0.008"	E = 0.012"	F = 0.016"
Spacing between pads = S	G = 0.009"	H = 0.012"	I = 0.015"

An example for an 0201 attachment pad design would be ADG (pad width A = 0.012", pad length D = 0.008", and pad spacing G = 0.009"). Four different component to component spacings of 0.008", 0.012", 0.016" and 0.020" were tested. Thirty components of a given attachment pad design were blocked together to test component spacing. All attachment pad traces were run out through the ends of the attachment pads, enabling only component spacing testing to be conducted between the component side to side (not end of component to end of component). A fully populated test vehicle contains 12,960 components. *Figure 4* shows the dimensioning legend for the 0201 attachment pads.

The test vehicle was designed at both zero and ninety degree component orientation for all designs. *Figure 5* shows the component orientation relative to the direction of board travel into the reflow oven.

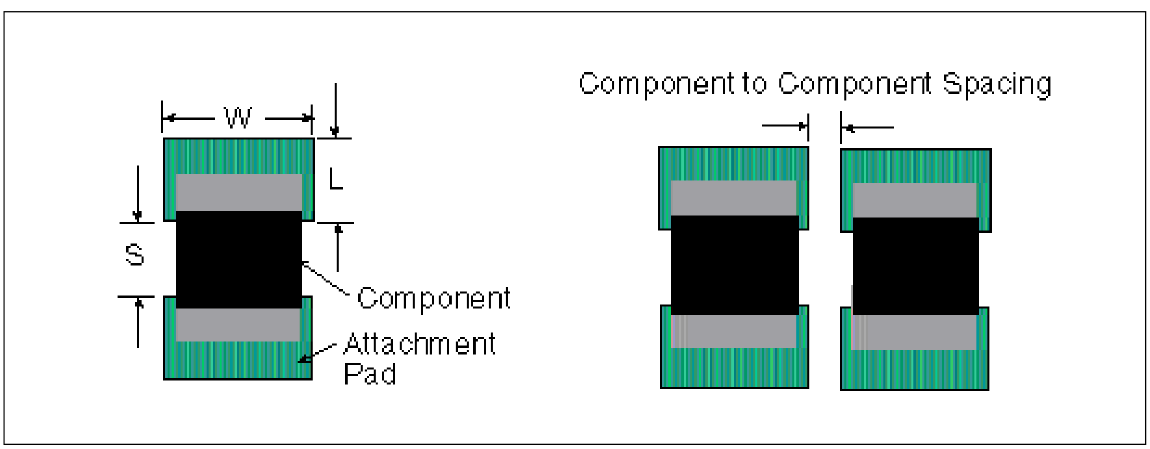

Figure 4 - Attachment Pad Dimensioning

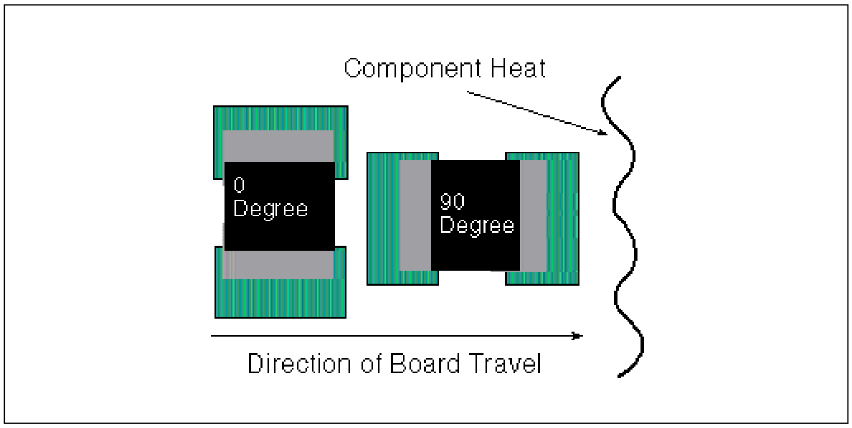

Figure 5 - Component Orientation Relative to Board travel & Reflow Oven

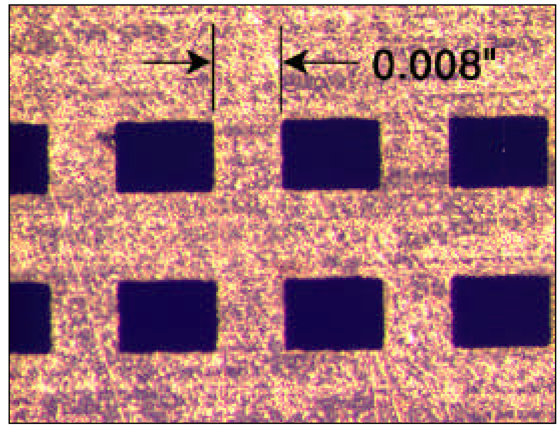

Figure 6 - Photograph of Laser Cut Stencil

All solder paste printing for the experiment was conducted using 0.005" thick stainless steel laser cut stencils. *Figure 6* is a photograph of the stencil apertures used for attachment pad design BEG. The spacing between stencil apertures is approximately 0.008". The stencils were not micro-etched or surface finish plated. A thickness of 0.005" was selected as a compromise between a 0.004" thick and 0.006" thick stencil. The thinner 0.004" stencil would provide better solder paste release for 0201 paste deposits, but would inherently reduce the solder paste volume available for other surface mount devices that are typically found on most applications. A 0.006" thick stencil was not selected because of unacceptable solder paste transfer that would result for 0201 components. The metal mask was "center justified" mounted in a 29" by 29" stencil frame. Two stencils were manufactured for the project. Stencil 1 was designed for the first (filter) experiment. Five different stencil aperture openings were tested for each attachment pad design. Stencil 2 was designed based on the results from stencil 1. Only one stencil aperture size was used for a given attachment pad design for stencil 2. *Table 2* contains the stencil aperture size; distance between solder deposits (stencil apertures) and aperture position for stencil design 2. *Figure 7* shows the three different types of stencil aperture positions that were used relative to the center of the component.

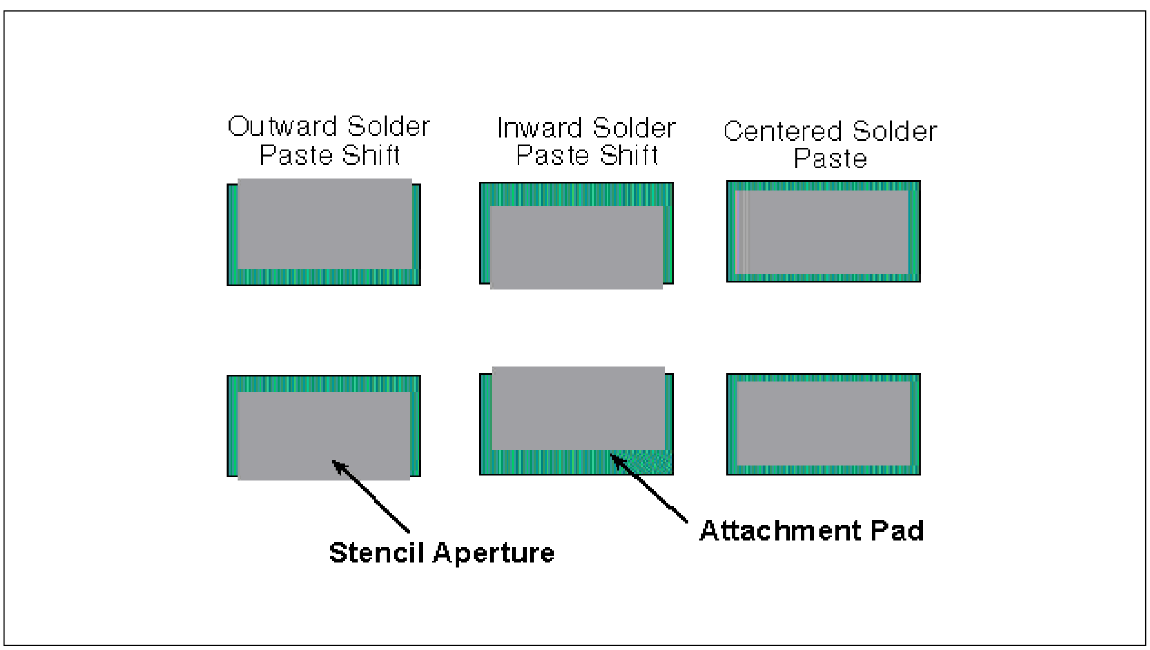

Figure 7 - Stencil Aperture Position Relative to Attachment Pad

Table 2 - 0201 Stencil Aperture Size & Position for Stencil 2

Attachment Pad Design	Stencil Aperture Size	Distance b/w deposits	Stencil Aperture Position
ADG	0.015" x 0.009"	0.010"	0.001" shift outward
ADH	0.015" x 0.009"	0.011"	Centered
AEG	0.015" x 0.011"	0.016"	0.003" shift outward
AEH	0.015" x 0.013"	0.012"	0.0005" shift outward
AFG	0.012" x 0.015"	0.009"	0.0005" shift outward
AFH	0.014" x 0.016"	0.012"	Centered
BDG	0.018" x 0.009"	0.011"	0.0015" shift outward
BDH	0.018" x 0.009"	0.012"	0.0005" shift outward
BEG	0.015" x 0.011"	0.009"	0.0005" shift outward
BEH	0.015" x 0.011"	0.010"	0.0005" shift inward
BFG	0.015" x 0.015"	0.009"	0.0005" shift outward
BFH	0.017" x 0.016"	0.012"	Centered
CDG	0.021" x 0.009"	0.011"	0.0015" shift outward
CDH	0.021" x 0.009"	0.012"	0.0005" shift outward
CEG	0.018" x 0.011"	0.009"	0.0005" shift outward
CEH	0.018" x 0.011"	0.010"	0.0005" shift inward
CFG	0.018" x 0.015"	0.009"	0.0005" shift outward
CFH	0.020" x 0.016"	0.012"	Centered

Both no-clean and water-soluble solder paste formulations were used during the project. Both solder paste types were 90% solids containing Type IV powder size. One no-clean and one water-soluble solder paste were selected to provide for the two most common flux chemistry types. Two different solder paste vendors supplied the two solder paste types. The viscosity of the two pastes was approximately 900 KCPS. *Figure 8* shows a photograph of printed solder paste on attachment design BEG. The photograph shows the aspect ratio of solder paste deposit height relative to the solder paste deposit area.

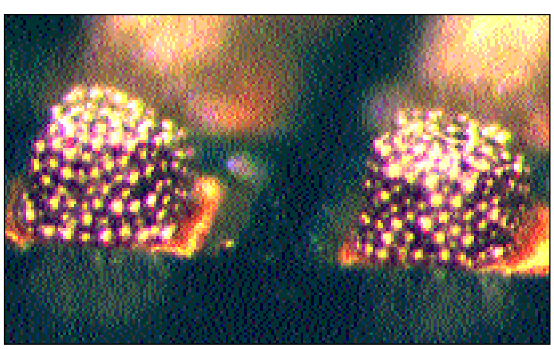

Figure 8 - Printed Solder Paste on Attachment Pad BEG

A DEK 265 GSX screen printer was used for all solder paste printing. The following screen printer process parameters were used for all stencil printing:

a) Print speed = 1.0 inch\sec.
b) Squeegee type = metal blades (Transition Automation)
c) Squeegee angle = 60 degree
d) Squeegee pressure = 2.3 pounds\inch of squeegee
e) Print gap = 0 (on contact)
f) Separation speed = 0.02 inch\sec.

Figure 9 shows a photograph of printed solder paste on attachment pad design BEG at a component to component spacing of 0.008". The dimensions of the attachment pads are also given.

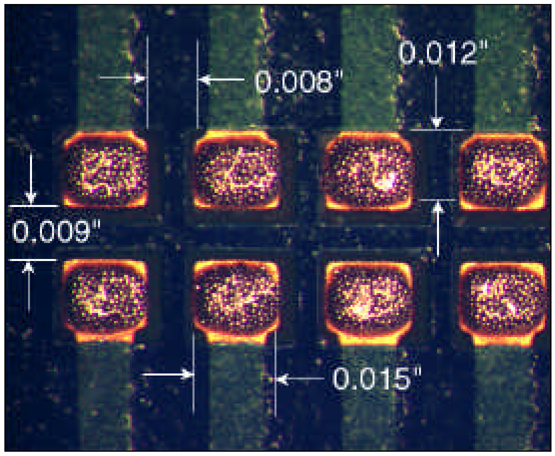

Figure 9 - Printed Solder Paste on Attachment Pad BEG

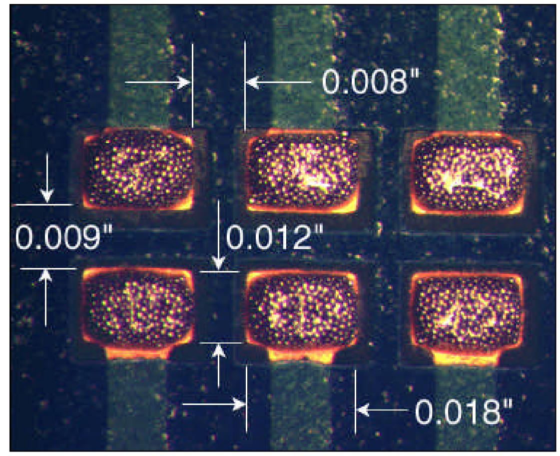

Figure 10 - Printed Solder Paste on Attachment Pad CEG

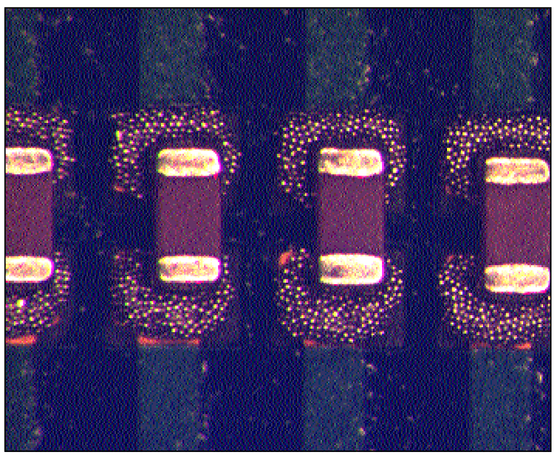

Figure 11 - 0201 Components Placed on Wet Solder Paste on Attachment Pad Design BEG

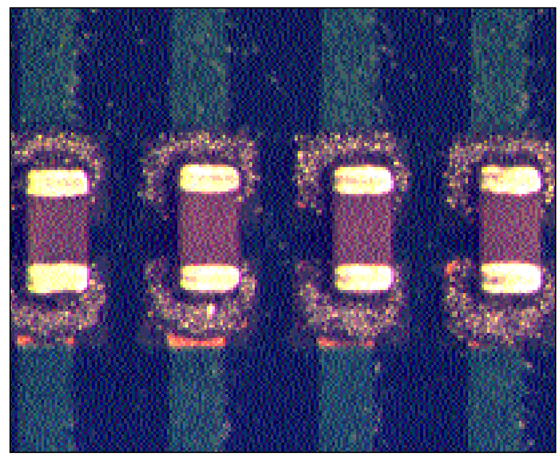

Figure 12 - 0201 Components Placed on Wet Solder Paste on Attachment Pad Design CEG

Figure 10 shows a photograph of printed solder paste on attachment pad design CEG at a component to component spacing of 0.008". The dimensions of the attachment pads are also given.

All component placement for this project was performed on a Universal 4796R HSP. Automatic component pick up correction in both the X-axis and Y-axis was used at all times. The automatic component pick up correction improves component pick up reliability. The fully controlled Z-axis (height) at component pick up and placement was utilized to increase pick reliability and to ensure that excessive or inadequate component placement pressure was not used during the experiments. All components were fed from tape and reel. Two local fiducials were used for board alignment. *Figure 11* shows a photograph of 0201 components placed on wet solder paste on attachment pad design BEG. *Figure 12* shows a photograph of 0201 components placed on wet solder paste on attachment pad design CEG. Both photographs show minimal displacement of solder paste caused by the placement of the components.

All solder paste reflow was performed in a Heller 1800W forced convection oven. The reflow system contained 8 heating and 1 cooling zone. Two reflow atmospheres were utilized in the experiment, air and nitrogen where the measured oxygen levels in the reflow zone of the oven were 50ppm or less. *Figure 13* is the thermal profile that was used to reflow all boards assembled during the project.

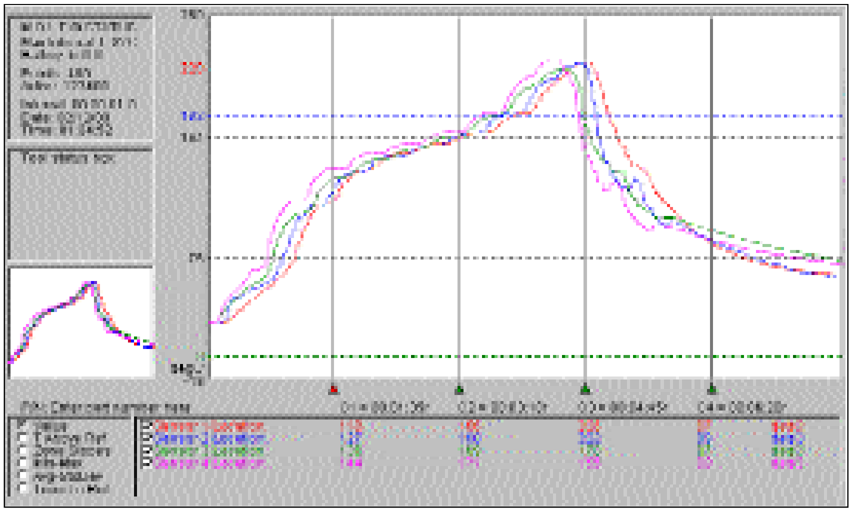

Figure 13 - Thermal Reflow Profile

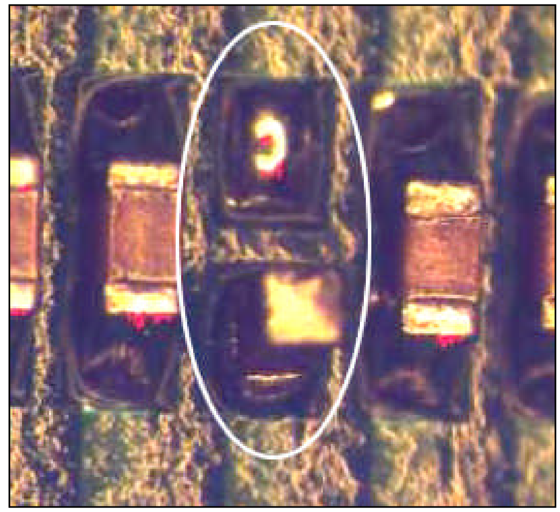

Figure 14 - Photograph of Tombstone

Definitions of Failures

Five types of assembly defects were observed on the test vehicle during the experiments. These failures are defined and discussed in the following section.

Tombstones (open solder joints) are a severe form of component misalignment where the components stand on their ends [1][Prasad, R., 1997]. A number of different influences can cause tombstones. One of the most common reasons for tombstoning is uneven heating between the two ends of the component. One side of the component achieves liquidus before the other and the resulting surface tension of the molten solder pulls the component upright. Flux wetting speed or the amount of time it takes the solder to wet is also a major variable to the formation of tombstones. Component terminations and/or attachment pads that show poor solderability will increase the probability of tombstones. Thermal profiles that heat too fast or do not provide adequate flux activation time will also increase the probability of tombstones. An example of a tombstone is shown in *Figure 14*, with the defective component having been pulled upright at the lower attachment pad.

Solder bridging is the undesirable formation of a conductive path of solder between conductors [1][Prasad, R., 1997]. Bridging is characterized by a mass of solder connecting two consecutive components as shown in *Figure 15*. As displayed, the components are drawn toward each other. This pulling together of the components was caused by the surface tension exerted by the molten solder between the components during reflow. Solder bridging that occurs during solder paste mass reflow processes is generally caused by poor solder paste deposition. Wet solder deposits or flux binder that is touching between components before reflow has a high probability of solder bridging. Solder paste displacement from the placement of the component, poor solderability of the component termination and/or attachment pad, improper thermal profiles and solder paste related problems can all cause solder bridging. Poor attachment pad design and large solder volumes will also increase the probability of solder bridging.

Solder balls (beads) are small spheres of solder that adhere to laminate, mask or conductors. Solder balls (beads) that are predominately generated by the displacement of solder paste from the placement of the component should not be confused with solder balls (satellites) that are generally caused by solderability issues with

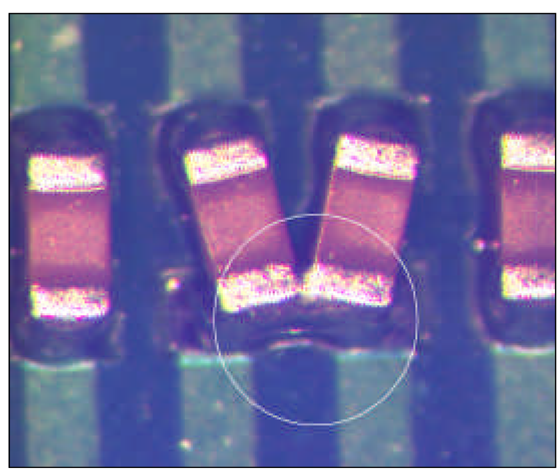

Figure 15 - Photograph of Solder Bridging

the solder paste, components, boards, environment and\or thermal profile. Displacement of solder paste off of solderable surfaces was the primary cause of the solder balls produced in this study. Stencil thickness and stencil opening design coupled with a proper attachment pad design will eliminate all or most solder balls (beads). *Figure 16* shows solder balling observed on the test vehicle.

Insufficient solder volume is defined for this study as any solder fillet that extends less than fifty percent up the face of the component termination. Low solder paste volume deposition or inconsistent deposition from the stencil printing process is generally the primary cause of insufficient solder volume. Stencil thickness, stencil aperture design, stencil manufacturing process, print process parameters, solder paste powder size and solder paste viscosity are the main attributes that influence the stencil printing deposition process. *Figure 17* shows a cross section of a component with insufficient solder volume.

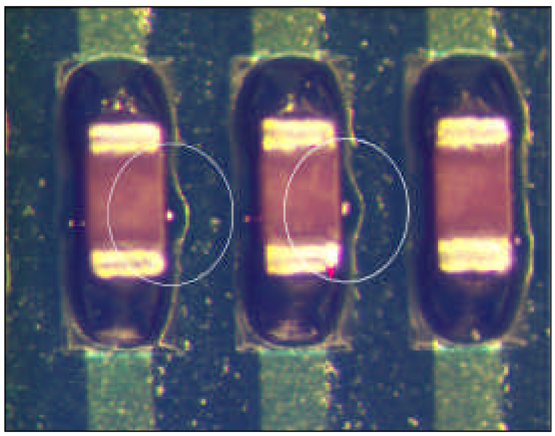

Figure 16 - Photograph of Solder Balls

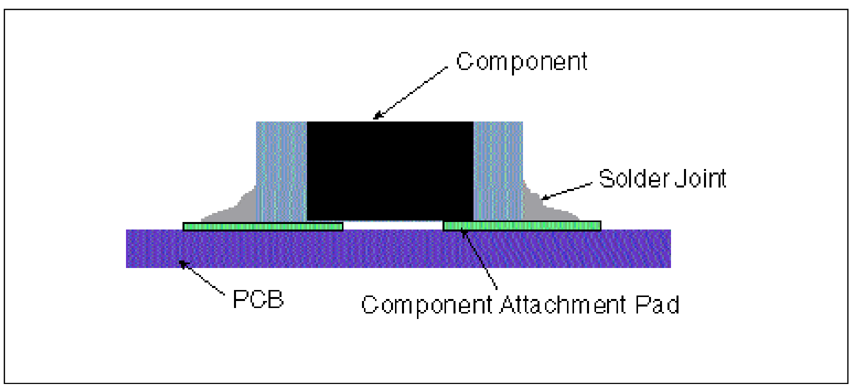

Figure 17 - Insufficient Solder Volume

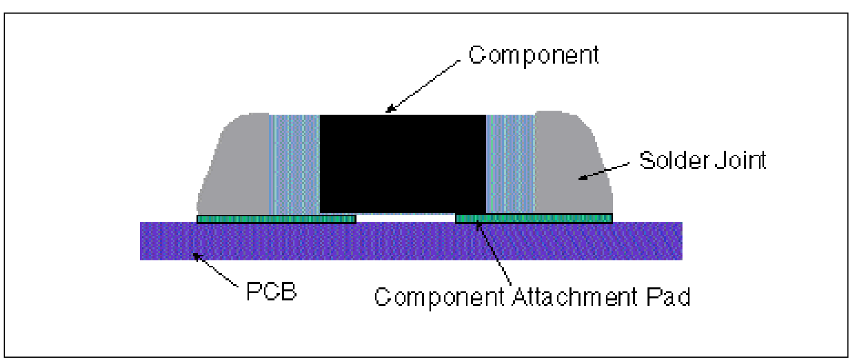

Figure 18 - Excessive Solder Volume

Excessive solder volume is defined for this study as any solder fillet that produced a convex shaped solder fillet. High solder paste volume deposition or inconsistent deposition from the stencil printing process is generally the primary cause of excessive solder volume. Stencil thickness, stencil aperture design, stencil manufacturing process, print process parameters, solder paste powder size and solder paste viscosity are the main attributes that influence the stenciling deposition process. *Figure 18* shows a cross section of a component with excessive solder volume.

Inspection Methodology

The inspection of the test vehicles was done manually using a Coordinate Measuring Machine (CMM). The optical, microscopic probe of the CMM was used to visually inspect each row on the test vehicle. The CMM was the equipment of choice, as it provided the ability to scan each row with ease while simultaneously providing adequate magnification for individual components to be inspected. Each row in both the 0-degree and 90-degree orientations was inspected for failures. If a failure was detected in a given row, then the failure mode and failure count was recorded.

Results

The project was conducted by performing two experiments. The first experiment, which was a filter experiment, was based on running four different processes. The four processes were no-clean and water-soluble solder pastes run in both air and Nitrogen reflow environments. Six fully populated boards were assembled for each of the four processes for a total of 311,040 components. Five different stencil aperture sizes/aperture positions were tested for each attachment pad size.

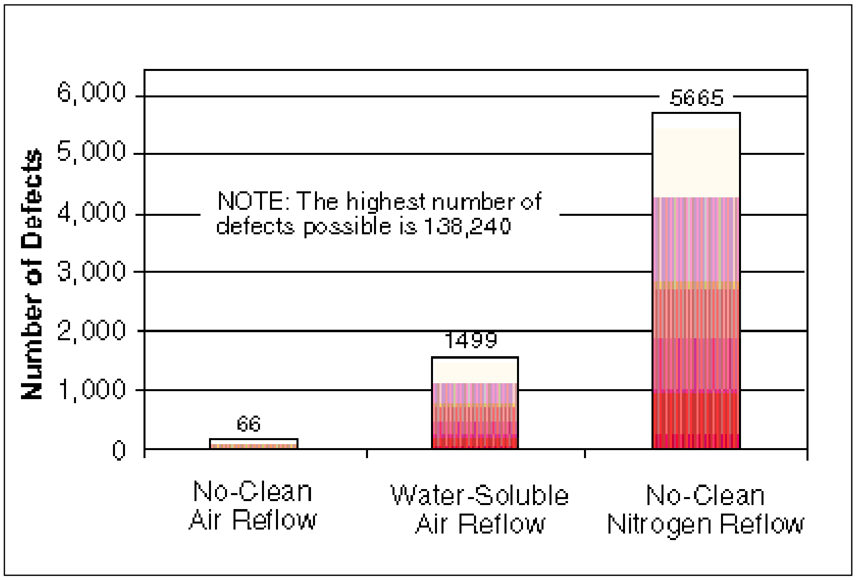

Figure 19 - 0201 Assembly Yield Per Assembly Process Type

The second and last experiment was based on running only three of the four processes. The water-soluble solder paste reflowed in Nitrogen was dropped. The combination of water-soluble flux chemistry and Nitrogen environment reflow is typically not used. Only one stencil aperture design was run per attachment pad design for experiment 2. *Table 2* contains the stencil aperture designs used. The stencil aperture design was selected based on assembly yield and assembly quality from experiment 1. All of the largest spacing between attachment pads (I = 0.015") were dropped from this experiment. This reduced the total number of attachment pads from 27 down to 18 different designs. Data from experiment 1 showed that the widest spacing (I = 0.015") produced more open solder joints than attachment pads with smaller spacing. A total of fifty boards were assembled for each of the three processes for a total of 1,116,000 components.

Figure 19 shows the assembly yield from the three different assembly processes. The no-clean solder paste reflowed in air produced the fewest assembly defects for a total of 66. The water-soluble solder paste reflowed in air produced the next lowest number of defects at 1,499. The no-clean solder paste process reflowed in Nitrogen produced the greatest number of assembly defects at 5,665. *Figure 19* shows that assembly defects increase when Nitrogen atmosphere reflow is used and when solder paste flux activity is increased (water-soluble solder paste).

Figure 20 shows the assembly failure mode distribution for each of the three different assembly processes. Tombstones (open solder joints) and solder bridging were the two main assembly defects. *Figure 20* shows that the water-soluble solder paste process reflowed in air produced the lowest percentage of solder bridges at 7.0%, followed by the no-clean solder paste process reflowed in Nitrogen at 15.0%. The no-clean solder paste process reflowed in air produced the largest percentage of solder bridges at 21.0%.

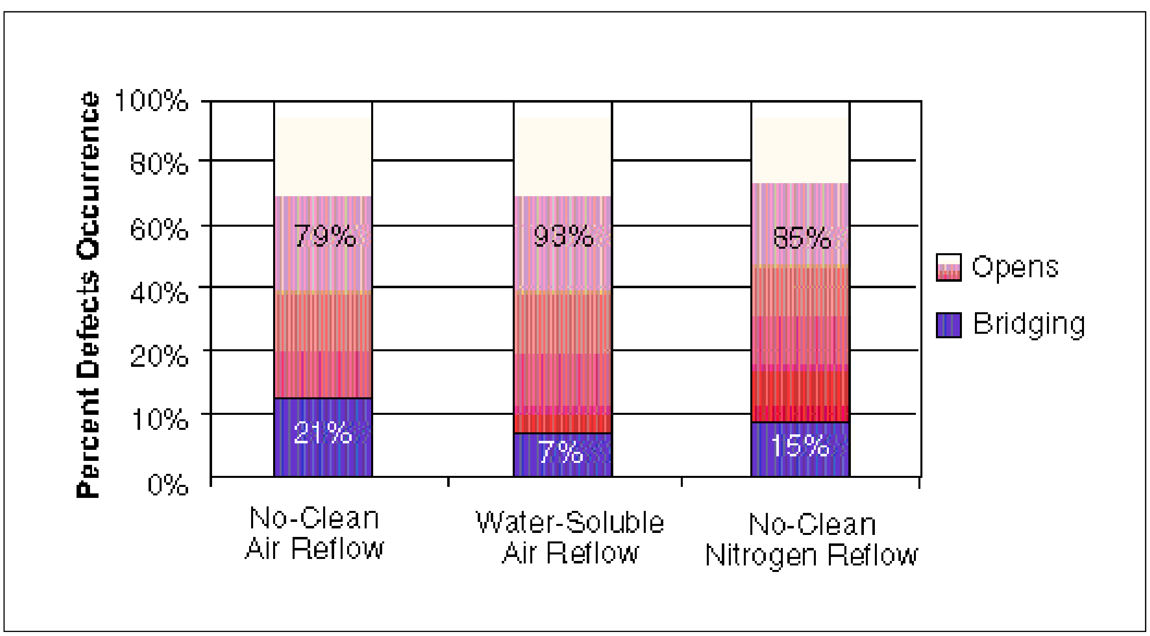

Figure 20 - Assembly Failure Mode Distribution by Assembly Process

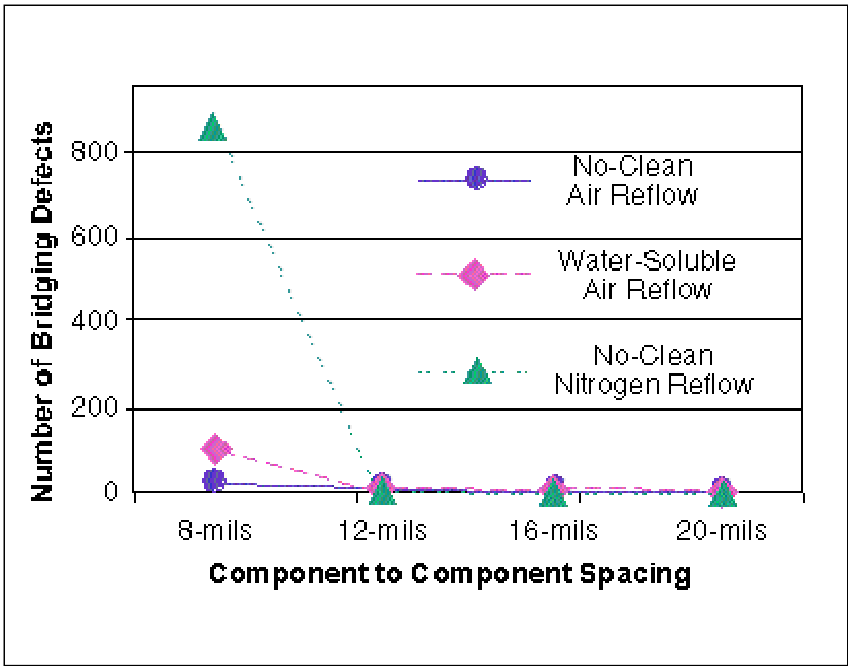

Figure 21 - Solder Bridging Defects by Component To Component Spacing and Assembly Process Type

Figure 21 shows the relationship between solder bridging and component to component spacing for the three different assembly processes. *Figure 21* shows that no solder bridging is recorded for any of the assembly processes at a spacing of 0.012" or larger. *Figure 21* also shows that the no-clean solder paste process reflowed in air produced the fewest solder bridges for a total of 14. The water-soluble solder paste process reflowed in air produced the next largest number of solder bridges at 99. The no-clean solder paste process reflowed in Nitrogen produced the greatest number of solder bridges at 866. Twelve attachment pad designs out of 18 did not produce any solder bridges at the smallest spacing of 0.008" for the no-clean solder paste process reflowed in air. Ten attachment pad designs out of 18 did not produce any solder bridges at the smallest spacing of 0.008" for the water-soluble solder paste process reflowed in air. Six attachment pad designs out of 18 did not produce any solder bridges at the smallest spacing of 0.008" for the no-clean solder paste process reflowed in Nitrogen.

Attachment pad design AEG (L = 0.012', W = 0.012", S = 0.009"), which contained the largest distance between solder paste deposits of 0.016", produced the fewest solder beads. Solder beads are reduced when the distance between solder paste deposits is increased. The amount of solder paste displacement by the component during placement is reduced when the distance between solder paste deposits under the component is increased.

An analysis of paired samples was used to determine if component orientation (0 degree & 90 degree) significantly influenced assembly yield. Zero degree orientation is represented by both component terminations going through the oven at the same time (parallel to the source of heat). Ninety-degree orientation is represented by one component termination going through the oven ahead of the second termination. The hypotheses tested were:

Null hypothesis: Z = 0: There is no statistically significant difference in the number of assembly defects between the 0 degree and the 90 degree orientations.

Alternate hypothesis: Z ≠ 0: There is a statistically significant difference in the number of assembly defects between the 0 degree and the 90 degree orientations.

The 't' test used: [2] t = (✓n x u)/s

The p-value for the no-clean solder paste process reflowed in air was 0.5765. Given the high value of p, we fail to reject the null hypothesis. Hence the no-clean solder paste process reflowed in air showed no significant difference in assembly yield when considering component orientation. The lower flux activity of the no-clean solder paste when reflowed in air does not increase the risk of tombstones (open solder joints).

The p-value for the water-soluble solder paste process reflowed in air was 0.001959. Given the low value of p, the null hypothesis was rejected. The increased flux activity in the water-soluble solder paste when compared to the no-clean solder paste produced a significant increase in tombstones (open solder joints) for the components that were oriented at ninety-degrees.

The p-value for the no-clean solder paste process that was reflowed in Nitrogen was 0.000002. Given the very low value of p, the null hypothesis was again rejected. The use of Nitrogen increased the number of tombstones in the ninety-degree orientation. The vast majority of open solder joints were on the component

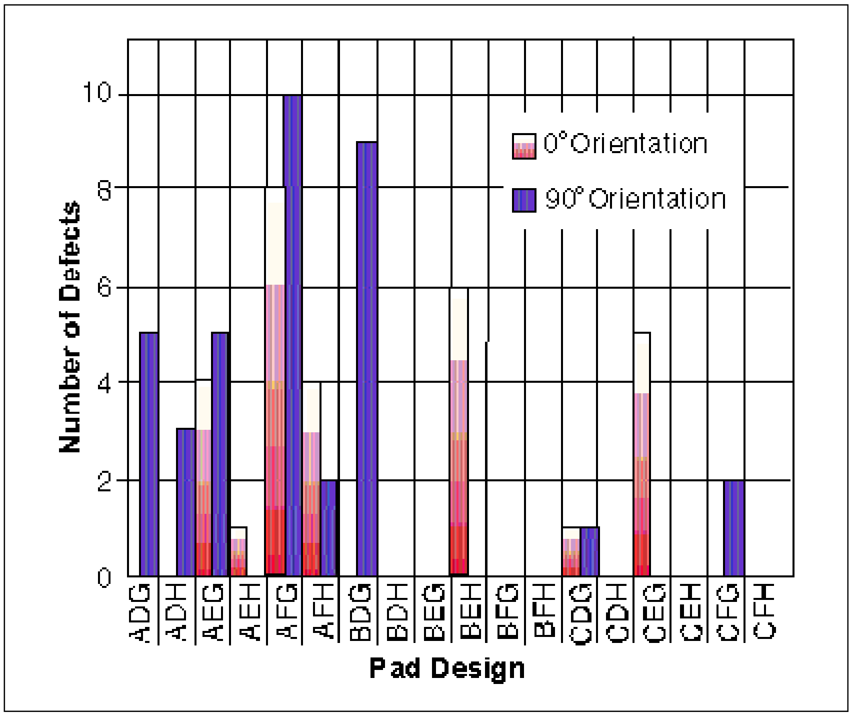

Figure 22 - Assembly Defects by Attachment Pad Design For the No-Clean Solder Paste Process Reflowed in Air

termination that was reflowed second (trailing termination). The use of Nitrogen increased the wetting speed of the molten solder and thus produced open solder joints at a significantly higher rate for components orientated at ninety-degrees versus zero degrees.

Figure 22 shows the assembly defects by attachment pad design for the no-clean solder paste process reflowed in air. Seven attachment pad designs (BDH, BEG, BFG, BFH, CDH, CEH & CFH) out of the 18 did not produce any assembly defects. Based on degree of difficulty for solder paste printing, solder joint shape quality, and attachment pad size, designs BEG and CEH are preferred. The smallest attachment pad designs require a smaller stencil aperture design that will tend to clog faster than a larger stencil aperture. Stencils designed at 0.004" in thickness will reduce 0201 stencil clogging, but other surface mount devices that require more solder may result in marginal or insufficient solder volume. Solder joint fillet shape on the smallest attachment pad designs did not produce the desired concave solder fillet shape. The largest attachment pad designs are good for solder paste release from the stencil aperture and also produce acceptable solder joint fillet shapes, but the larger attachment pad designs require more printed circuit board space.

Figure 23 shows the assembly defects by attachment pad design for the water-soluble solder paste process reflowed in air. The water-soluble solder paste process reflowed in air produced defects on all attachment pad combinations when considering both component orientations. Attachment pad CEG produced the fewest

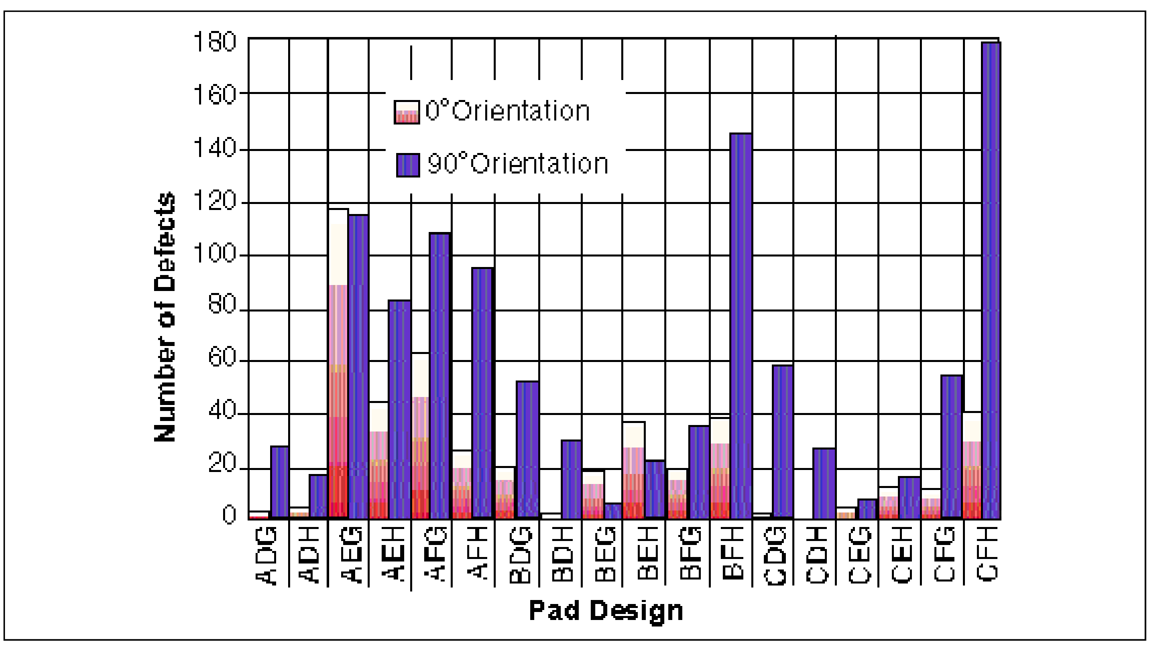

Figure 23 - Assembly Defects by Attachment Pad Design For the Water-Soluble Solder Paste Process Reflowed in Air

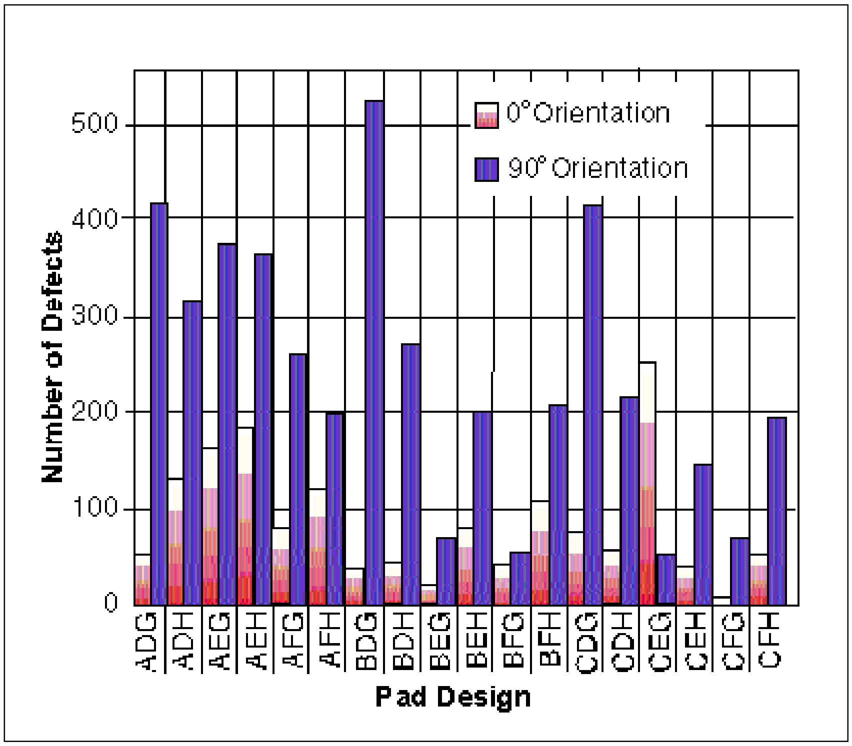

Figure 24 - Assembly Defects by Attachment Pad Design For the No-Clean Solder Paste Process Reflowed in Nitrogen

assembly defects. Attachment pad design CDH did not produce any defects in the zero degree orientation but did produce a relative high number of assembly defects in the ninety-degree orientation. Attachment pad design CEG produced good solder joint shapes and does not occupy as much printed circuit board space as the larger attachment pad designs. Solder paste clogging in the stencil aperture does not represent a problem for the CEG attachment pad design.

Figure 24 shows the assembly defects by attachment pad design for the no-clean solder paste process reflowed in Nitrogen. The no-clean solder paste process reflowed in Nitrogen produced defects on all attachment pad combinations when considering both component orientations. Attachment pad CEG produced the fewest assembly defects. Attachment pad design CEG also exhibits good solder joint shape and does not occupy as much printed circuit board space as the larger attachment pad designs. Solder paste clogging in the stencil aperture does not represent a problem for the CEG attachment pad design.

Figure 25 shows the number of solder joint defects tracked by attachment pad width and assembly process type. This data was generated based on the optimal attachment pad designs with respect to each assembly process type, holding the corresponding attachment pad length and attachment pad spacing parameters constant, and varying the attachment pad width across all experimental levels. Generally for the three assembly process types, the tendency is for yield to improve as the attachment pad width

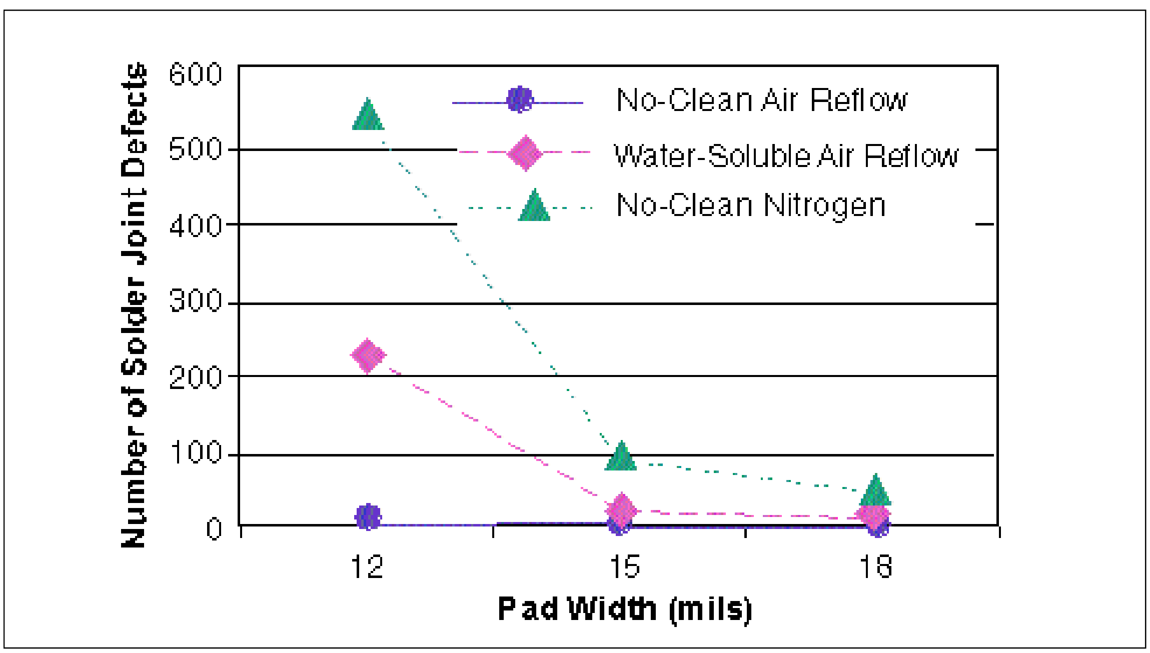

Figure 25 - Assembly Defects by Attachment Pad Width and Assembly Process Type

increases. Similarly, among all assembly process types the defect levels are more sensitive to attachment pad widths between 0.012" and 0.015". For both the water-soluble process reflowed in air and the no-clean process reflowed in Nitrogen, the minimum number of solder joint defects are achieved at the highest level 0.018" attachment pad width. This trend changes slightly for the no-clean process reflowed in air, where the best yield is actually produced at the intermediate level (0.015") attachment pad width. However, due to the limited number of defects found across the boards built by this assembly process type, the difference in the defect levels between attachment pad widths of 0.015" and 0.018" is found not to be statistically significant. Upon identifying the trends according to assembly process type, the yield produced by the no-clean process reflowed in air is least sensitive to attachment pad width, while the no-clean process reflowed in Nitrogen is the assembly process type where yield is most sensitive to attachment pad width variation.

Figure 26 displays the number of solder joint defects that occur as a function of attachment pad length and assembly process type. Similar to the previous graph, this data was generated based on the optimal attachment pad designs with respect to each assembly process type, holding the corresponding attachment pad width and attachment pad spacing parameters constant, and varying the attachment pad length across all experimental levels. The plotted results suggest that the optimal attachment pad length is the intermediate level of 0.012" for all three assembly process types. Generally, the largest impact on yield is shown to occur between the low and intermediate attachment pad length levels of 0.008" and 0.012". The no-clean process reflowed in Nitrogen is clearly the most sensitive process for affecting the number of defects, with a much more substantial dependence on attachment pad length than any other assembly process type. No defects were observed on any of the boards assembled with a no-clean process and air reflow for both the intermediate and high level attachment pad lengths of 0.012" and 0.016".

Figure 27 shows the relationship between solder joint defects, attachment pad spacing, and assembly process type. This data was also generated based on the optimal attachment pad designs with respect to each assembly process type, holding the corresponding attachment pad width and attachment pad length parameters constant, and varying the attachment pad spacing across both experimental levels. The three assembly process types all give similar defect trends, with more solder joint failures occurring at the larger 0.012" attachment pad spacing. The

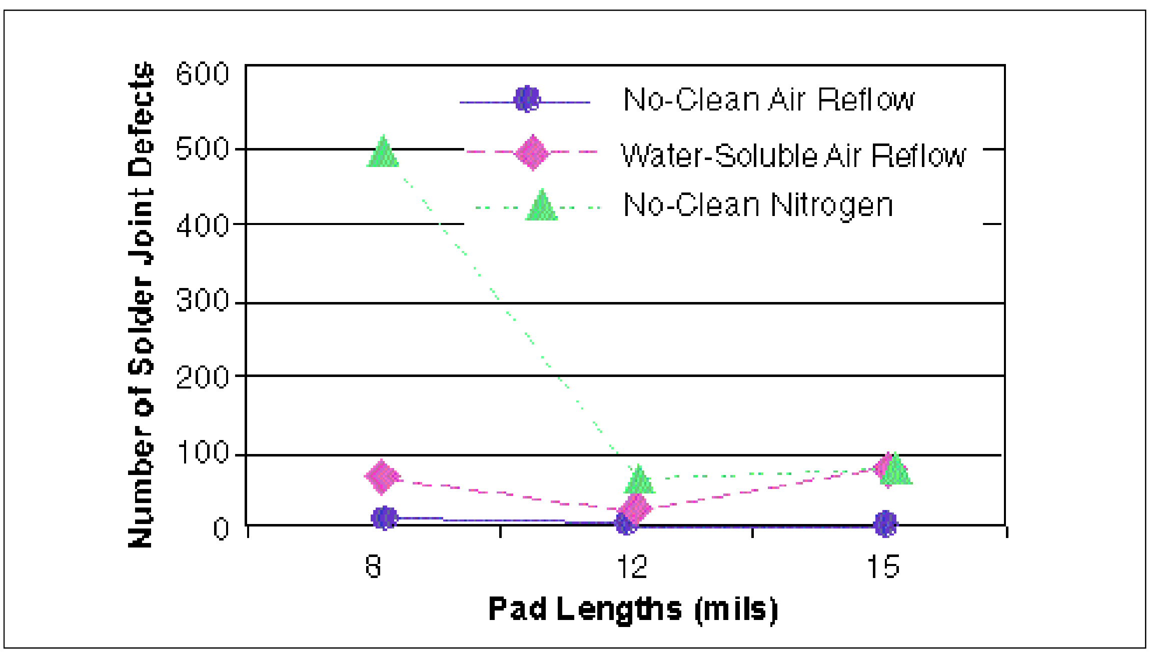

Figure 26 - Assembly Defects by Attachment Pad Length and Assembly Process Type

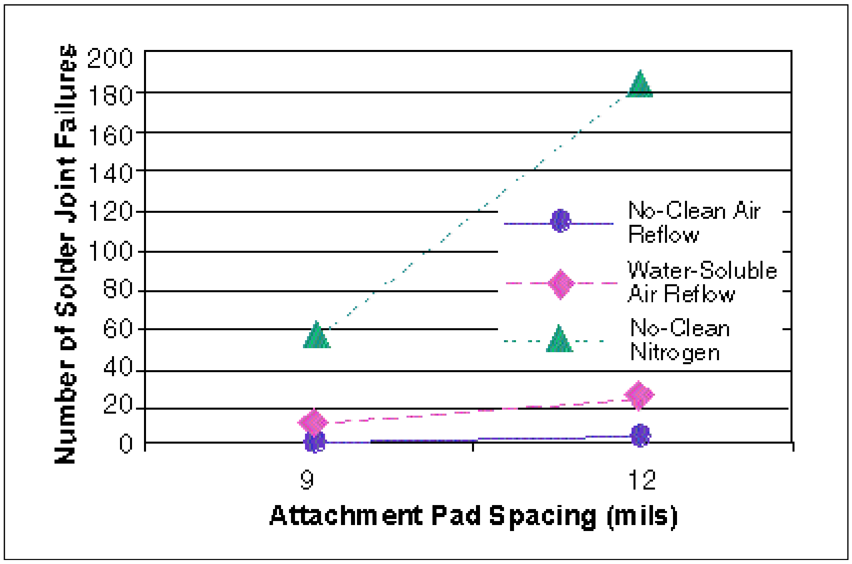

Figure 27 - Assembly Defects by Attachment Pad Spacing and Assembly Process Type

combination of no-clean process and Nitrogen reflow environment is the assembly process type that is most likely to impact yield with changes in the attachment pad spacing. The no-clean process reflowed in air is the assembly process most resistant to generating failures that can be attributed to changes in attachment pad spacing.

Conclusions

Of the three assembly processes tested, the no-clean solder paste process reflowed in air produced the fewest number of assembly defects for both tombstones (open solder joints) and solder bridges. The no-clean solder paste process reflowed in air also produced the most attachment pad designs that were free from assembly defects. Furthermore, this assembly process type was found to be the least sensitive (of the three considered in this study) in influencing the number of solder joint defects across a variety of pad designs. The water-soluble solder paste process reflowed in air produced the next fewest number of assembly defects followed by the no-clean solder paste process that was reflowed in Nitrogen. The use of low oxygen levels (under 50ppm) and more active solder paste flux chemistry decreases assembly yield and assembly robustness. Longer thermal reflow profiles may reduce the number of assembly defects for the water-soluble solder paste reflowed in air and for the no-clean solder paste process reflowed in Nitrogen. Higher oxygen content during reflow for the Nitrogen reflow process would most likely also reduce assembly defects. The use of Nitrogen generally increases solder wetting forces and reduces wetting times.

Component side to side spacing of 0.008" was achievable for all three processes without producing solder bridges. The use of Nitrogen during reflow and water-soluble solder paste increases the number of solder bridges. Small attachment pad sizes also tend to solder bridge more readily than larger attachment pad sizes. Combinations of either the smallest attachment pad width or smallest attachment pad length increase the probability of solder bridging. Research is currently under way to test component to component spacing under 0.008" to determine the absolute minimum spacing between components for a given assembly process.

Solder beads can be reduced or eliminated by reducing the amount of solder paste that is printed under the component terminations. It should be noted that the number of tombstones (open solder joints) increases as the distance between solder paste deposits increases. When designing the stencil, the distance between stencil apertures should be held to a maximum of 0.010" to 0.012". “Home plate” or “v-notch” stencil designs were not tested because of the small attachment pad sizes for 0201 components (too small of attachment pad distances to provide a V-notch or “home-plate” design).

Component orientation was determined to be insignificant for the no-clean solder paste process that is reflowed in air. Component orientation was statistically significant for the water-soluble solder paste process reflowed in air as well as for the no-clean solder paste process reflowed in Nitrogen. Increased flux activity of water-soluble solder pastes, compared to the no-clean solder paste and/or reduced oxygen content during reflow, increases the wetting force and\or wetting speed of molten solder. Components oriented at ninety degrees (one termination reaching the reflow zone before the other) are more likely to tombstone when higher wetting forces and reduced wetting times are experienced.

Seven attachment pad designs out of the 18 tested for the no-clean solder paste process reflowed in air produced no assembly defects. Attachment pad design BEG was selected as the top choice based on attachment pad size, solder joint quality, and ease of solder paste printing. The BEG design also uses the smallest distance between attachment pads. The wider distance between attachment pads for design CEH was the reason this design ranked second. The preferred attachment pad designs from the other two processes also contained the smaller distance between attachment pads of 0.009". The no-clean solder paste process reflowed in air is a more robust process when compared to the other two processes. Fewer numbers of acceptable pad designs are available for the other two processes. Attachment pad design CEG produced the best assembly yield for both the water-soluble solder paste process reflowed in air and the no-clean solder paste process reflowed in Nitrogen. The only difference in the design of BEG and CEG is the pad width difference of 0.003". Increasing attachment pad width and decreasing the distance between attachment pads reduces the amount of component placement accuracy needed and increases the robustness of the placement process. Attachment pad design BEG ranked third for assembly yield for both the water-soluble solder paste process reflowed in air and the no-clean solder paste process reflowed in Nitrogen. Unacceptable assembly yield results were produced from the no-clean solder paste process reflowed in Nitrogen for all attachment pad designs. Unacceptable assembly yield results were also produced from the water-soluble solder paste process reflowed in air for all attachment pad designs when both component orientations are considered.

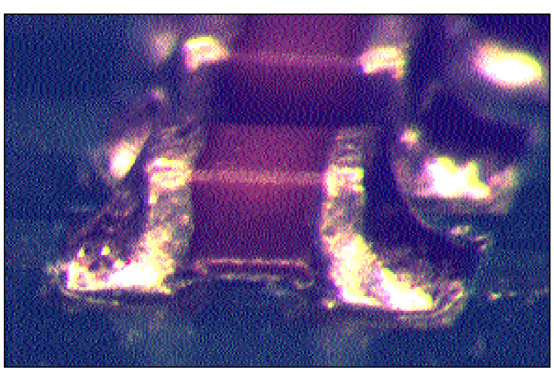

Figure 28 - Soldering Results from 0201 Assembly Process on Attachment Pad Design BEG

Figure 28 shows a photograph of an 0201 assembled on attachment pad design BEG. The photograph shows the soldering results from the optimized assembly process.

Figure 29 shows the recommended attachment pad design for solder paste mass reflow of 0201 components. The current recommendation is a attachment pad spacing of 0.009", a attachment pad length of 0.012" and a attachment pad width of 0.015" to 0.018" dependent upon flux type and solder paste reflow atmosphere. The 0.018" wide attachment pad should be used when Nitrogen atmosphere reflow is performed with low oxygen content (under 50 ppm). The 0.018" wide attachment pad should also be used when using solder paste flux binders that are very active and/or have fast wetting times. The narrower 0.015" wide attachment pad should be used for air reflow and when solder paste flux activity and wetting times are lower.

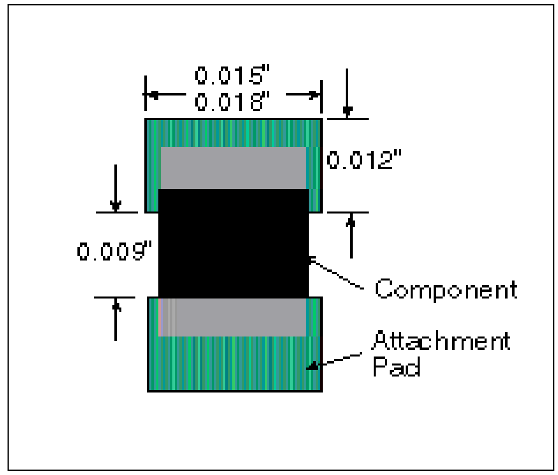

Figure 29 - Recommended Attachment Pad Design for Mass Reflow of 0201 Components

Figure 30 shows the cross section of an 0201 capacitor mounted on attachment pad design BEG. The photograph from the optimized assembly process shows proper solder volume and solder wetting angles. The solder fillets wet 90 to 100 percent up the face of the component terminations. The photograph also shows that the solder mask between the attachment pads is holding the component off of the attachment pads. The solder mask was measured at approximately 0.0015" to 0.0017" thick. The solder mask is approximately 0.001" taller than the attachment pads. Further research is currently underway to test printed circuit boards with

Figure 30 - Cross Section of 0201 Capacitor Mounted on Attachment Pad Design BEG

no solder mask under the component as well as a thinner (0.0007" to 0.001") solder mask thickness which is more typical. The significance if any of the solder mask lifting the component off of the attachment pads will then be determined.

Research is also currently under way to further investigate assembly placement accuracy, solder paste flux chemistry, smaller (under 0.008") component to component spacing and reflow parameter optimization.

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