Surface Mount Technology (SMT)
Failure Analysis of Solder Joints and Remedies
**3D Digital Microscope**

**Now You can See!**

As a pioneer of image observation, we have produced a digital microscope that provides answers. It has evolved from a “machine” that simply observes to a “partner” for the observer.

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I) Reflow

1) Temperature profile

One of the key factors of reflow oven is preheating. The preheating of a component and PCB is basically the same in leaded and lead-free soldering. Preheating is the range from room temperature to the melting point of solder.

Wettability of solder is influenced by the properties of flux contained in solder as well as the length of time between room temperature and melting point of solder. Minimizing delta T during pre-heat stage can lead to a greater delta T within a solder melting temperature, possibly resulting in longer heating or stronger convection, a direct cause of flux burnout and thermal stress on PCBs and components.

Recap: Delta T must be minimized during solder melting phase (as shown with red arrow) but not necessarily pre-heating (as shown with blue arrow).

![Temperature profile graph]

2) Self-alignment effect

If the temperature profile is appropriate and matches the flux properties, bridging and mis-alignment will not occur due to lead-free solder’s strong self-alignment characteristics.

Components are intentionally shifted after mounting and reflow. Due to self-alignment nature of lead-free solder, all components are positioned normally on the lands through the reflow process.

![Self-alignment effect images]

Flux reacts with heat first on an entire mounted PCB. Under the normal profile, flux reacts on component leads. Thus, observation of residual flux is important.

Residual flux (Figure 9) spattered by strong convection and (Figure 10) residual flux after adjustments of air flow.

Shifted QFP is re-positioned because of self-alignment effect.
Even with a good temperature profile, self-alignment will not occur if there is insufficient solder printed. A proper amount of solder is required to take advantage of the self-alignment effect.

Printing solder on resist:
Solder on resist area flows and coheres to component leads as shown in pictures 17 and 18. During mass production, aperture (shown with a red line) allows a consistent solder print.

Printing high volumes using a mask opening (as shown in the red dotted line) is more reliable than applying solder by hand.

The key point for good printing is to print the solder thin and wide to the resist line in order to allow sufficient heat transfer.

4) Reflow of through-hole parts
Through-hole parts can be done by reflow. Reflow minimizes soldering inconsistencies that often occur with a manual soldering process. The use of reflow instead of flow is environmentally friendly and improves cost performance and quality.

Selection of solder and printing conditions are key factors to determine solderability.
Residual flux found on both sides of the through-hole is an indication of good soldering.
No bridges despite leads inserted from the bottom side (Pictures 26 and 28)

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(Kojima Solder used in the pictures)
Examples of incorrect soldering

Combining the printed solder with the land increases thickness, resulting in slower heat reaction and a higher risk of bridge formation.

Using higher temperature resistant flux causes spattering. The selection of solder (flux) is extremely important in order to prevent bridges from forming and/or insufficient solder which can cause voids to occur more frequently.

Long leads have a high convective flow that reduces the risk of voids.

5) Flux characteristics

The temperature at the tips of the leads is lower due to the solder melting temperature and the flux vaporization overlapping, and/or the residual high temperature resistant flux repelling the solder.

In these pictures of solder and residual flux on an FPC, there is a significant amount of residual high temperature resistant flux. This leads to voids on the bottom of fillets. (Pictures courtesy of Yoyama Co. Ltd.)

Although they look like fibers or hair, these pictures show residual flux. The location of this phenomenon cannot be specified.

Some of the solder oxidizes and does not melt because of spattering flux. This leads to voids on the bottom of the BGA.
Residual wire solder using high temperature resistant flux and blowholes.

Soldier is printed on the FPC resist, quickly connected and placed in the oven. When the first FPC leaves the oven, the oven is turned off, the cover opened and the FPC removed.

At this point, the order of the oven heating elements, the temperature profile and the FPC order are recorded. The spattering of solder and flux is checked afterwards. The photographs show that a significant amount of temperature resistant flux did not evaporate and remain on the FPC and around the solder. If the heat is not properly balanced, this causes voids on the bottom of the fillet. (Picture 49,51,52) This is also true for a rigid circuit board.

Solder from Company A requires higher temperatures and is not appropriate for parts or boards with low temperature resistance.

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Solder from Company A (Picture 49,51) has melted. Even if the metals are the same, different flux (solvents, etc.) have different melting points. Soldier from Company A requires higher temperatures and is not appropriate for parts or boards with low temperature resistance.

Using lead-free solder requires working at even higher temperatures, which also require the use of high temperature resistant flux. This creates a cycle requiring higher heating capacity of equipment and tools. Using higher temperature resistant flux has an effect on quality in areas that are not directly visible. This means that production facilities need to re-evaluate their systems for observing and monitoring soldering quality.

Heat flows to the interior layers of multi-layered boards. To prevent this, infrared heaters are used to heat the boards themselves and reduce air movement. Then heat is supplied to the leads with an air heater to melt the solder.

With convection ovens, fans are used as little as possible during preheating and adjustments must be made to lengthen the main heating time of the profile. Strong air flow has a large impact on the heat of the board and the parts. Low air flow with high temperature resistant flux can result in voids and insufficient heat.

When using IR and convection reflow ovens, IR on the bottom of the oven is set high to heat the boards themselves while the heating elements on the top control the melting of solder. A strong fan in a convection reflow oven causes flux and solder to spatter. (Picture 60,62)

Pictures 53 and 54 show traces of spattered solvent in the 4th zone of the reflow oven and traces of depressions left by spattered flux. (Picture 55)

Using only a bottom heater, heat from the pattern melts the solder. (Picture 64) The opposite is true with robot soldering. Heat escapes from the pattern and immediate cooling creates good gloss on the fillet. (Picture 67) Also, since flux deteriorates quickly on ceramic boards, solder wetting is achieved by heat from the bottom heater causing the flux to spread to the land first. (Picture 66)

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Long profiles cause flux to deteriorate, creating voids. Using an IR oven on the bottom helps reduce voids; a common problem with BGA.

Thick solder bridges and un-melted solder occur even after a strong flow of heated air is added in a short period of time due to flux deterioration and the oxidation of particles. The upper heater is appropriately set to melt the solder. More important is preventing the deterioration of flux and solder particles during the preheating stage. Strong air flow during preheating works like an electric fan, causing flux deterioration and oxidizing solder particles, which inhibits melting. Controlling heated air in the preheater allows the solder to melt, even with a lower temperature.

**Mounting of BGAs**

Even with BGAs, if the upper heaters are set too high, oxidation of the ball exterior and deterioration of flux and the components occur and can result in warped bridges and potato-shaped solder.

Halation on the center of the solder ball shows horizontal straight joints, proving that the ball has a good spherical shape. Wettability can be effectively achieved by selecting a profile that suits the characteristics of the solder flux used with N2. If you review the preheating process, you can eliminate the use of N2 by setting the temperature of the bottom heater 20 degrees above the upper heater. By using the bottom heater, you can achieve good wettability without using N2.
An incorrect profile can cause balls because the solder cannot wick up to the same place as the flux. Instead of trying to resolve this by slowing down the conveyor belt, speeding up the belt helps prevent insufficient wicking.

Gas does not bleed well from components such as aluminum electrolytic capacitors. Making the lands bigger to facilitate the release of gas from these parts with solder convection helps to alleviate this problem.

Side balls are basically a problem related to the amount of printed solder. However, with lead-free solder, the amount of printed solder should not be significantly reduced, as reductions have an effect on wettability. Instead, the ratio of the land to the opening in the solder mask should be over 100%.
Reducing the amount of printed solder also reduces the amount of flux and inhibits the melting of the solder. The amount of heat at the preheating stage must be controlled, especially with the 0402 chip. However, temperature cannot simply be reduced because there are other parts to be mounted.

The solders on the left land of the 0603 chip did not melt because there was an insufficient amount. With the 0402, self-alignment works to correct misaligned mounts.

When simultaneously mounting parts with different amounts of solder and heat balances, a bottom side infrared heater can be used to provide heat directly to the circuit boards without having an effect on the parts on the bottom. The upper heater controls the melting of solder and prevents deterioration. Excluding special circumstances, the top temperature needed to melt solder is between 230 and 235 degrees Celsius.

If the plating on the part lead tips is insufficient, bubbling solder will wick up between leads and create bridges.

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The biggest problem with lead-free flow can be seen on the mounting surface. The contact surface of the board and the solder is limited because the angle of the board on the belt is set at 5 degrees. This results in insufficient heat, which can be prevented by increasing the temperature of the solder pots. Although flux has already deteriorated during preheating, hot air is blown by the first jets. After deterioration, cooled solder with a reduced flow remelts in the second pot. The remaining flux then adjusts the fillet.

II. Flow

1) Angle of delivery

The biggest problem with lead-free flow can be seen on the mounting surface. The contact surface of the board and the solder is limited because the angle of the board on the belt is set at 5 degrees. This results in insufficient heat, which can be prevented by increasing the temperature of the solder pots. Although flux has already deteriorated during preheating, hot air is blown by the first jets. After deterioration, cooled solder with a reduced flow remelts in the second pot. The remaining flux then adjusts the fillet.

This is an irrational mounting method from the viewpoint of flux. The problems with this method are summarized below.

- The board delivery angle is too great
- Application of flux is not uniform
- Insufficient wetting from the through hole through all board layers
- Inappropriate land design

When the delivery angle is 5 degrees, insufficient heat causes the part lead to quickly break away from the solder pot.

When the delivery angle is 3 degrees, break away time from the solder pot is slow and sufficient heat is supplied.

Amount of heat = Temperature x time x contact surface

Delivery angle of 5 degrees

Delivery angle of 5 degrees

When the delivery angle is 3 degrees, the contact surface between the board and the solder is over twice that of a delivery angle of 5 degrees.

When flux has been correctly supplied, the status of the applied solder changes by controlling the amount of heat.

Excessive heat

1) Lead is too long
2) Temperature in the solder pot is too high
3) Speed of conveyor belt is too slow
4) Contact surface between the board and the solder is too large

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If the flux is effective, setting the delivery angle of the board to 3 degrees creates a large contact surface between the board and the solder. Supplying a large amount of heat without increasing the temperature in the solder pots improves the wetting at through holes through all layers of the board and reduces bridges. In order to stop flux from softening and flowing in response to heat, the ability of flux to flow from the solder pot to the board must be maintained. Solder balls break away with excessive heat, and a lack of heat controls solder flow and hardens the balls.

Unused lands from mistakes in the design can often lead to bridges. With square unused lands, the edges of wetted solder become a bridge between leads. This problem can be alleviated by changing the roundness of the solder so the highest point is separated from the lead.

Bridges caused by board warping can be prevented by increasing the speed of the conveyor belt so the solder concentrates around the center of the connector lead. In this situation, switch to regular lead-solder flux if the reaction of flux cannot be controlled.

With normal flow solder, a large amount of heat causes dendrite formation and shrinkage cavities. Setting the conveyor belt speed over 1.7 m/minute alleviates the problems of shrinkage cavities and dendrite formation. This depends on the abilities of onsite personnel.

With sufficient heat and appropriate flux, solder wicks up to the top of the lead. Lead-free solder will have a gloss similar to that of eutectic solder.

Unused lands as shown in the red box, can lead to bridges.

With layer board with solid lands, temperature below 250 degrees and an immersion time of less than 5 seconds. Solder wetting to the top of the lead and shrinkage cavities, no dendrite formation.

Temperature
(1) Temperature at the top of the hole should be higher than the solder-melting point.
(2) If the temperature at the top of the lead is higher than the melting point of the solder, the fillet becomes higher.
(3) The larger the bottom of the land is, the easier it is to transfer heat.
(4) A smaller land at the top of the hole controls heat dissipation more effectively.

Roundness at the through hole requires both the temperature at the top of the hole to be higher than the solder melting point and the presence of effective flux. With sufficient heat and appropriate flux, solder wicks up to the top of the lead. Lead-free solder will have a gloss similar to that of eutectic solder.

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III. Rework and repair

1) Shiny solder joint

The most important points to consider when using wire solder are the tip shape of the soldering iron, the plating of the tip and the process of adding solder.

Picture 131: A good, shiny solder joint resulting from even heat dissipation on the land. The picture on the right shows dendrite formation due to slow cooling.

Picture 132: A glossy fillet only on the land is a result of rapid cooling of the land.

Solder does not wet to the inside of a through hole using a normal tip. Using a forked tip makes application of solder easy providing sufficient heat to form a micro dip well around the tip of the soldering iron. Because heat resistance of wire solder flux is high, failure to work with a tip that is equal to or below temperature recommendation will lead to poor solder joint quality.

Solder is applied with heat. Amount of heat = Temperature x time x contact surface

2) Soldering iron tip shape

Heat balance has a major impact on land pattern design during reflow and hand soldering with wire solder. The inner levels of multi-layer boards may experience problems related to either heat dissipation or heat absorption. These issues are easily managed in reflow by the use of infrared heat. However, manual soldering requires work to be done rapidly in order to provide enough heat to the area. Adding excessive heat causes potato-shaped solder joints and insufficient wetting because of flux deterioration and the majority of the heat taking a long time to pass through the land pattern and in to the board. A basic rule for both reflow and manual soldering is the application of solder at high temperature for a short period of time to parts with low heat resistance.

Picture 133: Insufficient through hole wetting

Picture 134: Forked soldering tip

Picture 135: Good wetting with a multi-layer board

The objective with parts that require high heat is to solder before the flux becomes ineffective by quickly providing the necessary heat to the specific point before the heat dissipates when removing the tip of the soldering gun while the land and the lead are in full contact. The process must be carried out while flux is activated on the soldering surface in order to prevent oxidation.

Wire solder is perfect for manual application on stainless steel in industrial applications. The proper shape and width of the soldering tip making contact with the land are important points to consider. With some exclusions, it is the board that requires ample heat rather than the parts. This is the same in soldering for repair of BGA as well. Repairs can be conducted easily and neatly eliminating preheat and only using the heat from a soldering iron.

Picture 136

Picture 137

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3) Repair

Through hole corrections cannot be made by adding solder on to the part surface because the added and old solder in the hole may not melt together. Solder wets to the part surface by providing additional flux on to the part surface and applying heat using a forked tip iron from the lead side to melt the solder.

Picture 138: Lead surface is good

Picture 139: Re-apply heat to the lead surface

Picture 140: Observation of solder wetting on the part surface

4) Defects due to insufficient soldering leaving a residue of poorly activated flux

Picture 141

Picture 142

Air bubbles are visible in the residual flux because the soldering iron tip was too small to provide sufficient heat. A void is likely in the through hole.

Picture 143

Picture 144

Differences in fillets created when applying solder numerous times with a small soldering iron tip to a large land.

Picture 145

Picture 146

Picture 147

Picture 148

Although the shape and plating of the soldering iron tip are important, excessive heat can reverse the effects.
The Hirox KH-7700 digital microscope allows for observation of halation by rotating the lens to change the angle of observation. This method can be used to check the status of residual flux. (MXG-5040RZ lens) In this case, the presence or absence of residual flux also indicates the presence or absence of land stripping.

Although a technician performed the tasks, the work has not been checked carefully.

IV. Inspection Process

1) Observation points and remedies

1) Voids and blowholes

- Picture 153: The small bubbles on the side of the fillet indicate the possibility of a void in the hole.
- Picture 154
- Picture 155: Blowhole

2) Land stripping

- Picture 156: High solder well temperature causes land stripping
- Picture 157: The land is not stripped, but there is residual flux.
- Picture 158

2) Observation angle

- Picture 161: Insufficient hole wetting
- Picture 162: Forked soldering iron tip
- Picture 163: Good wetting even on 4-layer boards
- Picture 164: Re-applied heat from the lead surface

The ability to change the angle of observation is extremely important for complete observation. This allows for different views of the same land surface.

The holes in the side of the land indicate that a long preheating phase caused solder particles to oxidize. The result is unmeltable solder balls that lost fluidity due to flux deterioration and were not attracted to the fillet. This problem can be solved by shortening the preheating phase.

Although boards are normally judged by observing the condition of residual flux, most observation equipment lacks a powerful light source to show the differences. The KH-7700 Hirox digital microscope uses a metal-halide lamp that is very bright and provides numerous lighting options.
Changing the angle of observation and the lighting during observation allows the checking of residual flux and joints. In picture 172, the lighting and the angle of observation do not show the true picture.

Rotating the lens and recording video, functions both available with the Hirox KH-7700 digital microscope, enhances observation. Normally, observations are made by first specifying an area for observation with optical equipment and then using a SEM, especially when observing whiskers. Microscopes that can observe the leads deep on the board while recording video are extremely important tools for observation.

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It is better, from a business perspective, for future design to be focused not on unreasonably extending the life of a product, but on making sure that defects appear during a prescribed period of time. There is a difference between defects and breakdowns.

Below are pictures of a working 15 year old TV that we took apart. The parts repaired by hand, using lead solder, were not significantly affected by heat. Yet the repairs are of poor quality. Moreover, although the QFP flow is problematic, they too have not been affected by heat. However, parts that have been affected by heat are clearly broken.

Looking at breakdowns in recent electronics, many are related to soldering. Most of these products were 10 years old and out of warranty.
On circuit boards, flux reacts the quickest to heat. Therefore, observations made at the factory should look at the condition of residual flux to analyze and judge the balance of heat. This is the easiest way to eliminate defects. Finding and fixing defects at the end of or after the whole process is too late. It is better to have the factory personnel curb problems by making an initial analysis before and immediately after reflow. Compared with leaded reflow soldering, failure ratio of lead-free reflow soldering is reduced rather quickly to 10 ppm or less. The point lies in the separate usage of upper and lower heaters that can create temperature differences to match the characteristics of flux and the movement of heat. In an oven that uses both far infrared and air heaters, the upper heater provides enough heat to melt the solder while the far infrared acts like a floor heater, providing even more heat directly to the board from the bottom. This prevents the deterioration of flux and allows parts with different heat capacities to be mounted simultaneously. This is possible even with small reflow ovens by adjusting the speed of the conveyor belt. Larger ovens require faster belt speeds and therefore hot air blows between the components, preventing proper heat balance. This is especially true in the preheat stage, where fans accelerate the rapid deterioration of flux and oxidation of solder particles. Adjusting the profile to flux, this problem is solved on most machinery by adjusting the speed of the conveyor belt. This reduces the switching time for machines. Soldering using flux that reacts quickly to heat curbs the impact of heat on the parts and board. At the same time, it also solves the problems of voids and spattering. Because excessive heat causes flux to deteriorate, flux deterioration must be prevented in the preheat stage until the solder melts.

Material sources
Kojima Solder
Yuyama Co. Ltd.
Kouei Electric
Nippon Antom Co., Ltd.
Edsyn International Co., Ltd.
Hirox Corporation

Photographic equipment
Digital Microscope
Hirox KH-7700/KH-1300
http://www.hirox.com