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SOLDERABILITY OF SURFACE MOUNT DEVICES

Nanette S. Holder

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INTRODUCTION

As electronic products become much smaller, a limiting factor in the reduction of product size has been the size of the electronic components which make up the product. The leads of the current electronic components are inserted onto a printed circuit board through holes. Due to the use of wire leads, it becomes more difficult to decrease the size of the components. A new method was created to mount components directly to the surface of the printed circuit board. This new technique is surface mount technology. A concern over the use of surface mount technology is experienced by the military. Since the leads are not inserted through the board and crimped before soldering as conventional components are mounted, there is some regard as to whether the components can be mounted securely to the board. Due to the high forces that many munitions experience when dispensed, it is imperative that the electronic components housed in the projectiles be soldered to the circuit boards so they will not slip out of place or fall from the board. The military also requires many munitions to lie dormant in storage bunkers for up to 20 years. When the munition is needed, it must perform reliably. Little work has been done to study the effects of this long-term storage on these surface mount devices particularly the ability of different soldering techniques used to attach surface mount components to printed circuit boards to withstand damaging effects of long-term storage.

DISCUSSION

Surface Mount Technology

The miniaturization of electronic products has been a continuing trend for the past several decades. The advent of solid state electronics has been the principal motivator of electronic miniaturization with push toward miniaturized electronic components. The use of wire leads to attach miniature components to electronic printed circuit boards becomes more difficult in size. A new means for connecting electronic components to circuit boards was required and from this evolved surface mount technology. This technology is a new technique whereby electronic components are attached directly to the surface of the printed circuit board. In conventional electronics the leads of electronic components are mounted onto a printed circuit board by inserting the component leads through holes. This method, however, may have reached a limit as far as advancements in cost, weight, volume reduction, and increases in reliability. Surface mount technology came about with the goals of reduced cost, reduced size, and increased reliability. These goals have been reached. There have been assembly cost savings of up to 50% and size reductions of over 40%. At high frequencies, the surface mount devices perform far better than conventional components and reliability is just as good. The problem comes in

military use. The military is very interested in the use of surface mount devices for the same reasons as others. There is a desire for lower cost and smaller devices. For example, entire radar systems can be housed in a smart munition projectile. The military is concerned over the effects of high-g forces and long-term storage. Studies are needed to determine the susceptibility of military electronics to these effects.

Surface mount components are attached to conductive tracks on printed circuit boards by solder or a conductive adhesive, requiring no need for holes to be drilled through the board. The ways to attach these components to the boards are wave soldering, reflow soldering and, not as common, conductive adhesive curing.

Wave Soldering

In wave soldering, the components must first be glued to the board. This is accomplished by either screen printing the glue on the board or applying the glue with a syringe. The components are placed on the board and the glue is cured. The board is then turned upside down and passed through a wave solder machine where the unit is fluxed then wave soldered. Since all of the components must come in contact with this hot wave of solder, they must be able to withstand the high temperatures and thermal shock. After the wave soldering, the board is cleaned, inspected, and tested. This method is common if both surface mount and conventional components are used on the same board.

The amount of glue used in the wave soldering is very crucial to the success of the system. Enough glue must be applied to hold the components in place to perform the soldering. If the amount of glue is insufficient, the components may come loose from the board or move. This will cause the contacts on the solder pads to be misaligned with the contacts at the terminations of the components. However, the amount of glue must be controlled so that it does not spread out and impinge on the conductive surfaces. If too much glue is applied, there could be contamination of the solder pads on the board or component terminations. This will decrease the solderability of the device which cannot be reestablished by any cleaning methods. Solderability is a very important factor for electronic components in gun launched munitions which are subject to high G-forces. These components experience significant set-back, set-forward, and spin forces which could cause components with a low solderability to loosen or become completely detached from the board. The amount of glue needed may vary for different components. Components can have different heights with respect to each other. A component with greater height will need more glue than one of lesser height. Therefore, it is not any easy task to determine the correct amount of glue to apply to the board.

There are two methods for curing the adhesive glue. The thermosetting type requires heat to cure and the ultraviolet (UV) sensitive type requires UV radiation. The viscosity of thermosetting adhesives, which are usually epoxy resins, first decreases

when the temperature starts to rise. The polymerization that is needed to cause the glue to bond does not begin until there has been a large change in temperature. This lower viscosity may cause the adhesive to spread out and the component it is adhering to move. Sometimes, solid fillers are added to the adhesive to reduce this effect. Other thermosetting adhesives are made so that polymerization occurs at a lower temperature. These adhesives start to cure at room temperature; therefore, the glue can start to set before the component is placed on the board. Another important factor about the adhesive is the amount of time required to cure. Some components cannot withstand prolonged exposure to high temperatures. Components that take a longer time to cure allow more moisture to be absorbed at the bond which could corrode the component during storage. A typical epoxy resin which would cure at room temperature in 8 hr would take about 30 min at 80 to 100°C. In using a thermosetting type of adhesive, it is important to choose one which accounts for the necessary polymerization temperature, curing temperature, and curing time.

Ultraviolet sensitive adhesives, which are usually acrylates with a photo-initiator added, are cured with UV radiation around 350 nm. The photo-initiators cause polymerization to begin at the moment it is exposed to the UV radiation. The difficulty with this method is that the adhesive is located under the components and is not in direct contact with the radiation. Therefore, some adhesive must extend beyond the component so that polymerization can occur at this spot. Once polymerization begins, it can spread into the adhesive that is not directly exposed to the radiation. The heat produced by this reaction helps the reaction to continue. With a conveyor system in a radiation tunnel, the curing can be completed in as little as 10 sec.

After the components are placed on the adhesive and the adhesive is cured, flux is applied to the board. The flux in liquid form is applied to cover all of the solder areas quickly and evenly. The flux is used prior to soldering so that the oxide film that is formed at the solder wave can be washed away. This helps to prevent solder drag-out from the wave which forms solder bridges and icicles. This will also occur if too little flux is used. Too much flux, however, can damage the wave soldering machine and affect solderability. Flux can be applied by foam, wave, spray, dipping, and brushing. Dipping and brushing are not used as often because they do not leave a uniform thickness of flux on the board. The problem with flux materials is that the amount of water in the solution has to be controlled. The flux must be chosen with enough water and other solvents in the solution to apply an even coat, but not too much that the moisture will corrode the solder joints.

Before the board can be wave soldered, it must be preheated in order for the solvent in the flux to evaporate and also to raise the board temperature to reduce the effects of thermal shock when it comes in contact with the solder wave. The amount of heat needed is dependent on the board design, component materials, and the flux properties. For example, foam fluxes usually are manufactured with solvents that have very high boiling points. If the printed circuit board is not heated enough, the flux

viscosity will be too low, and it will be washed off the board. This will cause solder bridges and icicles. If the board is preheated too much, the flux viscosity will be too high and it will start to polymerize. When the solder wave hits the polymerized flux, it will leave a layer on the surface of the board and will not be washed off. This will reduce the amount of solder at the contact points.

Once the board is preheated, it can then be wave soldered. The assembled printed circuit board is passed over a wave of molten solder. A problem that can arise in the soldering process is the bridge and icicle formation that was mentioned earlier. Another problem is shadowing. This occurs when the solder does not wet the far side of the component when being conveyed through the solder wave. This will cause a solder skip fault where the solder skips a portion of the connection, therefore leaving less solder, if any, at the solder joint. Skip faults can be reduced if a dual wave solderer is used and the correct conveyer speed is maintained. Due to disassociation of metals on the board into the solder bath, there is a constant deposition of impurities into the solder. The bath must be periodically tested for impurities which could contaminate the components. To prevent contamination from oxidation of the solder, the oxidation must be removed regularly. Also, oil is sometimes added to solder to inhibit oxidation. The oil has no detectable harmful effect on the solder. Another problem associated with wave soldering is that components can shift or fall off the board. In all probability, the force of the wave is not enough to displace the components. This, most likely, is caused by the cured adhesive being susceptible to thermal cracking. This effect can be reduced by preheating to at least 100°C.

The choice of solder metal is important in the manufacturing of the board. Most surface mount devices use a silver-based material for the solderable surfaces. A problem exists because silver has a high disassociation rate in the typical tin-lead solder. This causes the solderable surface to disappear very quickly, making the solder bonds very weak if existing at all. Some solders already have silver in the solution; therefore, the silver in the solderable surfaces does not disassociate into the solder solution. The problem with this method is that it is very expensive for wave soldering, which far outweighs the advantages of having less expensive components. Therefore, for wave soldering, it is advised to choose components that are manufactured with a barrier layer on the solderable surfaces.

Reflow Soldering

If the board is composed of all surface mount components, a good method of attachment to the printed circuit board is reflow soldering. Since this method does not require the board to be inverted, the gluing is not necessary. In this method, solder paste is screen printed on the board. It is tacky enough to hold the components in place when they are put on the board. After the components are placed on the board, it is cured.

Solder paste is a solution of solder powder particles in a flux binder. Therefore, the properties of the solder and the flux are very important in determining what solder paste should be used. Premixed solder pastes can be purchased and are very convenient, but any unused portion must be stored in small airtight containers. Some assemblers choose to mix their own paste so they can make the quantity that they desire. The difficulty with this is that the concentrations are not as controlled. The solder paste is very reactive with temperature, oxygen, and moisture and must be stored in a cold environment free from oxygen and water.

For screen printing, a wire mesh, which has pores large enough to allow the solder paste to pass through easily, is flooded with a UV-sensitive emulsion. The artwork is placed over the emulsion and then exposed to the UV radiation. The uncured emulsion is washed away and what remains is the screen. The screen is placed over the printed circuit board; solder paste is placed over it, and then a squeegee is run over the solder to create a uniform thickness. The edge of the squeegee must be restored frequently because of excess wear. A squeegee material that is too hard or that applies too much pressure to the screen will deform the screen and place the solder paste in the wrong places on the board.

The solder paste will require application with a syringe if the circuit board surface is very uneven. Either way, solder paste is very wet and must be sufficiently dried after the components are placed in position. If the solder paste is not sufficiently dried, then the components will shift or fall off of the board, or solder voids will form because solder particles clump together leaving areas of no solder. Since the solder paste is air dried, it is important that one is chosen so that the drying time is not too short or too long. Too short a drying time can produce voids, but too long a time will allow too much oxidation of the solder to occur. If this happens, the reflow will form voids and solder balls. After the board is dried, it is ready for reflow; however, many manufacturers do not reflow the boards immediately. Some companies will delay a few hours before taking the boards to reflow, but others take days, and in some cases over a year. The problem with the dried boards waiting for reflow is that in humid environments, solder ball formation is greatly increased.

Conductive Adhesive Curing

A less common method, conductive adhesive curing, is beginning to become more popular. In this method, electronic components are placed directly on the spots on the uncured board, like components for reflow soldering are placed on spots of solder paste. A conductive adhesive, rather than solder paste, is applied either to the bare copper board or directly to the component. The adhesive can be applied to the board by screen printing or syringe. It is not very common to place the adhesive directly onto the electronic component. The board is then heated.

A major advantage with this method, is that the board does not need to be cleaned after it is assembled. It is also easier to repair, replace, and rework components that are mounted with a conductive adhesive. The components can readily be removed with heat at about 80 to 100°C; however, the bond is very strong below this temperature. The major problem with conductive adhesives is that they absorb water from the atmosphere very easily, causing corrosion. Moisture also causes the silver in the adhesives to grow "whiskers" that can cause short circuits between adjacent conductive areas. To avoid this problem, gold can be used to replace the silver, but the cost is greatly increased. Due to the elastic properties of the epoxies in the adhesive, there are very low temperature and mechanical cycles to failure. Therefore, the solder joints of an item that must withstand many cycles of temperature or mechanical forces will become very weak or break if conductive adhesives are used.

Aging Process

The most important factor in the aging process of electronic assemblies is the deterioration of the solder joints. Electronic components that are placed in dormant storage may exhibit corrosion of the solder joints due to contaminants on the solderable surfaces which remain after manufacturing. Also important are the effects of the gases in the environment during storage. Since there is a continual change in temperature during long term dormant storage, the reaction rates between the solderable terminations and the gases in the environment are changing. This causes a deterioration at the solder joints that depends directly on the materials involved. Another problem that occurs on surface mount devices during the aging process is the diffusion between the solder and substrate that causes a thickening of the intermetallic layer and a change in the chemical makeup of the material at the interface. This intermetallic layer determines the strength at the solder joint. A joint will become more brittle with time; therefore, it is very important to take a few factors into consideration when these components are stored. Those developing the item must be concerned with:

- Oxidation or corrosion on the outer surface of the solderable terminations
- Separation of one or more chemical elements in the solder joints which may cause changes in the susceptibility to oxidation and corrosion
- Changes in resistance of the component when the flux is used to remove contaminants
- Coating-substrate interface and how it changes during storage with the presence of impurities, different temperatures, and different thicknesses and porosities of coating material

Accelerated Aging Testing

Testing the effects of long term dormant storage on electronic components can take a great deal of time, since the military has requirements up to 20 yr of storage. However, to estimate a mean lifetime that a component will survive in storage in the least amount of time, it may be necessary to perform accelerated age testing. The time scale can be compressed by overstressing the item in temperature to determine the time to failure. Some failure in electronic components is caused by diffusion which is very dependent on temperature as given by the equation:

$$D = D_0 \exp(-Q/kT)$$

where D is the diffusivity; D_0 is the diffusion constant; Q is the activation energy; k is Boltzmann's constant; and T is the temperature in Kelvin. For an activation energy of about 0.9 eV at approximately room temperature, the life of an electronic component is halved for every 6°C rise in temperature and halved for each 10°C rise at about 150°C.

To perform accelerated age testing, the lifetimes of the components are measured at various temperatures and plotted on an Arrhenius plot, which is a temperature versus the log of the lifetime plot. The graph is extrapolated to the actual storage temperature to find the mean lifetime. This is only an approximation of the determination of the life expectancy of electronic devices. Many do not place a great deal of faith in this measurement, because storage areas are not climate controlled; therefore, the components are not kept at a constant temperature.

CONCLUSION

There are many problems to be considered when developing an electronic item that uses surface mount technology. The production method and the chemical compounds that compose the components, solder, flux, etc. are very important aspects in the life expectancy of the devices. Testing must also be performed on items using surface mount devices to determine how well they will resist the effects of long term dormant storage.

BIBLIOGRAPHY

1. Anderson, Sam, et. al., "Accelerated Life Testing of Semiaquious-Cleaned Surface Mount Devices," Surface Mount Technology, Oct 1991.
2. Bullock, Kathy, "Photoimageable Solder Masks Revisited," Electronic Packaging & Production, June 1992.
3. Daebler, Donald, "An Overview of Gold Intermetallics in Solder Joints," Surface Mount Technology, October 1991.
4. Lea, C., A Scientific Guide to Surface Mount Technology, Electrochemical Publications Limited, Scotland, 1988.
5. Morency, Daniel, "A Discussion of SMT Solderability Issues and Relationship to Lead Finishes," Surface Mount Technology, June 1991.
6. Wesselmann, Carl, "Reflow Solder Forum - Don't Be Fooled By the Numbers...," Surface Mount Technology, March 1992.
7. Wood, Nelson, "Predicting SMT Solder Joint Reliability Using Calculated Temperatures," Electronic Packing & Production, June 1992.
8. Zarrow, Phil, "Major Factors for Success in SMT Reflow Soldering," Electronic Packaging & Production, June 1992.

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