An Introduction to Solder Materials

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Solder paste is a seemingly simple material that forms one of the foundations of the surface mount assembly operation. If the solder paste does not do its job correctly then first pass yield will be severely reduced. Understanding solder paste and how it works will lead to a better understanding of the interactions that occur in the SMT assembly process. Proper evaluation techniques ensure optimum performance on the line with maximum solder paste related yields being achieved. This paper will explore the solder paste and evaluation methodology.

Paste Composition

Solder paste is a complex material that has been likened to a mini chemical factory in a jar. This is because the demands on paste are varied and can only be met by a sophisticated system that utilizes the most recent advances in chemical technology. Solder paste is composed of a solder powder and a solder flux or vehicle system. These two materials are blended together according to established procedures. The resultant properties of the solder paste are directly established by the raw materials utilized. Control of the raw material characteristics are key to controlling the final properties of the solder paste. The control parameters for solder powder are size, shape, and surface chemistry. The flux system is controlled for chemical purity, consistency, and viscosity.

Solder Powder

Solder powder is pre-alloyed (typically composed of 63%Sn/37%Pb or 62%Sn/36%Pb/2%Ag although several other alloys are commonly utilized) and spherical in nature. It is extremely important that the alloy composition meet the requirements outlined in J-STD-006 as impurities can have a deleterious affect on solder quality and performance. Another important consideration is the Particle Size Distribution (PSD). Powder size and shape affects the solder paste by determining the application method, printability, and tendency to solder balling. Powder in the 40 to 75 micron range (type 2) is primarily used for non-fine pitch, stencil-printing applications. Powder in the 20 to 45 micron range (type 3) is primarily used for syringe, screen-printing, and fine pitch stencil applications. The smaller powder allows paste to flow easily through syringe openings as well as stencil openings without clogging. The small (0.010” x 0.070”) openings on a fine pitch stencil necessitate the use of small powder to achieve desired print volume and printability. For pitches below 20 mils a 20 to 36 micron (type 4) or smaller powder is utilized. Figure 1 shows typical PSD's for type 2 ,3 ,4 and 5 powders.

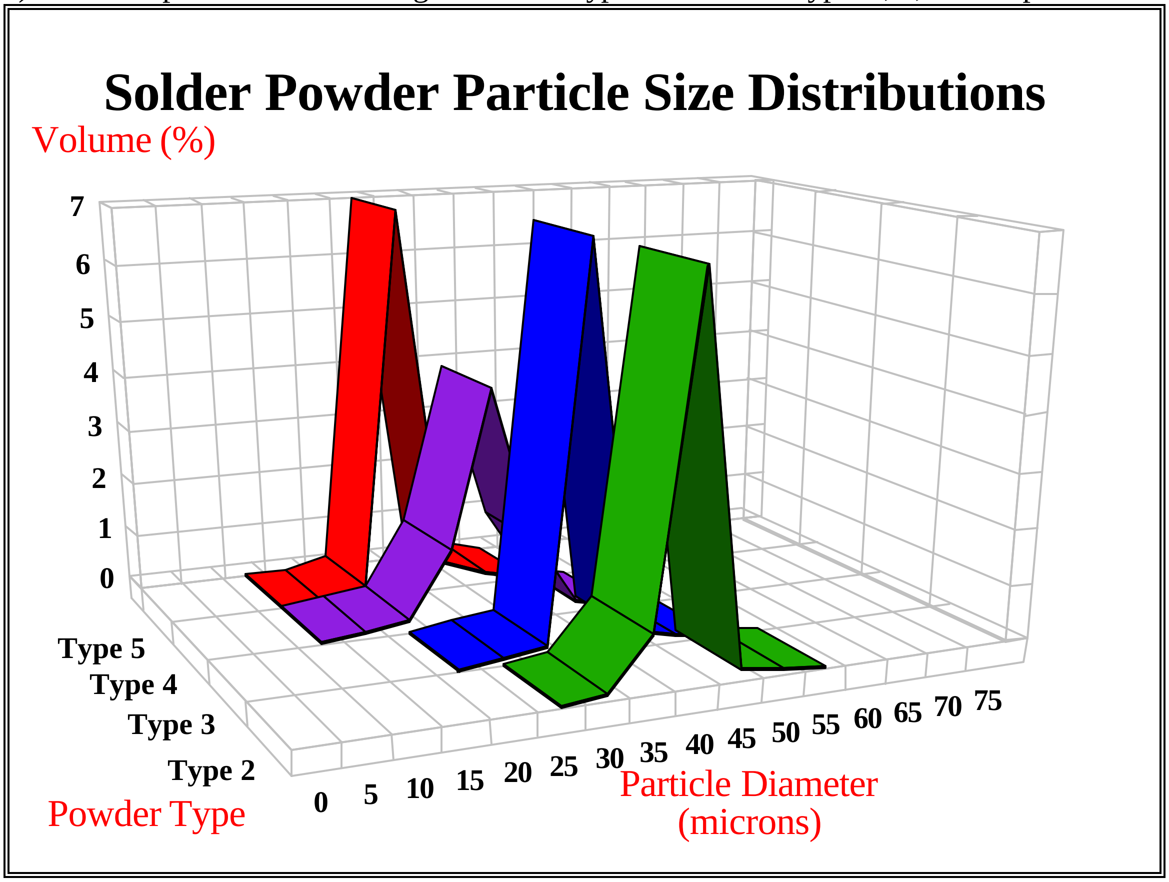

Figure 1 Powder PSD's

A solder powder that possesses a rough surface or is irregular in shape will adversely affect solder paste performance. Solder powder with an irregular surface will tend to oxidize faster than spherical powder which in most cases will lead to an increase in solder balling. Heavily oxidized powder can also contribute to viscosity stability and printability problems. Lead oxide on the surface of the powder will tend to dry the paste out which will lead to viscosity increase. A properly produced powder is spherical, contains little oxide, and has a very consistent particle size distribution.

Solder Flux/Binder

The flux is typically composed of a rosin/resin, solvent, rheology modifier, and activator. Rosin is naturally occurring material found in coniferous trees. It can be chemically modified to improve characteristics such as oxidation resistance. Rosin also acts as an insulator, which makes it ideal for no clean formulations. When choosing a rosin for use in solder paste the formulator must consider the following: acid content, melting point, fluid viscosity, color, and in some instances cleanability. In addition, rosin imparts tackiness to the paste that aids in ensuring that components do not shift during the assembly operation. Resin is similar to rosin but is man made and has an exact chemical formula. An advantage of resin is that it has very little lot to lot variation whereas rosin being a natural product can have significant variation.

The solvent acts as a carrier system for the solder paste. It is very important to choose the right solvent or solvent blends because they affect work life, tack time, slump and the profile requirements. A low vapor pressure solvent can increase work life and tack time while a solvent with a low boiling point can vaporize explosively during reflow and cause excessive solder splatter. Pastes are formulated to utilize the solvents that give excellent tack and work life but do not require excessive preheat or soak times.

Rheology modifiers are additives that influence print definition and the flow behavior of the solder paste. They also affect slump characteristics and play an important role in preventing paste separation during long term storage. Rheology modifiers are typically thixotropic in nature and also affect the viscosity and viscosity stability of the paste.

The activators purpose is to clean metal oxides and contaminates from metal surfaces during reflow. They also prevent the highly reactive molten metal from reacting with the atmosphere until the metal re-solidifies. Activators are typically acids and are usually halide free although halides are still used for some applications. In the past, pastes were classified according to their activity level. The categories were R (rosin), RMA (rosin mildly activated) and, RA (rosin activated). This classification system has largely been superseded by J-STD-004, which more precisely identifies solder pastes by flux composition and activity levels.

Paste Types

The passing of Federal Law and the adoption of the Montreal Protocol severely limits or prohibits the use of ozone depleting CFC’s. This has had a profound affect on the Electronics Industry and all but eliminated traditional pastes (RMA) and cleaning methods (CFC). While alternative solvents are used by many manufacturers, no clean and water clean systems have become the predominate products used in manufacturing today.

No Clean

No clean has become the method of choice due to decreased costs and the elimination of both a process step (cleaning) and the waste stream produced by cleaning. In the early days of no clean the pastes had issues with wetting due to the requirement of the residue to pass stringent no clean test requirements such as: SIR, Electromigration, Copper Mirror, and Silver Chromate. New generations of no cleans utilize advanced activator packages that allow for outstanding wetting performance on a variety of surface finishes while maintaining rigid reliability requirements. All other paste functions (printability, tack time, etc.) remain the same as the traditional RMA’s that were used in the past. The residue color is typically clear and minimal in nature, which eliminates potential cosmetic concerns. State of the art no cleans do not require special atmospheres such as nitrogen for reflow, and have performance that is equal to the most aggressive water soluble formulations, without the inherent risk that water soluble products can pose. With regard to RF interference by the residue, a large communication company reported no issues at 14Ghz.

Water Soluble

Water soluble pastes have been chosen for applications where residues need to be removed. The pastes feature excellent wetting but have had some issues with tack time and work life. Paste manufacturers are addressing these problems and increasingly better performing pastes are being developed. Of some concern is the ability of cleaners to remove the flux residue from underneath low clearance devices or areas where there is no direct spray such as under BGA devices. It is important to evaluate cleaning efficiency when using water soluble products.

Lead Free/Alternative Alloys

New areas for solder paste is in the development of lead free alloys and alloys that have improved performance over currently available systems. Most lead free work is being centered around tertiary or higher order systems that are primarily based on Sn/Ag/Cu. The melting points are typically higher than Sn/Pb but early testing has shown these products to be compatible with existing methodology. Extensive reliability data is being generated and some companies are in the process of evaluating or converting certain products to the new alloys. The search for better performing alloys is being driven by Automotive and Aerospace requirements for increased Thermal Mechanical Fatigue properties. As operating temperatures increase standard alloys are being found unable to deal with the increased fatigue caused by thermal cycling.

Paste Performance Benchmarking

Understanding the performance of your solder is the basis for yield improvement and cost reduction efforts. Steps 1 and 2 will benchmark the current functional and yield performance of your solder paste and serve as a sound engineering basis for future material work. If you are planning on switching to another paste formulation the following series of test events are recommended to ensure a successful implementation of a new material.

Step 1

Benchmark the current performance of your existing solder paste. Test the major functional characteristics that can effect your first pass visual and electrical yields. This is best done off-line on test patterns to be as repeatable and product non specific as possible. Functional tests that you should include in your benchmark are:

- Printability
- Slump behavior
- Tack and tack life
- Solderability

- Residue Level
- Cleanability (if applicable)

Step 2

Benchmark the product and process yields of your current solder paste on a product that tends to “challenge” the material. This product may have more fine pitch or finer pitch than your average product design or a greater variety of components. Try to select a product out of the prototype stage but early in its product life. This step will be repeated on the down-selected materials from step 3 and may be the product you want to implement the new solder paste on. Detail every rework event in the benchmark lot so that you understand what can be attributable to the solder paste performance. This is a good time to record your usage and waste. If possible record the conditions of the factory at the time your “benchmark” lot is built such as temperature, humidity, operators, lot numbers of boards, solder paste and even components. Pick a good lot size, one that is typical of your manufacturing environment, large enough to be statistically significant (e.g. > 50 boards) but manageable (e.g. < 500 boards). Obtain a detailed report of the test yields identifying specific causes of component rework and assign causes to each event such as insufficient solder, opens, solder bridges, tombstones, poor wetting, lead coplanarity, component misalignment and missing components. Since you have quantified the performance of your current material with respect to the major functional tests and characterized the yield loss associated with it, this may be a good time to rate the relative importance of the major performance categories. This will result in a custom set of performance expectations for the solder paste. Tackiness may be very important if the defect analysis indicates a high percentage of missing components. Solderability may need to be increased if insufficient solder and/or opens are top defect categories. If slump was found in step 1 and shorts are a major rework item then you should look for materials with little or no slump behavior.

Step 3

Test the new materials under the same set of conditions and methods that you benchmarked your current solder paste in step 1. Evaluate your results and down-select all materials that demonstrated poorer performance than your current material. In reality you may notice some trade-offs in performance and this is when you can apply your custom set of performance expectations derived in step 2.

Step 4

When you are ready to verify your new materials yield and/or throughput enhancements build another lot of the same product as close to the same conditions as was done in step 2. If there are significant differences in manufacturing conditions simply run an equal amount of boards with the current solder paste but be sure to detail all defects to accurately assess the effects of the material change.

Functional Tests

Solder paste tests, for most of the ones listed, can be found in ANSI/J-STD-005 *Requirements for Soldering Pastes*. This may be a good place to start but tests that are more directly tuned to your specific process requirements may correlate better to your product yields.

Printability

This attribute usually infers fine pitch printability. Use this as an off line test to compare and contrast the relative printability of solder pastes. Print on a flat substrate, a piece of FR4 from an industrial supply company will do fine, smaller test patterns on Alumina substrates (Al_2O_3) are equally effective. The logic of the flat substrate is to exclude the stencil to solder pad gasketing issues that can stem from excessive Hot Air Solder Leveling (HASL), poor stencil design , surface features such as bar code labels or even the white legend on the board being too close to the solder pads. With a flat surface you are very deliberately testing the printability of the solder paste. The test pattern should include features common to your product such as fine pitch , Ball Grid Array (BGA) or flip chip pads. The actual print process should be done on production equipment and you may want to quantify the printability at a faster squeegee speed than you are using in production to get a view of the limitations of the material you are testing. You should also print for some period of time such as 1 hour or 100 prints to get an idea of any changes in the performance of the solder paste over time. Whatever process you develop be sure to note every facet of the print process possible such as squeegee angle, type, speed, downstop and pressure, as well as separation speed (speed that the board separates away from the stencil after printing) and snapoff (distance between board surface and the bottom of the stencil) and lastly printer cabinet temperature and humidity.

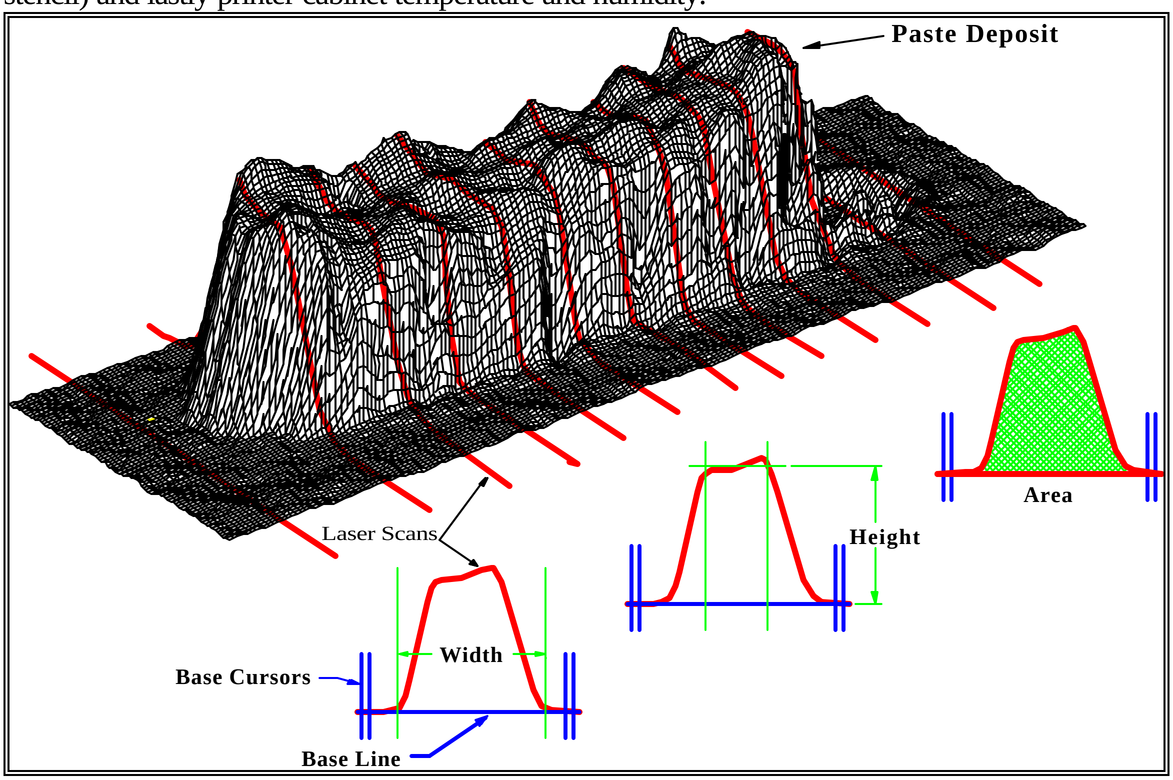

Figure 2 Printability Metrics

You can quantify the print quality in many ways, by observation of pad shape and height consistency and/or the amount of shorts or misprinted areas. Try to use a method that is as objective as possible. An elaborate method uses laser triangulation and measures pad width and height and calculates pad volume as can be seen in Figure 2. In this method paste printability comparisons are fully automatic and easy to interpret in that the results are converted from Coefficient of Variance data to “Print Points” as in Figure 3 where pad volume is 60% of the points, pad shape 30% and slump 10%. The chart in Figure 3 shows the effect of PSD on fine pitch printability.

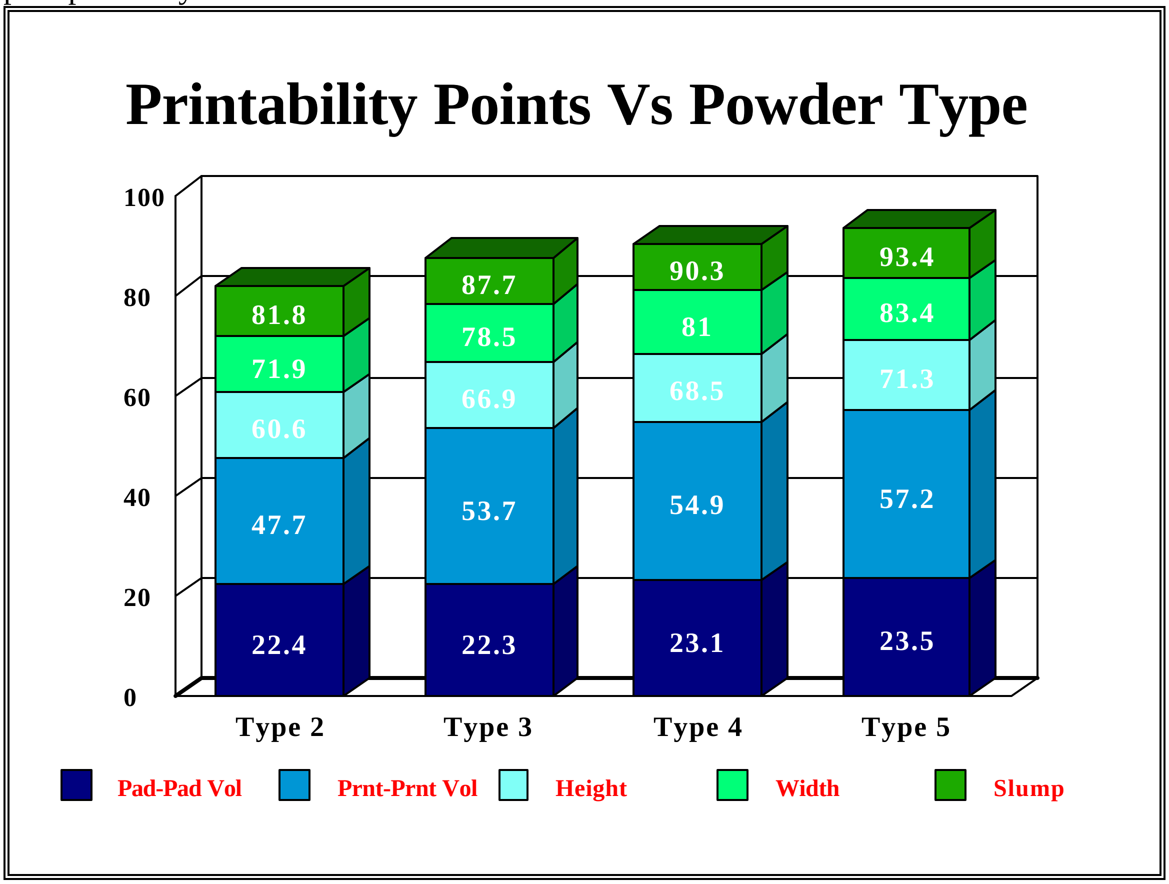

Figure 3 Powder PSD Vs Printability

Slump

Slump is the tendency for a solder paste to spread out over the pad surface after printing. If slump occurs before reflow it is usually referred to as “room temperature slump”. If the slump occurs in the preheat section of the reflow profile it is considered “hot slump”. All forms of slump can lead to fine pitch shorts and/or solder ball formation. A simple test for slump would be to print a few extra substrates during your print test, measure the pad widths immediately after print, condition the substrates (let one stand out in room temperature for 15 minutes and bake one at 150°C for 15 minutes), then re-measure the same area of the same pads, calculate the change in width and then the average change. For no cleans there should be no change in width at room temperature and a slight decrease in width at 150°C, this is shrinkage due to the evaporation of flux solvents. If you are testing a water clean solder paste you should also look at the effect of high humidity on the slump behavior. This can be done in a temperature and humidity chamber set at arround 30°C and 90% relative humidity. Typical water cleans will exhibit 10% to 15% "humid slump" when subjected to these conditions although many formulations have been found to have 80% to 100% humid slump. Materials with high humid slump will have seasonal variation in performance, in the winter when the humidity is low they may dry out and have a short stencil life and in the summer they may have excessive slump behavior.

Tack and Tack Life

Solder paste tack is basically the stickiness of the material. This property is what holds the components in place after placement up to the reflow operation. The method called out in the ANSI/J-STD-005 specifies that a probe be lowered slowly into a solder paste print, held for several seconds and then raised. While the probe is raising the peak tensile or pulling force on the probe of the solder paste is recorded. This is usually recorded in gr/mm^2. Readings that are >2 gr/mm^2 are generally considered to be good tack readings. This property should be tested every hour after printing up to 8 hours. Consistent tack force readings for 8 hours are common.

Solderability

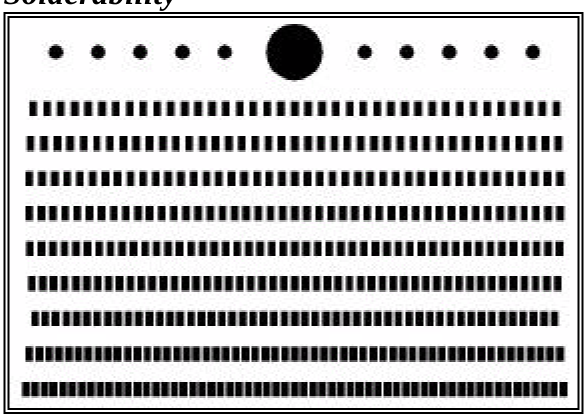

Figure 4 Solderability Test Pattern

The classic test for solderability of a solder paste is to build a board and inspect it. Although this method is highly subjective, this is the only practical way of comparing the luster and smoothness of the solder fillets. The test can be made harsher by heat or steam aging the board and components to lower their solderability prior to assembly. An effective quantitative method of comparing solderability involves printing solder paste through a test stencil such as in Figure 4 onto a piece of oxidized copper foil, reflowing and counting how many shorts are generated. Copper foil is a good substrate choice since it is the base metal that you are soldering to in most components (leaded) and PCB's. If copper clad FR4 is used it must be abraded and acid etched prior to oxidizing because most of the times it has a clear protective layer on it that will distort your solderability results if not removed. With this method, more shorts equals better solderability since the distance between pads increases for each row of pads. Measuring the increase in the diameter of a circular pad of solder paste can be effective as a gross test but is fairly subjective in that rarely does a solder paste reflow in a perfectly circular fashion and you are at best estimating the average diameter. The substrate should be oxidized at 150°C for one hour to produce an oxidized surface. You can also look at the relative profile sensitivity of a solder paste by reflowing your coupons in different profiles.

Residue Level

This test is primarily for no clean solder pastes. Residue level is best quantified by using a Thermogravimetric Analyzer (TGA). TGA results may not correlate with the appearance of the residue nor the probe-ability of the flux residue. A relatively low residue (<4%) no clean solder paste where the flux residue tends to spread out over the mask at reflow may appear to have more residue than a relatively high residue (>7%) material where the flux tends to cling to the solder joint. The TGA data is very useful in assessing the amount of flux that the reflow oven will have to remove.

Cleanability

This test is primarily for water clean solder pastes. The assessment of cleanability is best done with actual product in production. To look at worst-case cleaning scenarios, reflow the boards in a relatively hot profile before cleaning and/or wait several days before cleaning after reflow. After cleaning inspect for flux residues on the solder joints and under low components such as BGA's or large chip components. It is also recommenced to check the ionic residue level in your omegameter (Ionograph).

Other

There are many other tests for solder pastes that your paste supplier should be capable of providing you, preferably by a third party test lab. These tests are mostly for no cleans such as Surface Insulation Resistance (SIR), Ion Chromatography, Silver Chromate test for halides, Copper Mirror test for corrosion, Electromigration, PH and more.