

Stencil Printing SMT Adhesives: A Technology Review

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Introduction

Anyone closely involved with the process of surface mount assembly is familiar with the challenges of materials deposition. This complex process requires highly developed materials and equipment to produce reliable results. In the past, SMT adhesive deposition has been accomplished primarily by high speed automatic dispensing, pin transfer, and stencil printing. Each of these methods has its strengths and weaknesses and, as the needs of the SMT assembly industry change, careful consideration must be made to determine the appropriate method for new applications. The industry of high volume surface mount assembly is very competitive, with product designs changing rapidly. To remain profitable, assembly houses must maintain a high quality standard, while maximizing throughput and flexibility. Rising to meet the challenges of this fast-paced industry, SMT placement equipment manufacturers are now producing machines capable of more than 70,000 placements per hour. As a result, the assembly business is shifting the focus from placement equipment to materials deposition equipment¹. At present, the most widely used method of adhesive deposition is high speed automatic dispensing. This method is excellent for control of individual deposition volumes and dispense locations. The limiting factor, however, is speed. Current high-end dispensers are only able to produce up to 40,000 "dots" per hour. This process can quickly become a bottleneck in a high-throughput assembly line.

Pin transfer is a high speed alternative to dispensing, but it has several limitations. Deposition locations are fixed in complex and expensive tooling plates that make changeovers slow. In addition, product design changes are expensive and difficult to accommodate.

Stencil printing, recognized for many years as a viable and cost-effective method of applying adhesives, is now emerging as the chosen deposition method for high-throughput assembly environments. Increasing component counts and faster placement equipment require a method of adhesive deposition that is more rapid than dispensing and more flexible than pin transfer. Manufacturers of stencils and SMT adhesives, each have responded to this need by developing new stencil technologies designed for adhesive printing and as well as printable adhesives with rheological properties suited for stencil printing. While many board manufacturers have already been printing adhesives for SMT applications, much of the technology is not well understood. This paper reviews and recommends the principles that comprise a successful SMT adhesive printing process.

<p>Print</p> <ul style="list-style-type: none"> • Variable Dot Heights • Constant Cycle times (can be under 10 seconds) • Any Geometry Possible • Fixed Dot Locations <p>Print when:</p> <ul style="list-style-type: none"> • Component Count is High • Cycle Time is Critical • Adhesive Applied before other Materials/ Components* <p>* In most cases adhesive can be printed after solder paste has been deposited with a stencil that is recessed on the bottom side.</p>	<p>Dispense</p> <ul style="list-style-type: none"> • Variable Dot Heights • Cycle Time Depends upon Number of Dots • Only Dots are Possible • Programmable Dot Locations <p>Dispense when:</p> <ul style="list-style-type: none"> • Component Count is Low • Cycle time is not a concern • Other Materials and/or components applied before adhesive
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Fundamental Printing Theory

Because stencil printing has long been associated with solder paste, some of the basic facts of adhesive printing are often misunderstood. For example, it seems intuitive that all dots deposited by stencil printing would have the same height that is approximately equal to the stencil thickness. In fact, the relationship between stencil aperture design and adhesive can generate adhesive dot heights well above or below the stencil thickness^{2,3} (Figure 1).

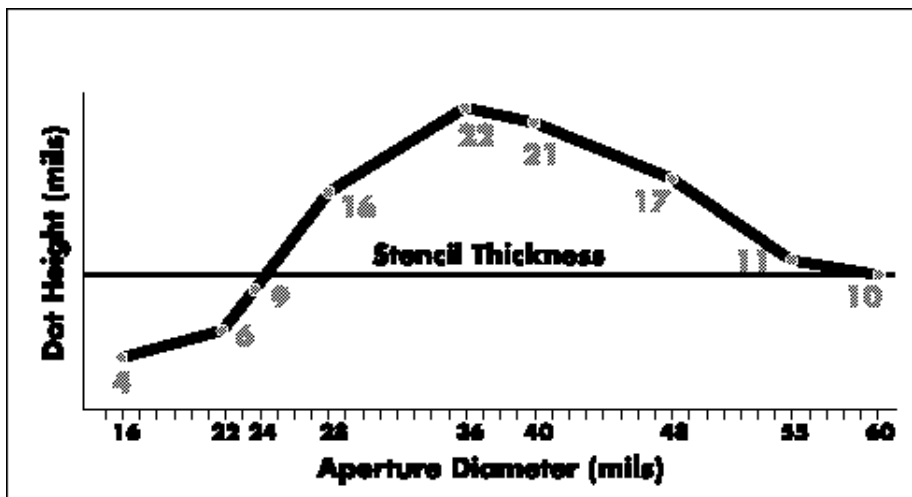


Figure 1. Stencil printing can produce deposition heights both above and below the stencil thickness.

This phenomenon of a single thickness stencil producing various dot heights is the key to successful adhesive printing. This phenomenon occurs because unlike solder paste, adhesives do not release completely from apertures. In most cases, more adhesive is left in the aperture than is deposited on the substrate. Small dots (smaller than the stencil thickness) are created with small apertures. These apertures act like miniature dispenser tips. The aperture fills with adhesive during printing followed by stencil and substrate separation. If the surface area of the inside wall of the aperture is large enough compared to the exposed surface area of the substrate, a small portion of the adhesive remains on the substrate while the rest remains in the stencil aperture. (Figure 2) Dots such as these will peak similarly to dispensed dots. With larger apertures, the peaked depositions are larger and taller and eventually exceed the thickness of the stencil. The highest dot heights are created from apertures where the ratio of aperture surface area to substrate surface area is 1:1. If the surface area of the substrate is much greater than that of the aperture, the deposition will release with a relatively flat top and will roughly equal the thickness of the stencil⁴.

Understanding the stencil release characteristics of adhesives is imperative, but dot height is only one component of the adhesive deposition process that requires attention. A successful adhesive printing process is comprised of several components:

- an adhesive suitable for stencil printing
- an appropriately designed stencil
- a stencil printer capable of vertical separation of board and stencil (preferably at a controlled speed) and a programmable snap-off distance



Figure 2.

Adhesives

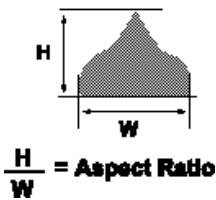
There is a multitude of SMT adhesives available. Formulations exist for dispensing, pin transfer and adhesive printing applications. Certain adhesives are best suited for a particular process.

Adhesives for stencil printing typically must possess several characteristics to produce reliable depositions. Most importantly, they must be suitable for long term exposure to ambient humidity. Many adhesives designed for dispensing are hygroscopic and can absorb moisture, particularly if used for stencil printing, where adhesive remains exposed to the atmosphere for long periods of time. This can cause problems for some formulations. Some attempts at stencil printing adhesives were considered failures because inappropriate materials were used. To be suitable for printing, an adhesive should be capable of remaining on a stencil for 3-5 days with no adverse effects.

Adhesives usually are characterized by rheological properties such as viscosity, yield point, thixotropic index, and green strength. For most adhesives these properties are

interdependent. A high viscosity adhesive typically has a high yield point and a high green strength, producing high aspect ratio deposits. A low viscosity adhesive typically has a low yield point, poor green strength, and produces low aspect ratio dots. Printable adhesives usually are thixotropic so that they can flow freely into apertures when sheared during the printing process, recovering quickly after printing to resist. Dispensable adhesives must have a similar quality to pass quickly through the syringe tip.

An important characteristic of adhesives is "yield point," described as the stress required to move the adhesive ⁵. This property will contribute to the height and "aspect ratio" of the dot. Aspect ratio is the height-to-width ratio of a deposited dot. Low yield point adhesives (yield points 150-200 Pa.) produce deposits with low aspect ratios. These will slump into a rounded deposit and may never peak higher than the stencil thickness. High yield point adhesives (yield points 200-500 Pa.) produce high aspect ratio deposits that hold peaks, which can easily extend above the stencil thickness.



Any adhesive, whether dispensed or printed, must have adequate wet or green strength to hold components during the placement process, as well as a yield point sufficient to avoid slump and give appropriate dot profiles.

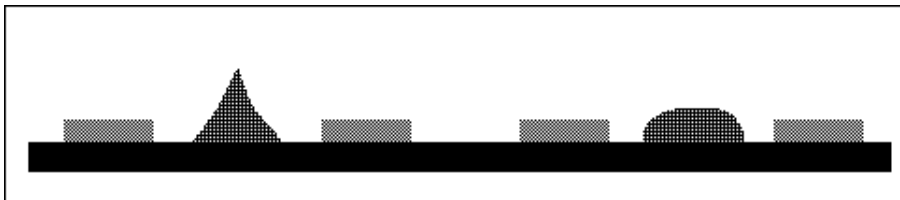


Figure 3. Adhesives with high yield points resist slump and create high aspect ratio deposits.

In order to choose the most suitable adhesive for printing, the requirements of the process must be considered. The mix of component types on the board has a significant effect on the choice of adhesive. Passive components can be attached with dots of minimal height. Larger (and higher) dots are needed to attach components with larger standoffs (Figure 4.). To create high depositions, a high viscosity (typically, also high yield point) adhesive is needed. These adhesives are appropriate since they create high aspect ratio dots easily and have good green strength. Usually, they must be printed slowly (0.5-2.0 in/sec.) in order to achieve complete aperture fill. If only passive components exist on the board, a lower viscosity adhesive may be suitable. These adhesives do not resist slump, producing lower aspect ratio depositions. Such depositions may suffice for components having standoffs of 6 mils or less. Lower viscosity adhesives typically can be printed at faster speeds (4-8 in/sec.). Since they suffer from low green strength, component shift or skewing can occur with high-speed, turret-based placement equipment.

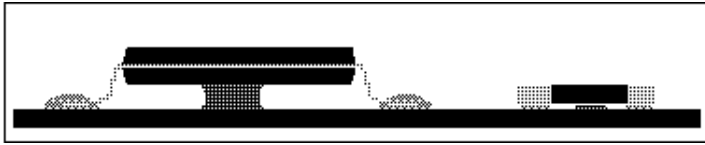


Figure 4 . In some cases, very large and very small dots must be deposited on the same substrate.

Stencils

Another important factor is the adhesive printing process is the stencil. Stencils are available in a wide variety of materials, and fabrication methods. Stainless steel and plastic are the most commonly used materials. Thickness ranges from a few mils to 0.040 depending on the components to be placed.

Stencil Material

Stencil material can be a critical variable in the stencil printing process. The dynamics of deposition and release are quite different between metal and plastic stencils. Stainless steel stencils, chemically etched or laser-cut, have been used for years in solder paste printing and work well for most adhesive applications. Plastic stencils have recently been introduced to the SMT industry specifically for the adhesive printing process.

Plastic stencils are professed by their manufacturer to have several advantages over metal stencils. The flexibility of the stencil is purported to make a better gasket between the substrate and stencil, which would minimize "squeeze-out" of adhesive onto the underside of the stencil. This, in turn, would eliminate (or at least reduce) the need for periodic wiping of the underside of the stencil. Anecdotal evidence supports this assertion, although no formal studies on the topic have been published. Flexibility also is reported to enhance release during "snap-off", better enabling "off-contact" printing, which provides higher dot profiles⁶. However, this is difficult to quantify because dot height is dependent on many other factors. The plastic stencil has disadvantages, as well. Since the apertures in the plastic stencil are drilled, only round shapes are possible. Also, since plastic stencil technology is new, they are not as widely available as are stainless steel stencils and may be more expensive. Finally, the plastic stencil may be harmed by metal squeegee blades and, therefore, only polyurethane or special blades (provided by the stencil manufacturer) are advised.

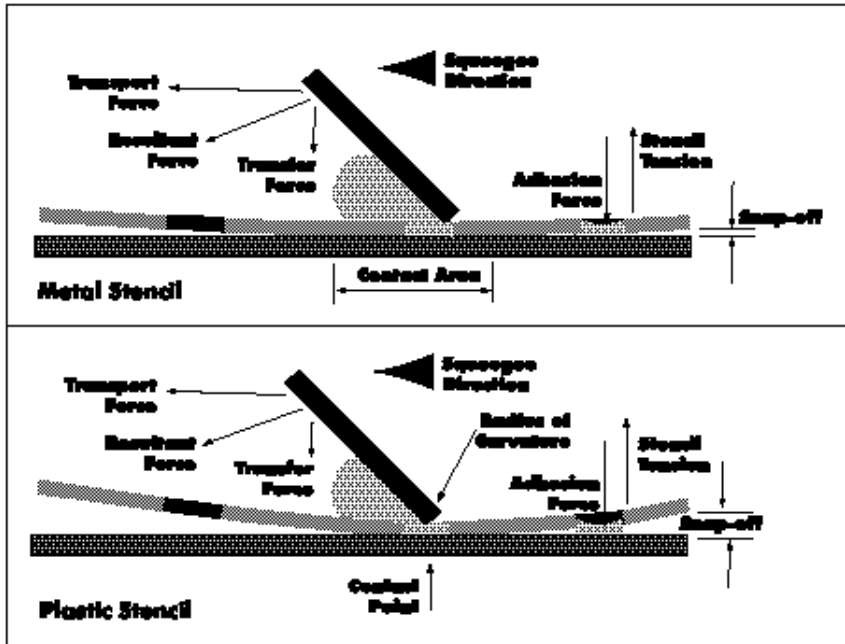


Figure 5⁷.

Metal stencils, available at comparatively low prices from an abundance of stencil manufacturers, offer complete freedom of aperture geometry. Stainless steel stencils for adhesive printing are often chemically etched. Laser cutting usually is more expensive and its benefits are not realized in the adhesive printing process. Plastic stencils have been recommended when the application requires a wide range of dot heights in a single print pass. Metal stencils were recommended when only small dots were needed (e.g., when only passive components exist on the assembly). However, data from a recent study suggest that metal stencils also are capable of printing variable dot heights through a single-thickness foil⁸. In most cases, either stencil material will provide acceptable results.

Stencil Design

Perhaps the most challenging part of the adhesive printing process is the stencil design. However, as with solder paste printing, aperture design only needs to be completed once for each part geometry and can be repeated wherever that part is used. Several patterns of adhesive deposition can be used to fix parts during wave solder. For two-pad devices, the "double dot" or "slot" design is most widely used⁹.

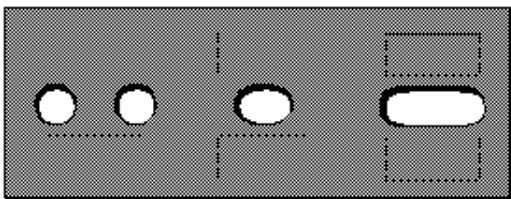


Figure 6. Deposition patterns for two-pad devices.

For higher standoff devices, arrays of larger dots are recommended. Circular apertures with aperture internal surface area roughly equal to the exposed substrate surface area, will produce the highest dot heights.

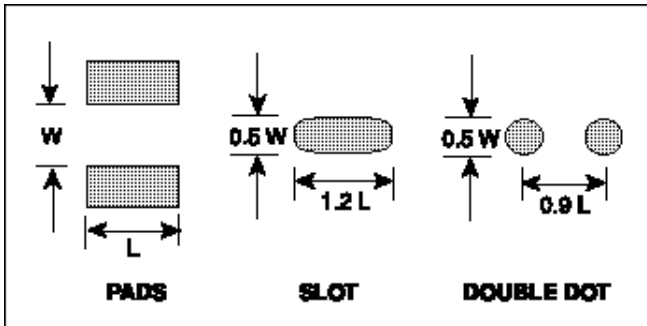


Figure 7.

Aperture Size

As explained above, the adhesive printing process can produce dot heights well above or below the stencil thickness. This makes the procedure of selecting a stencil thickness for adhesives quite different from that used for solder paste. When printing SMT adhesives, several different-thickness stencils can produce the same dot height. Conversely, the same thickness stencil can produce different dot heights. An understanding of the basic mechanics of adhesive printing and stencil release helps to explain how this is possible. For small depositions, adhesive is not fully released from the stencil when the stencil and substrate separate. Only a small amount of adhesive adheres to the substrate from the bottom of the filled stencil aperture. The rest remains in the top portion of the aperture. For these small apertures, the stencil thickness is unimportant as long as it remains thick enough to prevent the adhesive from releasing completely from the aperture.

For example, a 22 mil diameter aperture produces a 6 mil high dot with a 10 mil thick stencil. If aperture diameter were kept constant as the stencil thickness increased, there would be no change in the resulting adhesive deposit. A 12 mil stencil or 20 mil stencil would still produce the same 6-mil-high dot. Apertures in the stencil that produce dots close to, or greater than, the stencil thickness would be affected by a change in the stencil thickness because adhesive is releasing entirely from the aperture. These apertures would produce higher depositions if the stencil thickness were increased. In other words, the thickness of the stencil is determined by the highest dot height required. Choosing a stencil thickness also is adhesive dependent. Therefore, it is important to design the stencil according to the ability of a specific adhesive to print dots of adequate height and coverage as required by the specific application.

Stencil Thickness

As previously mentioned, the stencil thickness should be determined by considering both the highest dot height needed in conjunction with the rheology of the chosen adhesive. In most cases, dot heights should be about 1.5 to 2 times the component standoff height. With a printable adhesive that has the proper rheological properties, most passive components can

be accommodated with a stencil whose thickness is 6–8 mils (either plastic or metal). For SOIC's, a 10 –12 mil-thick stencil may be necessary. These are minimum thicknesses. Thicker stencils have been used with good results. In fact, some stencil manufacturers are recommending the use of very thick stencils (up to 1mm or 0.040") to accommodate all component types. Printing through and cleaning very small apertures in thicker stencils may be a problem. Also, some flexibility will be lost with plastic stencils.

Squeegee Blades

For adhesive printing, the selection of an appropriate squeegee blade is less critical than for printing paste. Unlike paste printing, the object is not to create flat-topped deposits, with heights equal to that of the stencil. The best adhesive printing results typically have been achieved with a polyurethane squeegee (90 durometer). The polyurethane “pushes” the adhesive down into apertures, helping to ensure full aperture fill and contact to the substrate. The “scooping” effect, common in solder paste printing, does not cause problems when printing adhesives because the adhesive deposit typically is pulled into a peak as the stencil releases.

Metal blades also can be used, but have been reported to cause undue wear on plastic stencils. The stencil manufacturer should be consulted regarding the use of metal blades. In some cases, plastic stencil manufacturers may provide special blades to be used with the plastic stencil. However, these blades may not work as well as do standard, polyurethane blades. Polyurethane blades can be used on any stencil type, regardless of whether special blades are offered.

Stencil Printers

Any stencil printer capable of depositing solder paste for fine pitch SMT assembly can be used for adhesive printing. In some cases, semi-automatic equipment may be adequate.

The most important feature of the printer is its ability to form a programmable “snap-off” or printing gap between board and stencil. The printer also should be able to perform a controlled separation of stencil and substrate. For these reasons “clamshell” type printers are not recommended. A vision system is encouraged, but the alignment requirements for adhesive printing are more relaxed than those of fine pitch solder paste printing. Other features of the printer (speed, automation, etc.) should be chosen to fit the needs of the production environment.

Printer Set-up

After the adhesive has been chosen and the stencil designed, the stencil printer must be set up for the best possible adhesive deposition. Printer setup is similar to that used in solder paste printing, with a few exceptions. For high viscosity adhesives, a large snap-off or printing gap (0.030" – 0.080") is recommended, helping to eliminate voids in the adhesive deposition due to air trapped in the apertures. For lower viscosity adhesives, a contact print (no snap-off) is recommended as lower viscosity materials can fill the aperture more easily.

Squeegee speed is largely dependent upon the adhesive. Lower viscosity adhesives typically can be printed faster. Some low viscosity adhesives print well at 8"/sec., while some high viscosity adhesives must be printed as slowly as 0.5"/sec.

As with squeegee speed, the optimum squeegee pressure is adhesive dependent. High viscosity materials require more pressure to print than do low viscosity materials. Also, more pressure may be required at higher squeegee speeds. The minimum pressure should be that which wipes the surface of the stencil clean of adhesive. A clean wipe should be seen over the entire area of the substrate, although some adhesive is always left behind in unsupported areas of the stencil.

For polyurethane blades, 5–10% more pressure than clean wipe pressure may be needed to ensure good aperture fill and contact of adhesive to pads. The intrusion of polyurethane blade material into apertures seems to help the aperture fill completely. For metal blades 10 – 20% more pressure than clean wipe pressure may be needed, since metal blades do not penetrate the apertures.

Squeegee downstop should be set at the minimum value allowable for complete squeegee pressure to be exerted on the board. For polyurethane blades, a downstop of 0.040" – 0.060" is recommended. For metal blades, downstop depends on the flexibility of the blade. A more flexible, thin metal blade (typically about 0.010" nickel plated steel) requires 0.070" – 0.090" of downstop, while a rigid metal blade might require as little as 0.040". If downstop is set too low, the ability of the squeegee blade to wipe the stencil clean will be impaired and a thin film of adhesive could trail behind the blade, regardless of the amount of squeegee pressure. If the downstop is set too high, a deformation or "coining" of the stencil could occur around the edge of the substrate after several squeegee strokes.

The separation of the board and stencil after the completion of the print stroke is crucial to the adhesive printing process. Because this parameter is adhesive-dependent, some experimentation may be necessary to optimize the separation speed and distance. Stringing of adhesive and/or inconsistent dot heights could result if the optimum settings are not chosen.

Process Management

Minimal process management is necessary if the printing process has been implemented correctly. Unlike solder paste, the printing characteristics of printable SMT adhesives do not change after a few hours on the stencil. The stencil life of most printable adhesives is measured in days. This means that the stencil does not have to be cleaned as often as with paste. Of course in any printing operation, the stencil will eventually need to be removed and thoroughly cleaned. For 24-hour printing operations, where a stencil is used continuously, cleaning is only necessary every 2–3 days. If a stencil is changed-out, it should, however, be cleaned immediately. The same rules for stencil cleaning apply for squeegee blades. Hence, the adhesive printing process is not affected by pauses in the printing cycle. Even after pauses of several hours, printing can resume immediately.

Periodic wiping of the stencil underside typically is not necessary when printing adhesive. This appears to be particularly true of plastic stencils. The improved gasket created by plastic stencils tends to minimize or eliminate the need for underside wiping. On any stencil, some adhesive material will "squeeze out" onto the underside of the stencil. This happens faster on metal stencils than on plastic stencils. In some cases, squeeze-out will cause a "halo" around the deposit, or two neighboring deposits will bridge together. In the latter case, the dots are most likely "double dots" for the same component and can be allowed to bridge. If halos start to form, periodic wiping may be necessary. Wiping can be performed

by hand with a lint-free wipe and a small amount of appropriate solvent or an automatic wiping system. On most printers automatic wiping systems are designed for solder paste and may not wipe adhesive effectively. The printer manufacturer should be consulted for details on the wiper's capabilities and its compatibility with solvents suggested for use with adhesives.

Adhesive Management

Most SMT adhesives are formulated, mono-component epoxies that must be stored refrigerated or frozen. Cold shelf life varies among adhesives, but most are between 6 and 12 months. If adhesive is used within a few weeks of delivery, room temperature storage may be acceptable. In preparation for printing, sufficient time should pass to ensure that the adhesive is completely thawed before printing. Thawing should always be done at room temperature.

Replenishing adhesive on the stencil can be performed either automatically or manually, depending upon the capability of the printer and the availability of the adhesive in appropriate containers. Most adhesive manufacturers offer adhesive in containers compatible with automatic replenishment systems. Although adhesive may be available in an appropriate container, most automatic replenishment systems are designed for solder paste. Printable adhesives are substantially more viscous than are solder pastes and may be difficult to expel from the container.

Cleaning up after printing SMT adhesives is relatively simple. A solvent, compatible with the adhesive, squeegee blade material, and stencil material must be used. Some of the most commonly used solvents for solder paste printing are incompatible with printable adhesives. Isopropyl alcohol and acetone are not recommended as they will dry out the adhesive or facilitate its curing, making it difficult to remove from stencil apertures. The stencil must be cleaned thoroughly as even a small amount of adhesive, allowed to harden inside the apertures, could render a stencil useless.

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