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How To Minimize Defects By Adjusting the Reflow Profile

A properly designed and adjusted reflow profile is one of the most important factors to achieve defect-free, high quality solder joints during a surface mount reflow process. Many defects or quality issues (such as bridging, solder balling, poor wetting, tombstoning, solder beading, voiding, dewetting, intermetallics formation, copper erosion, component cracking, PCB delamination or charring, etc.) can be minimized or eliminated by optimizing the reflow profile.

Fig. 1 and Fig. 2 show the two types of commonly used reflow profiles; a standard reflow profile and an optimized reflow profile.

Standard reflow profiles have a flat soaking zone (activation zone, equilibration zone) at about 150-160 °C to bring the PCB and components to an elevated equilibrium temperature. This type of reflow profile generally has faster ramp up rates at both the preheating zone (ramp zone) and the reflow zone (spike zone, final ramp up zone). Optimized reflow profiles have slower ramp up rates at both the preheating zone and the reflow zone. However, in some cases optimized reflow profiles will let the PCB and components be exposed to a higher overall heat input. Different defects and issues are related to the different types of reflow profiles at different temperature zones. In this paper the mechanisms of these defects will be discussed so that the reflow profiles can be adjusted accordingly.

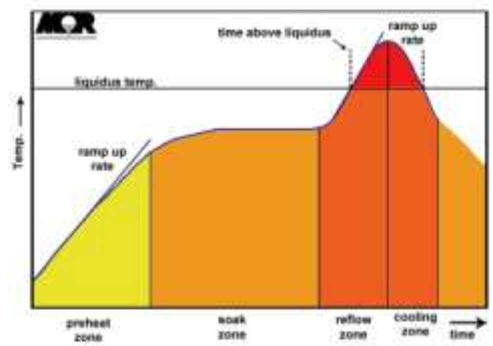

Fig 1. Standard reflow Profile

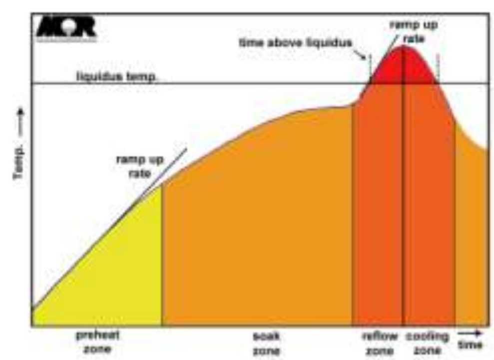

Fig. 2. Optimized Reflow Profile

I. Preheating Zone

When the ramp up speed is too high at the preheating zone it will cause solder paste to slump due to thermal agitation and induce defects such as bridging, solder balling, tombstoning, solder beading, and micro-cracking on ceramic components. When these problems occur, an optimized (or semi-optimized) reflow profile with a slower preheat ramp up rate is preferred.

Hot Slump

The viscosity of a pasty material decreases when temperature increases due to the thermal agitation. However, in the case of printed solder paste, solvents in the paste will evaporate faster with increased temperature, which will increase the viscosity. At a slow ramp up rate these two factors will offset each other and prevent the printed paste from slumping. However, at a high ramp up rate the solder paste does not have time to dry out enough to offset the thermal agitation and consequently causes hot slump.

Solder Bridging

The most common issue directly caused by hot slump is solder bridging. When the solder paste slumps it may smear and connect the adjacent component leads at the preheating stage and form bridges after reflow (Fig. 3).

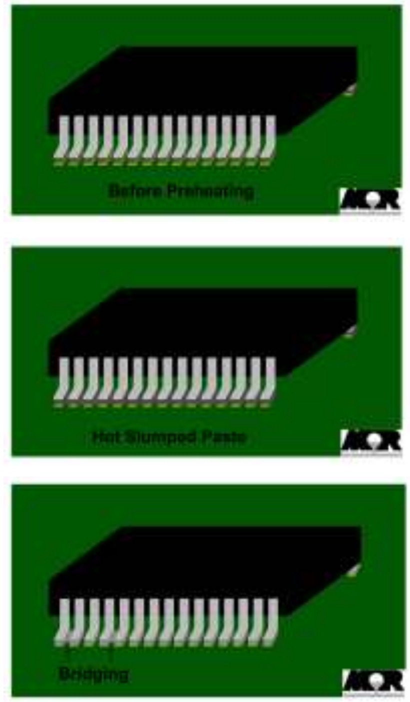

Fig. 3. Bridging

II. Soaking Zone

One of the disadvantages of a flat soaking zone for a standard reflow profile is the relative height of the reflow zone. In this type of profile, from the start of ramp up for the reflow zone (final ramp up) to the peak temperature usually involves a relatively large temperature difference (ΔT). High ΔT generally requires a faster ramp up rate which will cause vigorous flux vaporization and may introduce defects such as tombstoning, solder beading, and solder wicking.

If the temperature of the soaking zone increases on the whole to reduce the ΔT for the final ramp up in a standard reflow profile the overall heat input will be increased. This increase in heat input may cause poor wetting, solder balling, voiding, components damage and PCB delamination or charring.

An alternative approach is to make the soaking zone temperature a slow ramp up with a short plateau at the end to let the components and PCB reach an equilibrium temperature. A complete triangular shaped profile will cause temperature difference across the board and may induce defects such as poor wetting, cold joints, solder wicking etc.

Solder Balling

The primary root cause of solder balling is the oxidation of the solder powder in the soaking zone. Some of the heavily oxidized solder spheres in the solder paste will not coalesce with the bulk and result in isolated small spherical particles around the pads. If the solder paste was hot slumped during the preheating stage, it may spread off of the copper pad area, which will make it more prone to solder balling.

Tombstoning

There are two factors contributed to the tombstone phenomena: a) an unbalanced torque on two sides of the chip components due to the surface tension of the molten solder; b) an upward push by solvent vapors from flux or PCB during the reflow process. A fast ramp up rate during the reflow stage will aggravate the outgassing to increase the chance of tombstoning. A hot slumped solder paste will spread underneath the populated chip components and cause more upward solvent vapor push to increase the tendency of tombstoning (Fig. 4).

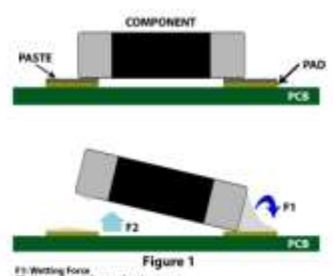

Fig. 4. Tombstoning

Solder Wicking

Solder wicking is a phenomenon where molten solder wets the component’s leads and flows upward to cause a starved joint or an open joint (Fig 5). It is a result of temperature difference between the component leads and the PCB pads at the reflow stage. If this happens, a longer plateau at the soaking zone is required to let the components and PCB reach an equilibrium temperature. A slightly higher bottom-side heating will also help.

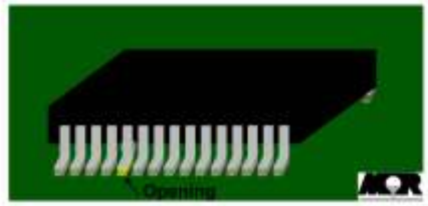

Fig.5. Solder Wicking

Poor Wetting

The primary root cause of poor wetting is excessive oxidation of solder powder, component leads, and PCB pads prior to the reflow. If the overall heat input is too high, and the solder paste has a limited oxidation tolerance, the flux activity of the solder paste will be weakened and lead to poor wetting. In this case the reflow profile should be adjusted more toward a standard type to reduce the overall heat input.

Voiding

The root cause of the solder voiding is primarily due to the entrapment of flux during the reflow stage. Formation of solder voids increases with the oxidation level of both solder powder and the PCB pads. Un-wetted spots on the pads, or un-digested solder oxide particles from solder powder in the bulk of molten solder will entrap small amounts of flux. This in turn will expand into a void at the solidification stage. A lower overall heat input and higher activity of flux will help in this situation.

Reflow Zone

The function of a reflow zone is to elevate the temperature to a peak temperature, which will allow the solder powder to reflow properly, and form good solder joints. If the peak temperature is too low it may cause cold solder joints and poor wetting. However, if the peak temperature is too high, it not only may cause damage to the PCB (warpage, delamination, and charring), but also promotes defects such as tombstoning, solder beading, and voiding due to higher ΔT at the final ramp up stage. A high peak temperature also increases the duration time above the solder alloy’s liquidus temperature (wetting time, timeover), which may cause dewetting and excessive intermetallics formation.

Solder Beading

One of the major root causes of solder beading is flux out-gassing. When solder paste spreads underneath the chip components due to hot slump, it will be isolated from the bulk of the paste by the solvent vapor of the flux. This will form a solid bead at the side of the chip components during the reflow stage (Fig. 6).

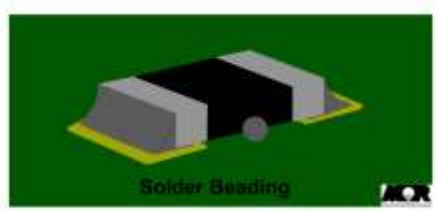

Fig. 6. Solder Beading

Dewetting

Dewetting is a phenomenon where either a component lead or a pad was wetted during the soldering process, but the molten solder withdrew from the wetted surface due to the excessive intermetallics formation and flux residue volatiles. If dewetting occurs, the peak temperature should be reduced and the wetting time should also be minimized.

Intermetallics Formation

During a SMT reflow process a thin layer of intermetallic compound (IMC) forms at the interface between component leads and the copper pads. Although IMC is required to form a good solder joint, an excessive growth of IMC may cause a reliability concern. The tin/copper IMC is brittle. A thick layer of IMC is prone to a failure during the thermal cycles of an electronic device being switched on and off. If possible, the peak temperature and the wetting time should be minimized.

III. Cooling Zone

In most cases it is preferable to set the cooling cure symmetrical to the ramp up cure of the reflow zone. If the cooling rate is too slow (>5° C/sec) it will not only cause excessive IMC formations, but also cause coarse grain structures and phase segregations in the solder alloys due to the annealing effect which may raise reliability concerns. On the other hand, if the cooling rate is too fast it may build up too much internal strain in the solder joints causing joint detachments and shrinkage voids. This is especially true during ead free soldering processes.

IV. Conclusion

The reflow profile should be optimized based on board design, board size, component size, component density, and solder alloy. A slower ramp up rate during the preheat stage will minimize hot slump, reducing the tendency of bridging, solder balling, tombstoning, and solder beading. A slower ramp up rate during the final ramp up will minimize tombstoning and voiding. A smaller ΔT at the final ramp up stage will reduce the chances for tombstoning, voiding, solder wicking, and component cracking. In general, lower peak temperature and shorter wetting time is always preferable as long as good solder joints are formed across the board.

David Bao has more than fifteen years of experience in developing new solder paste, wave soldering fluxes and other SMT consumables. David has conducted Research and Development work at Indium Corp. and currently serves as the Director of New Product Development at Metallic Resources Inc. He received a Ph.D. in Chemistry at Oklahoma State University. Email dbao@metallicresources.com.