# Application Note

Solder Reflow Report

Revision 1

## OBJECTIVE

The purpose of this report is to provide some basic information about solder and to provide some aid to customers on using solder paste to attach our products. Since Sn63Pb37 solder paste is considered to be an industry standard in 2nd level interconnection processing, it is being used as an example.The report contains a graphic representation of the Sn63Pb37 solder reflow profile, along with an explanation of the different profile zones. Factors influencing solder performance are also discussed, and information from the technical bulletin for Sn63Pb37 solder paste has also been added.

## SOLDER BACKGROUND

Solders are generally described as fusible alloys with liquidus temperatures below 400 °C. The elements commonly used in solder alloys are Tin (Sn), Lead (Pb), Silver (Ag), Bismuth (Bi), Indium (In), Antimony (Sb), and Cadmium (Cd). Solders are divided into two basic categories: eutectic and non-eutectic. Eutectic solders such as Sn63Pb37, have a distinct 183 °C melting point. Non-eutectic solders have a solidus and liquidus region. The solidus point is when the solid starts to melt and becomes soft but is not yet liquid. The liquidus point is defined as when the solder has completely melted into a liquid form. Figures 1 and 2 are phase diagrams of Sn-Pb and Sn-Sb solder alloys.

Solder can be applied in various physical forms including bar, ingot, wire, powder, preform, and paste. Generally, alloy selection is based on the following criteria:

- Alloy melting range in relation to service temperature
- Mechanical properties of the alloy in relation to service conditions
- Metallurgical compatibility, consideration of leaching phenomenon, and potential formation of intermetallic compounds
- Environment of service compatibility, consideration of solvent migration
- Wettability of specified substrate
- Eutectic versus non-eutectic compositions

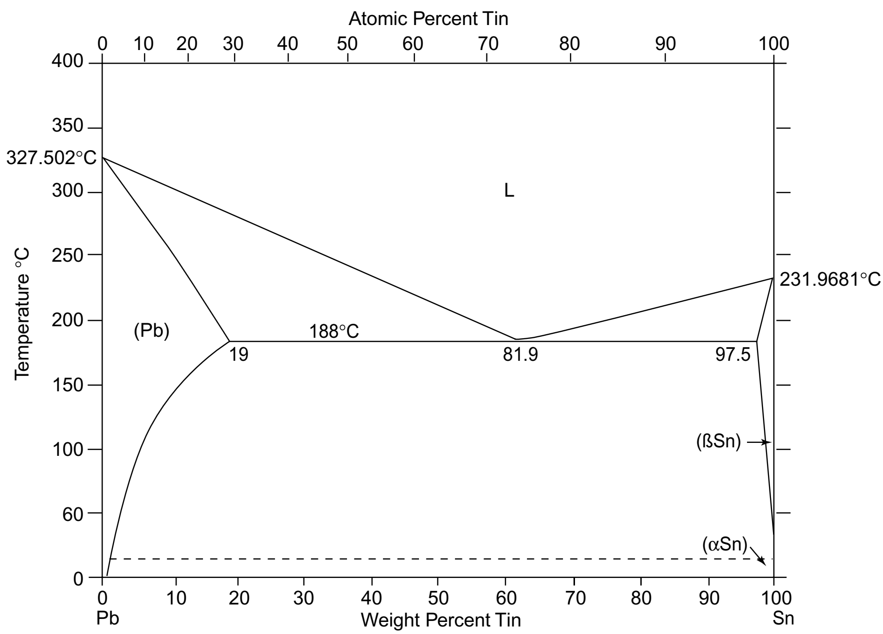


**Figure 1. Phase Diagram of Sn-Pb Eutectic solder**

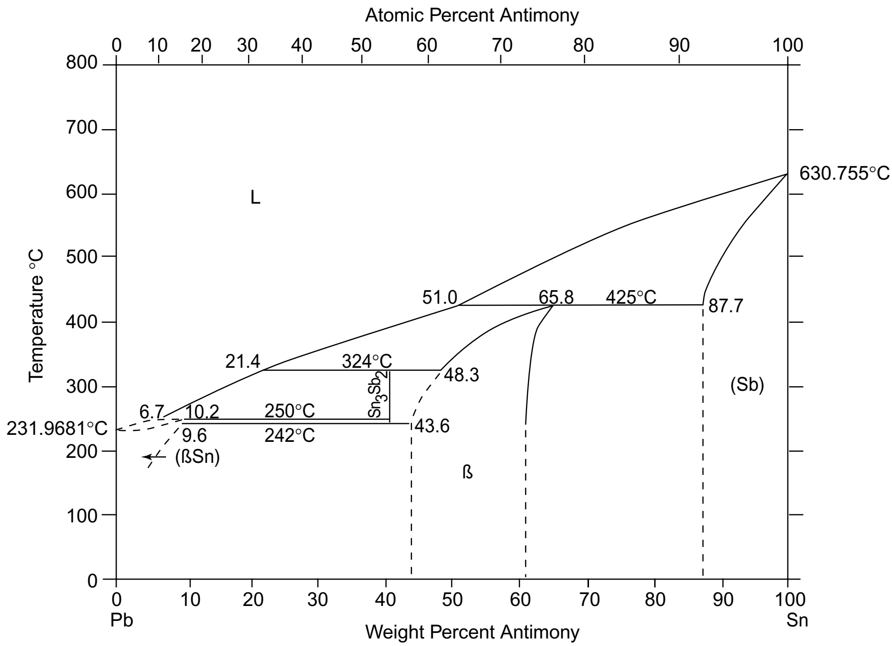


**Figure 2. Phase Diagram of Sn-Sb Non-eutectic solder**

## SOLDER PASTE DISCUSSION

Solder paste, by one definition, is a homogeneous and kinetically stable material which is capable of forming metallurgical bonds at a set of soldering conditions and can be readily adapted to automated production in making reliable, consistent solder joints.

In terms of functionality, a solder paste can be considered as being composed of three major components. These are solder alloy powder, vehicle system, and flux system. The vehicle system primarily functions as a carrier for the alloy powder, a compatible matrix for the flux system, and a basis for a desirable rheology. The flux cleans the alloy powder and the substrates to be joined so that high-reliability metallic continuity results and good wetting can be formed. The cleaning process is called fluxing. Several methods are available to achieve fluxing, though the most common is to incorporate the flux into the solder paste as opposed to applying it externally.

The flux is classified based on its activity and chemical nature, namely rosin-based such as RMA (Rosin Mildly Activated), water-soluble, and no-clean. Water-soluble flux is designed so that its residue after soldering can be removed by using either pure water or a water medium with an addition of a saponifier or an additive. No-clean solder paste, as its name states, is designed to not require cleaning after it is reflowed. The amount of residue left behind is often designed to not interfere with bed-of-nails/pin (short/open electrical) tests and is non-tacky.

The choice of flux depends primarily on the process and several factors including performance, process, reliability, and cost. All must be considered when choosing a flux.

The acceptance criterion for use of a particular paste should be as follows:

- The printed solder paste weight should not vary more than 10% among the average measurements taken on one substrate.
- The printed paste height should not vary more than ±1 mil among the average measurements taken on one substrate.
- The solder paste pattern sould have uniform coverage, without stringing and without separation of flux and solder (bleedout), and it should print without forming a peak.

## SOLDER PASTE APPLICATION METHODS

Solder paste can be applied using screen printing, stencil printing or dispensing, with screen/stencil printing being the most common high volume solder application method. In screen/stencil printing, the solder paste is manually placed on the screen/stencil with the print squeegee at one end. During the printing process, the squeegee presses down on the stencil to the extent that the bottom of the stencil touches the surface of the board. The solder paste is then printed on the lands through the opening in the stencil/ screen when the squeegee traverses the entire length of the image area in the metal mask.

The frames of the stencil and screen are similar; the differences lie in the construction of the individual openings used for depositing the paste. A screen will contain open-board wire mesh around which solder paste must flow to reach the substrate surface. A stencil opening is fully etched and does not obstruct paste flow. Stencils can be used for selective printing but screens cannot. Stencils however have the disadvantage of sometimes having larger than desired holes as over-etching can occur during their fabrication. The choice of stencil or screen depends on the application.

Solder paste can also be dispensed by being squeezed through the needle of a syringe. Since paste is dispensed one land at a time, it is a much slower process than screen/stencil printing. Dispensing is often used for its versatility in printing different shapes. Also, dispensing can be used for during repair or replacement of individual components. Dispensing may have special applications for fine pitch packages that require lower paste thickness than other components, such as PLCCs and SOICs on the same board.

## SOLDER PASTE PROPERTIES

### Metal Content

The metal content in solder paste determines the solder fillet size. This is due to the fact that flux activators and other additives, which take up some volume during print, are washed or evaporated away during the reflow and subsequent cleaning processes. Fillet size increases with an increase in the percentage of metal, but the tendency for solder bridging also increases with increase in metal content at a given viscosity. A higher metal content will result in higher thickness of the reflowed solder.

### Particle Size and Shape

Powder particle shape determines the oxide content of the powder as well as the paste's printibility. Larger particles have more surface area, thus greater oxide content which needs to be cleaned by the flux in order for the solder to function as desired. Failure to remove the oxide results in formation of solder balls, which are moved aside by surrounding oxide-free molten solder. Solder balls, after reflow, are a hazard since they can potentially short metallic conductors.

Solder pastes containing powders of irregular shapes are prone to clog screens and stencils. A commonly used powder size is -200/+325 mesh i.e., at least 99% by weight of the powder particles will pass thought the 200 (holes/square inch) and less that 20% of the powder particles by weight will pass through a 325 mesh. Figure 3 is a SEM micrograph of the -200/+325 mesh.

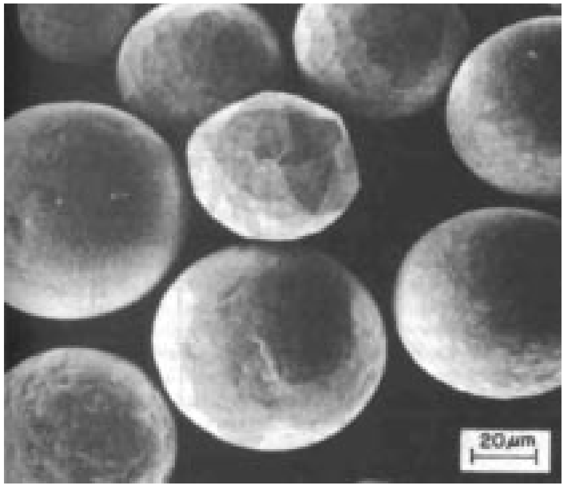


**Figure 3. SEM micrograph of Sn63Pb37 Powder -200/+325 mesh**

### Flux Activators and Wetting Action

The flux is one of the main constituents of the solder paste vehicle and is activated during the soak zone of the solder reflow profile. The flux activators promote wetting of the molten solder to the surface mount lands and component termination or leads by removing oxide and other surface contaminants. The type of flux has a direct impact on the cleanliness of the assembly. The wetting action of the paste is determined by the activity of its flux.

### Solvent and Void Formation

The solvent dissolves the flux and imparts the pasty characteristics to the metal powder in the solder paste. It controls the tackiness of the paste by its evaporation under ambient conditions. The solvent should not be hygroscopic. It should have a high flash point and should be compatible with the activator.

The two most important factors that control the formation of voids in fillets are the solvent in the solder paste and the reflow profile. Incomplete outgassing (gasses trapped in the solder joint) is the main cause of voiding and these voids, formed during reflow, lower the strength of the fillet. It is important to have sufficient dwell time in the molten state (above the melting point) to ensure that the gasses have enough time to separate and escape from the molten solder.

**Rheological Properties**

Rheological properties of solder paste such as viscosity, slump, tackiness, and working life are controlled by the addition of thickening agents or secondary solvents.

Additional factors affecting solder performance include equipment and set-up parameters, fabrication methodology, component lead density, operator skills, component and board solderability, as well as ambient temperature and humidity.

## PRINT THICKNESS

Print thickness determines the volume of solder in the joints. A print that is too thick will result in excessive solder joints or even solder bridges, and a print that is too thin will result in insufficient solder fillets. The thickness of the paste print is determined by the thickness of the metal mask of the stencil (or the emulsion thickness and mesh number for a screen) and the percent metal content of the solder paste.

## PROBE PLACEMENT

Thermocouple probes are the most common way to determine the temperature being experienced by a module/substrate, and in turn, the solder. This information is critical when determining proper reflow profiles, the details of which are discussed in the next section.

The probe location is based on the premise of obtaining the most accurate presentation of the temperature experienced by the module. As such, the probes should be placed as close to the actual device as possible. It is also advisable that the probe is resting on the same base as the die. If the die is attached to a panel, then the probe should be placed such that contact between the probe and the panel is not broken during the reflow process.

## REFLOW SPECIFICATIONS

The reflow profile is a critical part of the solder process and must provide adequate time for flux volatilization, pullback, proper peak temperatures, and time above liquidous. A typical reflow profile is made up of four distinct zones. The Preheat Zone, The Soak Zone/

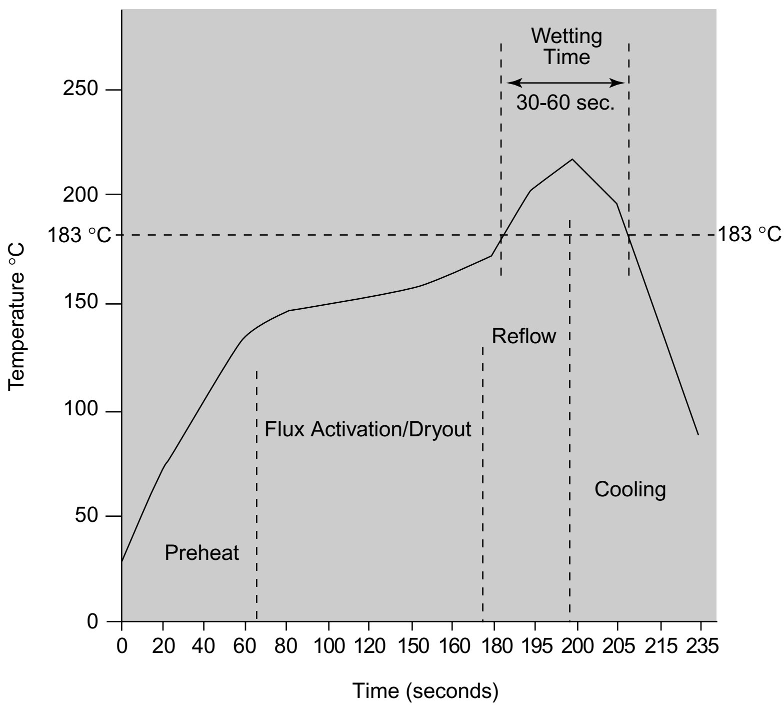


**Figure 4. Typical reflow profile of Sn63Pb37**

Flux Activation Zone, The Reflow Zone, and the Cooling Zone. Figure 4 shows a typical reflow profile for Sn63Pb37 solder.

### Preheat Zone

The heating rate in the preheat zone should be 2 °C to 4 °C/second and the peak temperature in this zone should be 100-125 °C. During preheat if the temperature ramp is too fast, the solder paste may splatter and cause solder balls. Also, to avoid thermal shock to sensitive components such as ceramic chip resistors, the maximum heating rate should be controlled.

### Soak Zone

The soak zone is intended to bring the temperature of the entire board up to a uniform temperature to minimizing temperature gradients. The soak zone also acts as the flux activation zone for solder paste. The ramp rate in this zone is very low, almost flat and the temperature is raised near the melting point of solder (183 °C in this example). The consequences of being too high in the soak zone are solder balls due to insufficient fluxing and solder splatter due to excessive oxidation of paste. Soak times are usually around the range of 130 -170 °C for 60 to 90 seconds.

### Reflow Zone

In this zone the temperature is kept above the melting point of the solder for about 30 to 60 seconds. The peak temperature in this zone should be high enough for adequate flux action and to obtain good wetting. The standard primary fluid used for surface mount assemblies has a boiling point of 215 °C at sea level. A peak temperature range of 215 - 220 °C is generally considered acceptable.

The temperature, however, should not be so high as to cause component or board damage or discoloration, or worst case, charring of the board. Extended duration above the solder melting point will damage temperature sensitive components. It also results in excessive intermetallic growth which makes the solder joint brittle and reduces solder joint fatigue resistance. Additionally high temperatures can promote oxide growth, depending upon the furnace profile, which can degrade solder wetting.

### Cooling Zone

The cooling rate of the solder joint after reflow is also important. The faster the cooling rate, the smaller the grain size of the solder, and hence the higher the fatigue resistance of the solder joint. Unfortunately, cooling too fast will result in residual stresses between TCE (Thermal Coefficient of Expansion) mismatched components. So the cooling rate needs to be optimized. For a given system, cooling rate is directly associated with the resulting microstructure which, in turn, affects the mechanical behavior of solder joints.

## SOLDER OVENS

The commercially available reflow methods include conduction, infrared, vapor phase, hot gas, convection, induction, resistance, and laser. Each of these reflow methods has its own advantages and benefits to cost, performance, or operational convenience. For localized heating, laser excels over other methods, with hot air in second place. For uniform temperature, vapor phase ranks first. For versatility, volume, and economy, convection/infrared are the choice. Conduction heating, however, is a convenience for low-volume and hybrid assembly. For conductive components requiring fast heating and high temperature soldering, induction heating meets the requirements. Table 1 provides the outlines and benefits of several reflow methods.

### Bandwidth and Shape of Profile

In addition to meeting the shape of the profile, the oven settings must also show a narrow bandwidth (5 °C to 10 °C). The bandwidth is defined as the total temperature difference across the board in any given zone. The tighter the bandwidth, the more consistent the yield.

It is important to note that it is necessary to develop a unique profile for each product because each board has a different thermal mass and one may have different loading patterns (distance between boards as they are loaded in the oven). Even the same double-sided board, depending upon component placement and distribution of copper planes on each side, may require different profiles for each side.

**Table 1. Outline of Benefits and Limitations of Reflow Methods***

| REFLOW METHOD | BENEFITS | LIMITATIONS |
|---|---|---|
| Conduction | Low equipment capital, rapid temperature changeover, visibility during reflow | Planar surface and single-side attachment requirement, limited surface area |
| Infrared | High throughput, versatile temperature profiling and processing parameters, easier zone separation | Mass, geometry dependence |
| Vapor phase condensation | Uniform temperature, geometry independence, high throughput, consistent reflow profile | Difficult to change temperature, temperature limitation, relatively high operating cost |
| Hot gas | Low cost, fast heating rate, localized heating | Temperature control, low throughput |
| Convection | High throughput, versatility | Slower heating, higher demand for flux activity |
| Induction | Fast heating rate, high temperature capacity | Applicability to nonmagnetic metal parts only |
| Laser | Localized heating with high intensity, short reflow time, superior solder joint, package crack prevention | High equipment capital, specialized paste requirement, limit in mass soldering |
| Focused infrared | Localized heating, suitable for rework and repair | Sequential heating, limit in mass soldering |
| White beam | Localized heating, suitable for rework and repair | Sequential heating, limit in mass soldering |
| Vertical reflow | Floor space saving, maintenance of desired throughput | Often more costly |

* *Taken from Electronic Packaging and Interconnect Handbook*

**Anadigic's Product Maximum Allowable Temperatures**
Note the maximum allowable temperatures specified assumes that JEDEC J-STD-020A floor life and handling requirements for the appropriate device MSL level are followed.

| MAX. RAMP UP RATE | MAX. PEAK TEMPERATURE | MAX. TIME 225-230 °C | MAX. TIME ABOVE 183 °C | MAX. RAMP DOWN RATE |
|---|---|---|---|---|
| 3 °C/sec. | 230 °C | 10 sec. | 60 sec. | 6 °C/sec. |

## APPENDIX

Technical information of UP78 Sn63Pb37 solder paste is being added to serve as an example and a reference to this report. UP78 solder paste is a product of Cooksen Semiconductor Packaging Materials. The following information had been taken from the technical bulletin provided by Cooksen.

### *Availability*

| | |
|---|---|
| Rheology | Stencil printing |
| Metal Percentage | 89% |
| Packaging Sizes | 350 and 700 gram jars<br>6" and 12" cartridges |

### *Chemical and Physical Properties*

| | |
|---|---|
| Melting Point | 183 °C |
| Type | Eutectic |
| Color Clear, | Colorless |
| Specific Gravity | 4.9g/cc |
| Reflowed Residue | ~5.5% ww, tack free after reflow |
| Tack Force | >2.4g/mm$^2$ @ 6 hours (72%RH, 25C) |
| Viscosity | (Malcom Spiral Viscometer) M-13 |
| Stencil Life | >6 hours |
| Slump | Suitable for fine pitch printing |
| Corrosivity | L - Copper Mirror Test |
| ATE Compatibility | 24g (<1.0oz) on 11.5mil thick flux deposit |

### *Reflow*

Use convection, infrared, or combination ovens; belt, hot plate, or vapor phase. Clean dry air or nitrogen atmosphere. Profile:

- Ramp @ 60 - 120 °C/min to 120 - 160 °C.
- Dwell @ 120 - 160 °C for 1.0 - 1.5 minutes.
- Ramp @ 60 - 120 °C/min to 215 - 220 °C peak temperature. Time over 183 °C for 30 - 60 seconds.
- Ramp down to R.T. @ 90 - 120 °C/min.

### Bibliography

[1] Ray P. Prasad; *Surface Mount Technology* - Principles and Practice; Van Nostrand Reinhold - New York; 1989; Pages 311-328.

[2] http://www.alphametals.com/products/solderpaste/PDF/zarrow.pdf

[3] http://www.alphametals.com/products/solderpaste/PDF/whatdo.pdf

[4] http://www.ecd.com/emfg/instruments/tech1.asp

[5] Charles Harper; *Electronic Packaging and Interconnect Handbook*; “Solder Technologies for Electronic Packaging Assembly”; McGraw-Hill 2000; Pages 6.1-6.83.

[6] Cooksen Semiconductor Packaging Material; Technical Bulletin - UP78.

**ANADIGICS, Inc.**
141 Mount Bethel Road
Warren, New Jersey 07059, U.S.A.
Tel:+1(908) 668-5000
Fax:+1(908) 668-5132

URL: http://www.anadigics.com
E-mail: Mktg@anadigics.com

SUNSTAR 商斯达实业集团是集研发、生产、工程、销售、代理经销 、技术咨询、信息服务等为一体的高科技企业，是专业高科技电子产品生产厂家，是具有 10 多年历史的专业电子元器件供应商，是中国最早和最大的仓储式连锁规模经营大型综合电子零部件代理分销商之一,是一家专业代理和分銷世界各大品牌 IC 芯片和電子元器件的连锁经营綜合性国际公司，专业经营进口、国产名厂名牌电子元件，型号、种类齐全。在香港、北京、深圳、上海、西安、成都等全国主要电子市场设有直属分公司和产品展示展销窗口门市部专卖店及代理分销商,已在全国范围内建成强大统一的供货和代理分销网络。 我们专业代理经销、开发生产电子元器件、集成电路、传感器、微波光电元器件、工控机/DOC/DOM 电子盘、专用电路、单片机开发、MCU/DSP/ARM/FPGA 软件硬件、二极管、三极管、模块等，是您可靠的一站式现货配套供应商、方案提供商、部件功能模块开发配套商。商斯达实业公司拥有庞大的资料库，有数位毕业于著名高校——有中国电子工业摇篮之称的西安电子科技大学（西军电）并长期从事国防尖端科技研究的高级工程师为您精挑细选、量身订做各种高科技电子元器件，并解决各种技术问题。

微波光电部专业代理经销高频、微波、光纤、光电元器件、组件、部件、模块、整机；电磁兼容元器件、材料、设备；微波 CAD、EDA 软件、开发测试仿真工具；微波、光纤仪器仪表。欢迎国外高科技微波、光纤厂商将优秀产品介绍到中国、共同开拓市场。长期大量现货专业批发高频、微波、卫星、光纤、电视、CATV 器件： 晶振、VCO、连接器、PIN 开关、变容二极管、开关二极管、低噪晶体管、功率电阻及电容、放大器、功率管、MMIC、混频器、耦合器、功分器、振荡器、合成器、衰减器、滤波器、隔离器、环行器、移相器、调制解调器；光电子元器件和组件：红外发射管、红外接收管、光电开关、光敏管、发光二极管和发光二极管组件、半导体激光二极管和激光器组件、光电探测器和光接收组件、光发射接收模块、光纤激光器和光放大器、光调制器、光开关、DWDM 用光发射和接收器件、用户接入系统光光收发器件与模块、光纤连接器、光纤跳线/尾纤、光衰减器、光纤适 配器、光隔离器、光耦合器、光环行器、光复用器/转换器；无线收发芯片和模组、蓝牙芯片和模组。