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Solder Preforms: Increasing Automated Placement Efficiency

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Abstract

Solder preforms are precise shapes of metal, produced by the high-speed stamping or forming of solder wire or ribbon. Preforms provide a highly repeatable volume of solder, with 100% metal content by volume. They are commonly used in conjunction with solder paste to incrementally increase the volume of solder joints, which increases reliability in connections subject to mechanical fatigue, and increases signal-to-noise ratios in interconnections delivering high frequency signals.

Dozens of OEM and contract assembly houses have realized that the use of solder preforms can solve issues related to inadequate solder volume in SMT processes. As with the adaptation of any new technology, issues arise and are resolved as the technology evolves into mainstream, high-volume production. Over the past two years of process evolution, the most common issues related to the implementation of perform assembly have been associated with high speed placement. Although the preforms are placed in a similar fashion to chip components, they have suffered higher pick error rates than chip components.

A series of studies were undertaken to understand the factors that influence pick error rates. This paper reviews the experiments that studied standard shapes, unique "super flat" geometries, component orientations, and machine feeder and nozzle selection. It also discusses the effect of preform shape and size tolerances, and compares the geometric specifications to those of chip components.

Background

Preforms provide an excellent solution when SMT process conditions do not allow for adequate solder volume deposit. This commonly occurs when through hole components/connectors are soldered using a pin-in-paste process. Solder paste deposit height may be limited by the use of thinner stencils (5 mils or less) to eliminate solder balls or slumping in fine pitch applications. Overprinting (using apertures larger than the plated through hole annular ring) often results in bridging or random solder balls. Even thick stencils (8 mils or more) cannot meet the solder volume requirements in certain cases, when thick boards (.092" or greater) are used, or when pins with rectangular cross sections are inserted into round through holes.

Square leads soldered into round plated through holes are the most common cause of a solder paste volume deficit in the pin-in-paste process. Then best case is a square pin with 0.025" sides and a 0.038" round hole, which is the smallest round hole that this pin would fit into. Even with a 0.010" thick stencil, a 200% overprint, an 0.062" thick board, 100% transfer efficiency of the paste, and no paste drips from the bottom of the hole, only 56% of the space between the pin and barrel will be occupied by solid solder after reflow.[1]

Over the past two years, numerous assemblers have found that solder preforms can be placed into solder paste deposits, yielding the correct volume of solder for the joint without creating the ancillary issues normally associated with thick stencils or oversized apertures. Preform shapes commonly used in high volume applications include both washers and rectangles. Figure 1 illustrates commonly-used rectangular components.

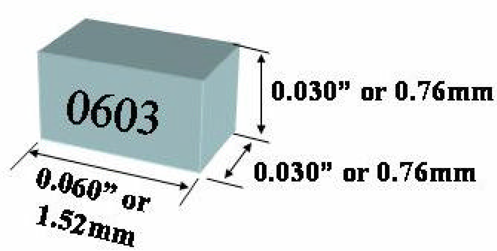

Figure 1 - Solid Solder Preform in the Shape of a 0603 Chip Component

Table 1 reviews the sizes and tolerances of chip components and solder performs. Despite the preforms' tighter size tolerances, they demonstrated higher pick error rates than chip components when implemented in high-volume assembly.

Microscopic examination of commercially available solder preform rectangles shows that they are not perfect geometric shapes, but rather cubic on 5 sides, and somewhat rounded on the sixth side. The rounded side has a large, flat surface, but the corners have been rounded down as part of the manufacturing process. Figure 2 shows the profile of a typical solder preform.

Table 1 - Dimensions and Tolerances of Chip Capacitors and Solder Preforms

Published Dimensional Tolerances
Chip Capacitors and Solder Preforms
(all measurements in inches)

	Device Type		
	0805	0603	0402
	Body Size (L x W)		
	0.080 x 0.050	0.060 x 0.030	0.040 x 0.020
	Size Tolerances		
Cap. Brand 1	0.008	0.006	0.002
Cap. Brand 2	0.008	0.004	0.001
Cap. Brand 3	0.006	0.004	0.002
Preform Brand 1	0.002	0.001	0.001
Preform Brand 2	0.002	0.001	0.001

Figure 2 - Typical 0603 Solder Preform

Figure 3 depicts the punching process used to produce performs. As the punch applies pressure to the material, it yields and flows into the die cavity. Rounding occurs on the cavity side of the slug as a result of the frictional resistance of the die against the flowing (solid) metal. The dimensions of the rounding are predictable and repeatable, and can be calculated using standard metal deformation equations. Proprietary technology can be used to further flatten the rounded side of the slug, resulting in what is termed an "ultra flat" perform, shown in Figure 4. It should also be noted that the sides of the slug will show "witness marks" that demonstrate where the shearing and tearing forces met during the punching process.

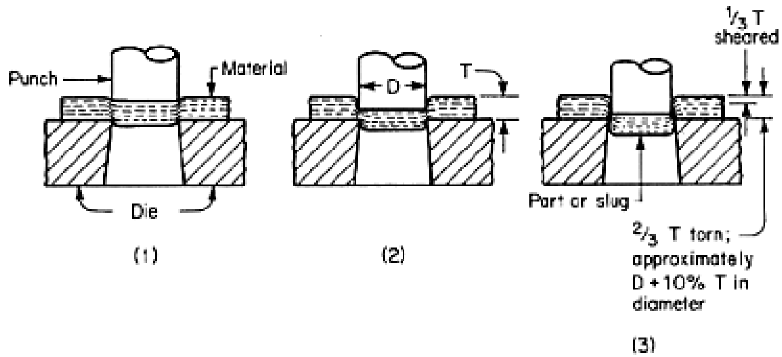

Figure 3 - Schematic Diagram of the Solder Preform Manufacturing Process

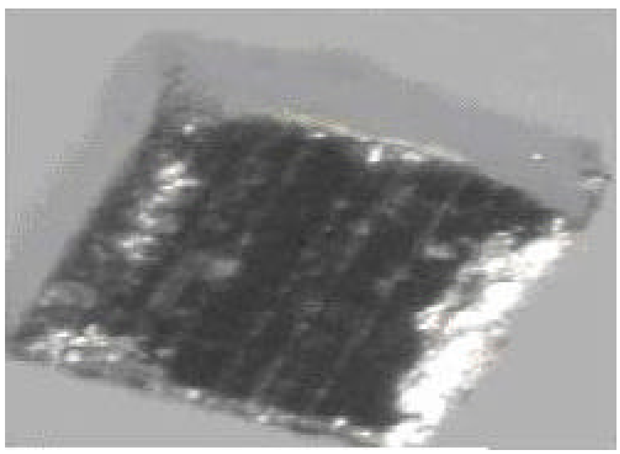

Figure 4 - Flattened 0603 Solder Preforms

Experimental Procedure

A series of studies were devised to understand the root causes of pick error rates of solder performs, so that both the design of the components and the assembly process itself could be optimized to produce the most cost-efficient solutions. It examined the effect of preform shape distortion in conjunction with vacuum nozzles, carrier tape and bulk feeder systems. Tests were conducted at three large OEM facilities, and at a large equipment manufacturer's test facilities. Two commercially available rectangular preforms were used as controls, and newly developed "ultra flat" rectangular performs were the subject of the experiments. All preforms were the size of 0603 chip components.

The tests were executed as follows:

- **Test #1:** took place on a popular brand of chip placement machines ("A"), at a large OEM in Asia, picking parts from standard tape (specified below).
- **Test #2:** took place on a different brand of placement machine ("B"), at a European location of the same OEM, picking parts from the same tape.
- **Test #3:** repeated Test #2 at the equipment supplier's applications laboratory, using a newer revision of the same pick and place machine, picking parts from the same tape.
- **Test #4:** took place on a third brand ("C") of placement machine, at a large OEM facility in North America, using a bulk feeder system. It should be noted that bulk feeding of performs is far more economical than tape and reel feeding systems.
- **Test #5:** took place again at supplier B's applications laboratory, optimizing the use of bulk feeders.

Each test consisted of approximately 1,000 preform placements, including typical and ultra-flat shapes in 0603 size (1.60 x .76 x .76 mm rectangles) of the Sn62 (62%tin, 36% lead, 2% silver) alloy.

8mm tape with pocket dimensions of 0.069" x 0.037" x 0.039" (1.75mm long x 0.95mm wide x 1.0mm deep) was used for all tests. The pocket geometry was selected to eliminate spinning or rolling of the device once it was placed in the pocket and covered with sealing tape. For the majority of the tests, the preforms were placed in the tape pockets using automated equipment, giving random orientations. For a portion of Test #2, the preforms were deliberately oriented in certain directions.

Results and Discussion

In Test #1, the assembler had been using preforms with typical geometries for some time. Pick and place failure rates had been reported to be 1.8%. A sample of 40,000 ultra flat preforms were delivered and run in production. The failure rate remained 1.8%. It was therefore assumed that the ultra flat preforms had no effect on the assembly process when using tape and reel feeding with equipment from supplier A.

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In Test #2, standard preforms had an average failure rate of 0.24%. Flattened preforms showed a failure rate of 0.27%. There were no statistically significant differences in these error rates. A follow up test was initiated. 8 reels of approximately 1,000 preforms each were prepared. Standard and flat preforms were placed in 1 of 4 orientations:

- Randomly in the carrier tape
- Bottom (rounded) surface facing up
- Top (flat) surface facing down
- Side (sheared) surface up

Table 2 shows the results of this orientation evaluation. In all orientations except random, the ultra flat preform provided lower machine error rates than the typical perform. Furthermore, the preforms packaged with the naturally flat side down in the tape generated less machine errors than the preforms packaged with the naturally flat side facing up in the tape. It is theorized that when the surface that is naturally rounded or subsequently flattened (i.e. cavity side in the punching process) is situated face down in the tape, the part can rock or tilt, making it more difficult for the machine to pick it up out of the tape. The worst error rates were witnessed with the parts packaged on their sides. The witness mark or burr that results from the stamping process creates an uneven pick surface on the component.

Table 2 - Pick Error Rates from Test #2

Pick Error Rates for Specific Preform Orientations in Tape Pocket

Orientation in Tape	Standard Preform	Ultra Flat Preform
Rounded Surface Down	0.61%	0.40%
Side Surface Down	2.02%	1.55%
Flat Surface Down	0.55%	0.14%
Random	0.24%	0.27%

In Test #3, equipment manufacturer B ran 2,000 pieces of typical preform, and 2,000 pieces of flattened preform with no failures whatsoever. Because results from production trials in Test #2 showed error rates averaging around 0.5%, approximately 10 failures were expected in each 2,000 piece run. The fact that no failures occurred at all merited further investigation.

The applications laboratory used well tuned equipment that is not regularly subjected to the rigors of high-volume production. The laboratory also chose vacuum nozzles that were sized optimally for the preforms, which is not always an option for production assemblers when many different devices are being placed on the circuit boards. The conclusion that can be drawn from this experiment is that, depending on the performance level of the equipment and the device demographics of the board being assembled, ultra flat preforms may or may not be required. A discussion of pick surface characteristics and calculations on equipment performance and nozzle sizing will be presented in a later section.

In Test #4, 10,000 standard preforms were fed in a bulk cartridge and presented to the placement head using a typical 0603 chip feeding mechanism in a placement machine from supplier C. In this test, 18%, or roughly 1 out of every 6 devices was lost. When 10,000 ultra flat preforms were tested on the same equipment, there were no failures.

The ultra flat performs were slightly larger (0.08mm in the length direction), but it was theorized that the geometry of the part was the main factor influencing the discrepancy. There are six sides to the component. All three pairs of opposing sides are the same size, but only two of the pairs have similar surfaces (the sheared sides). If the feeder fallout were due to surface area or texture of a side, then the error rate should have been 1 in 3. The feeder fallout must have been due to either the top (naturally flat) or bottom (naturally curved) surface topographies. Since the ultra flat performs exhibited zero feeding errors, the 1 in 6 fallout rate was attributed to the curved surface.

It was theorized that having the rounded surface facing down, the preform would be likely to tip in the bulk feeding mechanism. If the preform were smaller than the indexing mechanism of the feeder, it will tip, and jam the feeder mechanism. If the preform were flat, it will not tip.

In Test #5, the applications laboratory of equipment supplier B confirmed this theory. Standard preforms showed an 18% failure rate using feeding equipment similar to Test #4. The equipment manufacturer then modified the pitch of the indexing system, and the failure rate of the typical performs dropped to .01%. Ultra flat preforms showed a .02% failure rate (not statistically different with a sample size of 1000), using the new pitch on the feeder mechanism. Tests that combine the ultra flat perform with a coarser pitch indexing system will be executed, but were not available at the time of publication.

Optimizing the Assembly Process

Optimally sizing vacuum nozzles for the assembly of performs is a major factor in lowering pick error rates. The key to a good pick is a good pick surface. A good pick surface is flat and planar. It has no ridges, bumps, or depressions that can cause a vacuum leak. It is repeatably located within the positional tolerance of the placement head of the machine. Figure 5 shows a top view of the preform. The curved areas near the corners are visible due to the lighting of the photograph. From this photograph the pickable surface of the device is approximated in Figure 6. Figure 6 depicts the naturally flat, pickable surfaces of the component in white, and the naturally curved, non-pickable area of the surface in black. Also shown are the dimensions of the tape pocket, and the maximum nozzle size guaranteed to give a good pick for this device and tape size when used with a specific pick and place machine.

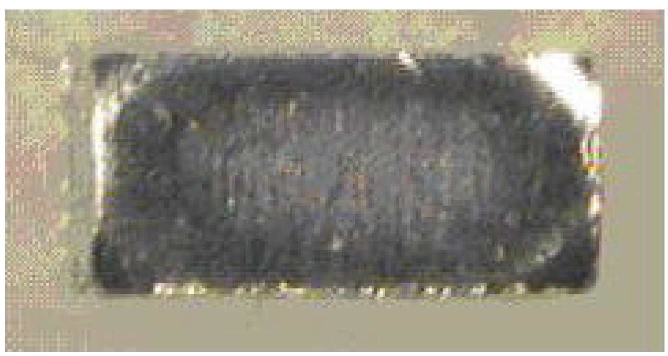

Figure 5 - Naturally Rounded Surface of Solder Preform

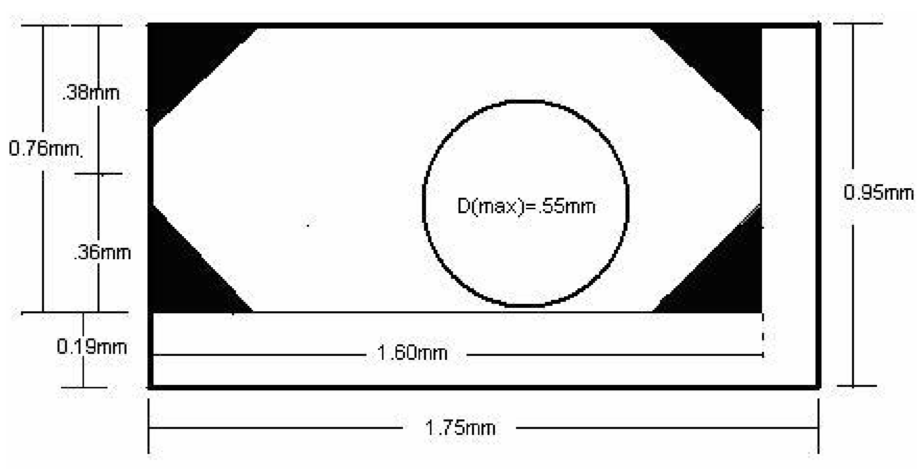

Figure 6 - Scale Drawing of Pickable Surface in Tape Pocket

When tape feeding, a tolerance analysis can be performed that considers component size, tape pocket size, and pick accuracy of the machine to determine the optimum nozzle size to minimize pick errors. It should be noted that Tests #1 and #2, with pick error rates of 1.8% were performed without optimizing the nozzle size.

Bulk feeding of performs is far more economical than tape and reel feeding, because the cost of taping the components is avoided. When considering bulk feeding, an economic analysis can be performed that considers component cost, feeder modification cost, and placement volumes to determine if the more cost-effective solution is to implement optimized feeder indexing systems or to use ultra-flat performs. It should be noted that whether the typical performs or the more costly ultra-flat performs are used, bulk feeding continues to be more cost effective than tape and reel.

Summary and Conclusion

Solder preforms can be successfully used to augment solder paste in applications where traditional stencil printing cannot deposit a sufficient volume of solder paste to assure joint integrity. As with any technology, there is no “one size fits all” solution, but a number of combinations that can provide the best solution. Preforms come in many sizes and shapes; the most commonly employed components are the size and shape of standard chip components: 0603, 0805, 1206.

While typical preforms can be implemented rather easily in most assembly processes, constraints associated with some types of assembly equipment and feeder styles spurred investigations of both the equipment and the perform devices. Ultra flat preforms were developed to help overcome some of those constraints.

It was found that, with some assembly equipment configurations, ultra flat preforms provide distinct advantages. In other configurations, typical performs function just as well as their ultra flat counterparts. The situations where one type of device is preferred over another are now clearly understood, and recommendations can be provided that address both equipment efficiency and cost advantages.