

Conductive Adhesive Dispensing Process Considerations

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Abstract

Dispensing conductive adhesives in an automated factory environment creates some special challenges. A robust production process starts with understanding the adhesives in their fluid state and which important parameters must be controlled. Developing this understanding requires experience with a large number of materials and valves over time. Common uses of conductive adhesives in surface mount applications, die attach applications, and gasketing are addressed. As vendors of dispensing equipment, the authors see a constant stream of such applications. Dispensing requirements, techniques, and equipment resulting from this experience are discussed. Guidelines for optimizing quality and speed are given.

Fluid Characteristics of Conductive Adhesives

Conductive adhesive fluids consist of two basic components: solid fillers and liquid adhesive. The fillers conduct electricity (and often heat) and are metal or metal-coated particles. The fillers are suspended in a fluid that, when cured, act as an adhesive and may have other mechanical characteristics favorable to their end use, such as shrinking slightly to promote electrical conductivity among the particles.

There are two basic types of conductive adhesives: isotropic (conducts electricity in all directions) and anisotropic (conducts electricity in a preferred direction).

Filler Types

Silver and sometimes gold, usually in the form of flakes, are common fillers for isotropically conductive adhesives, adhesives that conduct electricity in all directions (Figure 1). Flakes are favorable shapes to promote particle-to-particle contact and provide electrical conductivity. Relatively soft metals promote good contact by deforming during the adhesive shrinking that takes place during cure. Soft metal fillers are also prone to "coining," where the particles press together to form large lumps.

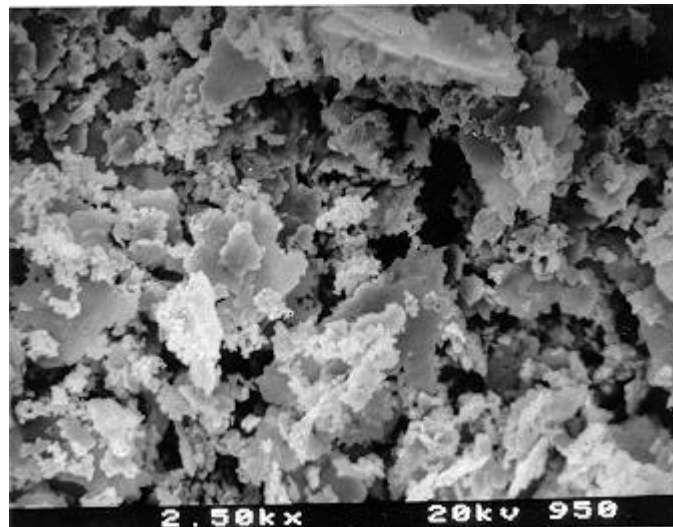


Figure 1. Silver flakes used in isotropically conductive adhesives (courtesy of Hereaus Inc.).

Silver and gold are also used in anisotropically conductive adhesives either as special shaped particles or to coat polymer spheres (Figure 2). These spheres or particles make an electrical connection between two contacts that are brought in close contact with each other. These types of fillers can be somewhat fragile if exposed to grinding or excessive shear during the dispensing process.

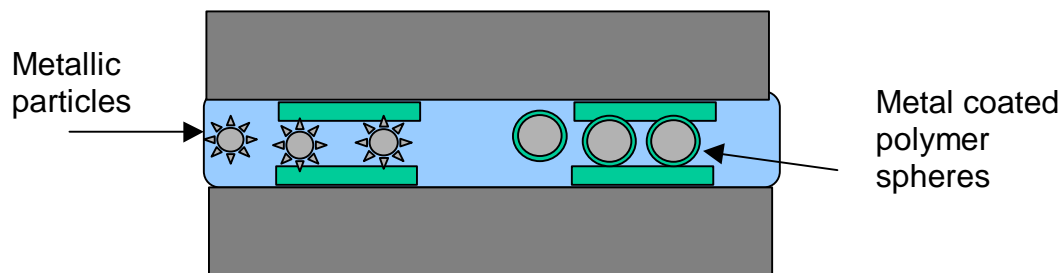


Figure 2. Example of two anisotropically conductive adhesives.

Liquid Adhesives

There are many different types of liquid adhesives that are used in dispensing and can be grouped according to their chemistry. While there are many variations of each type, the most common adhesives used are thermosetting; two-part epoxies (usually pre-mixed and frozen), materials with phase change hardeners, acrylics, and silicones (which can also be, UV cure, moisture cure, or two-part cure). It is beyond the scope of this paper to discuss advantages and disadvantages of the different chemistries, but it is important to understand some of the characteristics that can affect the dispensing process.

Regardless of the adhesive type, most fluids exhibit the following characteristics, which, to some extent, affect the dispensing process:

- Thixotropic (shear thinning)
- Viscosity ranging from 5,000 cps to 100,000 cps

- “Stringy” (drawing out a long tail when pulling the needle away from dispensed fluid).
- Viscosity sensitivity to temperature (except for silicones).
- Sensitivity to moisture.

Other characteristics specific to the different adhesive types are:

- Two-part epoxies:
 - Pre-mixed and frozen at $-40\text{ }^{\circ}\text{C}$ ($-40\text{ }^{\circ}\text{F}$) to extend shelf life
 - Viscosity is usually temperature sensitive, and can change an order of magnitude per $10\text{ }^{\circ}\text{C}$ temperature change.
 - Pot life can be short at room temperature (8 hours to several days).
 - Viscosity can change significantly at room temperature as a function of time.
- Adhesives with phase change hardeners:
 - Pot life ranging from several months to a year at room temperature.
 - Pot life shortened significantly by elevated temperatures.
- Silicones:
 - UV cures sensitive to light and some metal alloys.
 - Can absorb air in solution, making it compressible.

Dispensing Patterns and Techniques

There are, of course, many varied uses of conductive adhesives. The following general applications are discussed in this paper:

- Surface Mount Applications (or similar applications requiring small dots)
- Die Attach Applications (or similar applications requiring a bond between two parallel plates)
- Conductive Gasketing for electromagnetic shielding.

Surface Mount Applications

Conductive adhesives, usually those with two-part epoxies, are often used as a replacement for solder paste. It is beyond the scope of this paper to discuss the reasons why one might use conductive epoxies in this manner, but it is assumed that the reader has already determined that conductive epoxies are advantageous over solder paste for their application.

The adhesive acts as both the conductor and the structural element that holds the device to the board. Figure 3. shows a typical surface mount device (0805 component). There are many standards and design guidelines for surface mount devices, but most do not include design specification for use of conductive adhesives (References 1, 2, and 3). One can extend the design rules for fillet shape and pad coverage used for solder connections, but ultimately, the device must meet the requirements of the specific application. In general the adhesive must:

- Provide electrical contact
- Provide structural adhesion
- Not create electrical shorts to other contacts or devices.

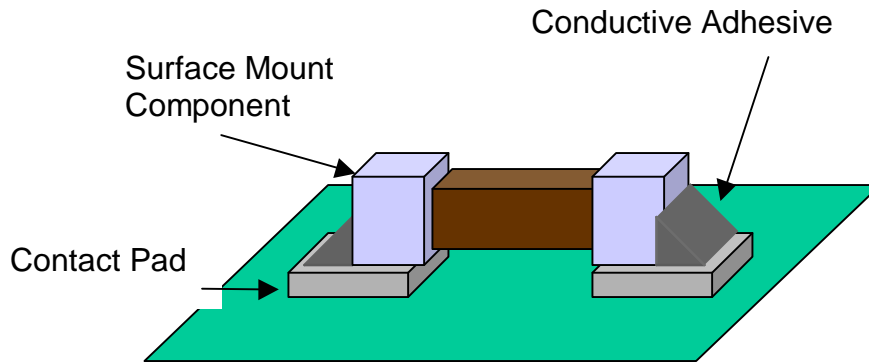


Figure 3. 0805 surface mount component

The small dots required for this type of application are placed with a needle. Some of the requirements include:

- The dots must be placed on the pad with sufficient placement accuracy to meet the above requirements (varies by component, but +/-125 microns is sufficient for most applications) .
- The proper volume of fluid must be dispensed to create a reliable connection (+/- 20% by volume is sufficient based on the successful use of most dispensing systems in production).
- The dispensing equipment must have sufficient capability to prevent “tails” that can cause electrical shorts.

There are some common dispensing parameters that affect dot dispensing. The dispensing process takes the following form for needle dispensing (see Figure 4.):

1. The needle is brought to the dispensing position by the dispensing robot (position is determined by any number of alignment methods).
2. The material is extruded through the needle by pneumatic actuation or some type of pump. This may occur while the robot is moving to the dispense position.
3. The material is allowed to “tack” by including a short dwell time in the dispensing position (optional).
4. The needle is lifted straight up to a retract position to allow any string or tail to fall directly on the dot.
5. The needle is moved to the next dispensing position.

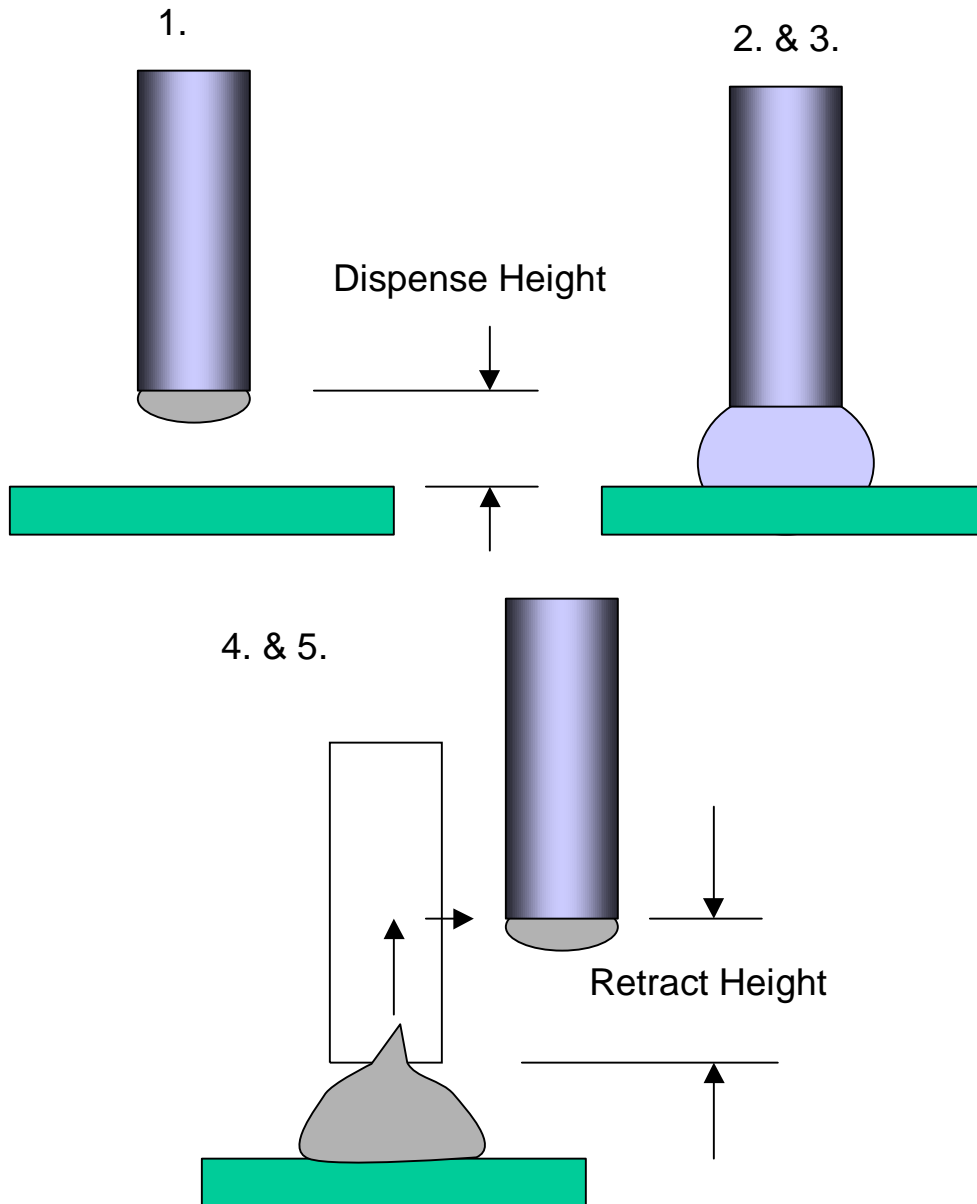


Figure 4. Dot dispensing sequence

Many factors affect dispensing quality, including needle choice, dispense height, and retract height.

Choice of Needle

The choice of the dispensing needle is critical to successful dot dispensing. It is most important to understand the relationship between needle diameter and dot size. There are many dispensing needles/tips/nozzles available on the market. Table 1. gives a description of the most popular single-orifice types. Multiple orifice dispensing tips are also available for special applications.

Needle Type	Comments
All-metal needle	This type of needle consists of a metal hub with a luer lock or custom fitting and a small metal tube, usually 6 mm to 13 mm long. Price can vary from a few dollars to over \$100, depending on degree of customization and quality. Many have a chamfered tip to reduce the outside diameter of the needle to aid dispensing (see text below). Metal needles are good for conducting heat when needed to control stringing.
Plastic hub needle	A very popular type of needle has a plastic hub with a standard luer lock fitting and a metal tube. These can be purchased for a fraction of the cost of all metal needles, are available with chamfered tips, and can be heated for small dot dispensing if required. They are often dismissed as being inferior due to low cost, but can be used successfully in precise applications.
Plastic hub with plastic shaft	Similar to the plastic hub needle, the shaft is made from a flexible plastic. Flexibility of the shaft can create problems in positioning for automated systems
Plastic cone or taper tips	Tip gently tapers from a luer lock fitting to a small diameter. They are usually used for applications where low flow restriction is required. Plastic cones or taper tips are very inexpensive and rigid enough for good placement accuracy. They are not good for use with heated materials because the plastic does not conduct heat well.
Metal cones	Usually shorter in length than plastic cones. They conduct heat well, but are often expensive. Metal cones are most often used in high flow rate applications.
Table 1. Dispensing needles, tips, and nozzles	

After the adhesive is extruded through the needle, the adhesive must adhere to the dispensing surface. When the needle pulls away, some material stays with the needle and some stays on the dispensing surface. It has been suggested that the dot size diameter should be at least 2X the inside diameter of the needle (Reference 4). While this is certainly a reasonable rule for many materials, it may prove impractical for many conductive adhesives. The particle size of the conductive adhesive may preclude the use of smaller diameter needles. In general, it is very difficult to get a consistent dot diameter that is smaller than the outside diameter of the needle. If the wetted area on the needle is larger than the wetted needle on the dispensed surface, the fluid tends to stay more with the needle.

As mentioned in Table 1, chamfered needles can help with dispensing small dots. Figure 5. shows a chamfered needle tip. Chamfering the tip effectively reduces the wetted outside diameter to the inside diameter of the needle. Table 2 lists the inside and outside diameter of common needles gages used in automated dispensing.

Gage	ID (mm)	OD (mm)
18	0.84	1.24
19	0.68	1.06
20	0.58	0.88
21	0.51	0.81
22	0.41	0.71
23	0.33	0.63
25	0.25	0.55
27	0.20	0.40
30	0.25	0.30
32	0.1	0.225

Table 2. Needle sizes

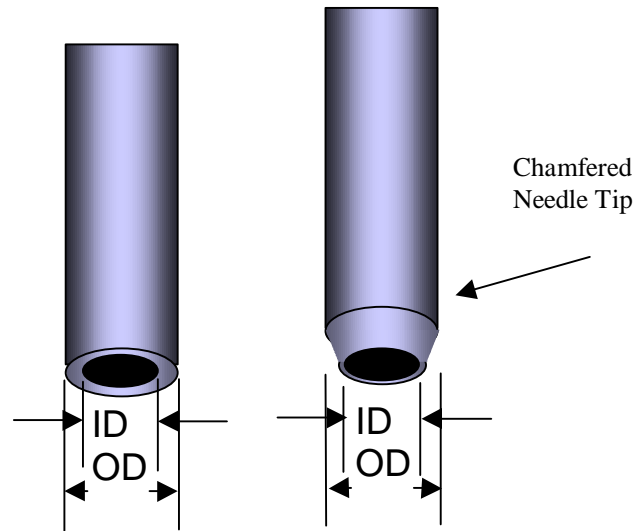


Figure 5. Needle inside and outside diameters.

Dispense Height

The dispense height should be low enough to allow the fluid to contact the surface with sufficient area so that the fluid is pulled from the needle when the needle leaves the dispensing position. The dispense height should be high enough to allow formation of a reasonable dot shape. Dots with high aspect ratios (ratio of height to width) are desirable because the fluid forms a good fillet with less chance of flowing off the pad when the component is placed. Many relationships of dispense height to dot diameter or volume have been discussed in the industry, but none have been adopted universally because of the vast differences in fluid rheology.

A good starting point for dispense height is to use $\frac{1}{3}$ to $\frac{1}{2}$ the desired dot diameter. If the dots appear flat, the dispense height can be raised. If the dot volume and diameter appear to vary greatly from dot to dot, the dispense height should be lowered. If using a "fixed height" dispenser, increasing the amount of material has the same effect as lowering dispense height.

Retract Height

It is important to have sufficient retract height to break the tail off the dot. Internal cohesion and surface tension holds the liquid together. Moving the needle up creates elongation shear stress in the fluid and decreases the fluid cross section. When the force created by elongation divided by the cross section creates sufficient stress, the fluid breaks into two pieces. (This ignores stress created by the weight of the fluid or the force induced stress from accelerating the mass of the fluid. The combination of viscosity and specific gravity of most conductive adhesives makes these latter factors insignificant.)

With this model in mind, one can easily see that increasing retract speed can reduce the length of the "tail" since the fluid breaks off shorter. There can be several advantages to increasing retract speed:

- The automated process runs faster.

- Tailing is reduced.
- Dot sizes are more repeatable.
- Retract height can be reduced, potentially speeding up the process.

Increasing retract speed can have drawbacks:

- It can aggravate the effect of improper dispense height and insufficient dwell.
- The fluid can break into more than one piece, creating “satellites” of conductive material that land in unintended areas.

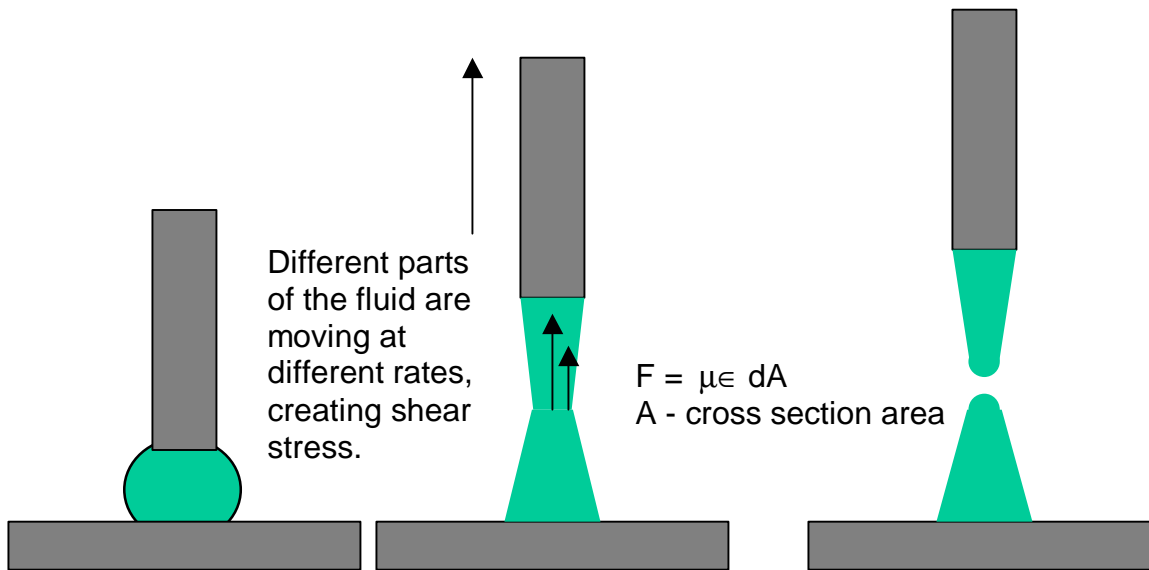


Figure 6. Break off of fluid after dispense.

Die Attach Applications

Die attach applications with conductive adhesives are accomplished with the following three objectives:

1. Mechanically attach the die to a substrate.
2. Create a thermal path to the substrate for heat generated by the die.
3. Create an electrical path for a ground plane connection. (If an anisotropic adhesive is used, IO connections can be made to the substrate.)

Figure 7 shows the components of a die attach package (bond wires or electrical connections are omitted). The die attach process takes the following steps:

1. The fluid die attach adhesive is dispensed on the die pad in a pattern (similar to that shown in Figure 8). This can be done on a pick and place machine, but an automated dispenser is often used to improve process speed at a relatively low cost.
2. The die is placed on the substrate with a pick and place machine. As the die is placed, the adhesive spreads to cover the die attach pad. A force transducer is normally used to measure and limit the placement force.

3. The adhesive is cured, usually with heat.
4. If this is a wire bonded package, wire bonding, encapsulation, and/or sealing take place.

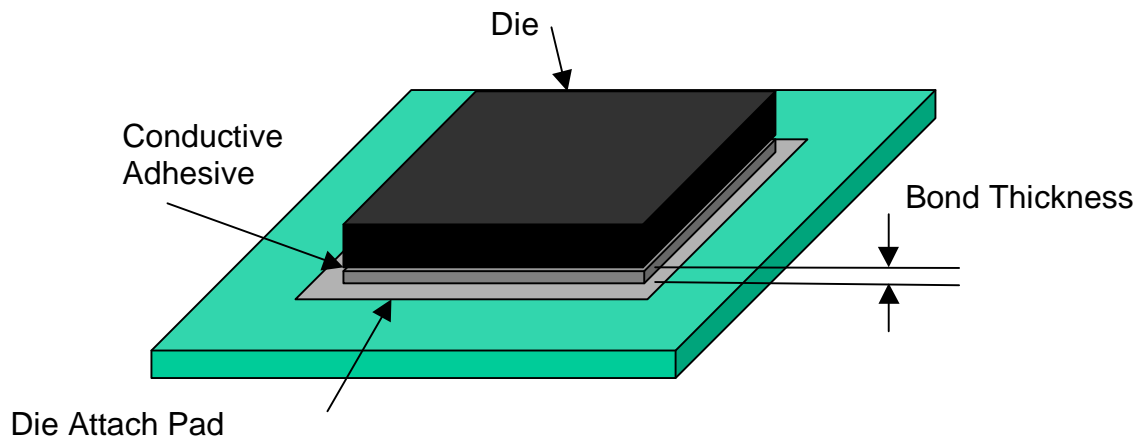


Figure 7. Die attach application

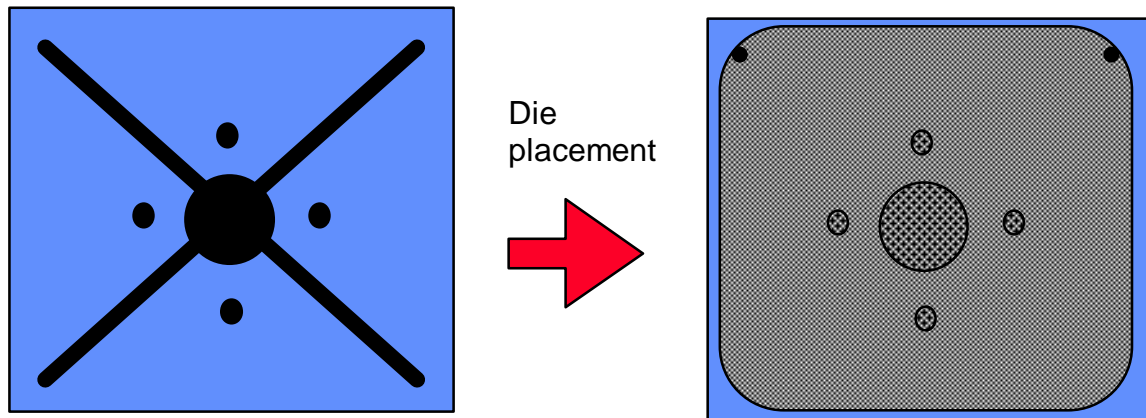


Figure 8. Die attach pattern and spread during placement.

The following package requirements are typical for this process:

1. A thin bond line is desirable to reduce electrical and, more importantly, thermal resistance.
2. Wire bond pads around the perimeter of the die attach pad create a “keep out” zone for the conductive adhesive for obvious reasons. The bond area must be limited to be within this “keep out” zone.
3. The adhesive layer must be void free to maximize strength, thermal conductivity, and electrical conductivity. This means that there must be enough material to cover the area under the die and all the air must be pushed out as the material spreads.

The amount of material to dispense is a simple calculation:

Adhesive Weight = Specific Gravity X Bond Area X Bond Thickness

It is important to note the relationship between the amount of material and the bond line thickness. Bond line thickness is controlled by the placement force. Placement force is a function of die size and fluid rheology. Keeping that in mind, the following conclusions can be drawn:

- If the amount of material dispensed changes, the bond area will change.
- For a given amount of material, if the bond line thickness varies, the area over which the fluid spreads varies by the above relationship.
- If the fluid rheology changes (viscosity and/or thixotropic index), the bond line thickness will change because the material will spread differently for a given placement force.

Therefore, it is very important to control the amount of fluid dispensed, the fluid rheology, and the die placement force to meet the above requirements.

Dispensing Patterns

Die attach patterns can vary from simple dot dispensing for small die (<5 mm on a side) to complicated patterns of lines and dots for large die as shown in Figure 8 (>20 mm on a side). The challenge for larger die is to have the adhesive spread to assume the shape of the die during the die placement process. There are many approaches to this problem and it can consume considerable process engineering time for critical applications. The following approach has been successful in the author's experience:

1. Determine a center dot weight that will form a circle that spreads to the edge of the die at the desired bond line thickness. For rectangular die calculate the weight of a line which will form an ellipse that spreads to the edge of the die. The dispense line length for a rectangular die should be the difference between the long and short side lengths (for a 10 mm x 15 mm die, the line length will be 5 mm).
2. The remaining material weight should be distributed between four lines that radiate from the center dot and go approximately 2/3 of the way to the corner (see Figures 8 and 9). For rectangular die, the lines should go about 2/3 the way from the end of the center line toward the corner at an angle of 45 degrees from the center line. A typical die attach pattern for a rectangular die is shown in Figure 9.
3. Dots, or other short lines, can be added to fill out areas that are not full covered. Lines should always radiate from the center. Dots should be arranged to avoid trapping air. If adding dots or lines, make sure to reduce the center dot or line weight to keep the overall material weight constant for the desired bond line thickness. Figure 10 shows an example of a specific die attach application.

This method may require fine tuning for specific applications. Very thin bond lines can create overly rounded patterns as they spread. It is best to keep the dispensing pattern as simple as possible to keep the dispensing process fast. Complicated patterns can slow down the dispensing process.

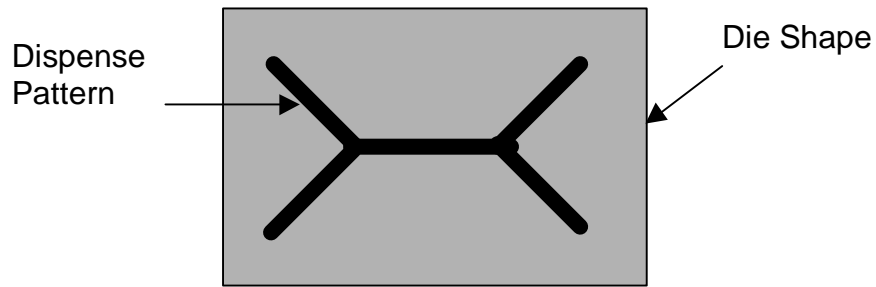


Figure 9. Die attach dispense pattern for a rectangular die.



Figure 10. example of large die attach application.

Line Dispensing Parameters

For the best process control, the lines must be dispensed consistently. When dispensing lines with automated equipment, the following parameters can be used:

- Turn on delay. The valve or pump is turned on at the beginning of the line prior moving the needle. This allows fluid from the needle to reach the dispensing surface and “tack” before motion begins. If no delay is used, the beginning of the line may be thin and start unevenly. If the delay is too long, the line will be thick at the beginning.

- Dispense height. As a rule of thumb, dispense height should be about ½ the width of the line. Adhesives tend to have a preferred aspect ratio of width to height usually ranging from 2 to 4 (the line is wider than it is tall). For a given line density (weight per unit length) there is a “natural” height of the fluid. If the needle is below the natural height for the line density, the needle will tend to plow through the fluid and give poor line quality. If the dispense height is too high, the line may be wavy and be given to excessive stringing.
- Shut off distance. Most automated dispensers can be programmed to turn off the fluid flow before the end of the line is reached. This allows the material to be pulled off the needle and can control the line thickness at the end of the line.
- Backtrack height and length. When dispensing a line, the needle can be raised slightly (backtrack height) and made to retrace its path (backtrack length). The purpose of these features is to control where the “tail” lands when dispensing with stringy fluids.

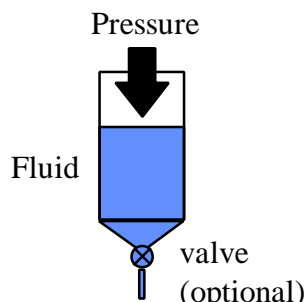
Gasketing

Conductive adhesives are sometimes used as a gasket material in radio frequency devices for shielding purposes. All of the above information about dispensing consistent lines applies to dispensing lines for form-in-place gaskets. Additionally, it is important to control the following two parameters:

- Dispensed volume or weight is more important to control than line width. A gasket is usually squeezed between two surfaces and the area it covers after spreading will be controlled by its volume.
- For large gaskets, it is important to control dispense height carefully by robotic control or by good fixturing techniques. If dispense height is allowed to vary significantly, it can change line density.

Dispensing Technology

There are various technologies available for dispensing adhesives. Three common dispensing technologies are available for conductive adhesives. Their characteristics are listed below.



Method: Time pressure. See Figure 11.

Speed: Viscosity, pressure, and needle dependent.
Typically < 25 µl/sec.

Repeatability: Typically > +/- 10%.

Advantages: Simple, cheap.

Disadvantages: Flow rate changes directly proportional to changes in viscosity, often requiring re-calibration. Often requires shutoff valve to prevent dripping for thin materials

Figure 11. Time Pressure Dispense

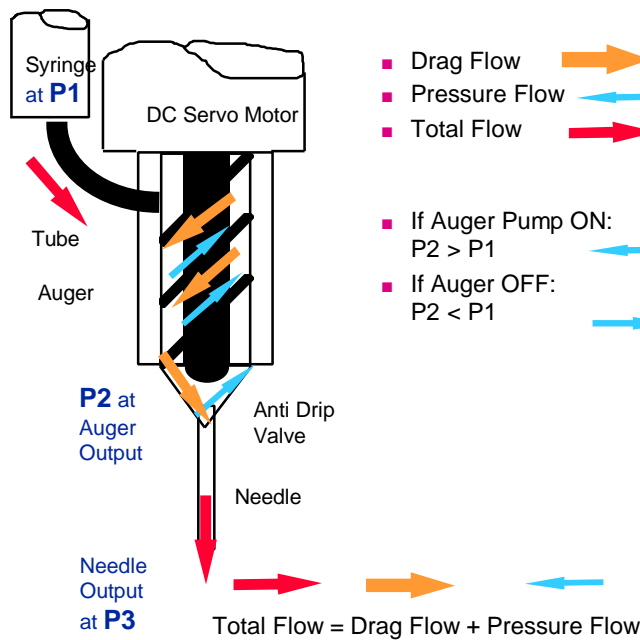


Figure 12. Rotary Auger Pump

Method: Rotary Auger Pump. See Figure 12.
Speed: Viscosity, pressure, and needle dependent. Typically < 50 $\mu\text{l}/\text{sec}$.
Repeatability: Typically +/- 4% to +/-10% short term (<30 minutes).
Advantages: Less viscosity sensitive and more accurate than time pressure.
Disadvantages: Flow rate changes with changes in viscosity, often requiring re-calibration to hold accuracy tolerance. Often requires shutoff valve to prevent dripping since pump is not positive displacement (flow equations can be found in Reference 6). Hard, abrasion

resistant augers can damage fillers. More expensive to purchase than time / pressure. Requires periodic cleaning and maintenance.

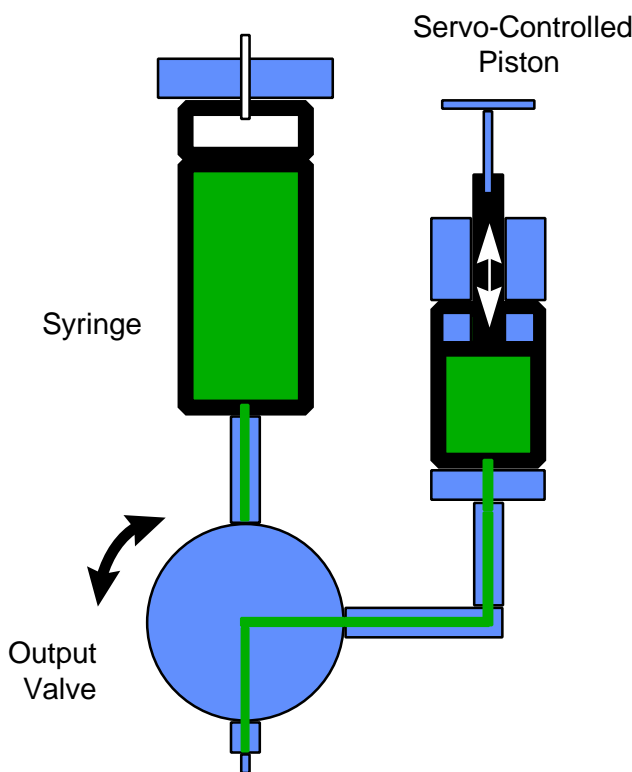


Figure 13. Positive Displacement Pump

Method: Positive Displacement Piston Pump. See Figure 13.
Speed: 5 $\mu\text{l}/\text{sec}$ to >250 $\mu\text{l}/\text{sec}$
Repeatability: < +/- 1% except for very small dispense volumes (< 20 μl)
Advantages: Fast, accurate, and less damaging to fillers than auger pumps. Dispense volume proportional to piston travel, so one-time calibration establishes accuracy for long production runs. Cost is about same as auger pump, but has lower cost of ownership. Fixed displacement shot pumps (not shown) can be used to make small, repeatable dots.
Disadvantages: Requires periodic cleaning with limited pot life materials.

Packaging Considerations

Conductive adhesive must obviously be packaged for convenient transportation, storage, and use. Fluid formulators will recommend packages for their fluids, but there are some important considerations for the user when specifying the package.

Package Size

Because many adhesives have a limited pot life at room temperature, the package size should match the usage so that all the fluid is used before the pot life expires. In the event that usage rate varies, consider using automated equipment that tracks pot life of the material on the machine. The package size should also be large enough to avoid excessive switching of syringes or cartridges during production.

Syringe and cartridge stoppers/followers

Syringes and cartridges usually contain some type of follower or stopper to seal the adhesive from air used to push the fluid out of the package. These devices serve to protect the fluid from absorbing moisture, preventing spills, and ensuring that most of the fluid is used. Care should be taken when choosing a follower or stopper. If it fits too tightly, it can prevent even flow of the material. Some pumps or valves are more sensitive to this than others, with time/pressure dispensing being the most sensitive.

Handling Conductive Adhesives

Conductive adhesives must be handled properly during storage, preparation for production, production, and disposal. Some guidelines are given below for consideration, but the fluid formulator should be consulted on all aspects of fluid handling.

Storage

Epoxy based fluids are often premixed and frozen at -40°C (-40°F). It is important to store these fluids in a freezer capable of maintaining this temperature in order to preserve the shelf life.

Cyanoacrylates, acrylics, UV cure materials, and other thermosetting materials can be sensitive to moisture, heat, and/or light. Some anaerobic materials cannot be stored in airtight containers or they will cure prematurely (Reference 5).

Preparation

Materials stored below room temperature must be allowed to warm up to room temperature before use. Most formulators recommend air thawing for frozen materials and do not recommend accelerating the thaw process by warming them in a water bath or other device. Accelerated thawing can cause the package to expand faster than the material and create voids. Thaw times vary depending on package size and fluid type. Five cc syringes can thaw in as little as 45 minutes while 6 ounce cartridges can take as long as 2 hours to reach room temperature.

Most fluid formulators recommend that the syringe be thawed vertically. Some specify “tip up” (thawing upside down) while others recommend “tip down” (thawing in the dispensing orientation).

Production

While the fluid is in the dispensing equipment, the consideration should be given to the operating environment. Elevated temperatures can limit pot life. Clean, dry air is usually required for pressure delivery systems. Some adhesives can be sensitive to excessive vibration and the acceleration of the dispensing equipment must be limited in certain cases.

Disposal

Obviously, government regulations must be followed for disposal of unused adhesive. Often, however, a fluid that is hazardous in the liquid state can be benign when cured. In this case, disposal can be made safer and much less expensive.

Conclusions

The use of conductive adhesives in electronics packaging is increasing in scope (new applications) and magnitude (higher volume of existing applications). Developing robust dispensing processes depends on understanding adhesive fluid properties, package requirements, and the technology available for dispensing. The guidelines described in this paper were created by developing many robust production processes with conductive adhesives.

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