

First Principles of Solder Reflow

Problem

Many solder users have preconceived notions and worries involving reflow profiling guidelines. Years of reading profiling recommendations in industry publications has made it clear that if the solder supplier gives them a tidy drawing on a piece of paper with times and temperatures that it will magically solve all their reflow problems. This is often an incorrect assumption.

Let us begin the discussion with a question. Do you believe you can get a good solder joint with a soldering iron: 'yes' or 'no'? (Figure 1).

The temperature of a soldering iron does not resemble the temperature required for a solder joint to form. The iron is at a much higher temperature than required for reflow of the solder joint. This large difference in temperature is used to force rapid heating. Peak temperature and time above alloy liquidus are in the hands of the operator and the heating capability of the soldering iron.

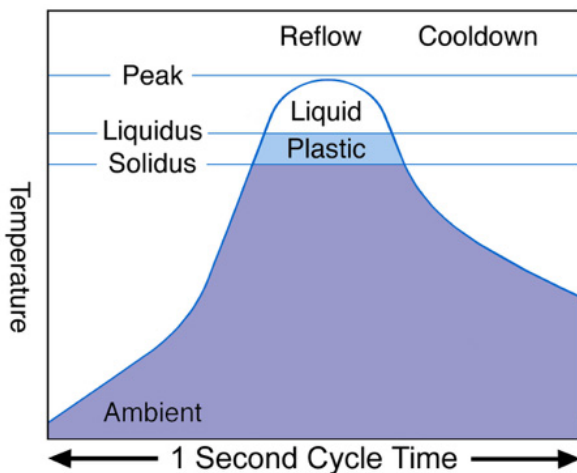


Figure 1

If your product goes in one end of an oven and comes out of the other end with no damage or defects in your product, can you tell what the reflow profile looks like? Does it matter what happened in the middle? Your goal in making a reflow profile is to ensure you don't have defects like flux and alloy spatter, tombstoned components, overheated substrates and components, cracked vias, cold solder joints and the like; nothing more and nothing less.

Maybe you don't use convection ovens. How does a reflow profile guide apply now? In most cases they do not apply except for the most general of concepts such as peak reflow temperature.

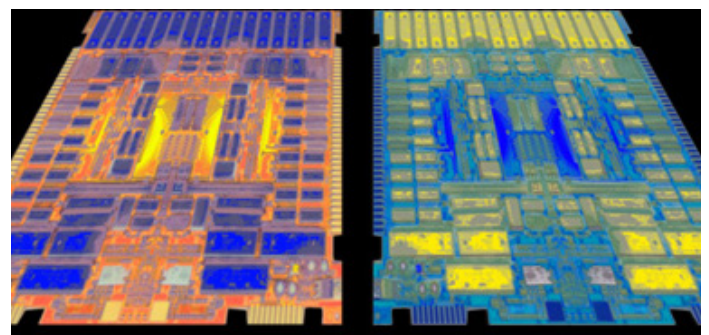
When it comes to reflow, it should be specific to what you are trying to accomplish with your product, not just duplicate the reflow profile on the solder supplier's profiling guide. If the suggested profile is not possible or not desirable with your product, you should contact your solder supplier to confirm it is intended to perform as needed with the heat cycle that best suits your product.

Recommended profiles are almost always written for use with convection ovens and circuit boards. They are also designed to meet customer expectations of what they should look like. In truth, for circuit boards, there is usually a fairly wide window of opportunity for success. Your heating process needs to be designed to achieve the highest yield with your products and your heating equipment.

A Brief History of Circuit Board Reflow

Much of today's reflow profiling philosophy evolved to compensate for the technology available when surface mount assembly was young. That technology was primarily infrared reflow ovens, vapor phase systems, and high mass convection reflow ovens. What follows is a brief and simplified history that explains why the electronics industry has mostly moved away from the early heating options.

Infrared energy is very inconsistently absorbed on a populated circuit board (Figure 2B). Due to uneven heating, the person in charge of profiles would heat the board up to a safe temperature below the solder reflow temperature, then have a "soak zone" to let the board equalize in temperature through conduction.



Convection

IR

Figure 2A

Figure 2B

The colder shadowed and reflective spots are allowed to catch up with other spots on the board that were significantly hotter due to color and reflectivity differences. Temperature differentials from point to point of more

than 40° C were not uncommon. It takes some time for thermal energy to spread through conduction and achieve point-to-point temperature differential of less than 5° C, hence the aforementioned “soak zone.” Next the heat is turned up to increase temperature to the next plateau until temperature equalizes at the desired peak. The philosophy behind “Ramp Soak Spike” reflow profiling grew because of infrared reflow and the need to get good results despite the limitations of that heating technology (Figure 3).

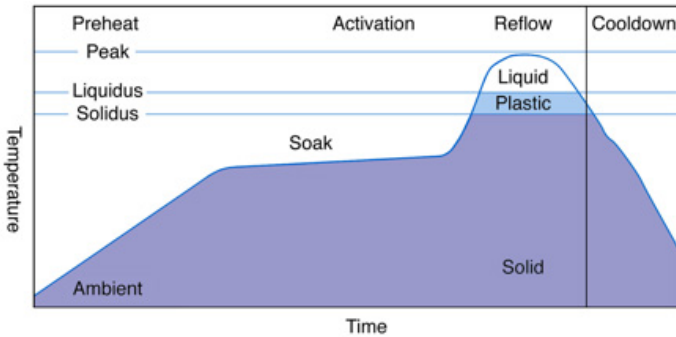


Figure 3

Many people choose to use the “Ramp Soak Spike” process with low mass, quick-response convection ovens that do not necessitate that kind of heating profile. While such a profile usually works, it is rarely optimal for today’s solder paste chemistry. In general, a solder paste will work best, wetting wise, if you take less time to achieve reflow.

Vapor phase heating does not promote the concept of a profile. Immersing a product into a boiling liquid causes very rapid temperature increase. Vapor phase is good for limiting peak temperature and ensuring all the solder melts at the boiling temperature of the fluid used. On the down side, the fluids are expensive and the rapid ramp can cause component tombstoning and other thermal shock-related problems.

High-mass convection ovens had to be profiled based on the long thermal recovery times inherent in the system. Attempts to use such ovens for short reflow profiles (without a soak time) would often overheat single boards, work well with a limited number of boards added at regular intervals, and fail to reflow solder if the ovens were fully loaded. With these ovens, longer profiles made for better consistency.

With the advent of low mass convection reflow ovens, most limitations on reflow heating process were taken away. Full or empty, black or green, the oven treats every product the same. Only the thermal mass of the parts plays a significant role in how long it takes to heat an entire product to the desired temperature.

With a shorter profile you minimize consumption of the oxide, reducing flux chemistry from pumping a lot of hot air onto the flux and the surfaces that it cleans. You get

better wetting with a shorter profile because there is more activity in the flux to get the job done, and the flux remains fluid enough to flow well. A typical example of a shorter profile is the “Ramp to Peak” profile with a fairly constant ramp (Figure 4).

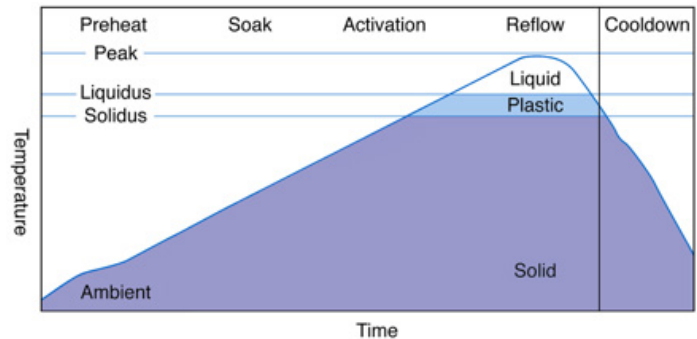


Figure 4

Keys to Success

There are four steps to success no matter what kind of product you have or what kind of reflow equipment you use. Some may be mere formalities based on the simplicity of your product.

Step one: Find out which components, if any, are temperature or thermal shock sensitive. Most parts aren’t sensitive at conventional reflow soldering temperatures. If you do have sensitive parts, they will limit how fast, how hot, and where you can heat your product. Some products require localized heating. It may be necessary to investigate alternative heating methods.

Step two: Find out if you have any relatively large, heavy, or otherwise difficult-to-heat parts. Such parts may limit to how fast your product may be heated, with the equipment in use, without damage. As with temperature sensitive parts, it may be necessary to investigate alternative heating methods and secondary reflow operations.

Step three: Match a solder product to the components and heating process you intend to use. Despite the seeming simplicity of this step, keep in mind that there are a bewildering variety of solder pastes, solder wire styles, and fluxes supplied in dozens of solder alloys. Each has a specific purpose as someone is using it to satisfy a particular need. Factors such as the equipment available, application method, operator training requirements, solder joint consistency, and flux performance in the heating and cleaning processes will be key to the decision-making process.

Step four: Test and tune your reflow process for optimal yield. Easier said than done, this step can push the process development cycle back to Steps 1, 2, or 3 due to unacceptable results. Here is where reflow profiling can in fact become critical.

Reflow Process Development, Condensed

If you are not heating with an oven, the heating cycle is unlikely to look like a published profile. That's fine. It doesn't have to. Your goal is to get the right amount of heat to the right location within your targeted cycle time. Success is measured in first pass yield and throughput, not degrees C per second and time above liquidus.

Temperature ramp rate and time above solder alloy liquidus are only important if they can damage your product. It usually only takes a second or three for liquid solder to finish moving and wetting to the available surfaces after it reaches reflow temperature. If you are heating slowly, it may take longer. The hotter the solder gets, the faster the solder wets.

Does the time above liquidus matter? Only to the extent that all the solder needs to reflow and finish wetting. The truth of the matter is that the solder joint is formed and the liquid solder alloy stops moving after about 1.5 seconds. Time beyond that spent above liquidus is not generating any benefit with regard to joint quality. Extra time thickens the intermetallic layer, which is more brittle than the bulk solder joint, and increases substrate scavenging.

Intermetallic compounds form when two unlike metals diffuse into each other. In soldering, this is tin into copper, nickel, and other solderable materials. During laser reflow of solder paste, the entire reflow heating cycle can be completed in under a second with full wetting and a textbook-perfect fillet. Excessively thick intermetallic layers can contribute to brittle fracture of solder joints.

Scavenging is most often of concern with plated parts and printed thin films. In extreme cases the entire solderable surface can be dissolved. Again, more time above liquidus is not a benefit.

The ideal heating cycle is no longer than the time it takes to make sure every joint has reflowed and wet out completely.

For those that do use reflow ovens, including circuit board assemblers, all the same rules apply. For circuit boards, Nordson EFD recommends you begin your heating experiments with a heating rate of somewhere around 1° C per second from room temperature to peak. If the oven available produces a stepped profile instead of a straight line profile, that is fine. If you need to slow things down to get a lower temperature differential from point to point on your product, go right ahead. Gradual, even heating results in fairly uniform product temperatures. It is a process that can be reproduced on a very wide variety of ovens.

Preventable Reflow Problems with Circuit Boards

There are techniques you can use to prevent defects through good profiling. The temperature and time ranges detailed in profiling guides are usually chosen to give a wide enough window to apply such techniques.

At the beginning of a heating cycle the single largest issue is explosive vaporization of low boiling point materials that are either part of the flux or have been absorbed during use. Alcohol and other solvents and absorbed moisture can explode if heated too fast. Solder and flux spatter are the most common indicators that you have a problem that deserves attention. If you need to, slow your heating rate up to 130° C to dry the paste more gradually so it does not explode.

Beyond the 130° C point, where water and most low boiling point materials will have finished evaporating, you have the temperature range up to alloy solidus. At these temperatures, the activators in the flux fulfill their function, cleaning the solder and substrate of oxides. Spend too long here and the flux activity can be mostly or completely consumed, resulting in poor wetting and what appears to be unreflowed solder despite achieving a peak well above alloy liquidus. Longer heating processes can be accommodated with higher activity flux formulations. As a goal, do not spend any more time between 130° C and the alloy solidus than is required for acceptable point-to-point temperature differential on your product.

The next critical point of the heating cycle is around the alloy solidus temperature. Once you get to just below the liquid point, some heating processes need to slow down. The most common reason for care during alloy liquefaction is to prevent tombstoning (Figure 5).

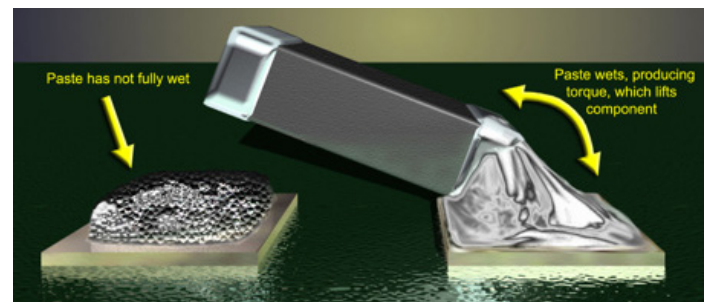


Figure 5

Tombstoning occurs when a difference in temperature between the two pads allows the paste on one pad to reflow before the other. The difference in surface tension between the two pads produces torque which lifts the part. By slowing the ramp as the metal liquefies, you will minimize the chance of generating a tombstone. Thinking of it a different way, instead of soaking below the liquefaction temperature of the alloy, utilize a slower ramp rate, something under 1° C per second, as you go through that liquefaction zone. Nordson EFD recommends controlling ramp from about 5° C below solidus to 5° C above liquidus of the alloy. As chip components get smaller and smaller, your risk for tombstoning increases.

Time spent above liquidus and peak temperature should be based on process robustness. Typical

recommendations of 15 to 40° C above liquidus are based on the fact that solder alloy wets better the hotter it gets. Temperatures in this range will ensure optimal wetting. Solder joints form at just a few degrees above liquidus but wetting will not look typical and may not meet reliability requirements.

These recommendations are also based on common processing limitation for circuit board materials. If your circuit board material is not as temperature-sensitive, getting hotter may not have a down side.

Time spent above liquidus is a function of the heating and cooling capabilities of your oven and the goal of reflowing the unmeasured cold spot on your product, every time. By adding five or ten seconds to reflow time, the likelihood of a cold solder joint can be eliminated. Exactly how long this time is for your product depends on the specific thermal constraints.

Conclusion

Some people use lasers to reflow solder in less than a second. Others have heating times of 20 minutes or more. Most fall in between these two extremes. All you have to do is match the heating process and solder product to your soldering need. Understand the limitations and opportunities your components, equipment and solder material present and take full advantage of them.

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