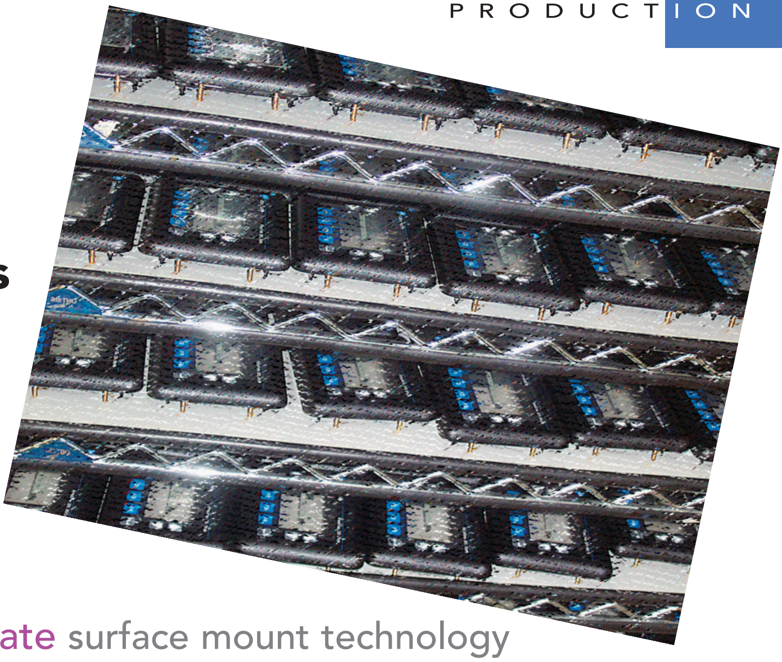
Surface Mount 101: A Primer For Applying LEDs And Other Components To Membrane Switches



To successfully incorporate surface mount technology into membrane switch manufacturing, it is essential to understand the limitations and trade-offs of different materials and processes.

Using surface mount technology to attach light-emitting diodes and other components to membrane switches is a relatively easy way to increase added value, and the resources required to adopt in-house surface mount capabilities are not beyond the reach of most small- to medium-sized manufacturers. To successfully incorporate surface mount technology into membrane switch manufacturing, it is essential to understand the limitations and trade-offs of different materials and processes. This is the first article in a two-part series addressing these topics.

What is Surface Mounting?

Surface mounting involves attaching an electronic component to the surface of a circuit, instead of passing metal leads of the component through a hole in the circuit and soldering the leads to hold them in place. Most applications for surface mounting use traditional solder paste, which is composed of small spheres of a metal alloy mixed into a paste that contains flux. The solder paste is stencil printed onto the surface of the board in small pads; the components are placed carefully onto the wet pads; and the circuit is heated in a reflow oven to melt the metal and attach the component to the circuit (Figure 1).

Sometimes temperature limitations of either the components or the circuit substrate prevent the use of traditional solder paste. In these instances, a conductive surface mount adhesive must be used to make the electrical and mechanical connection between the device and the substrate. Conductive adhesives require lower temperatures than solder pastes do to harden. However, they are more expensive than solder paste, not as strong as most solder pastes, and will not be as conductive as most solder paste. (For a complete explanation of this, see "Understanding And Measuring Electrical Resistivity In Conductive Inks And Adhesives," SGIA Journal, 2nd Quarter 2000.) Because of these limitations, conductive surface mount adhesives are typically used only when the circuit cannot accommodate the high temperature requirements of a solder paste reflow process.

Materials Issues – Reviewing the Chemistry

Most conductive surface mount adhesives are composed of specialty epoxy polymer binders filled with silver particles. Copper, nickel, aluminum and other low-cost metals cannot be used in conductive adhesives, because the oxide layers that form on the surface of these metals are not very conductive. The oxide layer that forms on the surface of silver and gold remains highly conductive.

Unlike screen-printable conductive inks that use solid polymer binders dissolved in solvents, conductive epoxy adhesives do not require solvents to liquefy the binder.

Another major difference between most conductive inks and conductive epoxy adhesives is apparent in the way they harden after applying them. Conductive inks harden by a drying process that evaporates the solvent, leaving behind a hard, solid layer of binder and silver filler. Even after a conductive ink is hardened by drying, it can be dissolved in solvents or melted at high temperatures. The ink polymer binders that can be dissolved or melted many times after drying are referred to as *thermoplastics*.

An epoxy adhesive hardens (cross links) by a chemical reaction. Once a conductive epoxy is cross linked, it cannot be easily dissolved with solvent or melted. These epoxy adhesive polymers are referred to as *thermosets*.

An endless combination of resins, hardeners and additives can be used to

By **Don Banfield,** Product Manager, Co-founder, Conductive Compounds, Inc.

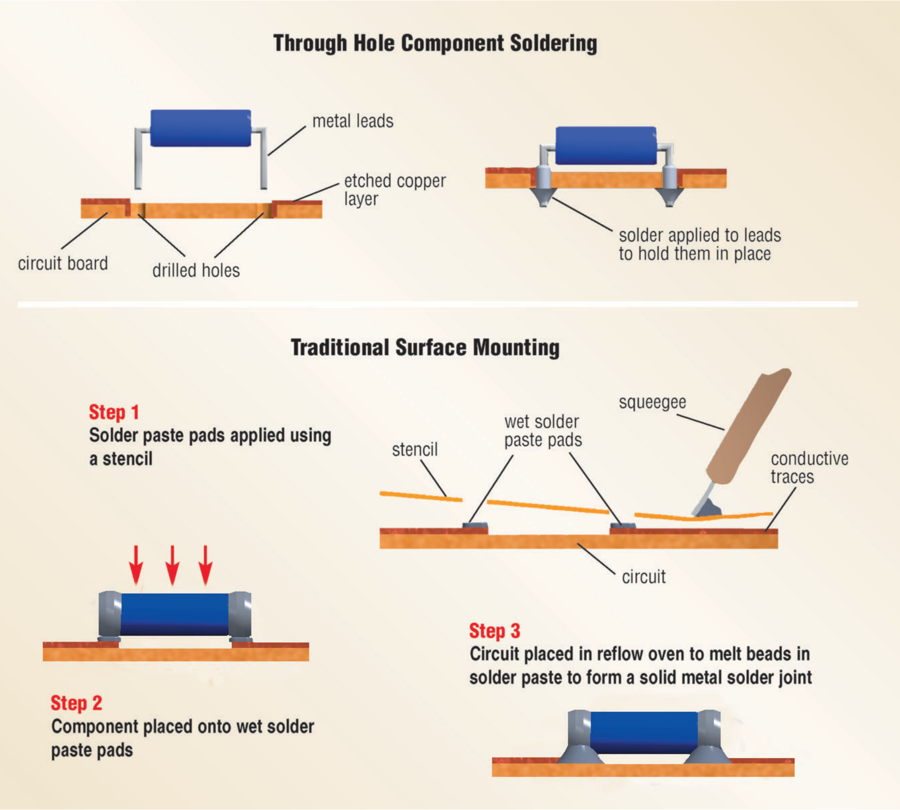


Figure 1

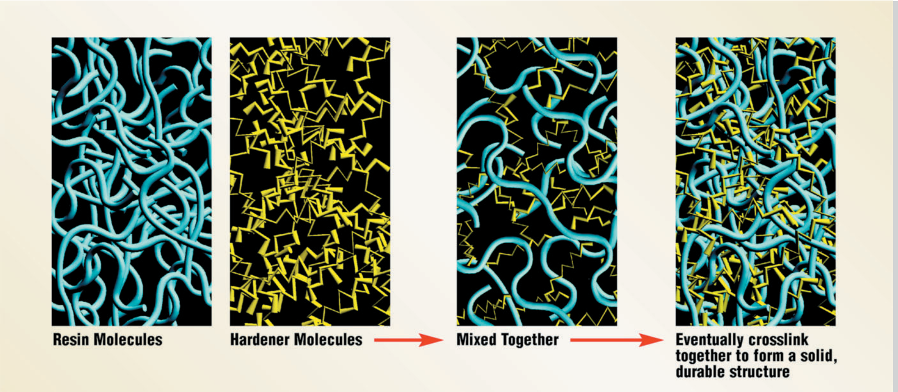


Figure 2

Once a **conductive epoxy** is cross linked, it **cannot be easily dissolved** with solvent or melted.

provide epoxy adhesives with a wide range of properties and performance characteristics. It is important to understand there are always trade offs for different performance characteristics. For example, adjusting the chemistry of the resin and hardener can make epoxy adhesives that, at room temperature, will harden in as little as 10 minutes or as much as one week. The obvious trade-off for the fast-reacting epoxy adhesive would be a very short working time after combining and mixing its components.

Electrical and mechanical performance characteristics of a hardened epoxy adhesive involve trade-offs as well. For example, it is possible to change an epoxy adhesive from a hard, brittle material into one with a soft, flexible rubbery consistency to allow for mechanical shock protection. The flexible epoxy adhesive would have very poor resistance to water absorption and solvent attack compared to the harder epoxy, and it would not withstand exposure to temperatures nearly as high as the harder epoxy. However, if it suffered a sudden blunt impact, the harder epoxy would tend to fracture, and it would fail more easily in a peel mode than the flexible epoxy.

An epoxy adhesive must provide the optimal balance of thermal, mechanical and electrical properties with the optimal curing time and working time to allow for easier processing in a given manufacturing environment.

One Part vs. Two Parts

There are two types of epoxies that can be used for surface mount applications: one-part and two-part. The more familiar two-part epoxy uses a liquid resin and a liquid hardener. When these two liquids are mixed together, the cross linking reaction begins immediately. Because both components are liquid, their molecules can move freely and come into contact with each other easily.

As molecules of the resin come into contact with molecules of the hardener, a chemical reaction occurs between select sites on the molecules, forming a strong bond (Figure 2). Most two-part epoxies will eventually harden at room temperature. If heat is added to the mixed epoxy, the molecules move more quickly and the reaction between them happens more quickly. Likewise, if the mixture is cooled, the molecules move more slowly and the cross link reaction slows.

One-part, or “latent” epoxies use a liquid resin and a solid, powdered hardener. At room temperature, the cross link chemical reaction occurs very slowly, sometimes taking weeks or months for the epoxy to thicken appreciably. It can never harden completely at room temperature because the only molecules of the hardener that are available to react with the resin are those directly on the surface of the solid particles of hardener. Collectively, the surface molecules represent a very small fraction of the number of hardener molecules contained in the entire volume of solid particles.

If the one-part epoxy is heated to the point where the solid hardener melts, the hardener molecules will be free to move about and interact with the resin molecules, and the cross linking chemical reaction will occur very quickly. One method to increase the shelf life while reducing the amount of time needed to cross link one-part epoxies when they are heated is to utilize a chemical "blocking" of the reactive part of the hardener molecule. This chemical block shields the reactive site on the hardener molecule from interacting with the corresponding site on the resin molecule. When a given temperature is reached, the reactive part becomes unblocked by a side chemical reaction, and is now able to participate in the cross linking reaction to harden the epoxy system. Catalysts can also start the cross link reaction quickly after reaching the activation temperature.

The table above summarizes the advantages and disadvantages of two-part vs. one-part conductive epoxy adhesives.

Adhesive Choices Affect Production Choices

Most membrane switch surface mount applications use a two-part conductive epoxy adhesive — its biggest advantage is that it is more forgiving in terms of cross linking than a one-part adhesive. A two-part adhesive will continue to cross link at room temperature after exiting the oven and cooling back down to room temperature.

The components of a two-part adhesive system must be weighed accurately and mixed thoroughly by the end user, but there are several types of packaging available that minimize the inconvenience of storing, weighing and mixing conductive adhesives. (Figure 3)

One of the more common pre-weighed packaging options is a sealed plastic pouch with the two components contained in the opposite ends, separated by a plastic removable clip seal. When the clip is removed, the two materials can be mixed together quickly in the sealed pouch. Pre-weighed packaging eliminates costly weighing errors, and the amount of adhesive contained in a single pouch can be adjusted to the exact amount of material needed by the end user in a given four- to six-hour window.

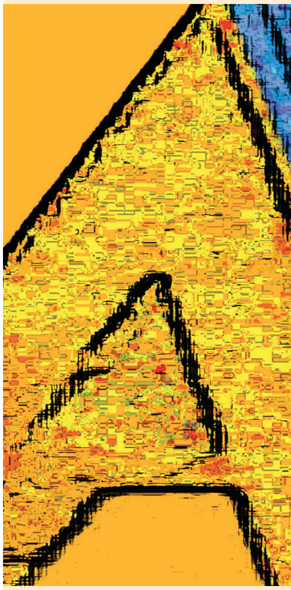
Another packaging option for two-part adhesives used in high volume dot dispense processes is a pre-weighed, pre-mixed syringe. With this option, the adhesive is quickly mixed, vacuum deaerated and put into a syringe. The syringe is then quickly frozen to -40ºC (-40ºF). This freezing slows the cross linking reaction down considerably, allowing the mixed material to be kept in cold storage for up to 30 days. The end user can simply remove a single syringe from cold storage, allow it to warm up to room temperature and begin using it. While this packaging option is very convenient for high-speed dot dispense processing, it can be very expensive. The end user must have a cold storage freezer that can reach -40ºC (-40ºF), and the syringes must be shipped overnight in airtight coolers filled with dry ice. Since dry ice is considered a hazardous material for shipping purposes, the shipping costs can be enormous.

One obvious disadvantage of a two part adhesive is the short working time after mixing. Most reliable two part conductive adhesives that can crosslink within the temperature limitations of the membrane switch manufacturing environment have working times of 4 to 6 hours after mixing. The problem is that working time is a general term for how much time elapses before the epoxy cannot be printed or dispensed reliably. The viscosity of the mixed two

Figure 3: Packaging options for two part epoxy adhesives. From left, (a) plastic pouch with resin and hardener weighed out and separated by a removable plastic clip. (b) Plastic open top containers with the exact amounts of resin and hardener. The end user adds the hardener to the resin container and mixes them. (c) Pre-mixed/frozen syringes that must be stored at –40 degrees C.

> Collectively, the surface molecules represent a very small fraction of the number of hardener molecules contained in the entire volume of solid particles.

Two Part Epoxies	One Part "Latent" Epoxies
Must be weighed and mixed accurately	Does not require weighing or mixing
Limited working time once mixed typically 4 to 6 hours	Long working time at room temperature (typically days or weeks)
Can cross link at room temperature	Must be heated to higher temperatures to cross link
Even if not completely cross linked at elevated temperatures, cross linking will continue at room temperature	Cross linking does not continue at room temperature after heating



One of the biggest uses for two-part adhesives is in applications where component attachment is performed after adhesive spacer layers are applied to the circuit.

part adhesive will be gradually increasing over the 4 to 6 hour window of working time. This can create problems for applications requiring very small LEDs, which require small adhesive pads spaced closely together. The manufacturing process must be monitored and adjusted if needed to assure that pad definition and spacing remain consistent as the epoxy viscosity builds over time.

Another disadvantage of a two-part material is that once it is mixed, any unused material at the end of the working time must be discarded. This can be minimized by careful planning to assure that the epoxy is mixed in quantities that will be used entirely within the working time. In stencil or screen printing processes, this scrap rate is larger than in a dot dispense process since a flood of adhesive must be maintained in order to print.

One of the biggest uses for two-part adhesives is in applications where component attachment is performed after adhesive spacer layers are applied to the circuit. The spacer layers have lower temperature limitation than bare polyester film, and the only option for a reliable conductive surface mount adhesive at these lower temperatures is a two-part epoxy.

If you perform component attachment on the bare polyester substrate after conductive ink and dielectric printing, then it is possible to use some one-part conductive epoxy adhesives. There are conductive one-part adhesives that have a room temperature shelf life of 30 days or more, with activation temperatures below 140ºC (284ºF).

While one-part adhesives do not require the weighing, packaging, mixing and cold storage associated with two-part adhesives, it is essential that they are cross linked completely after application. To do so, they must have sufficient time and temperature. One-part adhesives will not continue to harden after they have cooled to room temperature.

Another significant advantage of a one-part conductive adhesive is that its rheology will remain stable in the production environment much longer than that of a two-part adhesive.

Thermoset Adhesives Change Throughout Production

Thermoset adhesives are dynamic materials that undergo dramatic changes over the time they are used in a production environment. As the cross linking reaction of an epoxy progresses, three side effects occur that can have an impact on the overall reliability of the surface mount connection.

Cross linking Generates Heat — As cross linking begins, heat is generated from the molecules of resin and hardener joining together to create a lower energy state. This is referred to as an exothermic reaction, or exotherm. As the rate of cross linking accelerates the heat generated by this exothermic reaction starts increasing dramatically — in fact, if fast-reacting epoxy resins and hardeners are mixed in sufficient volumes, the material will generate enough heat to start a fire. This occurs when the heat generated by the reaction cannot dissipate quickly enough, and the heat trapped in the resin causes more molecules to cross link at a faster rate. Runaway exotherm is not even a consideration with conductive adhesives, however. The metal filler particles quickly dissipate any heat that is generated, and the volume of material mixed is very small. However, the small amount of heat generated from the reaction can impact other properties of the adhesive, such as viscosity.

There is a very effective laboratory instrument that can be used to evaluate the thermal properties of an adhesive while it is cross linking. The differential scanning calorimeter (DSC) measures the amount of heat a sample absorbs or releases as the sample is held at a fixed temperature. A DSC heats a small sample of adhesive to a fixed temperature and holds it at that temperature. It then activates precise heaters that rapidly turn on or off to maintain the set temperature. The plot generated by the DSC will show the amount of heat emitted by the sample (exotherm) or absorbed by the sample (endotherm) over a given time (Figure 4). From this plot, it is possible to predict how long it will take an adhesive to start hardening, and when it will be completely hardened at a given temperature. Some DSCs include software that allow a user to program an actual profile (time vs. temperature) from an oven used in production. The DSC will then mimic this profile, adjusting the temperature accordingly. From this test, you can determine if the oven profile will allow for complete cross linking of the adhesive in one pass.

Volume Changes — When the assembly is heated up, the various components, including the liquid adhesive, will expand at different rates. This expansion in response to temperature is expressed as the coefficient of thermal expansion. Figure 5 compares the CTE for some common materials. Notice the marked difference between polymeric materials and metals.

It is important to understand that the CTE changes once a material reaches its glass transition temperature (Tg). The Tg

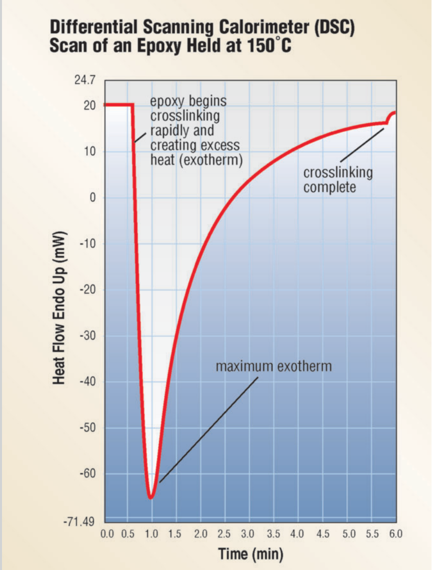


Figure 4

is the point at which a material goes from being a hard, brittle material to a more pliable material. For hard, rigid polymers like epoxies that have been cross linked, the Tg is very high, usually between 150°C (302°F) and 200°C (392°F). For softer rubbery materials like silicones, the Tg can be below 0°C (32°F). The CTE for a polymer material will be relatively constant at temperatures below the Tg but upon reaching Tg, the CTE increases. The material will expand more severely at temperatures above Tg, because the molecules move more freely once the material goes from a rigid state to a more pliable state.

While the surface mount adhesive remains a liquid or gel, the substrates and components are not locked into place and the differences in CTE between all of the different materials on a circuit are not as crucial. But once the adhesive cross links and hardens and the device begins to cool off, the materials begin to shrink at different rates. This can generate unresolved stress on the epoxy joint, and in extreme instances the joint can rupture in response to the stress induced by rapid and extreme temperature fluctuations.

Further, If an adhesive is not cross linked completely, the stress induced by materials shrinking at different rates as the circuit cools can cause fractures in the joint. To minimize or eliminate this tendency, surface mount adhesives for membrane switches should not be too rigid. Rigid adhesives are more likely to induce stress fractures because of the mechanical stress imposed by expanding and contracting materials. On the other hand, a surface mount adhesive that is too flexible will not have the adhesive strength or high temperature resistance of a rigid adhesive.

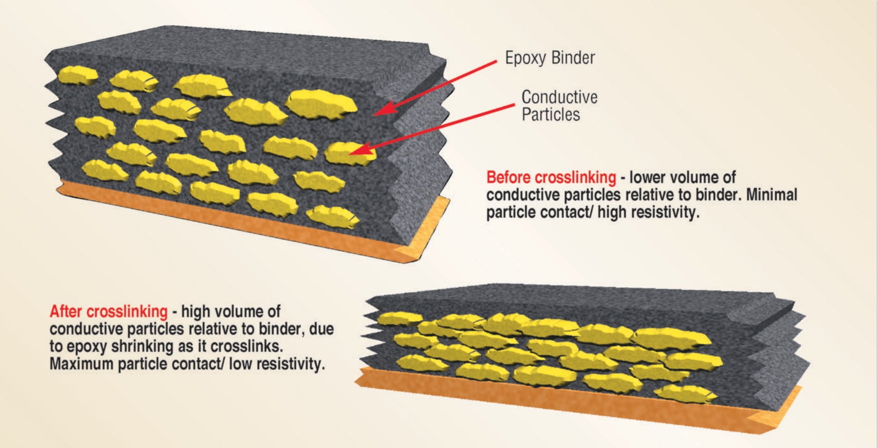
Compounding the effect of stress on a joint from different CTEs is an epoxy's tendency to shrink in volume as cross linking begins. This shrinkage, typically between 1 percent and 3 percent, results from the molecules pulling closer together and nesting as they link together — and it is essential to optimizing the electrical properties of an adhesive. As the silver particles are pulled together and nest, the amount of surface contact between particles is optimized, enhancing the conductivity of the cross linked system (Figure 6). This phenomenon explains why most liquid conductive epoxies are not conductive until they begin to harden.

Rheology Changes — The flow characteristics of an adhesive will change greatly from the time the adhesive starts heating up until it solidifies when cross linking is complete. When liquid is heated,

Coefficient Of Thermal Expansion

Material	(inch/inch/°C x 10^{-6})
fused quartz	1
glass	9
copper and silver	16 to 18
epoxy adhesive (unfilled)	70
silicone polymer (unfilled)	300

Figure 5: Coefficient of Thermal Expansion For Some Common Materials



Before crosslinking - lower volume of conductive particles relative to binder. Minimal particle contact/ high resistivity.

After crosslinking - high volume of conductive particles relative to binder, due to epoxy shrinking as it crosslinks. Maximum particle contact/ low resistivity.

Figure 6: Effect of epoxy shrinkage during crosslinking on conductivity

Another way to view rheology is to think of the viscosity of a fluid as a snapshot of the fluid's thickness at a given moment under a given set of conditions.

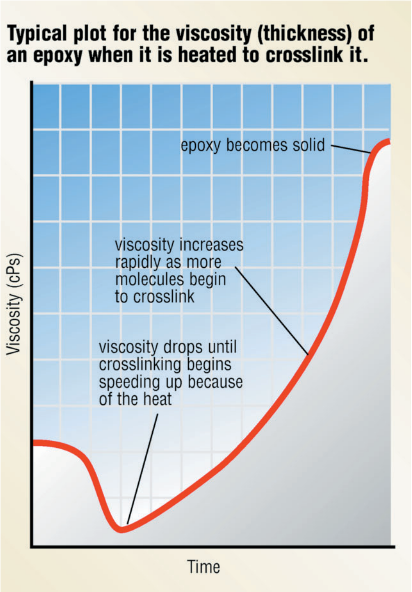


Figure 7

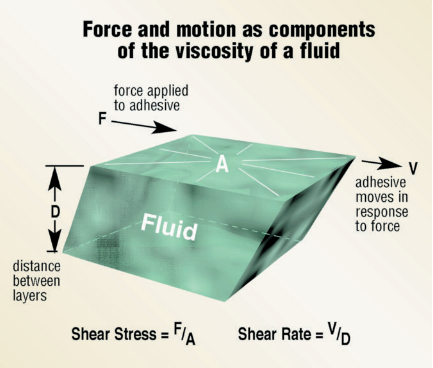


Figure 8

it will become thinner. Therefore, as the adhesive pads enter the oven, the viscosity quickly decreases because of the heat from the oven. When the temperature of the adhesive reaches a point at which the cross link reaction starts to accelerate, the viscosity will then increase rapidly until the adhesive solidifies (Figure 7).

Rheology is defined as the flow characteristics of a material. Another way to view rheology is to think of the viscosity of a fluid as a snapshot of the fluid's thickness at a given moment under a given set of conditions. Several of these snapshots, taken under different conditions are used to define a fluid's overall rheology. Of the effects we've discussed, rheology may be the most crucial to surface mount processing from a manufacturing standpoint.

All liquids have an inherent resistance to moving. This is primarily because the molecules become entangled with each other like a plate of thin pasta noodles. However, when a tangential force is applied to a liquid, the liquid moves away from the force. The rate at which a material flows in response to this force is its viscosity. To understand this better, picture a small block of a fluid (Figure 8) with its bottom stationary layer in contact with a surface such as a stencil or screen. A force, such as the movement of a squeegee is applied over a given area (A) on another layer of the fluid, parallel to and a distance (D) away from the stationary layer. This force over a given area (F/A) is referred to as "shear stress." The layer of fluid moves away from the force at a velocity (V). The shear rate of the fluid in response to the applied shear stress is calculated by dividing the velocity of the moving layer by the distance separating the moving layer from the stationary layer (shear rate = V/D).

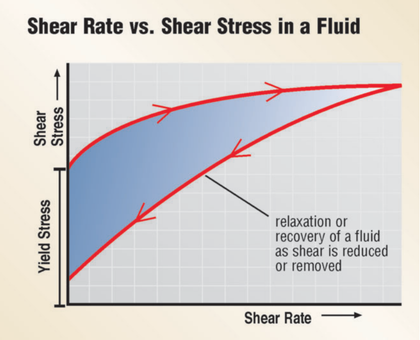


Figure 9

As the force, or shear stress on a fluid is changed the velocity, or shear rate of the fluid will also change. In almost all instances this change is not linear. Most liquids will begin to thin as more shear is applied.

The change in shear rate in response to shear stress for most fluids is shown on the graph in Figure 9. As shear stress is applied, the shear rate does not start increasing until a certain amount of force is applied to the fluid. This is the force required to start the molecules moving. Similarly, if you try to push a stationary car, you will have to exert a lot of force to start it moving. Once it is moving, you will exert less force to keep it moving than you did to start it.

The amount of shear stress required to start a fluid moving is referred to as the fluid's "yield stress." Once the fluid starts moving, the change in shear rate as shear stress increases follows a path similar to the upper curve in Figure 9. When the amount of shear stress is reduced, the shear rate of most fluids changes at a different rate than it does when the shear stress is increasing. This behavior, illustrated by the lower curve in Figure 9, is referred to as relaxation or recovery. The important thing to note here is that for any given value of shear stress, the shear rate of a fluid can be different, depending on whether the shear stress on that fluid is increasing or decreasing to the value.

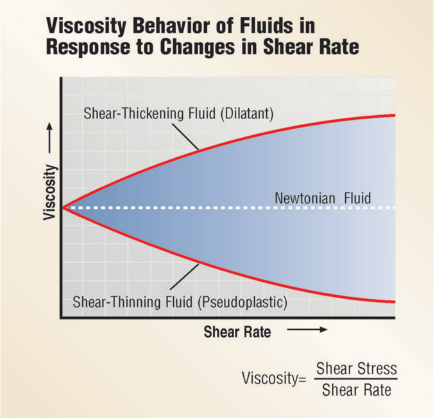


Figure 10

Viscosity of a fluid — i.e., shear stress divided by shear rate — is most commonly measured in centipoises (cPs). A plot of viscosity (shear stress/shear rate) vs. shear rate will show the viscosity of a fluid at a given shear rate (Figure 10). Because the viscosity of a fluid changes in response to shear rate, we refer to the viscosity value for a fluid at a given shear rate as "apparent viscosity."

There is a class of fluids called Newtonian fluids that do not change viscosity appreciably as the shear rate of the fluid increases. The best example of a Newtonian fluid is pure water at room temperature. Solvents also behave like Newtonian fluids.

In non-Newtonian liquids, though, the viscosity does change in response to a change in shear rate. When the viscosity of a material increases as shear rate increases, we refer to the material as a "shear-thickening fluid" or "dilatant." One example of a shear-thickening fluid is quicksand. If you try to move quickly in it, the increased stress on the fluid causes it to thicken and prevents you from moving. If you move very slowly, the quicksand will yield and you can move through it. Dilatants are not common materials.

Most fluids show a decrease in viscosity as shear rate increases. These materials are called shear thinning or pseudoplastic fluids. One practical example is a can of house paint: When the paint is mixed aggressively, it quickly becomes much thinner than when the can was first opened. If the mixing is stopped, and the paint is left undisturbed, it will thicken over time until it eventually reaches the same consistency it was before mixing.

What this means from a practical standpoint is that the viscosity of most materials decreases in response to a small amount of applied force and increases as the force is reduced or eliminated.

Materials that thin dramatically when mixed or sheared are called thixotropic. Conductive adhesives are shear thinning, highly thixotropic fluids. A small amount of shear, such as the action of a squeegee moving the adhesive on a stencil surface, can change the highly thixotropic adhesive from a heavy paste to thick oil-like consistency. Figure 11 shows pictures of a highly thixotropic epoxy hardener.

Fortunately, a certain degree of thixotropy in materials used in a screen or stencil printing process is desirable. Ideally, a screen-printable material would remain thick on the top surface of the screen until the shear action of the squeegee instantly reduced the viscosity to a water-like consistency so that the material flowed quickly and easily through the mesh. When the screen lifted, the material from each aperture would flow together to form a uniform flat film, and then immediately return to a thick state once the shear force was removed from it.

In reality, materials do not respond this quickly or dramatically to changes in the amount of shear applied, and a thixotropic material can exhibit varying degrees of this behavior in a manufacturing process.

As if the concept of viscosity were not confusing enough, there are factors other than the amount of shear that can change a material's viscosity. Adding solvent, or allowing solvent to evaporate from a material will greatly change its viscosity. As a material is heated, its viscosity decreases. As mentioned earlier, thermoset materials such as conductive epoxy adhesives increase in viscosity as they cross link until they become solids.

Measure Viscosity to Control Production Variables

To understand and control material variations in a production process, you must have the means for measuring viscosity.

You can measure the viscosity of liquid with using two different types of viscometers (Figure 12). A spindle viscometer operates using a long thin spindle with a plate attached. The spindle is placed into a container of fluid, and rotates at a constant speed (Figure 12). The torque exerted on the

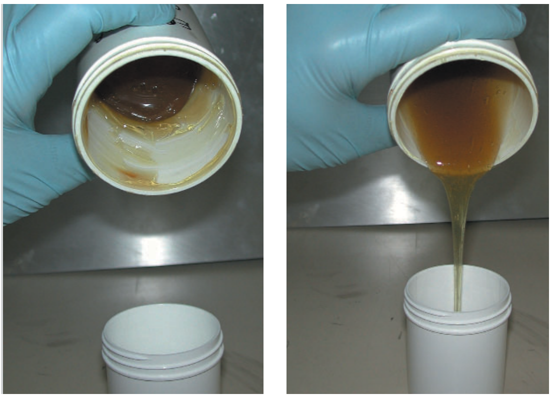


Figure 11: Highly thixotropic epoxy hardener. Material does not flow (left) until it is stirred for a few seconds (right).

Figure 12: Two types of viscometers (left) cone and plate viscometer and (right) spindle viscometer.

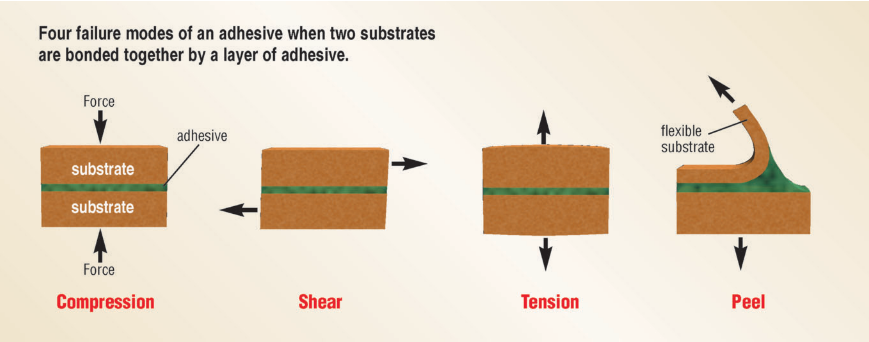


Figure 13

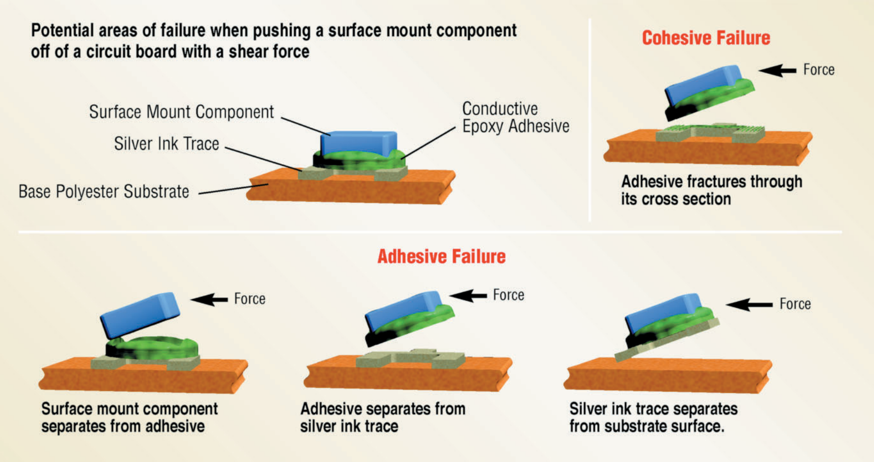


Figure 14

The weakest link in the overall joint will usually be the interface between the conductive ink and the polyester.

spindle by the fluid is recorded on a dial on a scale of 0 to 100. Once the reading is obtained, a slide chart provided by the viscometer manufacturer provides the viscosity of the material for a given spindle number and speed of rotation (rpm). Spindle viscometers are inexpensive, quick and easy to use, but are generally limited to relatively low viscosity materials. They also require a fairly large amount of fluid as a test sample. When comparing viscosities of materials using a spindle viscometer, the same spindle number and speed must be used; there is no way to accurately correlate one apparent viscosity value to another if the speed and/or spindle number are different. Reports of viscosity data collected from a spindle viscometer always include the temperature, spindle number and rotation speed.

The other type of instrument for measuring viscosity is a cone and plate viscometer, which is similar to the spindle viscometer in that it uses a slightly tapered cone plate attached to the very end of small metal shaft. The cone is spaced very closely to a very flat metal surface. This flat surface is the bottom of a metal cup that encloses the entire assembly during testing. A small amount of material is placed in the center of the cup, and when the cup is attached the cone mashes the material to produce a very thin film between the cone and the plate. The cone is then rotated against this film at either constant speed or constant torque to measure viscosity (Figure 12). Cone and plate viscometers are more expensive than spindle viscometers, but they only require small samples for testing, and they can measure extremely high viscosities. When reporting viscosity data collected from a cone and plate viscometer, the temperature, cone number and rotation speed or torque are included.

Regardless of the method used to determine viscosity, there is another easily-measured common value that will indicate a material's rheology. The "thixotropic index" or "thixotropic ratio" is simply the ratio of a material's apparent viscosity at one speed (rpm) to the apparent viscosity at a higher speed. Typically the viscosity is measured at one rpm and at 10 rpm. The thixotropic index is then the viscosity at one rpm divided by the viscosity at 10 rpm. A good stencil-printable adhesive will have a thixotropic index between three and six. As we will see in the second article in this series, thixotropic index is not as crucial when the adhesive is applied by a dot dispense process.

Material Selection — Consider Design

To achieve a robust adhesive joint when placing a surface mount device, it is essential to understand the potential failure modes of the joint.

Epoxy adhesives exhibit outstanding tension, shear and compression resistance, but are very weak when they are forced into a peel mode (Figure 13).

Because of the flexible substrate used, a surface-mounted device on a membrane switch can be easily subjected to a peel mode if the circuit is flexed near the device. For this reason, most manufacturers will use a clear UV curable encapsulant to surround and anchor a device attached with a conductive surface mount adhesive. This encapsulant protects the small, fragile conductive adhesive pad from external forces that may fracture it, creating an electrical open or break in the circuit.

One of the most common means for verifying the strength of a surface mount adhesive is to measure the die shear strength of a component mounted using the adhesive. This test involves using a small metal probe attached to a force gauge to apply a lateral force to the mounted component, and measuring the amount of force needed to push the component off of the circuit. This test is also referred to simply as component push-off. The ASTM committee of SGIA has developed an ASTM test procedure, number F1995, SMD Bond Strength On A Membrane Switch. For more information, visit the ASTM Web site: www.astm.org.

While this test is a very reliable indicator of poor pad definition, component placement or adhesive failure, it can also provide misleading results if the only information used is the amount of force needed to push a component off of a circuit.

When a component is pushed off of a circuit, the adhesive joint has four possible areas where failure can occur (See Figure 14). The first area is between the device anode or cathode and the surface of the adhesive pad. The second area is between the adhesive pad and the surface of the silver ink trace and/or polyester substrate. The third area is where the silver ink trace separates from the polyester substrate. These two types of failures are referred to as *adhesive* failures. The fourth type of failure is when the adhesive fractures through its cross section, leaving part of the adhesive on the device and part of the adhesive on the circuit substrate or silver ink trace. This is referred to as a *cohesive* failure.

When investigating component push off as an indication of joint reliability, evaluate the type of failure along with the actual value obtained for push-off force. In most instances, a properly cured epoxy adhesive will force the silver conductive ink pad to lift off of the polyester substrate surface when a component is shear tested. The weakest link in the overall joint will usually be the interface between the conductive ink and the polyester.

This is important to understand. If you obtain a low value for component push-off, and the failure is between the conductive ink trace and the bare substrate, then the only way to improve the overall joint integrity is to either improve the adhesion between the silver ink and the substrate, or to design the silver ink trace termination so that the conductive epoxy adhesive can contact bare polyester substrate. Figure 15 shows some common silver ink trace configurations that can be used to allow the conductive epoxy adhesive to make contact with the silver ink for an electrical connection and bare polyester substrate to enhance mechanical adhesion. In some instances, the bond between the polyester substrate and the conductive epoxy adhesive will be so strong that the print treat layer on the polyester film will be removed if the epoxy joint is forced to fail.

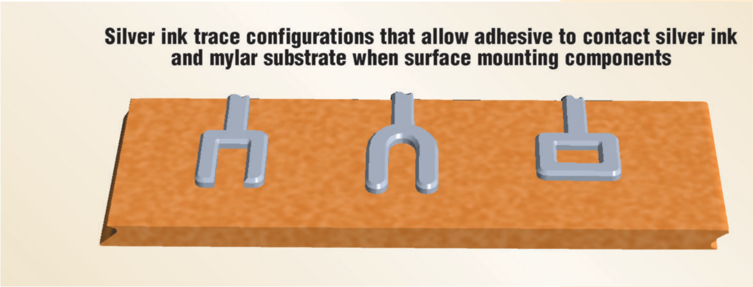

Silver ink trace configurations that allow adhesive to contact silver ink and mylar substrate when surface mounting components

Figure 15

If a complete cohesive failure is obtained during component push-off testing, it means that the epoxy adhesive is not completely hardened or was mixed incorrectly. A properly hardened adhesive joint will usually force the failure to occur at the ink/polyester substrate interface. In some instances, the failure will be at the device/epoxy interface, or even the ink/epoxy interface.

Sometimes the type of failure is not consistent, or can involve failure at more than one interface. One of the reasons why this may occur is that when the component push-off test is used, particularly on a flexible substrate, the device is not being forced to fail in a pure shear mode. Depending upon the placement of the test probe and how much the substrate is allowed to flex, the actual failure will be in peel mode. This can lead to a combination of adhesive/cohesive failure because the failure will propagate from the first small fracture that appears.

From a design consideration, maximizing the amount of surface area for the adhesive joint will provide optimal bond strength. However, care must be taken not to allow the conductive adhesive from opposite ends to run together under the device. This can create an electrical short when the device is placed. This phenomena, referred to as wicking, can be minimized by placing adhesive pads farther apart, or even utilizing a small line of dielectric as a dam under the device to keep the adhesive from running together.

Author's Note: There are two methods available to dispense conductive adhesive pads onto membrane switch substrates – dot dispense and stenciling. For prototype runs using larger components, some manufacturers will use screen printing to apply the adhesive pads. Stencil printing will give much more consistent and clean pad definition than screen printing.

The second article in this series will provide an overview of stencil printing and dot dispensing with a special focus on dot dispense processes.

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