ISSUES FOR THE PRACTICAL PRODUCTION USE OF DISPENSING TECHNOLOGIES

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Introduction

The Process Engineer faced with making decisions about dispensing faces a difficult task. While there are volumes written about solder paste and component placement, dispensing in SMT applications is relatively undocumented. Testing adhesives routinely involves methods and equipment inaccessible to the average Process Engineer. Each adhesive has a set of characteristics that may lend itself to the requirements of the assembly or may not. There is relatively little written about how to select adhesives for specific requirements. Most often an approved adhesive is a "one size fits all" solution. There are also a variety of dispensing alternatives and specialized tooling available. There is relatively little written about the merits and demerits of each alternative. The various options available all have merit. Each may be the best or the worst solution for the requirements at hand. Too often the dispensing tool selected (End Effector) is also a "one size fits all" solution. Understanding the alternatives greatly aids in avoiding a haphazard selection. There are 3 areas where a working understanding and good working knowledge can be put to good practical use in managing the SMT adhesive process. The three areas where Process Engineers can effectively make decisions that create a great fit are: 1)End Effectors (pumps and other methods), 2) Materials and 3) The Equipment Platform. This paper explores the first two and briefly outlines the third. More detailed information is available on request from the authors.

Finding the Best Fit / Dispensing Alternatives

There are two back side assembly processes in wide use. The first is mixed technology where through hole and surface mount are both used. Mixed Technology boards have passive components such as resistors and capacitors mounted on the back side (with adhesive) and sent through the solder wave. The second method commonly seen is Double Sided Surface Mount. This method, also

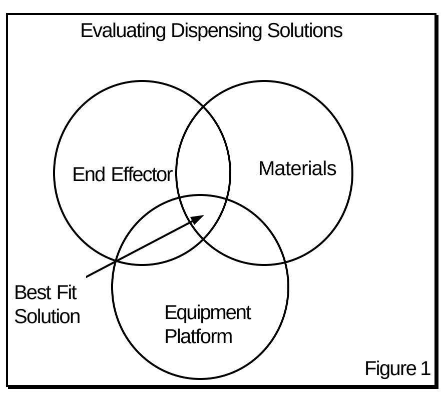


Figure 1

may have through hole components (normally connectors) but relies on surface mount components for the bulk of the requirement. Double Sided Surface Mount makes use of solder paste. There are high speed alternatives to dispensing: 1) Pin Transfer, and 2) Printing. Each of these has advantages and disadvantages. The specific selection of the best fit for the assembly depends on the materials, board layout, change over frequency and equipment issues.

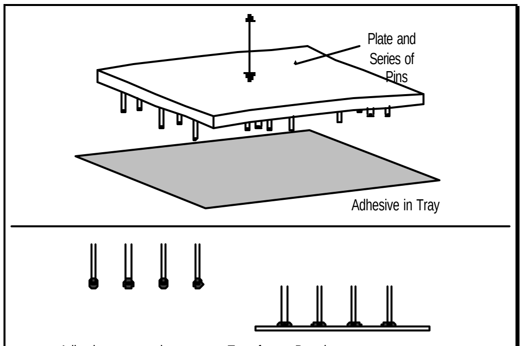


Figure 2

Pin Transfer shown here, is one of the fastest method of applying adhesive to PCB. Pin transfer enjoys the advantage of producing all dots at the same time. This method is able to keep up with mass placement lines. Being a fixed tooling method, very long runs of the same pattern ideally suit the Pin Transfer method. It is very common in Automotive applications such as car radio PCB production. Pin Transfer is well suited for long, large runs of mid-sized and large passive components. Pin Transfer suffers from several drawbacks. Including: Changeover, which is a concern in short runs, a unique plate and series of pins is required for each new pattern. These are expensive and inconvenient to set up frequently. The process requires a squeegee to level the surface of adhesives in a heated tray, then the pins are lowered into the tray and adhesive wets to these pins. The adhesive in the heated tray has a large exposed surface area. Adhesives absorb water over time and over exposed surfaces. Pin Transfer operations heat the adhesive to the 30 to 35^{o}C range. Adhesives tend to gradually cure at elevated temperatures and over time. The working life of the adhesives in pin transfer applications is a maximum of 6 weeks. Selecting the wrong adhesive can cut this time dramatically. The ability of the adhesive to wet in a repeatable and stable way depends on stable material properties. Small dots such as those required for 0603 and 0805 components are not easily produced. Routine handling can easily damage pins. No board stretch or rotation adjustments are possible with such fixed tooling methods. All adhesives wet differently and only a select few resist water absorption well enough to be reasonable choices. Higher viscosity adhesives require pin diameters of about 1:1 while lower viscosity adhesives require about a 1:1.2 pin to dot ratio. Viscosity changes over temperatures, age of the adhesive, batch to batch and with different adhesives. Pin Transfer technology trades flexibility and material availability for speed. Pin Transfer occupies an extreme position in the graph shown (figure 10) at the end of this section. Pin Transfer captures a very specialized segment of the market.

Printing, like Pin Transfer is very fast. Printing is currently enjoying a small resurgence. Printing itself, is well established and will continue to be a main line process. The recent change in the market for printing adhesives is due to some very clever techniques allowing for variable heights in one print. Thick film engineers, trying to print resistors, have known for years that it is very possible to print different thickness on the same board. With adhesive printing this traditional negative attribute turned into a positive and was actively developed. This technique has all the traditional advantages of printing. It is fast, conceptually simple, repeatable, and cheap. It is capable of small geometry and multiple heights. It is also quick to change over patterns. Different materials are easily adjusted with standard equipment. Printers now use fiducials to adjust for rotation. Unlike Pin Transfer plates and pins, Stencils are comparably cheap and easily available from a multitude of sources. Printing suffers some negative attributes. Like Pin Transfer, printing is a form of fixed tooling. Flexibility to add a dot or adjust a height without a tooling change does not exist. The adhesive is exposed to the air. This allows water absorption, and/or solvent loss. The squeegee introduces some air into the adhesive and is a problem because air expands during the curing. No board stretch is possible. Printing characteristics change with viscosity. Constant adjustments for 1 or 2 degree temperature variations are unrealistic. Room temperature (23^oC to 27^oC) operations vary widely enough to change the viscosity of the adhesive by as much as 30%, see figure 4. Cleaning of the stencil and squeegee requires manual involvement. It is widely known that many people develop dermatitis around SMT adhesives. Printing increases this exposure. While technically possible, printing solder paste and adhesives on the same side of a PCB is not reasonable in most assembly operations.

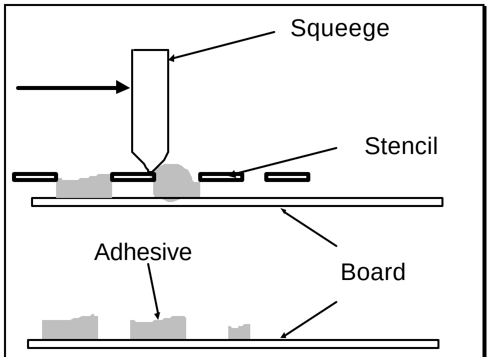


Figure 3

Currently the positive outweigh the negatives in many applications and this fuels this technique's growth. Printing can use a wider variety of materials than Pin Transfer. Printing is a very fast, fixed tooling technique. Printing is relatively inflexible compared to dispensing techniques described here.

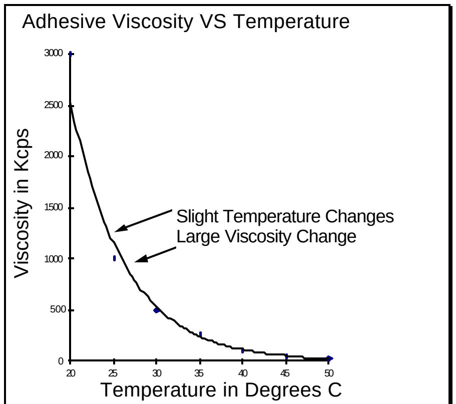


Figure 4

Finding the Best Fit / End Effectors for Dispensing. There are several competing technologies in the dispensing field. Each of these have positive and negative attributes making them suitable for some applications and not others. These technologies include 4 main, commercially available forms of End Effectors. These are: 1) Time Pressure (also called Air Over) 2) Archimedes Metering Values, 3) Piston Pumps, and 4) Ink Jet technology. All of these technologies have carved out a niche with the exception of the Ink Jet. The Ink Jet technology is new and still finding the correct balance of advantages and disadvantages. The other three technologies have very predictable characteristics even over the multiple suppliers of the commercially available examples. More information is available from the authors on request.

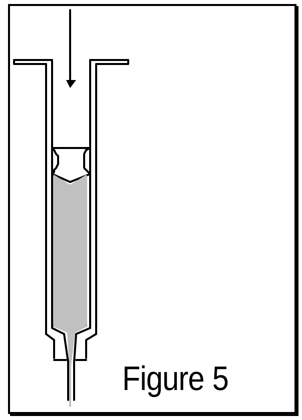


Figure 5

Time Pressure Systems, are the most widely available. This technology was the first to be introduced for SMT and is still the most widely accepted. These systems have seen more development over a longer time than any other dispensing technologies. Due to its age and level of development, Time Pressure has well defined advantages and disadvantages. Time Pressure allows the user to throw away the syringe and clean or change the nozzle quickly. This simple cleaning and maintenance approach lend this technology an advantage over all other approaches. It is conceptually simple and very reliable within its abilities. The main disadvantages have appeared as the chip shooter speeds have increased. Speed - As chip shooters continually increase speed the Time Pressure dispensers have gone from 10,000 dots per hour (dph) to rates of more than 40,000 dph. These speeds strain the ability of a pulse of air to respond quickly enough and repeatable enough to form consistent dots. Vision correction and temperature control are normally required to overcome this weakness. The Time Pressure technology derates as the syringe empties, shown in figure 6.

Very small dots for 0805, 0603 are inconsistent. 0402 dots are very difficult and not generally considered for general production use. As the weaknesses are further exposed through higher and higher chip shooter demands, this technology is stressed. Most of the growth in printing, Archimedes Metering Value (AMV) and Piston Positive Displacement Pumps (PPDP) come from the ranks of Time Pressure dispensers that could not keep up or show too much inconsistency. The Time Pressure systems are inherently slower than the other techniques outlined in this paper. Time Pressure is very flexible and can use a reasonably large variety of materials.

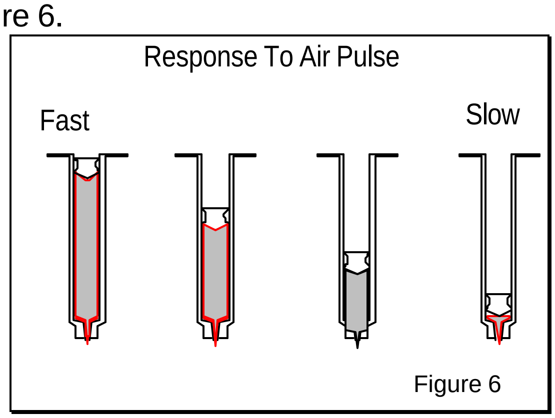


Figure 6

Archimedes Metering Value. The development of this pump type has been dramatic. At least four companies are involved in making this screw based type pump. The explanation of this pump over a period of years make it the best understood alternative technology. The advantages include compatibility with all but the most hostile materials. The dot size is related to the time the motor runs and the flow behavior of the adhesive. The screw has a clearance that allows most materials to pass without significant pump wear. The disadvantage is that cleaning required is greater than Time Pressure. The pump derates with dot size just as Time Pressure because the motor “on” time is related to dot size. In figure 7 the Archimedes screw is shown. The adhesive wraps around the screw and flows. The screw shears the material creating a flow rate out of the pump. The flow is dependent on the viscosity of the material. The biggest misnomer concerning this pump is that it is a positive displacement pump. Positive displacement implies that a set mechanical movement produces a set volumetric output. In this pump the mechanical rotation produces different outputs with different viscosities or different nozzle diameters. Viscosity varies with temperature, from batch to batch, over adhesive shelf life and from adhesive formulation to adhesive formulation. The market for this pump will continue to grow as it takes market share away from Time Pressure. It also has applications in pin & paste, dam & fill and underfill among other uses. The Archimedes Metering Value is faster than Time Pressure in most situations, but slower than the other approaches described here. Archimedes Metering Values are very flexible in dot size, filling operations and lines. The material usability in this pump is excellent. The Archimedes Metering Value is used with materials in the 100-1500 Kcps viscosity range.

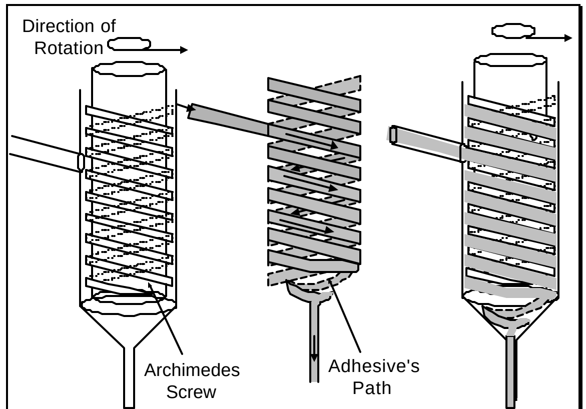


Figure 7

Piston Positive Displacement. This pump technology relies on a matching piston and cylinder. The adhesive fills a chamber in the open cylinder. The piston then seals the cylinder and forces the adhesive out the open port at the bottom of the cylinder. This volume is $\pi r^2 h$. This pump is true positive displacement as the mechanical movement (stroke) produces a set volumetric output. The advantage is : little to no

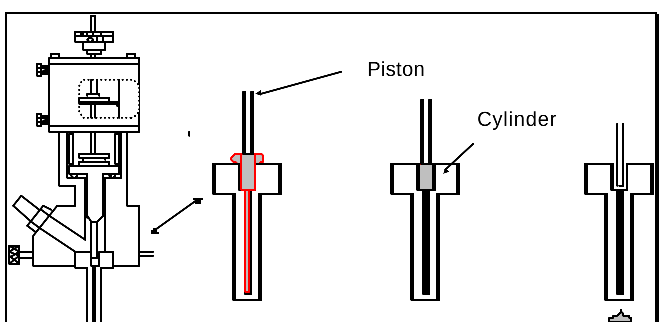


Figure 8

deration over dot size. A small or large stroke take identical time. Different materials normally come with widely different viscosities. The advantage of dispensing a set volume means that the viscosity differences do not effect volume. These two attributes; no deration for dot size and dispensing a volume regardless of the viscosity, create a very fast, accurate and repeatable combination. The disadvantage is that the cleaning required is greater than Time Pressure. It lacks programmable dot size control. The mechanical clearance between the piston and cylinder sometimes becomes a problem with materials having large particle sizes. The Positive Displacement Piston Pump is faster than Time Pressure or Archimedes in most situations, but slower than the fixed tooling approaches, within this article. Piston Positive Displacement Pumps can dispense a variety of materials with different viscosities. This pump is best suited for dot dispensing.

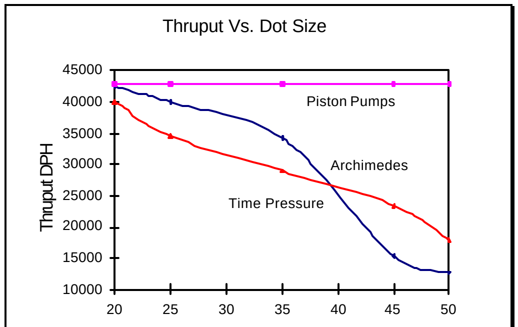


Figure 9

Adhesive Jetting Technologies. The use of this technology is new to SMT. As such the niche for this technology is still to be determined by the industry as a whole. The basic concept is to create a pressure wave through the material that forces material out a small opening with such force that it separates and a droplet flies out toward a board. The advantage is that the tooling never need travel in the Z direction. The Z travel is a significant source of time in the other systems. The dispense rate is very fast. The dots themselves are slightly shorter and have a mottled surface. The main disadvantages are; the mechanical issues are complex and cleaning requires disassembly. The unit requires a heater and takes about 20 minutes at start up. The Z height is a key factor in preventing satellites. One dot size is available at a time, adjustments are available only through “nozzle” change and require a ‘purge’ after such change. As the pump develops it may have some impact on the market. Adhesive Jetting is fast enough to keep up with the fastest placement methods. Adhesive Jetting is faster than the Time Pressure, Archimedes Metering Value and piston pump technologies. Adhesive Jetting is slower than Printing or Pin Transfer. Unlike any other option it produces one dot size at a time (although it can ‘multiple hit’ a single site). In this respect it is like fixed tooling. The materials usable in this pump are fairly limited. Long term data is currently being evaluated to establish the ideal manufacturing situations for the adhesive jetting technology.

Summary for Dispensing and Its Alternatives

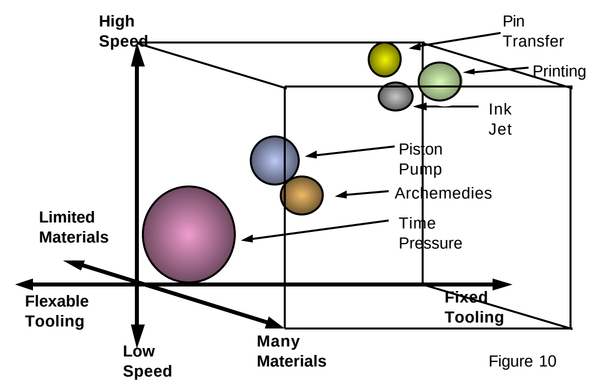


Figure 10

With the information above one should be able to understand the relative fit of each approach. All of the technologies have a set of positive and negative attributes that make them viable alternatives for specific SMT assemblies. Assuming the target assembly operation has a constant stable flow of roughly similar boards a "best fit" selection is possible. Each approach also has advantages over the others, making it potentially the solution of choice. All of these alternatives overlap each other in some areas. These make it possible to have more than one correct solution in many situations. In situations where the types of boards and requirements vary greatly, it would be ideal to have a number of the alternatives described above.

Finding the Best Fit / SMT Adhesives

While there are more than two dozen companies making dispensers, there are only 7 major suppliers of SMT adhesives. Within these 7 suppliers there are 15 adhesive formulations that account for the vast majority in common use. There are big differences between these various adhesives.

What is in them - filler, epoxy resins, hardener, rheology modifiers and die colors. The filler is normally fused silica. It could also be Alumna, Zerconica, glass or any other dielectric material. Its purpose is to be in a matrix with the epoxy. The thermal expansion of these fillers is low and the epoxy is high, the 2 materials bring the composite material closer to matching the chip and the board as well. The epoxy resin is basically the binder that holds everything together. It is a light weight material and is usually clear, or light brown liquid. These are the triggering component in the formula. The hardener in normally a solid. At some temperature it melts. When it is a solid it reacts very slowly with the epoxy resin. The adhesive is curing from the first day. This continues until it is totally solid. This can take 6 months, 6 days, 6 minutes or even 6 seconds. It is totally dependent on the rate of reaction between the hardener and the epoxy. This reaction is very quick in heat. The hardener liquefies and moves around the epoxy causing it to crosslink. Different harders have different reaction times. The two basic colors for adhesives are yellow and red. The adhesive without any die has a gray or amber color. The addition of the die mixes with the raw adhesive color and changes the final color. This makes light colors like white difficult to produce. Also the die "takes" to the adhesive differently over different die lots and raw material lots. Batch to batch variation is common. The color is mainly used for contrast against the PCB. Solder mask colors also vary from different shades of green to yellow and blue. The ideal color for your application depends on the contrast between the board and the adhesive. Rheology modifiers. - One of the most important attributes of adhesive is its flow behavior. The way the dot is formed, the shape and the speed are largely due to the Rheology of the adhesive. The most common modifiers are thickeners. Flow behavior is measured in a variety of ways but not very well explained. Most adhesives (maybe all adhesives) have characteristics not unlike ketchup. In way of illustration, picture this. When a ketchup bottle is opened and held upside down no ketchup flows out. If you hit the bottom of the bottle with the palm of your hand the ketchup breaks lose and flows out freely for a short period of time. The force it takes to make the ketchup flow is its yield value. Adhesives all have yield values as well

Evaluating Adhesives can be a real challenge. There are dozens of tests available. Of these the best developed are from the manufacturers of adhesives. However, there are two limitations on adhesive manufacturers. Few material manufacturers have 1) the equipment and the knowledge to test the most important attribute - Dispensing! The dispenser manufacturer rarely has the in-house material expertise and test equipment to completely test the full range of adhesives. The result is that many adhesive manufacturers, equipment suppliers and customers evaluate adhesives without understanding what testing is really relevant. The most important test is how it runs on the machine. Different materials do run differently. Universal has an on going program to test adhesives and evaluate characteristics important to dispensing.

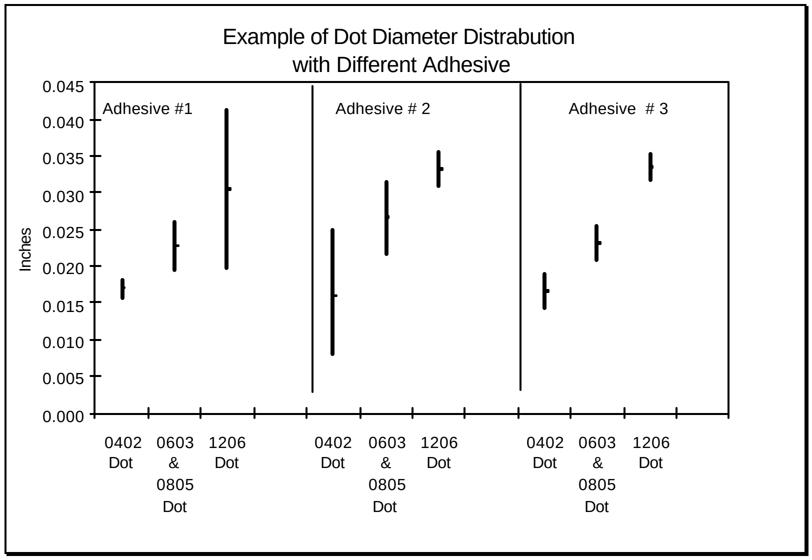
Rheology

Viscosity is a resistance to flow (stress). Adhesives have an internal order to them that resists deformation. When air pressure, or a mechanical stress is applied to the adhesive the internal order changes and the adhesive moves (flows). A force can push an adhesive lightly, and it will not move. More (force) and it will break away, starting to move (flow). The break away point, is the yield point. Higher yield points (or yield values) indicate more force is required. It takes more stress to change this internal order. Plasticity or elasticity is the memory in the material. The ability to resist flow is one quality, but as the force is reduced, the material may bounce back.

Date	Yield Point / Pa	ETA Pas	Targeted Speed	Quality at 45,000 dots / hour
1986	270.7	13.1	10,000 +	poor
1988-9	391.7	10.2	18,000 +	fair
1992	282.4	5.88	18,000 +	poor
1994	229.2	6.98	28,000 +	good
1997	261	4.2	40,000 +	very good

Table 1

In general, each manufacturer is refining and improving materials. The table above shows adhesives from one manufacturer over the last 10 years. Each adhesive in the development improved the basic performance of the material. These changes are in the materials, the material manufacturing process and the attributes for dispensing. This case the Rheology of the material shows an unmistakable trend. Each of these adhesives has been extensively tested. The newest version out performed all the others. The oldest is the most difficult to run and requires machine adjustments to make the material work acceptably. The formulations are closely related, reporting is nearly identical and the commercial issues (price) are unchanged. The first and easiest step in improving yields is to switch adhesives to the most modern offering from the current supplier.



One of the most surprising observations made in our studies is the number of 5 and 10 year old adhesives in wide use, having real processing difficulties. One of the first and easiest improvements that can be attempted is updating the current adhesive with the most up to date variant.

The next step is to run the adhesives against each other. In many cases defects rates can be lowered. However, adhesives have characteristics that allow them to perform differently in different cases. For example, defect rates and variation in dot diameter are closely related. In the following test data it can clearly be seen 3 adhesives have very different diameter variance patterns. The first adhesive is a excellent small dot material. The deviation around the mean actually tightens up as the dots get smaller. It is much less effective as a large dot

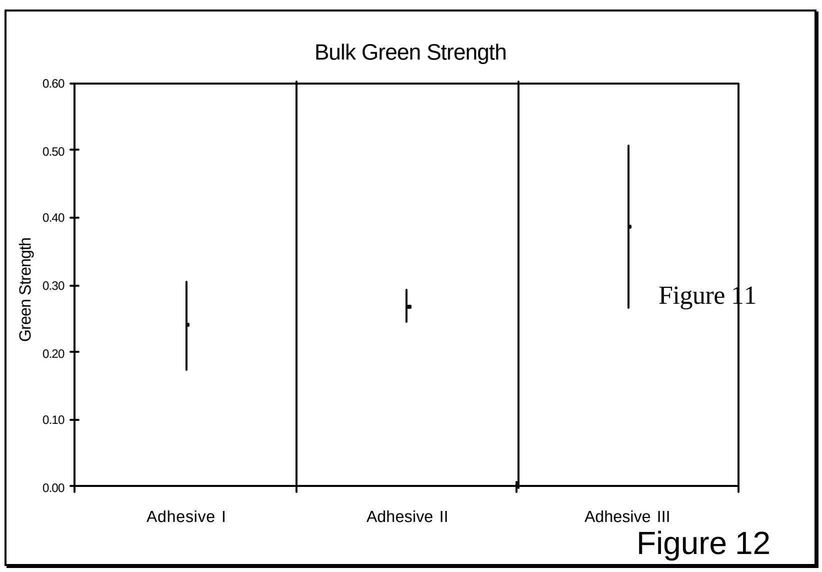


Figure 11

Figure 12

adhesive. The variations increase as the dots get larger. The center adhesive shows exactly the opposite effect, with good large dot performance but significant small dot variations. The last adhesive shown seems to solve the problem. The performance is even over all dot sizes. This adhesive is not the best choice for very small dots or large dots, but it is a better overall performer. Defects, such as stringing, generally track this pattern.

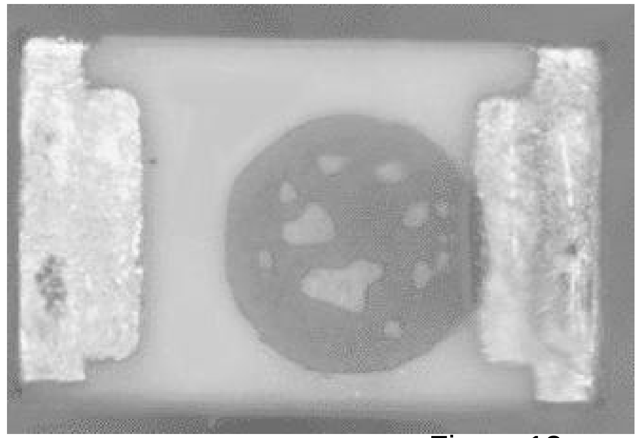


Figure 13

After selecting several adhesives that dispense well, the other attributes of the adhesives should be tested. These include green strength. Green strength is an example of a characteristic that some manufacturing environments demand and others don't. In all chip shooters the board moves. These movements can skew 'adhesive held' parts if the momentum is sufficient. There is a great deal of variation in the movement and the forces the board is exposed to. Also the mass of the parts and the amount of adhesive used vary widely. The following is an example of the tested values for bulk adhesive green strength for 3 selected adhesives. As can be seen the distribution and the average green strength vary greatly.

Figure 13 here shows another unfortunate characteristic of adhesives. Nearly all tend to absorb water. This example shows voiding under an 0805 capacitor. Water absorption lowers adhesion. The adhesion loss may vary and is related to exposure time and relative humidity. In extreme cases voiding can allow solder to create a conductive path from pad to pad effectively shorting the component.

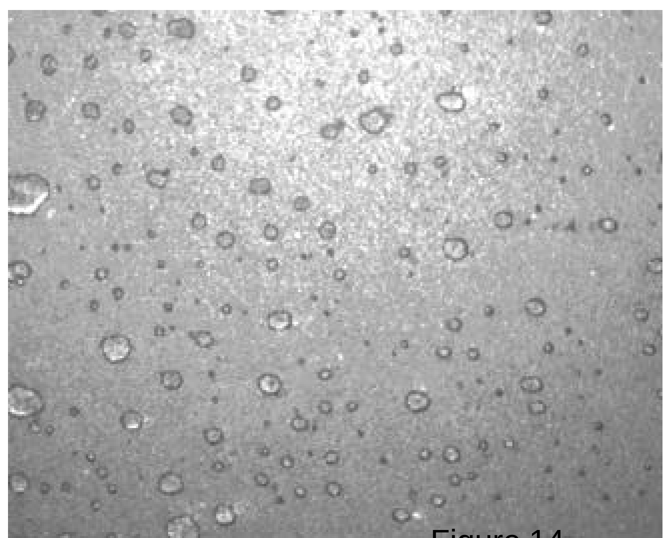


Figure 14

Voiding is caused by 3 things. These are 1) water absorption, 2) air entrapment, 3) solvent loss. In determining which of the three are occurring one can take the following approach. Water absorption, tends to be a problem for several reasons. Extreme exposure, or prolonged exposure tends to cure the adhesive along the surface exposed. This can be seen occasionally in production when the adhesive "dries out". In the most extreme cases the look of the adhesive changes from shinny to dull. Water absorption effects the adhesives' ability to wet and adhere to the component. The water within the adhesive must escape or be trapped during the curing process. The figure 14 shows water absorption and subsequent voiding during the cure cycle. Entrapped water is also a long term reliability concern.

When air entrapment occurs the weight of the adhesive does not change. Air entrapment can be a problem because air expands during the curing cycle at a much faster rate than the adhesive. One can get a growing pocket of air that will lower adhesion, skew the part or provide a place for flux to escape the cleaning process. There was some limited air entrapment in all samples tested. Air entrapment occurs during the manufacturing process or the deposition process. Solvent loss also contribute to voiding. Several of the samples tested seem to have solvents. Solvent loss can be detected through a weight loss over time.

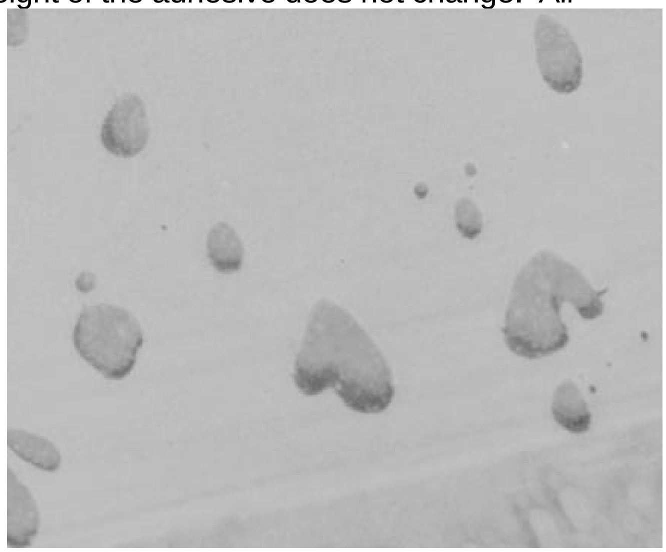


Figure 15

Summary for SMT Adhesives

Other characteristics that should be tested include cured adhesion at elevated temperatures (like those seen during reflow) and particle size. Many of the tests actually show that most adhesives perform similarly. Only those tests that are relevant to the manufacturing process and show differentiation for the specific application are useful. At the time of this writing several tests are being performed and several other substitute testing methods, suitable for use on the production floor, are being studied. The goal is to predict the dispensing attributes from testing. If the reader is interested in more information please contact the authors.

Best Fit Platform Equipment

The final step for the Process Engineer is the evaluation of the supporting Platform Equipment. While beyond the scope of this article the following issues should be explored. Figure 16.

Conclusion

In finding the best fit solution companies and process engineers need to understand the alternatives. There are large numbers of cases where simple changes in adhesives, or better selection of the disposition method can make major improvements in the overall performance. The best fit solution requires the Process Engineer to understand 1)End Effectors (pumps and other methods), 2) Materials and 3) The Equipment Platform.

Base Platform Equipment Features
Positioning System Accuracy and Repeatability
Control Architecture
User Interface
Communication Abilities
Board Handling
Vision Abilities, Fiducials
Data import
Training
Maintenance Requirements
Spares Availability, Service
Reconfigurability and Convertibility
Other Special Features

Future Work

Work is ongoing to better define the statistical differences between End Effectors. Additional information concerning End Effectors is available. Adhesive testing is also ongoing. Several 'simple' tests are being studied for production floor use. Additional information is available on request.