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SOLDER CHARGE SMT: THE DESIGN AND VALIDATION OF NEW SOLDER ATTACH TECHNOLOGIES

Jim Hines, Kirk Peloza, and Adam Stanczak
Molex
Lisle, IL, USA

David Geiger
Flextronics International
San Jose, CA, USA

ABSTRACT
Surface mount technology (SMT) has been in existence for decades and is continually becoming more important because as printed circuit board (PCB) assemblies become more advanced and dense with componentry the real estate savings afforded with SMT become more valuable and necessary. It allows for improved electrical performance when compared to through-hole vias and offers a conventional reflow process versus the traditional wave solder techniques. While the reliability data behind certain common surface mount technologies is in abundant supply and an operator's comfort level in processing such components is high today, introducing a new SMT concept requires many levels of support before design engineers, process engineers, product technicians and processing operators gain a high level of acceptance of the new design. When choosing components for a PCB layout and selecting a preferable solder attach method, board designers must consider processing capabilities such as reflow oven limitations, operator handling or placement, solder joint formation, effectiveness of inspection methods like x-ray or in-circuit-test (ICT) as well as reliability concerns such as product life, circuit board retention and harsh environment resistance. Solder Charge SMT technology is a new PCB solder attach method introduced for the high density interconnect market to improve on shortfalls in some of the surface mount designs that exist today. The new technology required many steps of development before being introduced to the electronics industry. This paper outlines the process of introducing a new SMT technology with a focus on three primary areas: the grass roots design and research involved in the development of a new solder attach technology, the proof of concept studies and partnership with experienced contract manufacturers and processing experts to validate the technology works and the reliability testing involved to analyze and predict the performance through harsh environments or industry standard specifications.

Key words: Solder Charge Technology, SMT Processing, Reliability

BACKGROUND
SMT processing has been used for electronic designs for decades and certain PCB adhesion technologies continue to be refined as the processing methods mature. Thus, the introduction of a new surface mount solder attachment technology utilizing common reflow soldering equipment and processes requires a high level of research in design and focused efforts in the validation of the technology. People from many different groups with varying levels of expertise must work together in an SMT design and validation. Areas such as automated pick and placement, vision recognition, inspection, PCB adhesion, thermal reliability, rework procedures and electrical or mechanical impacts must all be considered when a new SMT design is established.

As can be expected, the first point of contention for a new SMT process is the ease and effectiveness of its implementation into current manufacturing processes. Customers must be comfortable with the compatibility a new SMT solder attachment technology has with other components in the system and contract manufacturers must feel confident that their operators and equipment are able to process the part without added resources required. The reflow requirements have to be sufficiently documented and verified.

A second focus for new SMT designs are the reliability of the reflowed component. Oven reflow profiles and inspection at a contract manufacturer can only confirm reliability so much as PCB retention and effects from environmental variables can have many effects on the performance and robustness of new SMT processes so such tests as IPC-9701 and retention pull forces were performed to confirm the reliability of the new solder joint.

Thirdly, mechanical effectiveness of a new SMT product must be confirmed. A component has to be proven to have a mechanically robust solder joint, show retention to the PCB is sufficient and solder cracking is eliminated so long term product life on a PCB is sound.

Finally, the electrical performance must not be impacted and any electrical drawbacks from a new SMT process are minimized. Particularly when dealing with high-speed signals, a new SMT process should minimize any noise or reflection in a signal transmission. Test boards and electrical simulation software can be used to verify the electrical effectiveness of any new SMT structures in system environments. While the analysis is not documented in this white paper and can completely justify a second white paper in itself, the electrical impact of any new technology must be analyzed, accounted for and optimized when being applied to new components where signal transmission speed and clarity is considered to be important.

COMPONENTS

This new SMT product will be referred to as SMT SC. A picture of a SMT SC soldering feature is shown in Figure 1. This technology is fabricated using only standard metal stamping technology. The soldering element is cut from strip made from Lead free or Tin/Lead soldering alloys.

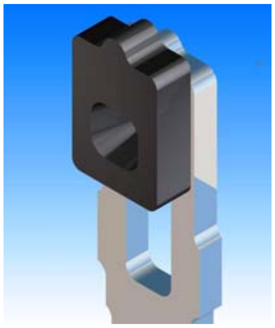

Figure 1: SMT SC prior to reflow

Many processing factors were taken into consideration when designing the new surface mount solder attach technology so SMT SC has specific features to enhance soldering. The solder element itself extends beyond the end of the terminal; so as the solder melts, the solderable device as a whole is lowered towards the PCB engaging solder points that were previously more distant (which helps compensate for coplanarity errors). Also, the malleable tip of the solder element deforms when pushed into the PCB; again compensating for coplanarity errors. Likewise, the protrusion on the end of the terminal can push through solder paste to help compensate for coplanarity errors.

When reflowed, the SMT SC solder engulfs the stamped terminal and adheres to the PCB's solder pad to form a bugle shaped fillet (See figure 2). The exact shape of this fillet is controlled by the size/shape of both the solder pad and the wettable surfaces of the SMT SC terminal. These wettable surfaces of the terminal are defined (i.e. limited) by a laser ablated zone, which stops unwanted wetting, and so keeps the molten solder from "running up the terminal."

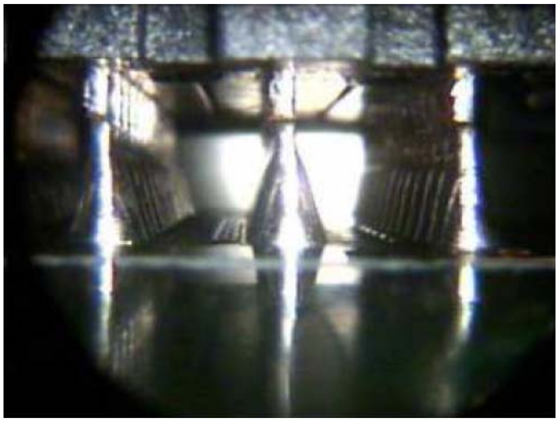

Figure 2: Magnified view of the reflowed SMT SC

Also, the wettable surfaces of the SMT SC terminal and the PCB's solder pad may be configured to produce a convex fillet that is sufficiently buoyant to "self-center" the solderable device during reflow. In addition, this convex shape (when molten) may be used to help compensate for warp that the PCB or solderable device might have. Finally, it is possible to configure SMT SC to be interchangeably compatible with a device using a BGA foot print.

It is informative to compare the SMT SC to conventional BGA technology. A picture of reflowed BGA solder joints is shown in Figure 3. BGA technology is used in many products such as interconnects and sockets and has been in existence for well over 15 years.

Figure 3: Magnified view of a reflowed BGA

Two interconnect solutions were developed that use SMT SC technology. Both products were configured as mezzanine connectors and will be referred to as Mezzanine A and Mezzanine B. The main difference between the two is the range of stack heights they each support and, in effect, a difference in thermal mass of each part, with Mezzanine A ranging from 7 to 15mm with a smaller thermal mass and Mezzanine B ranging from 16 to 38mm with a larger thermal mass. A picture of Mezzanine A can be seen in Figure 4 while a picture of Mezzanine B can be seen in Figure 5.

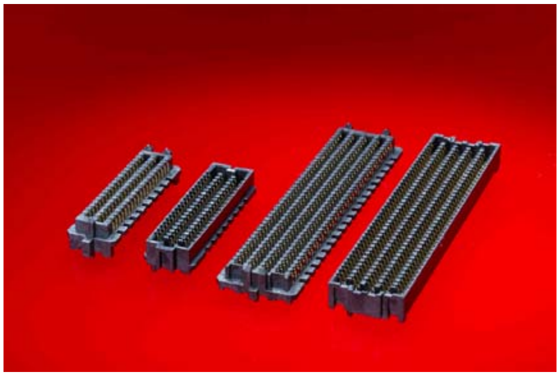

Figure 4: Picture of Mezzanine A

Figure 5: Picture of Mezzanine B

PROCESSING

The introduction of a new SMT solder attachment technology clearly requires sufficient testing to validate that the technology will be processed effectively and repeatedly using current manufacturing conditions and common SMT production equipment. In the early stages of design, it is best to work with an accredited contract manufacturer in light of the high level of processing experience and large variety of components that are processed at such a location. Teams within a contract manufacturer, particularly in the New Product Introduction (NPI) group, can help identify any unique challenges in the reflow process and provide feedback on ways to improve a new SMT process.

During processing validation of SMT SC common SMT production equipment and processes were used to rely on existing reflow technologies that would not require additional training for contract manufacturing operators. The equipment and processes used for validation included an MPM UP3000 automated screen printer, a Universal GSM fine pitch placement machine, a BTU Pyramax reflow oven, a standard 2DX transmission X-ray machine and an Agilent 5DX X-ray machine. Figure 6 shows a 2DX transmission of a reflowed SMT SC.

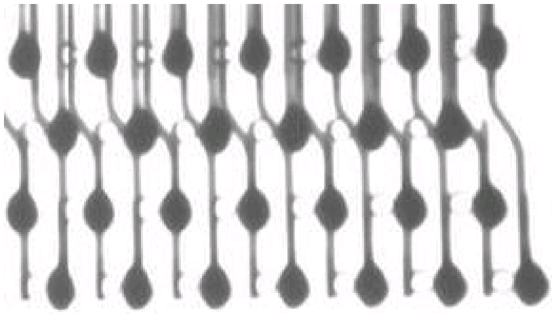

Figure 6: 2DX X-ray transmission of SMT SC

In light of recent leadfree initiatives, it was important to include both a tin-lead and leadfree alternative along with processing instructions and test data on each one. The new solder attachment technology was designed to be available with a SnPb alloy or a SAC alloy and was validated using either a SnPb reflow profile with a peak temperature of 225C or a Lead free reflow profile with a peak temperature of 245C.

This new solder attachment technology follows a traditional SMT process flow beginning with screen printing solder paste onto the corresponding PCB pads, followed by automated pick and placement, reflow soldering, and X-Ray inspection.

For use in fully automated assembly designs, the new solder attachment technology is easily taught for automated pick and place vision recognition and requires no new vision algorithm. Also, true positioning of the new solder attachment technology onto the component terminals ensures accurate solder placement onto the solder pads. Such true positioning could increase the accuracy of the automated placement of the component and eliminates the need for any self aligning of the solder attachment during reflow soldering.

Other feedback from the contract manufacturing NPI teams recommended to allow for compliancy in the x, y, and z directions resulting in more reliable solder joints as well as a feature that allows the terminal itself to be seated into the screen printed solder paste eliminating concerns over the potential for "head in pillow" solder joint defects. Such recommendations came from the experiences with processing BGA type components.

Finally, while 5DX X-Ray was used during the new solder attachment testing inline 3D AXI as well as 2D transmission X-Ray have also shown to be very effective at identifying any reflow soldering defects, thus potentially eliminating the need for 5DX X-Ray inspection and lowering overall costs in assembly. Figure 7 shows the 2DX X-ray transmission of an improperly processed SMT SC where the square shape can be identified without the requirement of an offline 5DX X-ray process. Because of the unique design of the new solder attachment technology engineers and technicians found that there is no need for specialized X-Ray operator training to correctly identify any reflow soldering defects during production.

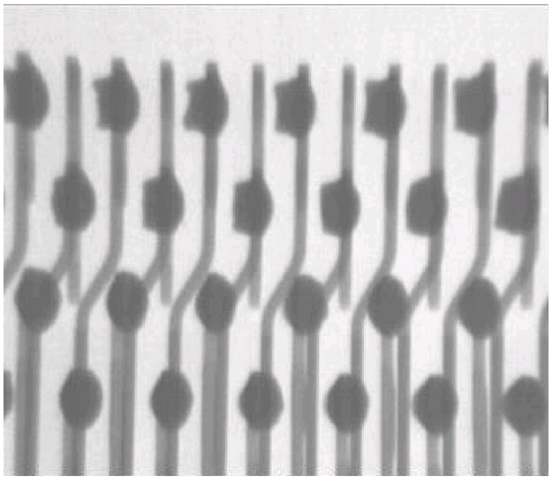

Figure 7: 2DX X-ray transmission of improperly reflowed SMT SC (rectangle shapes toward top)

RELIABILITY

The next task at hand is to prove the reliability of a new SMT process and validate that the technology will be able to face environmental variables as well as proper adhesion to a PCB. Industry standard tests can be performed to follow a consistent set of test parameters and review data that is gathered uniformly with other components facing the same test.

To address reliability of SMT SC, an industry standard test called IPC-9701 was done. Under such test parameters, a connector undergoes temperature cycling from 0C to 100C for a total of 6,000 cycles. The test vehicles were laid out with 4 mated sets of connectors per board to also test mechanical tolerance stack up in parallel. The test board layout for the daughtercard is shown in Figure 8.

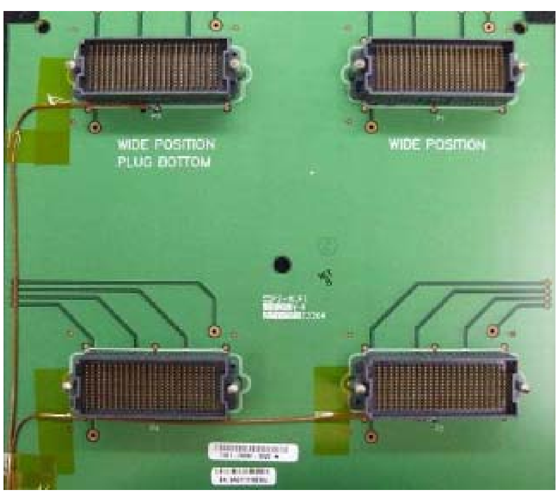

Figure 8: IPC-9701 daughtercard layout with 4 plugs per card for mechanical tolerance stack-up.

Each board had a daisy-chain circuit running through the interconnect with SMT SC so electrical continuity can be confirmed at different points in the test sequence. The boards were taken out of the chamber and tested every 500 cycles to roughly identify the point in the test process where failures were found. A picture of the motherboard with 4 receptacles per card can be seen in Figure 9.

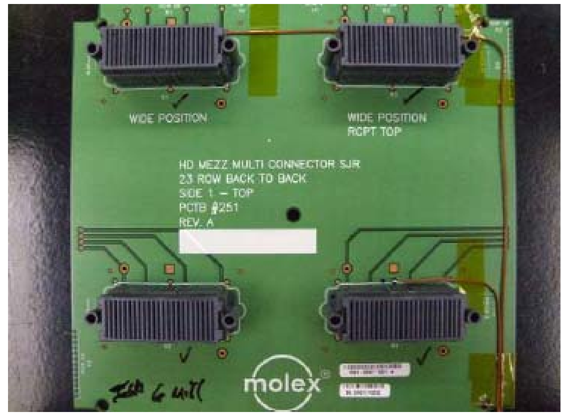

Figure 9: IPC-9701 motherboard layout with 4 receptacles per card

The temperature cycle with specified time sequences was identified for IPC-9701 and the overall test required 6,000 cycles. The temperature profile used for each of those cycles can be seen in Figure 10.

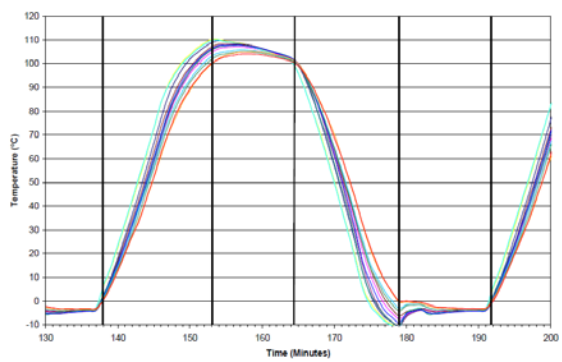

Figure 10: IPC-9701 temperature cycles

The completion of the test provided data which concluded that none of the solder joints were cracked to the point of failure detection. By definition, failure was considered to be the identification of an electrical discontinuity in-situ in the daisy chain, meaning a delta of 10Ω in resistance lasting over 1 millisecond. Thus, a cracked solder joint would result in contact resistance increasing over time and negatively affect the signal transmission capability. Such cracks are caused by stresses. The results of SMT SC in the IPC-9701 test sequence can be seen in Table 1.

Table 1: Results of IPC-9701 testing for SMT SC

DESCRIPTION	TREATMENT	REQUIREMENT	NUMBER OF FAILURE EVENTS		
IN-SITU EVENT DETECTION	TC-1 0℃ to 100℃ 6000cycles	RECORD FAILURE EVENTS (Ten consecutive 10 Ω Change in Resistance lasting over 1 millisecond)	0 FAILURES		
Loop Resistance (Across 53 ckt Daisy Chain)			AVG	MIN	MAX
	Initial	1.25 Ω Nominal, Reference-No Limit set.	1.25 Ω	1.171 Ω	1.406 Ω
	500 cycles	Delta Resistance Ω (Reference)	-0.019 Ω	-0.028 Ω	0.064 Ω
	3000 cycles	Delta Resistance Ω (Reference)	-0.008 Ω	-0.017 Ω	0.009 Ω
	6000 cycles	Delta Resistance Ω (Reference)	-0.017 Ω	-0.023 Ω	0.014 Ω

MECHANICAL FACTORS

Aside from processing and reliability concerns for a new solder attach technology, mechanical robustness must also be included in the overall analysis. The strength of the solder joint to the PCB is an integral part of any system designer's consideration when choosing components for their design. It helps to compare the cross sections of SMT SC with those of a BGA to understand the solder volume on a solder pad and the make-up of the structure it has with respect to the terminal.

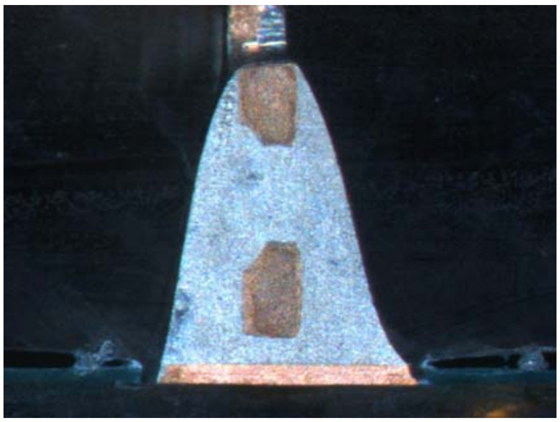

Figure 11: Cross section of SMT A in X-Axis

Because of the shape of the design, it is beneficial to look at the cross section of the solder charge in both the x and y axis's. Figure 11 above shows the cross section of SMT SC in the x axis, with the terminal seen within the solder having a copper color and Figure 12 below shows a cross section of SMT SC in the y axis where solder can be seen creating the engulfment which was mentioned earlier. In the y axis the flow of solder through the hole in the terminal provides a path to assure the engulfment of the terminal, then acts as a "solder nail" after freezing. At the same time, the protrusion in the terminal was designed to create a pivot point on the solder pad and avoid the properties of a dreaded "butt joint". Having a protrusion provides added surface area for solder to flow around and form to the bottom side of the terminal along with added real estate on the solder pad.

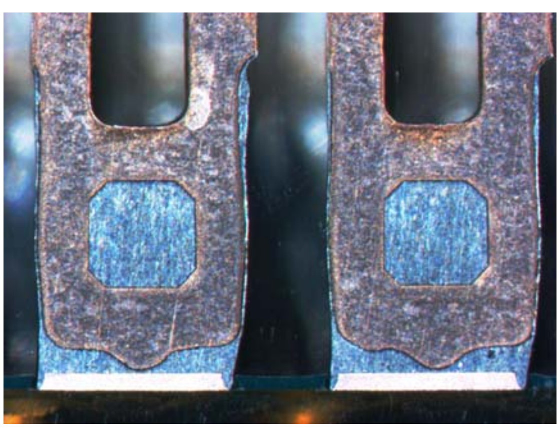

Figure 12: Cross section of SMT A in Y-Axis

For comparison's sake, it makes sense to look at the cross section of a BGA. One of the main differences is the overall shape of the solder fillet. The reflowed BGA joint is seen in Figure 13. Its cross section reveals a generally spherical shape, which is preserved by using relatively small soldering pads on the PCB. If these pads become too large, then the BGA ball may collapse and cease to be buoyant.

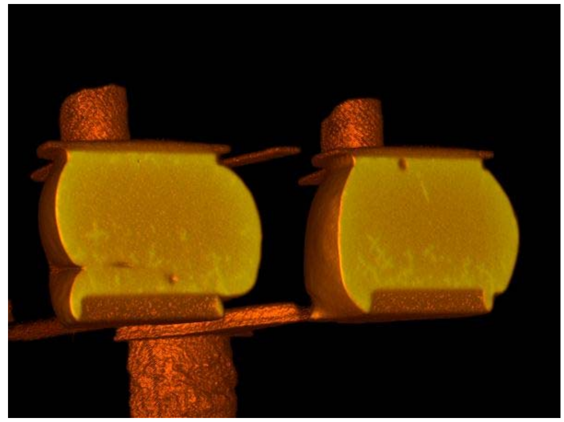

Figure 13: Cross section of reflowed BGA solder joints

PCB retention for SMT SC was found by performing pull tests and measuring the strength per solder joint. Both tin-lead and leadfree parts were tested with a tin-lead solder joint providing 2,658 g/joint and leadfree being measured as 2,887 g/joint. The bugle shape of the SMT SC fillet allows the widest point of the solder to form onto the PCB and provides higher retention forces than a common BGA. When BGA joints were tested, the retention strength per pin was 1,008 g/joint, so roughly 35% of the strength of the leadfree SMT SC and 38% of a tin-lead SMT SC.

The SMT SC has a rectangular shape with distinct edges prior to reflow, then it attains its rounded bugle shape after reflow -- This geometric transformation is easily detected optically and/or through x-ray analysis, which makes inspection easy. A BGA begins as a generally spherical shape and is still nearly spherical after reflow, whether it actually melted (or not) during reflow; this can be tricky and make inspection more difficult.

Side loads also play a major role in mechanical robustness of a solder joint so lateral and longitudinal forces were calculated versus deflection in the contact. A side load test was performed on two mated Mezzanine B components with 299 contact points after SMT SC processing to a PCB. Figure 14 shows the reading of lateral travel (x axis) versus pound force of a side load (y axis) applied to a free PCB when the other PCB is fixed. Resistance of the daisy chained system was monitored during loading.

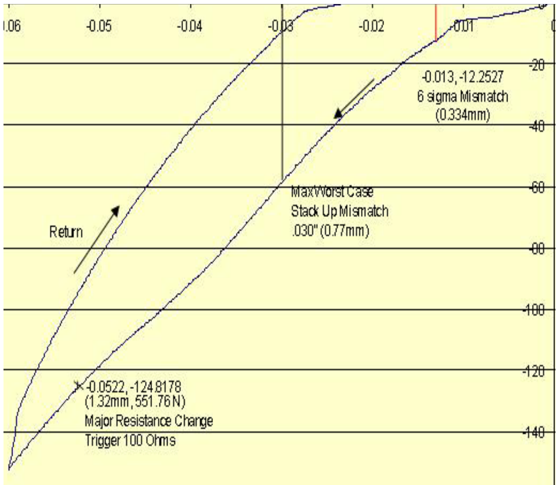

Figure 14: Lateral load deflection of force (lbf) versus deflection (inch)

There are two conditions for mismatched positional values that must be considered for a side load: mechanical tolerance stack for 2 mated components that are forced out of position by the PCB mounting hardware and mechanical tolerance stack of multiple parts per board. Each of these positional mismatches generate side loads which must be withstood by the solder charge. In this case, the statistical 6 Sigma tolerance stack for a multiple part per board set of Mezzanine B connectors was found to be 0.013". The resulting side load force of 12.25 lbs (or 0.041 lbs per solder joint) was measured at this amount of forced travel. The worst case stack mismatch of 2 sets of mating components on the same board can be up to 0.030", resulting in a side load of 58.3 lbs (or 0.195 lbs per solder joint). The test continued until a deflection of 0.052" with a side load of 124.8 lbs (or 0.417 lbs per solder joint) created significant change in contact resistance. The load was released shortly after this event and electrical resistance returned to its original value.

CONCLUSIONS

Many different aspects must be considered when designing and validating a new solder attach process. SMT SC performed well in regards to tests performed to validate processing capabilities, reliability through thermal cycling and mechanical factors such as PCB retention and positional mismatches through side load forces. Both Mezzanine A and Mezzanine B had no failures during the first 6,000 temperature cycles of the IPC-9701 test. Also, retention forces for SMT SC were over 2.5x the pull force of similar surface mount technologies and retention strength from side loads showed a significant safety buffer when considering 6 sigma tolerance stack for both multiple parts per board and a mated set of components with SMT SC.