As originally published in the IPC APEX EXPO Proceedings.

3 Steps to Successful Solder Paste Selection

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Abstract

Choosing a solder paste can make or break an assembly process. By choosing the right solder paste for the application, you will achieve the highest process consistency and solder joint quality.

This paper covers the most significant issues in solder paste selection to meet the goals of manufacturing. The goals of any assembly operation are to maximize both quality and throughput while controlling costs. Quality is maximized by choosing a paste that has the best performance with the materials, geometry and heating processes used to manufacture a product. Throughput is maximized by picking a solder product that accommodates the optimal deposition and heating methods. Cost of production is a complex calculation that includes material, direct labor, inspection, rework, and scrap value. Quality and throughput play key roles in cost control.

Not all solder products are created equal, even if they seem the same according to their classification. Specialty solder pastes provide enhanced performance over off the shelf products. There are differences in wetting characteristics, void control, flux residue, alloy strength, alloy flexibility, and other performance measures that can all play significant rolls in achieving quality, throughput, and cost goals. The key is to identify the solder product that best accommodates the processes required to meet these goals.

Introduction

Solder paste is not just for SMT assembly. Solder paste can be used to design out defect modes, accommodate product requirements and compensate of process limitations in ways that other forms of solder cannot. Solder paste is a homogeneous mixture of paste flux and powdered solder alloy *(Figure 1)*.

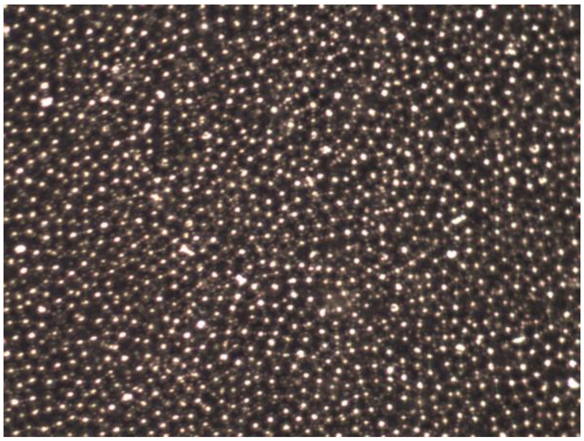

Figure 1: Solder Paste

Choosing a solder paste can make or break an assembly process. By choosing the right solder paste for the application, you will minimize problems with process consistency and solder joint quality. Choosing the right solder paste is a three-step process:

1. **Alloy Selection**. The alloy requirements must be evaluated and an alloy identified as meeting all the product requirements.

2. **Flux Type Selection.** The flux types that are valid options must be identified. This is a process of elimination where fluxes with unacceptable criteria are removed from consideration.

3. **Identifying Required Special Flux Characteristics.** Issues such as difficult-to-solder surfaces, rapid reflow conditions, cleaning options, and solder joint voiding concerns should be considered before choosing a paste, not after a problem is discovered.

Alloy Selection

When choosing a solder alloy, there are four key considerations: lead content, melting temperature, alloy powder particle size, and tensile strength. Lead content, melting temperature, and strength are typically addressed at the same time. The Alloy Table *(Table 1)* lists melting and strength statistics along with composition for fifteen solder alloys. The green shaded alloys are lead free.

At temperatures below the solidus, the alloy will be completely solid. At temperatures above the liquidus, the alloy will be completely liquid. In-between, the alloy is in a plastic state and neither fully liquid nor fully solid and strength is near zero. For best wetting, a peak temperature 15ºC or more above liquidus is required. If physical integrity must be maintained during a later operation, such as a second reflow process, the peak temperature of the later operation needs to be below the alloy solidus.

Solder alloy tensile and shear strength values are only valid at 25ºC at a particular strain rate for a particular age of the alloy sample. Tensile strength drops as temperature increases. Near the solidus, tensile strength approaches zero.

When using strength values to make a decision, keep in mind that the listed values are a reference. Use them for comparison to determine if one alloy is likely to be better than another. Include a factor of two or more as a safety margin for joint variability and to compensate for any inaccuracy in the tensile strength value reported. Be mindful that alloys with higher solidus retain more strength at higher temperatures. Example: Sn95 Ag5 at 210ºC is weaker than Sn5 Pb95 at 210ºC, despite the large difference in tensile strength *(Table 1)*.

Metals expand as they change state from solid to liquid. In many applications involving part encapsulation, excessive stress induced by alloy expansion can cause cracking due to strain. Molten alloy tends to follow these cracks, either breaking the part outright or creating a future field failure. When encapsulating, try to avoid using an alloy that will fully liquefy during a later heating step.

Table 1: Alloy Table

Alloy:	Solidus (°C)	Liquidus (°C)	Tensile Strength (MPa)
Sn42 Bi58	-E-	138	55.2
Sn43 Pb43 Bi14	144	163	42.2
Sn62 Pb36 Ag2	179	189	46.2
Sn63 Pb37	-E-	183	46.2
Sn60 Pb40	183	191	42.7
Sn96.5 Ag3.0 Cu0.5	217	219	50.6
Sn96.3 Ag3.7	-E-	221	61.4
Sn100	MP	232	12.4
Sn95 Sb5	232	240	40.7
Sn95 Ag5	221	245	69.6
Sn89 Sb10.5 Cu0.5	242	262	82.7
Sn10 Pb88 Ag2	268	290	33.8
Sn5 Pb92.5 Ag2.5	287	296	29.0
Sn10 Pb90	275	302	31.7
Sn5 Pb95	308	312	28.9

Note: green highlighted alloys are lead free

Having picked an alloy, the particle size required is the next item to identify. The Powder Size Table *(Table 2)* cross-references particle size to typical printing and dispensing requirements. The dimensions listed for gullwing, square/circle and dispense dot sizes represent the smallest feature recommended for that size powder. If the feature is smaller than this use the next smaller powder size.

Using too large a powder size will cause printing and dispensing difficulties, compromising quality. Using too small a powder size will just cost more than necessary.

Table 2: Powder Size Table

Powder Type	Powder Size (micron)	Gullwing Lead Pitch (mm)	Square/ Circle Aperture (mm)/(in)	Dispense Dot Dia. (mm)/(in)
II	75-45µ	0.65 / 0.025	0.65 / 0.025	0.80 / 0.030
III	45-25µ	0.50 / 0.020	0.50 / 0.020	0.50 / 0.020
IV	38-25µ	0.30 / 0.012	0.30 / 0.012	0.30 / 0.012
V	25-20µ	0.20 / 0.008	0.15 / 0.006	0.25 / 0.010
VI	15-5µ	0.10 / 0.004	0.05 / 0.002	0.10 / 0.004

Flux Type Selection

Both specifications and industry usage have contributed to current naming conventions for fluxes. Industry convention includes five basic categories of fluxes to choose from: R, RMA, RA, NC, and WS. The following summary is a short explanation of how specifications affected the categories.

There are four categories of flux to choose from as defined by Military Specification QQ-S-571E. The names are Rosin (R), Rosin or Resin Mildly Activated (RMA), and Rosin or Resin Activated (RA), and non-rosin or non-resin (AC). In most cases, the AC name has been replaced in industry with WS for Water Soluble. Each category of flux is available with a variety of activity levels, with the limits of each defined by applicable test results.

IPC also has a flux rating system. The system uses four characters to describe any flux as published in J-STD-004. These four characters describe the product in terms of material type, including but not limited to such categories as rosin and inorganic, along with an approximation of activity level and halide content. Example: A halide-free, rosin based solder paste with low activity is categorized as ROL0. RO stands for rosin, the L is for low activity and the number 0 is for no detectable halides.

In addition, the IPC standard added a category of flux called No Clean. This new category of flux is rosin based like an RMA but is defined by non-tacky residue and compliance with a Surface Insulation Resistance (SIR) test to a value of $1x10^8\Omega$.

Each of the five flux categories can be described in brief by noting their activity, the physical qualities of their residue, and the cleaning methods that may be used in their removal.

Rosin (R) flux consists of rosin and solvent. Rosin flux has very low activity and is suited only to clean and easy-to-solder surfaces. IPC classification is usually ROL0. R residue is hard, non-corrosive, non-conductive and may be left on many types of assemblies. Residue may be removed with an appropriate solvent.

No-Clean (NC) flux consists of rosin, solvent, and a small amount of activator. NC flux typically has low-to-moderate activity and is suited to easily solderable surfaces. IPC classification is usually ROL0 or ROL1. NC residue is clear, hard, non-corrosive, non-conductive, and is designed to be left on many types of assemblies. Residue may be removed with an appropriate solvent. Some, but not all, NC fluxes are more difficult to remove than RMA fluxes.

Rosin mildly activated (RMA) flux consists of rosin, solvent, and a small amount of activator. Most RMA flux is fairly low in activity and best suited to easily solderable surfaces. IPC classification is usually ROL0, ROL1, ROM0, or ROM1. RMA flux residue is clear and soft. Most are non-corrosive and nonconductive. Cleaning requirements will be based on the activity of the flux and the product it is used on. Many RMA fluxes pass Surface Insulation Resistance (SIR) testing as a NC flux. Residue may be removed with an appropriate solvent.

Rosin activated (RA) flux consists of rosin, solvent, and aggressive activators. RA flux has similar and higher activity than RMA for moderately and highly oxidized surfaces. IPC classification is usually ROM0, ROM1, ROH0, or ROH1. RA flux residue is considered corrosive. Assemblies sensitive to corrosion or the possibility of electrical conduction through the residue should be cleaned as soon as possible after assembly. Residue may be removed with an appropriate solvent.

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Water soluble (WS) flux consists of organic acids, thixotrope, and solvent. WS flux comes in a wide range of activity levels, from no activity to extremely high activity for soldering to even the most difficult surfaces, such as stainless steel. Because WS flux covers all activity ranges, the product specification must be referenced for corrosion and electrical conductivity hazards. IPC classification normally starts with OR for organic. They come in L, M, H activity levels and halide content of 0 or 1. By definition, residue may be removed with water.

The Flux Comparison Chart *(Figure 2)* is a graphical representation of the activity range each category of flux is typically available in and the activity relative to each other. As can be seen, there is quite a bit of overlap.

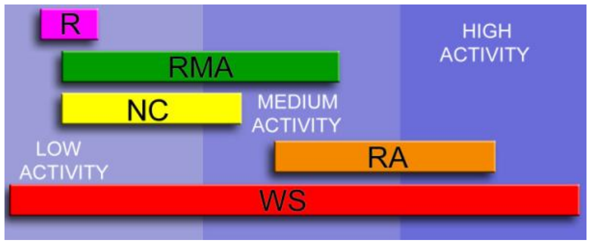

Figure 2: Flux Comparison Chart

The Solderability Matrix *(Table 3)* shows compatibility of the various flux types with common metals. For brass, bronze and stainless steel, there is enough variety in alloy composition that each alloy must be checked against the flux type you wish to use.

Table 3: Solderability Matrix

Finish	RMA	RA	WS	NC	High Activity WS
Aluminum	✘	✘	✘	✘	✘
Beryllium Copper	✔	✔	✔	✔	✘
Brass	?	✔	?	?	✔
Bronze	?	✔	?	?	✔
Cadmium	✔	✔	✔	▲	✘
Chromium	Non-solderable				
Copper	✔	✔	✔	✔	✘
Galvanized Steel	✘	▲	▲	✘	✔
Gold	✔	✔	✔	✔	✘
Kovar	▲	✔	✔	✘	✘
Magnesium	Non-solderable				
Mild Steel	✘	▲	✘	✘	✔
Monel	✘	▲	▲	✘	✔
Nichrome	✘	✘	✘	✘	✔
Nickel	✔	✔	✔	▲	✘
Nickel Iron/ Alloy42	▲	✔	▲	✘	✔
Nickel silver	✔	✔	✔	▲	✘
Palladium	✔	✔	✔	✔	✘
Platinum	✔	✔	✔	✔	✘

Silver	✔	✔	✔	✔	✘
Solder Plated	✔	✔	✔	✔	✘
Stainless Steel	✘	✘	✘	✘	?
Tin	✔	✔	✔	✔	✘
Titanium	Non-solderable				
Zinc	✘	▲	▲	✘	✔

Key: ✔ Recommended ▲ Wets clean surfaces
✘ Not Recommended ? Alloy-specific

Special Flux Characteristics
The last area to consider when finalizing solder paste selection is any other special characteristics. Two flux formulas can differ greatly in performance despite having the same QQ-S-571E and J-STD-004 classifications *(Table 4)*. Solder pastes with specific characteristics can be used to solve technical assembly problems that other forms of solder do not.

Table 4: Flux Classification Challenges

	Paste A	**Paste B**
QQ-S-571E	RMA	RMA
J-STD-004	ROL0	ROL0
Hermetic seal of irregular gap	Fail	Pass

The following are examples of flux characteristics that modify how a solder paste performs.

Reduced Slump: The reduction of solder paste spread after deposition, resulting in loss of definition. This feature is important when pads are close together and bridging is a risk.

Restricted Residue: The flux residue remains either on or very close to the fillet after reflow. This feature is most important with NC formulations where the joint is visible or the spread of flux to surrounding areas can cause a problem.

Halide-free: Halide-free solder pastes have an IPC J-STD-004A rating of 0 for the fourth character. Example: ROL0. Halides may be found in some flux activators. They assist in oxide removal due to their high energy state. Halides are materials that contain a halogen: Chloride, Bromide, Fluoride, or Iodide.

Low Residue: The quantity of flux residue left over after reflow is less than with normal solder pastes. Either there is less flux to begin with, or a larger percentage evaporates as part of the reflow process.

Difficult to Solder Surfaces: Difficult to wet metals and oxidized surfaces can both require flux with higher activity or different activators that work better with the metal involved. Aged components, Alloy42 leads and the like are a special consideration for flux selection.

Gap Filling and/or Vertical Surfaces: The flux is designed to hold the alloy in place until liquidus is reached. These formulas are suited to bridging gaps, filling holes, and soldering joints on vertical surfaces.
Note: They are not normally successful in forcing a bridge between two adjacent, empty, pads on a circuit board in place of a zero ohm resistor. Surface tension of molten solder alloy is too high and the bridge breaks in the absence of opposing surfaces to stretch between.

Rapid Reflow: A term used to describe the heating of solder paste in under 5 seconds. A rapid reflow solder paste will not spatter when heated as quickly as ¼ of a second. Typical reflow methods that achieve rapid reflow include laser, solder iron, hot bar, and induction.

UV Traceable: A fluorescent dye is added to aid in the inspection of the solder deposit using UV lighting. Un-reflowed solder paste can be inspected with appropriate vision systems. Post reflow inspection can be conducted both with vision and human inspection under black light.

Pin Transfer or Dipping: An application technique where the solder is applied by dipping a component or pin into the solder paste. A thin, consistent layer of solder paste sticks to the component. This technique is useful in applying solder to products that do not lend themselves to printing or dispensing, such as pin arrays. Dipping paste is a useful way to apply additional solder paste to a through hole component when the amount of paste that can be printed for paste-in-hole is insufficient due to stencil thickness.

Low Void: IPC-7097A is the Specification for the Design and Assembly Process Implementation for BGAs. The inspection criteria for Ball Grid Array (BGA) and MicroBGA often call for voiding under 20% of area and some under 9% or even 4% depending on the location in the ball. A low-void solder paste is required to meet the very low voiding limits for Class 3 assemblies.

Conclusion

Solder paste selection can make or break a solder joining process. Specialty solder pastes provide enhanced performance over off the shelf products. This paper covers the most significant issues in solder paste selection. There are additional details of alloy and flux performance not covered here that can be very important in the solder paste selection process. It is always worth a call to your solder products vendor to review your requirements to ensure you are using the best solder paste for the job.