ABSTRACT
This paper will address the importance of thermal profiling in today's electronic assembly. It is a summary of the points presented at the conference.

Today's electronic assembly have tighter lead spacings. The use of BGA components where it is difficult to visualize the condition of the solder joint after the reflow process makes it even more essential than ever to develop an understanding of the paste chemistry and what occurs during the reflow process.

This understanding can enable an engineer to optimize the reflow conditions to suit the chemistry of the solder paste. The net result of this optimization is increased yields, less soldering defects, reduced costs, and increased reliability. The electronic assembly market has, in fact, become mature and surface mount assembly here in America is no different than surface mount assembly in Mexico or other global markets. Maintaining an efficient soldering operation is essential for overall competitiveness.

Solder paste chemistries have also undergone major changes, improvements in formulation to accommodate the more stringent needs of the industry.

Today's solder pastes are more rheologically stable, have higher print repeatability, greater open time and abandon time on the stencil than older versions. New surface active agents, activators and resin systems have made the solder paste user-friendly. User friendliness however is only appreciated if an understanding of the solder paste chemistry and how it reacts in the thermal cycle it sees in the reflow process is first obtained by the process engineer.

SOLDER PASTE CHEMISTRIES
There are three types of solder paste chemistries in the market today. Each type is suited for specific types of assemblies. Electronic assemblies for extreme reliability such as avionics, space, and medical applications may still require the circuitry to be cleaned of flux residues after soldering. Cleaning may also be required if circuits are conformal coated. Many electronic products destined for the general public do not require removal of the flux residues after soldering, by far this is the part of the electronic industry which is the largest user of solder paste. In North America about 70% of the assemblies are not cleaned. About 25% use solder pastes which are water-soluble, rosin based pastes still used in military assemblies account for less than 5% of the total paste usage.

Solder pastes types available today can be summarized as follows:

No-Clean – Benign residues does not require removal of flux residues.
Water washable - Requires complete removal of flux residues after soldering.
Rosin based - May require removal in solvent or water / saponifier solution.

Typically no-clean solder pastes are designed intentionally to be of lower activity. Activity can be defined as the chemical efficiency of the acidic components of the paste to remove the oxides present on the surfaces to be joined. More active fluxes enable the removal of more tenacious oxide layers and improve the overall soldering process. More active solder pastes contain a higher concentration of organic acids or may contain the addition of organic halides but the amount used is always incremental as to insure the non-corrosive nature of the flux residue is not jeopardized.

The amount of resin incorporated is no-clean flux systems for solder pastes can also vary and impact on the amount of residue left on around solder joints after soldering. Lower amounts of resin will normally give cleaner looking boards due to the lesser resin left after reflow. This resin is a high boiling, high molecular weight mix of organic compounds, which does not volatilize at the temperatures encountered in SMT processes and remains on the board.

Typical weight percentages of solids found in most no-clean pastes in the market today are stated below. Lower solids require a nitrogen atmosphere in the reflow oven to achieve optimum soldering results. Solids contents lower than 50% by weight will require nitrogen assisted reflow to reduce the incidence of solder balls.

Ultra-low residue no-clean - 15-50% solids, nitrogen atmosphere required.
Medium residue no-clean - 50-70% solids, nitrogen or air atmosphere.
High residue no-clean - 70-80% solids, air atmosphere acceptable.
The solids in solder paste flux chemistry are comprised of the resin, gelling agents, wetting agents, and activators or acid components. These ingredients will remain as part of the flux residue after soldering, the activator may remain in its reacted form and some of it will have volatized.

No-clean solder pastes, due to the choice of acids that have to be chosen to insure a non-corrosive, non-conductive residue, weak organic acids and often weakly reactive organic hydro-halides are added to promote better soldering. These components are more affected by the temperatures encountered in the reflow process and special attention must be executed when profiling the oven to not expose the solder paste to high temperatures in the soak zone and also in avoiding excessive time above the melting temperature of the alloy.

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The water washable solder paste flux chemistries in the industry today are typically based on water soluble resin systems with organic and/or inorganic halide additives as their main activators. The amount of acid reactant is more generous thus these pastes are most suitable for difficult soldering, metals which are oxidized or more difficult to wet by molten solder are joined more easily. The residues are corrosive and conductive in nature and must be removed after the soldering process. Due to the corrosiveness of the flux residue, a hot water wash and ionic contamination testing of the board after washing is highly recommend-ed. Water washable solder pastes are used extensively by contract assemblers and electronic assemblies which cannot tolerate any remaining flux residues.

Water washable solder pastes due to the more active or acidic flux systems used in their preparation are less affected by excesses in temperature in the soak zone and less affected by excessive time above the alloy liquidus temperature, the melting temperature of the alloy.

A typical flux formulation in weight percentages for a water-soluble solder paste is defined below.

**Typical water washable flux system**
- Water soluble high molecular weight resin - 60%
- High boiling point solvents - 26%
- Wetting agents - 5%
- Gelling agents - 5%
- Activators- 4% (halide and organic acid)

The other types of solder pastes are those based on rosin flux systems. These are the traditional solder pastes used by military assemblers and are still used today. They account for about 5% of the solder paste consumption in the United States. The flux system is based on natural or modified gum rosin with the addition of organic acids and incremental additions of organic halides. These additives are used to increase the wetting efficiency of the solder, since rosin alone is too weak an activator to promote rapid wetting of solder.

Rosin based solder pastes are available still in the traditional types of RMA (rosin mildly activated), RA (rosin activated), or R (rosin non-activated), and the mostly used here is the RMA type. These pastes usually give amber flux residues and are removable in solvents or water / saponifier blends of cleaners.

The rosin flux systems used traditionally have higher solids contents in the range of 70-80% . During the reflow process, the higher solids content, contributed heavily by the rosin content act to shield the activators add to the flux and enable the solder paste to sustain slight extremes in heating. These rosin-based pastes can tolerate slightly higher soak temperatures, higher peak temperatures and time above the alloy’s liquidus.

**CHEMISTRY AND SLUMP PROPERTIES**

Besides the lack of activity of a solder paste, which depends on the paste type, contributing to poor wetting, the next major contributor of defects in SMT assembly is the slump property of the solder paste. Not all pastes have excellent slump resistance. Slump resistance can be described as cold slump, relaxation of the paste after deposition or hot slump, relaxation of the paste during heating. Initially when paste is printed it should ideally give well defined deposits, the more defined the paste deposits after print and during the initial heating in the reflow process, the less likely will be the solder balling potential and bridging between soldered pads. This is particularly critical in no-clean assemblies with fine pitch devices.

The factors which affect the slump properties are described below. Many of these depend on paste selection, it is therefore important to select a solder paste, which has excellent cold and hot slump properties. Slump tests are normally performed at 25 and 85 degrees Celsius.

**Factors Affecting Solder Paste Slump**
- Choice of gelling agent used in flux system
- Amount of gelling agent used in flux system
- Metal percentage of solder paste selected
- Thermal profile used during the reflow process
- Environmental conditions of the printing process
- Solder particle size distribution
- Amount and type of solvent used in flux system
- Amount of resin used in flux system

During the reflow process the solder paste will slump somewhat regard-less how good is its slump resistance. Excessive soak temperatures, long soak times will promote slumping. Slumping will increase the risks of solder balls and bridges. The recommended practice is to check with the solder paste supplier and determine which thermal profile is recommended for the particular paste, these are normally available for the asking.
Water-soluble pastes traditionally have been prone to slumping. The reason for this is due to the hydroscopic nature of the resins used in water washable flux systems. The resins and activators used pick up moisture from the atmosphere, low humidity is preferred when printing these pastes. Typically the relative humidity should not exceed 50%, and frequent disposition of paste may be required.

In recent years, development of polymer based water washable pastes has reduced the slump phenomena due to water absorption. These water washable solder pastes contain reactive resin systems, which are not hydrophilic and therefore are less likely to absorb water from the printing environment and slumping is reduced considerably during printing and prior to reflow.

No-clean and rosin based solder pastes are made up of resins or modified rosins which have extremely high resistance to water absorption and therefore can have excellent slump characteristics. These solder pastes can tolerate higher environmental humidity with little slumping at printing.

**THERMAL PROFILING CONSIDERATIONS**

During the reflow process the solder paste will experience different temperature gradients which will impact its chemistry and the final soldering results. Proper optimization of the thermal profile will result in a net reduction of defects and increased reliability of the solder joint.

In the initial ramp up stage of the profile the low boiling solvents in the flux system will volatize. The recommended ramp up temperatures are 2-4 degrees Celsius, depending on the thermal stability of the components. Excessive ramp up temperature may at times cause explosive release of these low boiling solvents and cause solder balls to appear away from the pad areas.

The soak zone is the most critical part of the profile and the area where many defects have their origin. If the soak temperature is excessive the flux activator package in the flux system may deplete itself. The result will be the re-oxidation of the surfaces to be soldered and the oxidation of the solder powder spheres. The observable defects will be solder balling and poor wetting of the surfaces to be joined.

If the soak temperature is too low the flux may not activate to its full potential. De-oxidation of the surfaces to be joined and the solder powder will not be sufficiently accomplished to give good wetting. Typical soak temperature is usually 120-160 C for no-clean pastes. Water washable solder pastes tradition-ally can sustain higher soak temperatures as high as 170C, due to the higher activity of their flux systems. Rosin solder pastes would function within the same limits as the water-washables, the higher solids, composed mainly of rosin or modified rosins will protect the activator package at higher temperatures.

The time spent above the liquidus temperature of the alloy also affects the solder joint reliability and overall defects. Normally it is recommended that a board spend under 60 seconds above this temperature, with a peak temperature of 20-35 degrees Celsius above the melting temperature of the alloy. As an example, if SN63 is used, its melting temperature is 183 degrees Celsius, the peak temperature should be in the range of 203-218 degrees Celsius.

Excessive peak temperatures, tend to darken flux residues and cause oxidation of the solder joint, especially if an air atmosphere is used in the reflow oven. Excessive time above the liquidus temperature will also promote intermetallic growth within the solder joint and jeopardize joint reliability. This can occur particularly with bare copper boards or with component leads made with copper alloys.

Low peak temperatures and/or very low time above the liquidus temperature can also be a problem. The issues encountered could be insufficient wetting of the parts to be joined, or flux voids within the solder join. In the later case, insufficient time was given for the solder spheres to melt completely, enabling the flux to float to the surface of the solder joint and down around its perimeter. It is recommended to remain at least 30 seconds above the liquidus temperature of the alloy.

The defects which can result due to poor thermally set-up are mentioned below:

**Some defects due to thermal profiling:**

- SOLDER BALLS
- POOR WETTING
- DULL JOINTS
- INTERMETALLICS
- BRIDGES
- VOIDING
- FLUX RESIDUE DISCOLORATION
- TOMBSTONING

Rapid cool down is also essential to insure fine grain structure of the solder joint. A slow cool is will cause solder joints to look frosty and at times dull.

No-clean solder pastes due to their lower solids content and lower percentages of activators are more affected by air during reflow and oxidation is more likely with these types of solder pastes. Water washable flux systems on the other hand are more active and the corrosive nature of the residue may at times contribute to this phenomena. Leaving water soluble residue in contact with solder joints can craze and pit the solder in time, water washing shortly after the soldering is complete is therefore important. Rosin based solder pastes are prone to polymerization if excessive temperatures and times above liquidus are used, the flux residue will be more difficult to remove using conventional solvents or saponified solutions.
CONCLUSION
Proper selection of solder paste chemistry is essential in the efforts to reduce solder defects and increase the reliability of solder joints. Besides the proper paste selection, proper equipment and settings, the environmental conditions at the SMT line, and the thermal profile chosen will impact considerably the defect count. A basic understanding of the flux chemistries can only benefit an engineer here.

Different board thermal masses will require individual profiling of these boards. If thermal masses can be determined, several boards can be run with the same profile. Proper soak temperatures and times will determine reduce many defects due to slump and de-activation of the flux system.

If proper consideration is given to the paste chemistry and its thermal profiling during soldering, defects will be maintained low.