SMT

How Challenging Conventional Wisdom Can Optimize Solder Reflow

By Marc Peo

As a manufacturing technology, SMT has acquired a "heritage" of widely accepted assumptions about its processes. However, yesterday's practices are continually confronted by the shifting paradigms of today's production line.

With solder reflow, relying on commonly accepted practices can lead engineers to overlook some relatively simple factors that are critical to optimizing the process. An examination of six "conventional wisdom" tenets reveals that challenging them can contribute significantly to improved yields.

All full convection reflow ovens are engineered to handle the special requirements of double-sided PCBs.

No. 1 — A Standard Profile?

Figure 1 on page 110 includes the "ideal" reflow profile. It is characterized by a 2° to 4°C/sec ramp to a dwell zone of 30 to 90 sec at approximately 150°C, followed by a second ramp to about 210°C.[1] This graph *does* represent a satisfactory profile for *certain* pastes and *some* ovens, but it is by no means suitable for all situations. Applications for which the (a) profile are appropriate include pastes that require a dwell time at 150° to 160°C to allow for flux activation, and for IR-based ovens that create large temperature differentials (ΔT) on the surface of the PCB. In the latter case, the time in the dwell zone reduces the ΔT by permitting lower temperature areas to "catch up" to the higher thermal areas, at which point the entire board achieves near equilibrium.

Today, however, many no-clean pastes are used with greater frequency and actually require a reflow profile *without* a dwell zone. The typical form for such a profile, Figure 1b, is commonly referred to as a "tent" or "straight ramp" profile. For no-clean pastes, which have less active fluxes, excessive dwell time serves only to deplete the flux before reflow.

A second advantage of the tent profile is that it speeds the reflow process, since residence in the oven is reduced by the time formerly required for the dwell zone. Hence, when typical four- to five-minute profiles can be completed in three to four minutes, throughput increases of 20 to 25 percent are likely. On the other hand, a shorter oven also can be used to achieve the same throughput and to conserve factory floor space.

No. 2 — Avoid Reflow of Double-sided PCBs?

Reflowing double-sided boards in a full convection oven is generally proscribed since it can cause components to be blown off the bottom. In fact, all full-convection reflow ovens today are engineered to account for the special requirements of double-sided reflow. They include improved controls for interior air velocity, combined with the surface tension of solder paste, to hold bottom-side components in place and to eliminate the possibility of blowing the parts off during double-sided reflow.

Additionally, after eutectic solder is first melted, the alloying that occurs at the solder joint during reflow effectively increases the remelting point. Here, the alloy no longer has eutectic properties, making it uncommon for bottom-side components to be released during a second run through the oven. In some applications, components as large as 68-pin PLCCs can even be

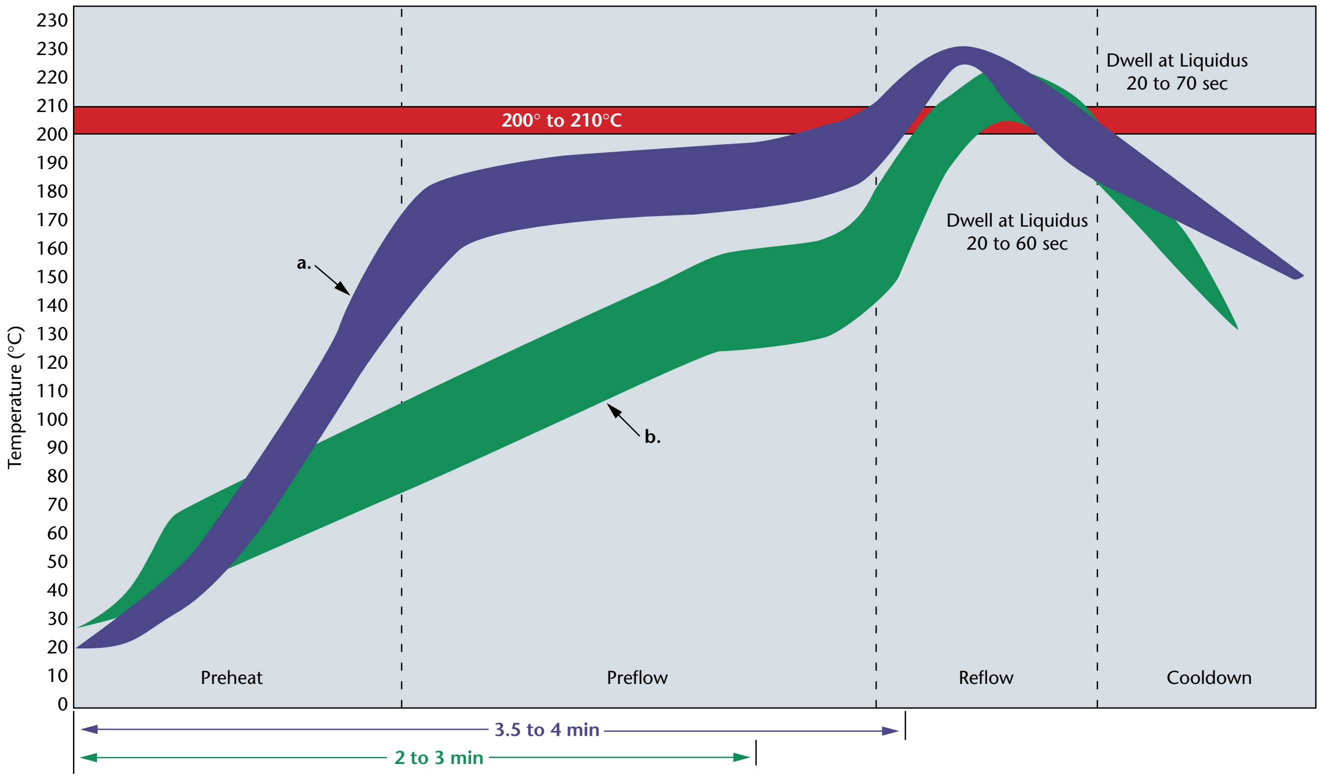

Figure 1. The "standard" reflow profile (a) is compared to the "tent" or "straight ramp" pattern. While the former is suitable for solder pastes that require dwells at specific temperatures, the growth in the use of no-clean pastes demands more controlled high temperature periods lest the flux be depleted.

suspended on the bottom purely via surface tension of the solder. Thus, a formula for secondary side mounting can determine a component's candidacy for bottom-side attachment:[2]

$$C_g/P_a$$

Where C = component's weight in grams; P = total pad area in square inches (g/in² must be ≤ 30 for second-side mount).

To anchor components larger than 68-pin PLCCs (e.g., relays and other high mass/low lead count packages), most PCB assemblers use an epoxy. In other cases, solders with different melting points can be used. For example, if the bottom-side is reflowed first using a high melt point solder (greater than 183°C), then the top-side can be reflowed using a eutectic solder (melting point: 183°C). With this procedure, the bottom-side cannot be reflowed a second time. Communicating such issues back to the design stage (and developing strategies to deal with them) is an important factor in resolving process challenges.

No. 3 — What *Really* Causes 'Tombstoning'?

Tombstoning, or the displacement of a chip component during reflow into a near vertical position with only one terminal soldered, is caused by *accelerated* heating: When exceptionally high ramp rates (e.g., 6° to 7°C/sec) are in effect, the solvents in the paste can boil, creating bubbles with sufficient force to pop components out of place.

This was certainly a possibility until recently. However, the development of water-insoluble solvents having higher boiling points has effectively eliminated the bubbling issue. Nor do water-soluble solvents attract moisture that can boil off as heating progresses. Instead, tombstoning can be caused by the following conditions that can occur at various stages of the assembly process:

Inaccurate Component Placement. As shown in Figure 2a, the greater wetting force exerted on one end of an incorrectly placed component will pull it up on end, creating the characteristic "Manhattan" or tombstoning effect.

Excessive Pad Size. A greater amount of paste relative to the surface area of the part's terminal can also result in tombstoning (Figure 2b). Also, a greater wetting force can be created during reflow in the case of an uneven deposition of paste on the pads.

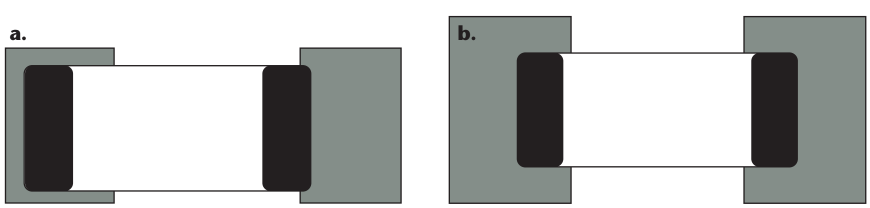

Figure 2. Conditions that lend to the possibility of component tombstoning during reflow include inaccurate placement (a) in which a greater wetting force at one end serves to erect the opposite end, and (b) excessive pad size vs. the part's terminal size, leading to the same effect.

No. 4 — Using Nitrogen (vs. Air) Improves the Process?

In fact, a nitrogen atmosphere in the oven *does* improve reflow results. It creates solder joints that are shinier, improves wetting angles and increases the "margin for error" in the process. In addition, certain applications such as ultra-low-residue fluxes actually *require* nitrogen owing to their lower levels of activity. However, in applications where nitrogen is not stipulated, many assemblers have found the gas to be a "Band-Aid" in compensating for situations that can be fixed by careful process control.

Poor soldering can result from many causes including improper deposition of paste, use of an inappropriate paste, paste that has been on the stencil too long, inaccurate component placement or an improper reflow profile. While nitrogen reflow may mask the effects of those problems, a simple process adjustment may be all that is required to improve results. More importantly, making process control adjustments carries no ongoing costs, while nitrogen usage is certainly expensive, i.e., there are usage, facilities and setup charges to be accounted for with N_2 processing. Accordingly, it is necessary to review costs vs. benefits before committing to the process.

During the review, nitrogen consumption becomes paramount. Obviously, reflow ovens that consume less nitrogen will cost less to operate, as shown in the table, and are easier to justify when they are required.

No. 5 — Lower Oxygen, Better Results?

Field testing has shown virtually no difference in quality from reflow units whose oxygen levels are held from 15 to 100 ppm. In fact, wetting angles and joint strengths have been found to be basically identical. In certain cases, it has even been reported that wetting forces at very low oxygen levels may actually be too strong, creating yet another cause of tombstoning on small parts. Since running at a higher oxygen level makes no difference to the overall process (while operation at the very lowest consumes significant amounts of nitrogen), this is certainly an area in which cost savings can be realized, as shown in Figure 3.

Certain ovens offer a closed-loop nitrogen controller that permits a minimization of the gas' consumption by maintaining a specific ppm oxygen level. These systems regulate nitrogen flow automatically and compensate for changes in board load, ambient air conditions and other factors by maintaining ppm levels within an acceptable tolerance band.

No. 6 — Processing in N_2 Means More Maintenance/Downtime?

With nitrogen processing, the cooling zones cause flux condensation, and it is thought, more frequent maintenance and increased downtime. While the temperature of the water in the heat exchanger does cause flux condensation, several systems now address this issue:

Flux Burn-off. Certain ovens provide a periodic burn-off system that heats automatically to vaporize flux as it accumulates. The flux turns into a fine ash and is exhausted with no ill effect on the process.

Flux Filtration. Another system traps and removes flux before its entry into the heat exchanger. Result: Very little flux enters the cooling chamber to condense on the heat exchanger. The flux filters may be removed and replaced even while the oven is running, eliminating the need for downtime to perform this maintenance.

Waterless cooling eliminates recirculated water heat exchangers, thus removing the possibility of condensation inside the oven. In this enclosed system, the flux-laden gas is diverted from the heating zones and precipitated out using a cyclonic separation system and air-to-air heat exchanger. The cooled, flux-free gas is then reintroduced into the cooling zone as the flux is collected outside the oven chamber, again allowing preventive maintenance to be performed while the oven is running and eliminating the need for maintenance downtime.

A review of these commonly accepted reflow practices indicates that the surface mount process often defies generalization. In many cases, each process is unique and requires individually designed methods to satisfy its own requirements. And, of course, there is no substitute for rigorous process control. However, manufacturers are not without resources to assist in fine-tuning their processes. To take advantage of rapid developments in advanced technology, assemblers should work in partnership with all their vendors including suppliers of placement equipment, screen printers, solder paste, conveyors and reflow ovens. The sales and technical support staffs of these companies have experienced literally thousands of applications. Hence, their expertise can provide valuable process contributions usually at no cost. In fact, when vendor consultation is combined with a manufacturer's own engineering resources to challenge commonly accepted practices and to optimize process control over each step in an assembly line, the stage is set for creating a highly successful operation with high productivity levels. SMT

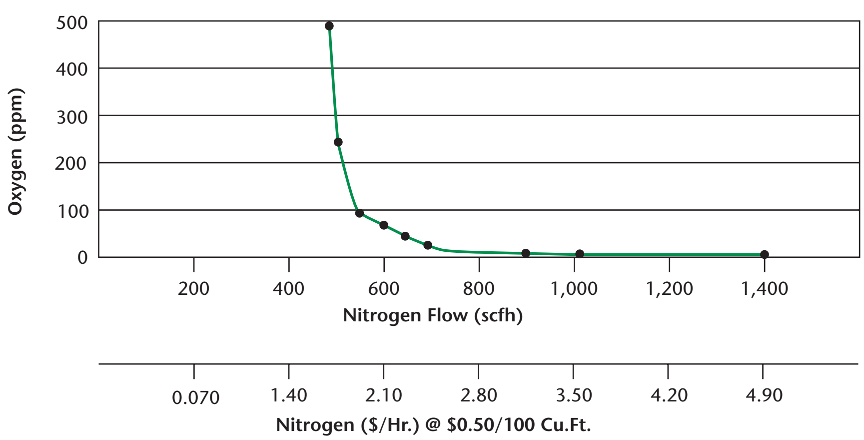

Figure 3. How the cost in nitrogen consumption escalates as the oxygen ppm level is reduced in a reflow oven's atmosphere.

TABLE 1

Worldwide Cost of Nitrogen in Reflow vs. Consumption

Country	Base Cost /ft³	AOC 2,000 scfh*	AOC 600 scfh*
United States	$0.0035	$14,560	$3,640
Continental Europe	0.0070	29,120	7,280
United Kingdom	0.0070	29,120	7,280
Scandinavia	0.0018	7,280	1,820
Mexico	0.0070	29,120	7,280
Thailand	0.0105	43,680	10,920
Israel	0.0175	72,800	18,200
Singapore	0.0350	145,600	36,400

*Annual operating cost, continuous single shift, 2,080 hr/yr.
Cost's source: ITM

REFERENCES

[1] Philip Zarrow, "Fine-pitch Soldering," *Circuits Assembly*, September 1991, p. 47-48.

[2] Philip Zarrow, "Fear and Loathing with Double-sided Reflow Soldering," *Circuits Assembly*, June 1997, p. 26

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