

Optimizing Reflow Profile Via Defect Mechanisms Analysis

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Abstract

The reflow profile is engineered to optimize soldering performance based on defect mechanisms analysis. In general, a slow ramp-up rate is desired in order to minimize hot slump, bridging, tombstoning, skewing, wicking, opens, solder beading, solder balling, and components cracking. A minimized soaking zone reduces voiding, poor wetting, solder balling, and opens. Use of a low peak temperature lessens charring, delamination, intermetallics, leaching, dewetting, and voiding. A rapid cooling rate helps reduce intermetallics, charring, leaching, dewetting, and grain size. However, a slow cooling rate reduces solder or pad detachment. The optimized profile favors a temperature that ramps up slowly until reaching about 180°C. The temperature is then gradually raised to 186°C within 30 seconds, then raised rapidly until reaching about 220°C. After that, the temperature is brought down with a rapid cooling rate. The conventional profile was developed due to the limitation of past reflow technologies. Implementation of the optimized profile requires the support of a heating-efficient reflow technology with a controllable heating rate. Vapor phase reflow can provide a rapid heating, but has difficulty in controlling the heating rate. Infrared reflow can regulate the heating rate, but is sensitive to variation in parts features. Emergence of the forced air convection reflow provides a controllable heating rate. In addition, it is not sensitive to variation in parts features, thus allowing the optimized profile.

Key Words: reflow, profile, defect, flux, solder paste, soldering, convection, infrared, vapor phase, SMT.

Introduction

Reflow solder paste is the primary method of forming solder joints at board level assembly in SMT industries. In general, when properly done, the reflow process provides high yield, high reliability, and low cost advantages. Among all of the process considerations, the reflow profile is one of the most important factors in determining the soldering defect rate.

The types of defects [1] affected by reflow profile include component cracking, tombstoning, wicking, solder balling, bridging, solder beading, cold joints, excessive intermetallics formation, poor wetting, voiding, skewing, charring, delamination, leaching, dewetting, solder or pad detachment, etc. Therefore, it is extremely important to have the reflow

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profile engineered properly in order to achieve both high yield and high reliability.

In general, a reflow profile can be roughly divided into three major elements: the peak temperature, the heating stage, and the cooling stage. Each element has its impact on the reflow results. Based on the understanding of defect formation mechanisms, the discussion will focus on how each part of the profile can be engineered to minimize the defect rate and to maximize the reliability.

Fluxing Reaction

In the SMT industries, soldering normally starts with fluxing to clean up the metal oxides, then is followed by solder wetting to form the solder joints. Before discussing any profile setting, it is essential to understand the time and temperature requirement for fluxing reaction.

1. Time/Temperature Requirement for Fluxing Reaction

The fluxing reaction usually can be monitored by determining the wetting time S with the use of a wetting balance, as illustrated by Figure 1. A short wetting time normally reflects a fast fluxing reaction. It can also be investigated by examining the coalescence, or reflow, behavior of solder paste. Again, a fast solder paste coalescence process indicates a fast fluxing reaction.

Reflow of solder pastes typically can be completed in a very short time. This can be demonstrated easily by printing a small dot of Sn63/Pb37 solder paste onto a copper coupon, followed by reflowing this sample on a hot plate with a reasonable surface temperature. The paste reflow and solder spreading processes usually can be completed in merely a few seconds.

This rapid reflow, or fluxing, behavior of solder paste can also be confirmed by examining the wetting time of fluxes with the use of a wetting balance. Table 1 shows the wetting time of four fluxes, A, B, C, and D, from several commercially available Sn63/Pb37 solder pastes at 200 and 240°C, respectively. The copper coupons tested have been pre-baked in a forced air convection oven at 100°C for 3 hours to simulate the “difficult to solder situation”. The solders used in this study are Sn63/Pb37 and Sn62/Pb36/Ag2. Results indicate that the wetting time is around several seconds at the designated temperatures. Therefore, it can be concluded that fluxing reaction does not require more than a few seconds as long as the temperature can be raised up to 200°C or higher. A simple, extremely rapid heating profile is sufficient to complete the fluxing and yield a good reflow and wetting result.

2. Fluxing Contribution at Temperature Below Melting Temperature

In order to understand the contribution of the fluxing reaction at a temperature below the melting temperature, the wetting time of fluxes F1, F2, F3, and F4 from four RMA solder pastes is measured with the use of a low melting temperature solder (43Bi/34Sn/20Pb, with a melting point 100°C). Although this low melting temperature solder shows a slower wetting behavior than eutectic SnPb solder, the wetting time measured at various temperatures is expected to reflect the relative fluxing reaction rate at the corresponding temperature. As shown in Figure 2, results indicate that the wetting time is proportional to the reciprocal of absolute temperature. This is true at least for the temperature ranging from 150 to 240°C. At 150°C, the wetting time is about 1-2 order of magnitude longer than the wetting time from 210-240°C. It can be concluded that (1) temperature is the dictating factor in fluxing reaction, and (2) with equal dwell time, the contribution of the fluxing reaction at a lower temperature is negligible when compared with that at a higher temperature.

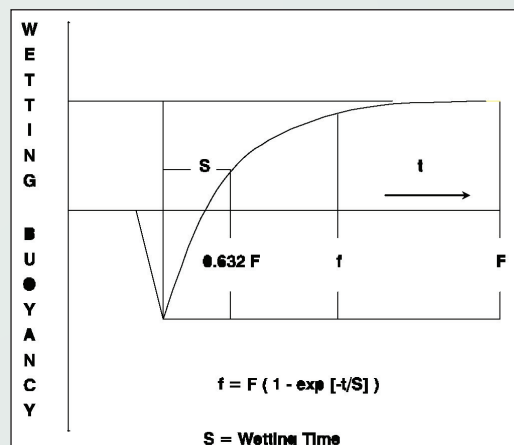


Figure 1. Kinetics of wetting.

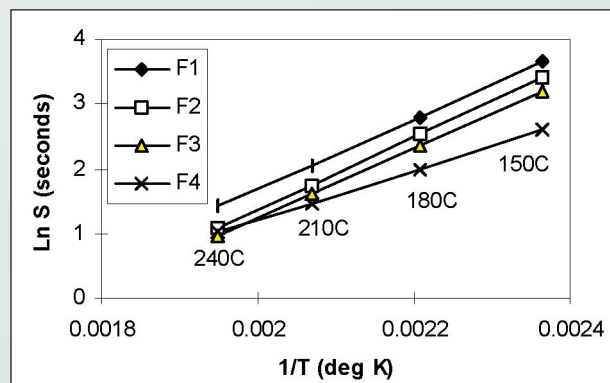


Figure 2. Wetting time S of fluxes as a function of temperature.

Fluxes	Wetting Time (seconds)			
	Sn63/Pb37		Sn62/Pb36/Ag2	
	200°C	240°C	200°C	240°C
A	2.87	1.48	4.68	2.52
B	1.03	0.50	1.44	0.63
C	1.65	1.00	2.60	1.03
D	2.50	1.44	3.48	2.10

Table 1. Wetting time of several fluxes tested at 200 and 240°C using Sn63/Pb37 and Sn62/Pb36/Ag2.

Peak Temperature

1. Cold Joint and Poor Wetting

The peak temperature of a reflow profile usually is determined by the solder melting temperature and the temperature tolerance of the board and parts to be assembled. Being heterogeneous in nature, solder pastes typically take a longer time to coalesce than what is shown by the wetting balance test. Accordingly, the minimal peak temperature should be about 30°C above the solder melting temperature. Reflow with a peak temperature lower than that will have more of a chance of yielding cold joints as well as having insufficient wetting. In the case of eutectic SnPb solder, this minimum peak temperature is approximately 210°C.

2. Charring, Delamination, and Intermetallics

The maximum peak temperature desired is about 235°C. Beyond that, the charring and delamination of epoxy boards and plastic parts may become a concern. Furthermore, an excessive amount of an intermetallic compound may be formed and result in a brittle solder joint.

3. Leaching

Leaching [2] is a concern in hybrid applications when an excessive amount of base metal is extracted into the solder. The extent of leaching is dictated by the peak temperature, and can be reduced by using a lower peak temperature. Using a shorter time at temperature above the liquidus would also help reducing the leaching.

Cooling Stage

1. Intermetallics

The optimum cooling stage is also relatively easy to determine. A slow cooling rate at a temperature above the melting temperature of solder will result in excessive intermetallics. To minimize the intermetallics, a fast cooling rate is desired.

2. Grain Size

A slow cooling rate often results in solder joints with large grain structure due to annealing effect. This is mainly referring to the temperature range between the melting temperature and a temperature below it. This large grain structure typically exhibits a poor fatigue resistance and is not desired. Solder joints with a fine grain structure can be produced with the use of a fast cooling rate. However, the cooling rate effect diminishes with increasing temperature gap. A 50°C temperature gap is believed to be sufficient to have a negligible annealing effect.

3. Internal Stress-Component Cracking

The maximum cooling rate allowed is often determined by the tolerance of the components against thermal shock. For components such as chip capacitors, the maximum cooling rate tolerable is approximately 4°C/min.

4. Deformation of Joints

The cooling mechanism of a reflow oven is typically conducted by using forced cold air. A fast cooling rate requires the use of fast cold air blowing onto the molten solder joints, that may result in deformed solder joints. In general, the solder joint deformation phenomenon is negligible at cooling rate no higher than 4°C/min.

5. Internal Stress-Solder or Pad Detachment

The cooling rate may also affect the delamination of pads from the board or detachment of solder joints from the pads. A fast cooling rate may result in too high a temperature gradient between components and board, and accordingly yield a mismatch in thermal expansion. This in turn will create internal stress around the solder joints, and consequently result in detachment of solder joints from the pads, or delamination of pads from the board. For example, in some instances, the result is detachment of the corner solder joints of BGAs.

Heating Stage

The heating stage can perhaps be regarded as the most complicated part of reflow profile. Similar to the cooling stage, the parameters involved are both time and temperature.

1. Slumping and Bridging

Bridging is a direct result of slumping. Therefore, the discussion here will focus on the slumping of solder paste. Since slumping only occurs at the paste stage, the temperature in this discussion will be at or below the melting point of the solder.

In general, the viscosity of materials with a fixed composition and chemical structure decreases with increasing temperature, due to the increasing thermal agitation at the molecular level. This decrease in viscosity at a higher temperature will yield a greater slump. On the other hand, the increase in temperature usually dries out more solvent of the flux and results in an increase in solid content, thus increasing the viscosity. These two opposite effects, thermal agitation effect and solvent loss effect, are exemplified in Figure 3.

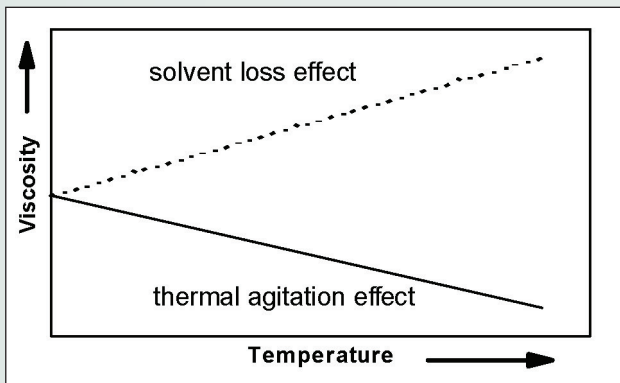


Figure 3. The effect of thermal agitation and solvent loss on viscosity as a function of temperature.

The thermal agitation effect is an intrinsic material property. It is a function of temperature only and is independent of time. Therefore, the ramp-up rate has no effect on it. However, the solvent loss effect is a kinetic phenomenon and will be affected by the ramp-up rate. The solvent vaporization rate is proportional to the thermal energy, or temperature, of the solvent. The solvent loss quantity is proportional to the product of the vaporization rate and the time allowed for vaporization. In other words, the total solvent loss is a function of both time and temperature, hence it can be regulated by varying the reflow ramp-up rate. At a slow ramp-up rate, the viscosity of solder paste is higher than that of the fast ramp-up rate at any given elevated temperature due to a greater amount of solvent loss, as shown in Figure 4.

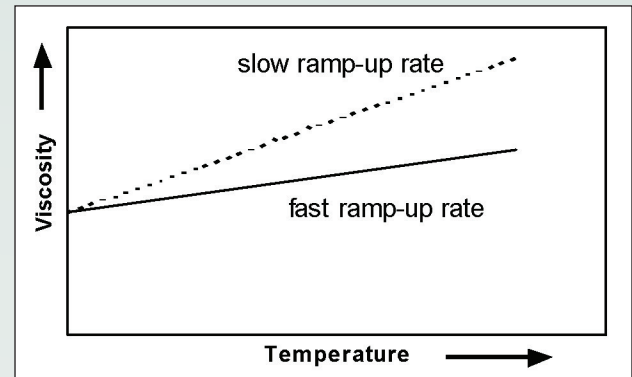


Figure 4. Relationship between ramp-up rate and viscosity due to solvent loss effect.

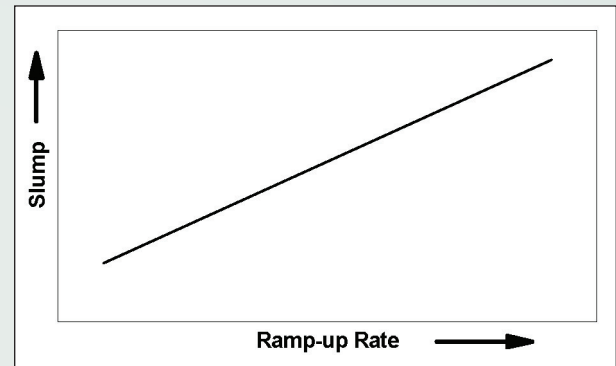


Figure 5. Relationship between slump and ramp-up rate.

Therefore, by applying a fairly slow ramp-up rate, the solvent loss effect can be enhanced and override the thermal agitation effect. This will result in either a less viscosity decrease or a net viscosity increase with increasing temperature. Consequently, the slump decreases with decreasing ramp-up rate, as exemplified by Figure 5. In general, a ramp-up rate of 0.5 to 1°C/sec from room temperature to melting temperature is recommended.

2. Solder Beading

Solder beading [3] is caused by flux outgassing which overrides the paste's cohesive force during the preheat stage. The outgassing promotes the formation of isolated paste aggregates underneath the low-clearance components. At reflow, the isolated paste melts and, once it emerges from the underside of the components, coalesces into solder beads. The outgassing rate can be controlled by controlling the ramp-up rate at heating stage prior to melting of solder. At a very slow ramp-up rate, the outgassing of flux can occur via a diffusion process instead of rigorous vaporization. This prevents the formation of isolated paste aggregates caused by the erupting outgassing force, and avoids the formation of solder beading.

3. Wicking

Wicking [4] is a phenomenon where the molten solder wets the component lead and flows up the lead away from the joint area, to such extent that a starved joint or an open joint is formed. It is a result of the lead being hotter than the pad of PCB at the solder melting stage. This can be prevented by using more bottom-side heating or a very slow ramp-up rate at a temperature around the melting point of solder. By doing so, it will allow the temperature of leads and pads to reach equilibrium before any solder wetting occurs. Once the solder wets onto the pads, the solder fillet shape will remain stable and will no longer be sensitive to the ramp-up rate.

4. Tombstoning and Skewing

Tombstoning [1] and skewing [2] are caused by uneven wetting occurring at the two ends of the chip. Similar to the wicking defect, these can be minimized by using a very slow ramp-up rate profile around the melting point of solder to allow the temperature of the two ends of the chip to reach equilibrium.

5. Solder Balling

Solder balling can be caused by spattering. In many instances, this can happen at a ramp-up rate greater than about 2°C/sec prior to the solder coalescence. A slow ramp-up rate is a very effective means of preventing spattering.

Solder balling can also be caused by excessive oxidation at temperature prior to the solder coalescence. To minimize this oxidation, the heat energy input prior to solder melting should be minimized. When both spattering and oxidation factors are considered, the optimal heating process to minimize overall solder balling phenomenon would be a profile with a linear ramp-up until the solder melting temperature is reached.

6. Poor Wetting

Poor wetting can result from excessive oxidation at temperature prior to the solder coalescence. Similar to the solder balling discussed above, the heat energy input prior to solder melting should be minimized in order to minimize this oxidation. The profile desired is a heating time as short as possible. If the heating time can not be shortened due to other considerations, then a linear ramp-up profile from ambient temperature to solder melting temperature is crucial for minimizing the oxidation.

7. Voiding

Voiding [5] is primarily caused by outgassing of flux entrapped at the unwetted spots at the interface of the solder-substrate or

the solder-lead. The unwetted spots can be reduced by reducing the oxidation, as described in the poor wetting section. That is, using either a heating time as short as possible or a linear ramp-up profile from ambient temperature to solder melting temperature. If the solderability is very good, such as a HASL board, then the wetting is not an issue, and the voiding can be further improved by reducing the viscosity of flux remnant. This can be accomplished with the use of a cooler profile [6].

8. Opens

Opens can be caused by either wicking or non-wetting. In the case of wicking, the symptom can be lessened by using the profile described in the “Wicking” section. This profile uses either more bottom-side heating or a very slow ramp-up rate at temperature around the melting point of solder. As to the non-wetting case, it is often observed as a “Pillow Effect”. Here, the lead sags into the solder bump without formation of a real bonding or wetting. Problems such as this can be minimized by reducing the oxidation, as discussed in the “Poor Wetting” section. Again, a linear ramp-up profile from ambient temperature to solder melting temperature is desired.

Timing Considerations

1. Ramping-Up Stage

It has been discussed in the previous sections that to minimize most of the defects (such as slump, bridging, solder beading, solder balling, etc.), a slow ramp-up rate is desired. In the heating stage, the temperature range should be between the ambient and the melting temperature of solder. It is recommended that a linear ramp-up rate be applied between the room temperature and the temperature slightly below the melting temperature.

2. Soaking Zone

Although the mass reflow technology is improving in heating efficiency, a small temperature gradient may still exist across the board. In order to minimize the defects (such as tombstoning, skewing, and wicking) caused by a temperature gradient across the melting temperature of solder, a short plateau is recommended as soaking zone. In general, the less efficient the heating is, the longer the soaking zone should be. However, adapting a soaking zone may imply a compromise in a slow ramp-up rate prior to solder melting. With an overall profile length being constant, the longer the soaking zone is, the higher the ramp-up rate prior to the soaking zone will be. A soaking period of 30 seconds is considered adequate for a heating-efficient reflow technology.

Table 2. Desired profile features for minimizing defects.

Subjects	Defect Mechanisms	Desired Profile Feature	Ramp-up Rate	Peak Temp	Cooling Rate
Parts cracking	Too high an internal stress due to fast temperature change rate	Slow down temperature change rate	Slow		Slow
Tombstoning	Uneven wetting at both ends of chip	Use slow ramp-up rate at temperature near and above solder mp to minimize the temperature gradients across the chip	Slow		
Skewing	Uneven wetting at both ends of chip	Use slow ramp-up rate at temperature near and above solder mp to minimize the temperature gradients across the chip	Slow		
Wicking	Leads hotter than PCB	Slow ramp-up rate to allow the board and components reaching temperature equilibrium before solder melts; more bottom side heating	Slow		
Solder balling	Spattering	Slow ramp-up rate to dry out paste solvents or moisture gradually	Slow		
Solder balling	Excessive oxidation before solder melting	Minimize heat input prior to reflow (slow ramp-up rate, no plateau at soaking zone) to reduce oxidation	Slow		
Hot slump	Viscosity drops with increasing temperature	Slow ramp-up rate to dry out paste solvent gradually before viscosity decreases too much	Slow		
Bridging	Hot slump	Slow ramp-up rate to dry out paste solvent gradually before viscosity decreases too much	Slow		
Solder beading	Rapid outgassing under low standoff components	Slow ramp-up rate prior to reflow to slow down the outgassing rate of paste	Slow		
Opens	Wicking	Slow ramp-up rate to allow the board and components reaching temperature equilibrium before solder melts; more bottom-side heating	Slow		
	Non-wetting	Minimize heat input prior to reflow (minimize soaking zone, or use linear ramp-up from ambient to solder melting temperature) to reduce oxidation	Slow		
Poor wetting	Excessive oxidation	Minimize heat input prior to reflow (minimize soaking zone, or use linear ramp-up from ambient to solder melting temperature) to reduce oxidation	Slow		
Voiding	Excessive oxidation	Minimize heat input prior to reflow (minimize soaking zone, or use linear ramp-up from ambient to solder melting temperature) to reduce oxidation	Slow		
	Flux remnant too high in viscosity	Cooler reflow profile to allow more solvents in flux remnant		Low	
Charring	Overheat	Lower temperature, shorter time		Low	Fast
Leaching	Overheat at temperature above solder mp	Minimize heat input at temperature above solder mp by using lower temperature or shorter time		Low	Fast
Dewetting	Overheat at temperature above solder mp	Minimize heat input at temperature above solder mp by using lower temperature or shorter time		Low	Fast
Cold joints	Insufficient coalescence	Use high enough peak temperature		Medium	
Excessive intermetallics	Too much heat input above solder mp	Lower peak temperature and use shorter time		Low	Fast
Large grain size	Annealing effect due to slow cooling rate	Fast cooling rate			Fast
Solder or pad detachment	High stress due to mismatch in thermal expansion	Slow cooling rate			Fast

3. Onset Temperature of Spike Zone

The profile section around the peak temperature and with both a fast ramp-up rate and a fast cooling rate is often referred to as spike zone. Considering the internal-stress related component cracking possibility, the ramp-up and cooling rate used is normally between 2.5-3.5°C/sec, with the maximum change rate no higher than 4°C/sec. This onset temperature of spike zone is adequate for a reflow technology to be able to maintain the temperature gradient on the board within 5°C.

Optimization of Profile

1. Summary of Desired Profile Feature

Table 2 lists the major reflow-related defect type, mechanisms of defect formation, and the desired profile features, as well as the breakdown of the desired profile elements for each of those subjects in discussion.

2. Engineering the Optimized Profile

The desired profile features are also tabulated in Table 2. The dominant trend can be summarized below: a slow ramp-up rate to a low peak temperature, followed by fast cooling rate. Combined with the timing considerations discussed above, the optimized profile can be represented by Figure 6. Here the temperature ramps up slowly with a ramp-up rate between 0.5 to 1°C/sec until reaching about 180°C. The temperature is then gradually raised further up to 186°C within about 30 seconds, then raised quickly at a rate about 2.5-3.5°C/sec until reaching about 220°C. After that, the temperature is brought down with a rapid cooling rate which is no higher than 4°C/sec.

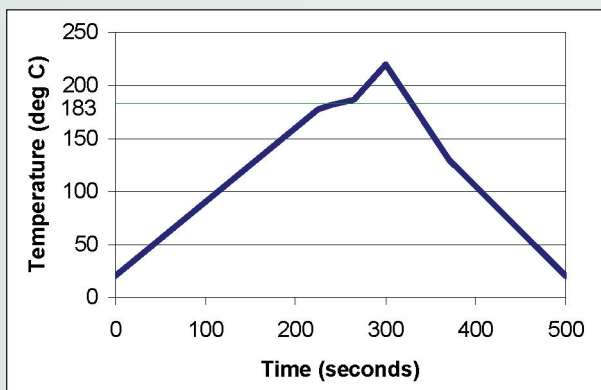


Figure 6. Optimized profile via defect mechanisms analysis.

Comparison with Conventional Profiles

1. Summary of Desired Profile Feature

It is interesting to compare the optimized profile with the conventional “textbook profiles” prevailing in the past, as shown in Figure 7. The conventional profiles typically are composed of an initial rapid ramp-up as preheat until 150-160°C, then levels off for a couple of minutes as a soaking zone. It is then followed by the spike zone with a relatively slow cooling rate after reaching the peak temperature. The primary difference between the optimized profile and the conventional profiles is that the former has a negligible plateau structure in the curve.

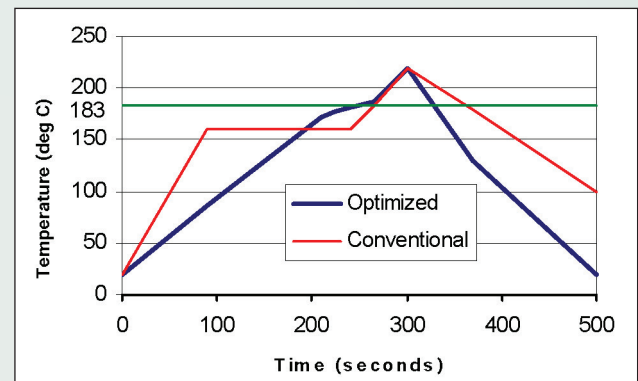


Figure 7. Optimized profile vs. conventional profile.

2. Background of Conventional Profiles

The conventional profiles were generated due to the constraint of reflow technologies used in the past. Before the emergence of modern forced air convection reflow technology, infrared mass reflow ovens were the reflow technology of choice. Although it has provided relatively satisfactory reflow results, infrared reflow technology suffers several major constraints, including sensitivity toward uneven thermal mass distribution, difference in color and material type of board or parts, component shadow effect, etc. As a result, a considerable temperature gradient can be developed quickly across the board. With a linear ramp-up profile, such as the profile shown in Figure 6, the temperature gradient can become so significant that the hot spots may be just right but the cold spots may still be under-reflowed, or the cold spots may be just right but the hot spots may already be burned, as exemplified by Figure 8.

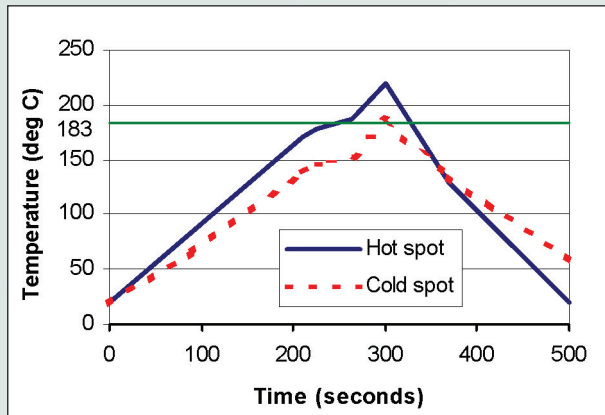


Figure 8. Typical temperature gradient developed using linear ramp-up profile on an infrared reflow oven.

3. Approach of Conventional Profiles

In order to minimize the temperature gradient, a plateau-shaped equilibrating zone then become necessary, as shown in Figure 9. By bringing the temperature of the hot spots down to a temperature below the melting temperature of solder and holding it there for a couple of minutes, the temperature of cold spots will be able to catch up with it. After all parts have reached the same temperature, another rapid ramp-up process will bring the parts to the peak temperature. Since all parts start at a temperature near the melting point, the new temperature gradient that is developed becomes much smaller and is much more tolerable.

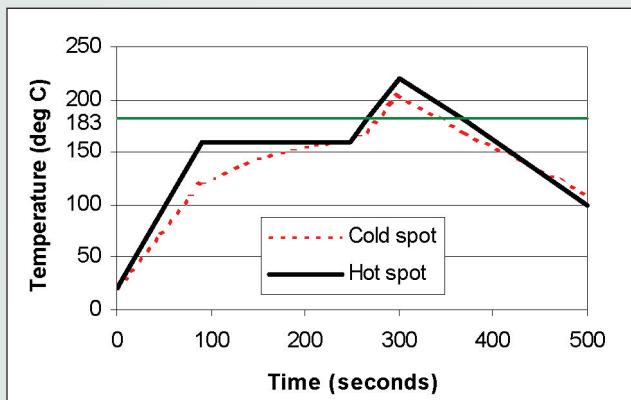


Figure 9. Typical temperature gradient developed using conventional profile on an infrared reflow oven.

4. Compromise of Conventional Profiles

The rapid ramp-up from room temperature needed to form the plateau is not desired due to the reasons discussed in the previous sections. However, without the plateau, or equilibrating zone, the board will encounter an even more serious problem. In addition to the defects caused by the temperature gradient, the board may also suffer by being either charred or under-reflowed. Therefore, the conventional profiles with the plateau structure yield a relatively better performance than a profile without the plateau structure.

5. Earlier Mass Reflow Technologies

Implementation of the optimized profile (Figure 6) requires the support of a heating-efficient mass reflow technology with a controllable heating rate. Vapor phase reflow can provide a rapid heating, but has difficulty in controlling the heating rate. The high defect rate caused by the significant temperature gradient eventually results in the phasing out of this mass reflow technology. Infrared reflow can regulate the heating rate, therefore it is more competitive than the vapor phase reflow. However, it is sensitive to the variation in parts features, as described above.

6. Forced Air Convection Reflow Technology

The forced air convection reflow also provides a controllable heating rate. In addition, it has a better heating efficiency than the infrared reflow and is not sensitive to the difference in material type, color, and thermal mass of components or boards, as its infrared counterpart does. As a result, the temperature gradient across the board becomes much less significant and the justification for the equilibrating zone is no longer valid. Consequently, the plateau structure can be minimized, and the rapid initial ramp-up rate can be slowed down to allow the realization of the optimized profile.

7. Defect Potential Associated with Conventional Profiles

The unfavorable attributes of the conventional profiles can be categorized as (a) rapid initial ramp-up, (b) long soaking time of 150-160°C, therefore resulting in excessive heat energy input and oxidation, (c) rapid ramp-up when passing through the melting point, and (d) slow cooling, resulting in excessive heat input, as noted in Figure 10. The types of potential defects associated with each of those attributes are summarized in Table 3.

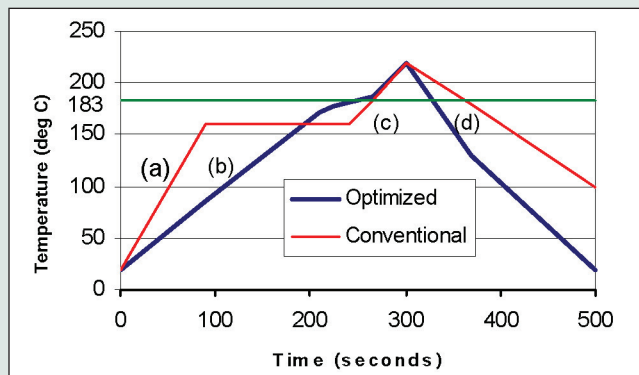


Figure 10. Unfavorable attributes of the conventional profiles when compared with the optimized profile.

Attributes	Defects
a	Solder balling, hot slump, bridging, solder beading
b	Voiding, poor wetting, solder balling, opens
c	Tombstoning, wicking, skewing, parts cracking, opens
d	Intermetallics, large grain size, charring, leaching, dwelling

Table 3. Defects associated with conventional profile characteristics.

DISCUSSION

The profile discussed in this work is aimed toward eutectic SnPb solder pastes with the use of typical flux systems. For solder pastes with other solder alloys or with flux systems with more constraints, the defect mechanisms and the principals of optimization are still the same. However the emphasis can be different and, accordingly, the resultant optimized profiles can also be different. Several examples are discussed below.

1. Profiles for Low Temperature Solder Pastes

When dealing with low melting solder alloys such as Bi58/Sn42 (mp 138°C) using a low temperature profile, the dictating factor usually is the heat energy input. In general, the higher the temperature and the longer dwell time allowed for the peak temperature, the better the reflow results will be. This is attributed to the fact that (1) oxidation of metallization is not an issue at a low heating temperature, and (2) most current flux technologies developed for solder pastes often exhibit a relatively high activation temperature. The latter is particularly true for no-clean solder paste systems. Therefore, under low temperature reflow process conditions, poor wetting and solder balling usually are the main defect types, and the additional heat energy input becomes the most crucial approach for reducing defect rate.

As a result, the optimum profile may resemble a bell shape, as exemplified in Figure 11. Here, the temperature is brought up to the peak temperature quickly, then held there as long as possible before cooling down.

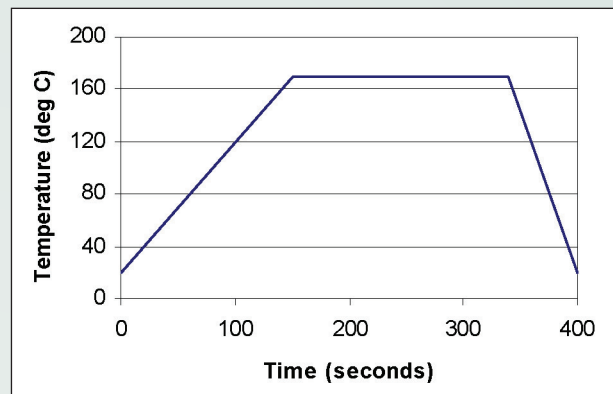


Figure 11. Profile for low temperature solder pastes.

2. Profiles for High Temperature Solder Pastes

For high temperature solder paste systems such as Pb90/Sn10 (mp 275-302°C), flux residue charring is often one of the main concerns. Hence, the preferred profile may exhibit a minimal exposure to high temperature in order to avoid the flux-charring phenomenon. As a result, the optimized profile usually has a higher ramp-up rate than that of the eutectic SnPb reflow profile, as demonstrated in Figure 12.

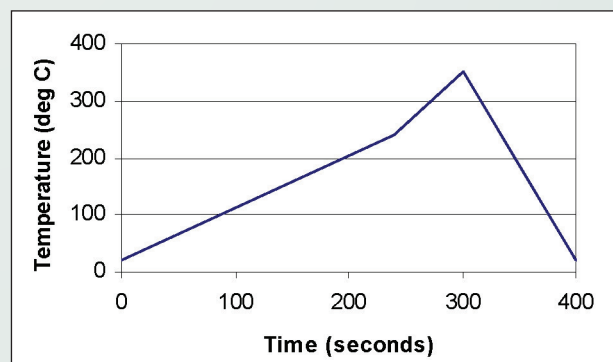


Figure 12. Example of reflow profile for high temperature solder paste.

3. Limited Oxidation Tolerance

Some solder paste systems may have very limited oxidation tolerance. For instance, most of the low residue no-clean solder pastes belong to this category [7]. If exposed to heat under air beyond the tolerance limit prior to solder melting, the solder paste may not reflow. Accordingly, the optimum profile often is a short profile with a linear ramp-up all the

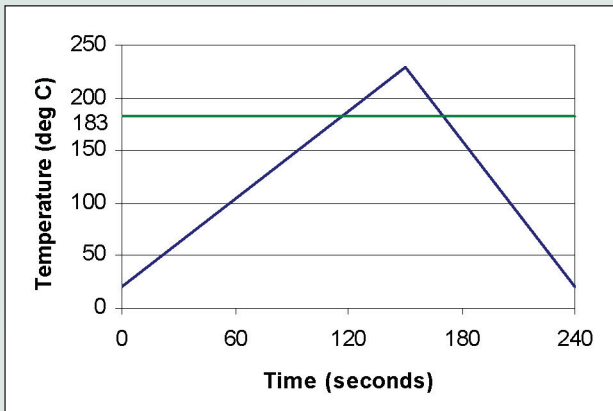


Figure 13. Profile for solder pastes with limited oxidation.

way to the peak temperature, as shown in Figure 13. This short and linear ramp-up profile minimizes the oxidation of metallization prior to solder melting. By eliminating the rapid ramp-up spike zone, it also maximizes the dwell time above the melting temperature allowed by this short profile. The trade-off of this type of profile is being limited in utilizing the advantage of a slow ramp-up rate.

4. Unevenly Distributed High Thermal Mass Systems

For a system where the thermal mass of some components is very large and is fairly unevenly distributed on the topside of the board, the profile needs to be lengthened. In addition, more bottom-side heating plus a long dwell time above the solder melting temperature should be utilized to allow establishment of temperature equilibrium. In order to minimize the intermetallics formation and charring, the peak temperature should be lowered considerably, as exemplified in Figure 14.

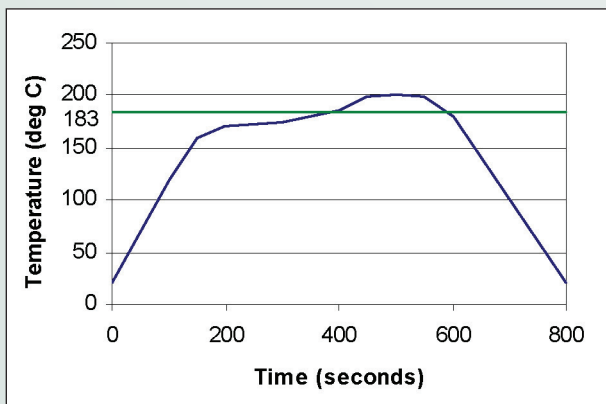


Figure 14. Profile for an unevenly distributed high thermal mass system.

5. Nitrogen Reflow Atmosphere

The oxidation concern associated with extended soaking dwell time is caused by oxygen in the air. When the reflow is conducted under a nitrogen atmosphere, the oxidation factor is minimized and can be ignored during the optimization consideration.

6. Air Flow Rate

Some forced air convection oven designs utilize fairly high air flow rates to deliver heating efficiency. This often aggravates oxidation and results in poor wetting and poor solder balling. If the air flow rate can not be reduced, a profile with shorter heating time usually will help lessen the symptoms.

7. Adjustment of Optimal Profile

The optimal profile characteristics are a function of reflow technology. When the heating-efficiency or control of the heating rate differ from that of an efficient forced air convection reflow system, the timing requirement for the ramp-up rate, soaking zone dwell time, and the total heating time should also be adjusted accordingly. It is recommended that the optimized reflow profile described in this paper should be used as a starting point. The adaptability of it should be checked by monitoring the temperature gradient and the type and extent of soldering defects developed. For instance, if too large a temperature gradient is developed, then the heating efficiency of the reflow oven used is not high enough and the profile should be adjusted to have a longer dwell time for soaking zone.

Conclusion

The reflow profile is engineered to optimize the soldering performance based on defect mechanisms analysis. Generally, a slow ramp-up rate is desired in order to minimize hot slump, bridging, tombstoning, skewing, wicking, opens, solder beading, solder balling, and components cracking. A minimized soaking zone reduces voiding, poor wetting, solder balling, and opens. Use of low peak temperature lessens charring, delamination, intermetallics, leaching, dewetting, and voiding. A rapid cooling rate helps reduce intermetallics, charring, leaching, dewetting, and grain size. However, a slow cooling rate reduces solder or pad detachment. The optimized profile favors that the temperature ramps up slowly until reaching about 180°C. The temperature is then gradually raised further up to 186°C within about 30 seconds, then raised rapidly until reaching about 220°C. After that, the

temperature is brought down with a rapid cooling rate. The conventional profile was developed due to the limitation of past reflow technologies. Implementation of the optimized profile requires the support of a heating-efficient reflow technology with a controllable heating rate. Vapor phase reflow can provide a rapid heating, but has difficulty to control the heating rate. Infrared reflow can regulate the heating rate, but is sensitive to variation in parts features. Emergence of the forced air convection reflow provides a controllable heating rate. In addition, it is not sensitive to variation in parts features, thus allowing the optimized profile.

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