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IPC-HDBK-005

Guide to Solder Paste Assessment

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A standard developed by IPC

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Developed by the Solder Paste Task Group (5-24b) of the Assembly
and Joining Processes Committee (5-20) of IPC

Users of this publication are encouraged to participate in the
development of future revisions.

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Table of Contents

1	SCOPE	1	4	PRINTING SOLDER PASTE	7
1.1	Purpose	1	4.1	Printing Needs	7
1.2	Checklist	1	4.2	Printing Variables	7
1.3	Terms and Definitions	1	4.3	Primary Control Variables	7
1.4	Using Solder Paste	1	4.4	Printing	7
2	APPLICABLE DOCUMENTS	2	4.4.1	Apparatus	7
2.1	IPC	2	4.4.2	Procedures	8
2.2	Joint Industry Standards	2	4.4.3	Evaluation	8
2.3	Military	2	4.5	Solder Paste Print Quality Control Variables	8
2.4	International Electrotechnical Commission Documents	2	4.5.1	PCB Variables	8
2.5	Telcordia	2	4.5.2	Solder Paste Variables	9
2.6	ASTM	2	4.5.3	Stencil Variables	9
3	SOLDERABILITY	2	4.5.4	Screen Printer Variables	9
3.1	Theory of Wetting	2	4.5.5	Environmental and Operator Variables	9
3.2	Degrees of Wetting	3	5	ABILITY OF SOLDER PASTE TO RETAIN COMPONENTS (TACK)	9
3.3	Wetting Measurement	3	5.1	Background	9
3.4	Factors Affecting Solderability During Reflow Soldering Process	3	5.2	Tack Test Shortcomings	9
3.4.1	Land Surface Finish	3	5.3	Tack Life	10
3.4.1.1	Hot Air Solder Leveling (HASL)	4	5.4	Increased Tack Strategies	10
3.4.1.2	Plating/Immersion Coating	4	5.5	Increased Tack Life Strategies	10
3.4.1.3	Organic Solderability Preservatives (OSP)	4	5.6	Control Variables	10
3.4.2	Component Lead Composition/Finish	4	5.7	Improved Testing	11
3.4.2.1	Base Metal	4	5.7.1	Production Testing	11
3.4.2.2	Coating Composition	4	5.7.2	User Test Guidelines	11
3.4.2.2.1	Sn-Pb Coated Leads	4	6	SLUMP	11
3.4.2.2.2	Au Coated Leads	4	6.1	Slump Testing Apparatus	12
3.4.2.2.3	Pd or Pt Plated Leads	5	6.2	Test Procedure	12
3.4.2.3	Lead Coating Processes	5	6.3	Evaluation	12
3.4.3	Reflow	5	6.3.1	Cold Slump	12
3.4.4	Solder Paste	5	6.3.2	Hot Slump	12
3.4.4.1	Flux	5	6.3.3	Slump Performance	12
3.4.4.2	Solder Alloy	5	6.3.4	Visual Inspection	12
3.4.4.3	Powder Particle Size	5	6.4	Differentiation	13
3.4.5	Summary	6	6.5	Major Control Variables	13
3.5	Solderability Testing	6	7	SOLDER PASTE FUME COLLECTION AND DISPOSAL	13
3.5.1	Solder Paste Wetting Tests	6	7.1	Background	13
3.5.2	Solderability Test Documents	6	7.2	Flux Vapor Collection	14
3.5.2.1	Special Solderability Test Methods	6	7.3	Residue Toxicity	14
3.5.3	Solderability Test Method Selection	6	7.4	Collection System Maintenance	14

8	SOLDER BALLS	14	12.2	Evaluation	20
8.1	Solder Ball Tests	14	12.3	Control Variables	21
8.2	Forms of Solder Balling	14	APPENDIX A	Mass Reflow Assembly of 02101 Components	22
8.2.1	Solder Beads	15	APPENDIX B	Qualification of Solder Beading and Tombstoning in Passive Devices using Designed Experiments	29
8.2.2	Solder Paste Segregation	15	APPENDIX C	A Materials Based Solution for the Elimination of Tombstones	38
8.2.3					
8.2.4	Lack of Coalescence	15			
8.2.5	Formulation Strategies	15			
8.2.6	Process Strategies	16			
8.3	Improved Testing	16			
9	TOMBSTONING	16			
9.1	Tombstone Causes	16			
9.2	Minimizing Defects	17			
10	CLEANABILITY OF SOLDER PASTES AND RESIDUES	17			
10.1	Cleaning Methods and Materials	17			
11	COMPATIBILITY OF SOLDER PASTE FLUX RESIDUES (PROBE TESTABILITY)	18			
11.1	Test Plan Overview	18			
11.2	Approaches for Improved ATE-Compatibility	18			
11.3	Main Characteristics	18			
11.4	Major Control Variables	18			
11.5	Residue Open Time	20			
11.6	Temperature	20			
11.7	Reflow Conditions	20			
11.8	Test Points	20			
11.8.1	Test Probe Design and ATE Equipment	20			
11.8.2	Probe Build-up	20			
11.8.3	Residue Dryness	20			
12	SHELF LIFE	20			
12.1	Test Procedures	20			

Figures

Figure 3-1	Surface Tension and Contact Angle of Molten Solder	3
Figure 3-2	Effect of Alloy Composition on Area of Spread	6
Figure 5-1	The Extensional Nature of "Tack"	10
Figure 5-2	The Interaction of Various Factors Affecting Solder Paste 'Working Life'	10
Figure 8-1	Solder Beading	15
Figure 8-2	Solder Spatter	15
Figure 9-1	Tombstoned Component	16
Figure 9-2	Floating Tombstone or Draw Bridging Defect	17
Figure 11-1	Overview for ATE Testing Plan	19

Tables

Table 3-1	Factors of Wetting and Their Effects	4
Table 3-2	Common Solderability Test Methods	6
Table 5-1	Main Control Variables Affecting Solder Paste Working Life	10
Table 11-1	Questions for Probe Testing Flow Chart/Guide	19
Table 12-1	Test Recommendations for Shelf Life Determination	21



Guide to Solder Paste Assessment

1 SCOPE

This handbook is a companion to the solder paste standard J-STD-005 and should be considered to be a guide to help assess the applicability of a solder paste for its use in surface mount technology (SMT) processes. This document also suggests some test methods that can help with designing and testing solder pastes. It is intended for use by both vendors and users of solder paste.

1.1 Purpose Solder pastes are unique materials, whose performance in a surface mount process depends on a variety of variables, many of them interacting. J-STD-005 provides test methods for classification of solder paste based on the use of a variety of testing techniques. However, these solder paste classifications do not have a direct correlation to identify the type and characteristics of a specific solder paste that is needed in any given SMT assembly process.

This document has been written as a guide to assess the applicability of a solder paste for a specific process, given the tremendous number of permutations of different materials, atmospheres and process variables currently available.

Where appropriate, references are given to papers and documents with further information. Due to the sheer number of possible interacting factors, specific solder paste selection criteria cannot be given. The solder paste selected and the assembly process used will need to form solder connections that meet the requirements of industry standards such as J-STD-001 and/or IPC-A-610.

1.2 Checklist Solder paste vendors often provide practical information about their products. When this information is available much time and money can be saved in qualifying the product's capabilities. The following listings are examples of information that is usually of value to process engineers and designers. Items marked with an asterisk (*) are usually of greatest value.

- *Is the paste recommended for use in clean or no-clean processes and is there a recommended cleaning process?
- *What is the ideal or recommended reflow profile?
- *What is the flux classification per J-STD-004 or equivalent flux standard?
- *What are the results of copper mirror testing?
- *What is the halides content?
- *What percentage of Flux Solids (Non-Volatile Content)?
- *Corrosion
- *Surface Insulation Resistance (SIR)

*What is the characterization of solder paste per J-STD-005?

- *Powder Size
- *Powder Shape
- *Metal Percent
- *Viscosity
- *Slump
- *Solder Ball
- *Tack
- *Wetting

*What is the solder powder alloy designation per J-STD-006?

- Acid Value
- Flux Specific Gravity
- Paste Flux Viscosity
- Visual
- Flux Spread
- Wetting Balance
- Fungus

Does it meet Telcordia (formerly Bellcore) GR-78-CORE requirements?

- Copper Mirror
- Halides by Silver Chromate
- SIR - Electromigration

1.3 Terms and Definitions This handbook uses terms and definitions common to the electronics manufacturing industry and defined in **IPC-T-50 Terms and Definitions for Interconnecting and Packaging Electronic Circuits**.

1.4 Using Solder Paste Solder paste is the material that provides a wetted solder connection between solderable surfaces. To accomplish that end, it consists of:

- A flux vehicle to break down surface oxides on the surfaces to be wetted, and
- Solder alloy in the form of very small solder balls that will coalesce into a solder connection when reflowed.

To be usable, the solder paste must:

- Have reasonable working life under ambient temperature and humidity conditions.
- Have sufficient surface tension, called tack, to hold the component leads/terminations in position until and during reflow.
- Not contribute to the formation of undesirable solder balls/solder fines on the assembly.

Solderability, printability, stencil life, slump, tack, fume collection during reflow, formation of solder balls, tombstoning, cleaning, probing through solder paste residue after reflow, and solder paste shelf life will be discussed in the following sections.

2 APPLICABLE DOCUMENTS

The following specifications and standards form a part of this handbook / guideline to the extent specified herein. If a conflict of requirements or guidelines exists between IPC-HDBK-005 and the listed applicable documents, IPC-HDBK-005 **shall** take precedence.

2.1 IPC¹

IPC-A-20/21 Standard Pitch Stencil Pattern for Slump

IPC-SC-60 Post Solder Solvent Cleaning Handbook

IPC-SA-61 Post Solder Semi-Aqueous Cleaning Handbook

IPC-AC-62 Aqueous Post Solder Cleaning Handbook

IPC-CH-65 Guidelines for Cleaning of Printed Boards and Assemblies

IPC-A-610 Acceptability of Electronic Assemblies

IPC-TM-650 Test Methods Manual²

2.2.14.3 Determination of Maximum Solder Powder Particle Size

2.4.34 Solder Paste Viscosity - T-Bar Spin Spindle Method (Applicable for 300,000 to 1,600,000 Centipoise)

2.4.34.1 Solder Paste Viscosity - T-Bar Spindle Method (Applicable at Less Than 300,000 Centipoise)

2.4.34.2 Solder Paste Viscosity - Spiral Pump Method (Applicable for 300,000 to 1,600,000 Centipoise)

2.4.34.3 Solder Paste Viscosity - Spiral Pump Method (Applicable at Less Than 300,000 Centipoise)

2.4.35 Solder Paste - Slump Test

2.4.43 Solder Paste - Solder Ball Test

2.4.44 Solder Paste - Tack Test

2.4.45 Solder Paste - Wetting Test

2.4.47 Flux Residue Dryness

1. www.ipc.org

2. Current and revised IPC Test Methods are available on the IPC website (www.ipc.org/html/testmethods.htm).

3. www.ipc.org

4. <http://assist.daps.dla.mil/online/start>

5. www.iec.ch

6. www.telcordia.com

7. www.astm.org

2.2 Joint Industry Standards³

J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

J-STD-002 Solderability Tests for Component Leads, Terminations, Lugs, Terminals and Wires

J-STD-003 Solderability Tests for Printed Boards

J-STD-004 Requirements for Soldering Fluxes

J-STD-005 Requirements for Soldering Pastes

J-STD-006 Requirements for Electronic Grade Solder Alloys and Fluxes and Non-Fluxed Solid Solders

2.3 Military⁴

MIL-STD-203 Aircrew Station Controls and Displays: Location, Arrangement and Actuation

MIL-STD-883 Test Method Standard, Microcircuits

2.4 International Electrotechnical Commission Documents⁵

IEC 68-2-20 Environmental Testing. Part 2: Tests. Test T: Soldering

2.5 Telcordia⁶

GR-78-CORE Generic Requirements for the Physical Design and Manufacture of Telecommunications Products and Equipment

2.6 ASTM⁷

ASTM D 1210 Standard Test Method for Fineness of Dispersion of Pigment-Vehicle Systems by Hegman-Type Gage

3 SOLDERABILITY

This handbook will help the user understand solderability and wetting and their role in SMT soldering. Referenced test methods are generally accepted by the industry and are currently used to provide the data for product acceptability.

3.1 Theory of Wetting Wetting of solder to a metallic surface is driven by the thermodynamic surface energy of the substrate and liquid solder before and after the soldering process. In SMT soldering, the high surface energy of the substrate plays a key role in creating a wettable surface.

For molten solder to form a strong solid state bond with a given metallic substrate, the following conditions must be fulfilled:

- Metal substrate and solder alloy should be compatible;
- Both the solder and the substrate must be free of oxides and foreign material and remain so during the reflow cycle; and
- Temperature must reach a sufficient level.

When solder paste reflows and wets a metal substrate, three components are present: molten solder metal, substrate metal (a solid) and flux.

As the molten solder wets the substrate, its area of spread is dependent on the conditions listed above. Depending on the solder alloy, good wetting may be indicated by a contact angle that is less than 75° (see Figure 3-1).

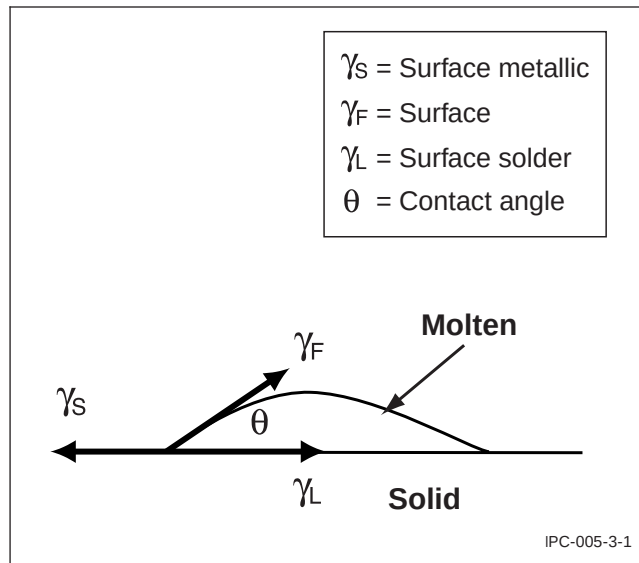


Figure 3-1 Surface Tension and Contact Angle of Molten Solder

The wetting is governed by the equation: $\gamma_s = \gamma_F \cos \theta + \gamma_{LS}$

In general, for wetting of the substrate by the liquid solder to occur, the surface free energy of the substrate (γ_s) must be larger than the sum of the surface tension of the molten solder metal (γ_{LS}) and surface tension of the flux (γ_F) times the cosine of the contact angle. In most cases, the surface energy of the substrate (γ_s) and the molten solder metal (γ_{LS}) is much larger in magnitude than γ_F . Their effects play a greater role in determining wetting. In other words, if the surface tension of the substrate is larger than that of the molten solder, the solder wets the base metal well. A metal free of surface oxide has a larger surface energy and thus, fluxing, or removal of oxide, improves wetting (γ_s increases).

Using the example of a Pb-Sn solder on a clean Cu substrate:

- Pure Pb does not wet a pure Cu substrate at typical soldering temperatures. This is due to a large interfacial ten-

sion between Pb and Cu; if Sn is added to the Pb, the wetting improves. The addition of the Sn reduces the interfacial tension between the solder alloy and the Cu substrate. Further addition of Sn to the Pb causes the surface tension of the molten solder to increase, and the contact angle of the Sn-Pb alloy to increase.

- These same principles of theoretical wetting of a substrate by molten solder apply to lead-free alloys also. The specific wetting angle of each alloy has to be considered in evaluating lead-free alternatives to each other and Sn-Pb alloys.

3.2 Degrees of Wetting Non-wetting between two metals occurs when the molten solder is unable to adhere to the base material. No attachment or bond is formed, the solder does not spread, and the base material is visible.

Dewetting is caused if the liquid to solid interface is not continuous, and areas exist where there is no adhesion. The solder spreads and then retracts, resulting in areas exhibiting uneven coverage with irregularly shaped solder mounds separated by a thin layer or film of solder. Some areas of the base material may be exposed.

Insufficient wetting is caused when the solder layer on the surface of the base material does not completely wet the entire surface. The layer is continuous, but only partially covering the surface of the base material.

Factors to be considered as causes of these conditions, and their effects are listed in Table 3-1.

3.3 Wetting Measurement Changes in the area coverage by the solder can be measured as adjustments are made to the controlled variables. These include temperature, time and materials. The angle of the fillet produced during soldering indicates the degree to which the base material was wet by the solder and can be measured from the cross section of the solder connection.

3.4 Factors Affecting Solderability During Reflow Soldering Process The factors that affect the solderability of a given substrate are:

- Land surface finish
- Component lead composition/finish
- Reflow profile
- Solder paste

3.4.1 Land Surface Finish Type, quality and thickness of surface finish on the PCB can greatly affect solderability. Coating thickness and quality both have a large impact on how the solder paste wets the land. A thin coating could be entirely consumed during the reflow process, especially if the boards are reflowed twice. The intermetallics formed can passivate very easily, and result in poor solderability. The quality of the coating is another factor in determining

Table 3-1 Factors of Wetting and Their Effects

Factor	Effect
Uneven heating	During the reflow portion of the profile, the liquid solder will flow towards the areas of higher temperature. These areas may not be in the area of the required fillet.
Incompatibility of solder and substrate	The incompatibility of materials, metallization, surface finish or composition may not allow the formation of intermetallics thus prohibiting wetting.
Oxide formation	Oxides may occur on any of the metal surfaces involved in the forming of the fillet, either prior to or during reflow, and will inhibit the wetting of the solder through the formation of intervening oxides.
Presence of foreign non-metallic materials	Substrate manufacture, surface finishes and material handling are sources of contamination. All types of contamination can reduce the strength of a connection or prevent wetting.
Presence of additional thermal mass	Portions of the board with a high thermal mass will heat less quickly than the rest of the board and may not reflow even though the rest of the board does. Thermal load in the oven due to fixtures used in assembly process or other boards can cause cool spots in an oven and prevent complete and consistent reflow.
Surface or area of preferential metallization.	Lead finish, board finish and surface exposure will influence solder flow. Solder will wet to those surfaces which were cleaned by the flux, but difficult to clean surfaces, due to location or material, may be left unsoldered.

free of unwanted organic materials and be a uniform thickness.

3.4.1.1 Hot Air Solder Leveling (HASL) Hot Air Solder Leveling is the most common board finish. In general, it provides a good surface for the solder paste to wet the land. In addition, it retains its solderability well. However, problematic thickness control which leads to a domed upper surface and lack of flatness can cause coplanarity, component skew, stencil smear and machine vision recognition issues.

3.4.1.2 Plating/Immersion Coating Electroplating, electroless plating, and immersion coatings are all alternative methods for depositing a metallic finish on a PCB. Noble metals such as Pd or Au are often used, especially on Ni surfaces. Gold and silver coatings that are too thin can cause dewetting and may be entirely consumed during long and multiple reflow exposures. The intermetallics formed can passivate easily, and will result in poor solderability.

3.4.1.3 Organic Solderability Preservatives (OSP) These protect the copper land surface with organic complexing agents such as benzamidazole or benzotriazole. OSPs provide a more level surface for soldering. However, they suffer both with un-assembled printed board shelf life and ease of solderability when compared to HASL when it comes to solderability because the protective monomolecular layer of organic molecules is so thin, it may not be robust enough. In some cases, it is easily removed by friction experienced during handling of the board. Multiple thermal excursions during storage or assembly can also degrade the coating, which may affect solderability. It is a characteristic of connections made over OSP coatings that wetting occurs only where the solder paste was placed. If the solder paste does not cover the entire land, it may not wet to the edge of the land.

3.4.2 Component Lead Composition/Finish Solderability of component leads are affected by the following factors:

- Base metal
- Coating composition
- Coating technique

3.4.2.1 Base Metal The base metal of the lead may consist of one or the following metals/alloys, each of which exhibits different wetting characteristics:

- Copper
- Copper alloys
- Alloy 42 (41-42.5%Ni, Balance Iron)
- Kovar® (29% Ni, 17% Cobalt, 53% Iron, 1% others)

3.4.2.2 Coating Composition Most component leads are coated with easily solderable metals to improve solderability. Sn and Sn-Pb coatings are commonly used. However, if additional requirements such as low contact resistance are required, coatings of Pt, Pd or Au may be applied.

3.4.2.2.1 Sn-Pb Coated Leads Sn-Pb coatings can be applied by electrodeposition or immersion. Sometimes an intermediate layer of Ni is applied between the copper substrate and the Sn-Pb coating to minimize formation of brittle Cu-Sn intermetallics on the lead.

3.4.2.2.2 Au Coated Leads While using Au plated leads, the cleanliness of the underlying material is very important, because the coating is generally very thin. Thus, it dissolves rapidly in the molten solder because of the high solubility of Au in Sn. If the underlying substrate is dirty or oxidized, it will dewet after the dissolution of the Au top layer into the molten solder. Finally, if all the Au is not dissolved, a layer of Au-Sn intermetallic can make the interface weak.



Au coatings are applied as thin as possible for a number of reasons:

- Cost
- Au forms an intermetallic with Sn that is very brittle
- By limiting the amount of Au available, this embrittlement can be minimized. It has been shown that more than 3% Au in the solder connection leads to unacceptable embrittlement of the connection. Also, dull-looking connections are often observed because of the Au-Sn intermetallic.

Thin Au coatings are generally very porous, and components that are stored for a long period of time can exhibit oxidation of the substrate material. This degrades the solderability of the leads.

3.4.2.2.3 Pd or Pt Plated Leads Pd or Pt leads may require a higher peak temperature and/or longer time above liquidus than normal Sn-Pb coated boards in order for the Pd to completely dissolve and expose the solderable Ni underneath. The finished connection also has a noticeable transition from the solder to the lead. Although the solder may show a higher contact angle on Ni than on Cu, the angle is acceptable as long as there is good wetting to the heel of the lead. Wetting forces on Ni are lower than on Cu so the force criteria used for copper substrates in the wetting balance solderability test should not be applied to Ni.

3.4.2.3 Lead Coating Processes Common component lead coating processes include the following:

- **Electroplating** This provides perfectly flat lead surfaces but it usually contains organic contaminants from the plating bath. Such organic contaminants can cause solderability problems.
- **Electroplating and Fusing** This process yields a surface that is as uniform as a plating surface and lesser organic contaminants.
- **Hot Dipping** Hot dipping process provides a nice coating of Sn or Sn-Pb but the coating thickness uniformity cannot be controlled.

3.4.3 Reflow The method of reflowing the solder connection greatly influences wetting, as discussed in the following:

- **Inert or Reducing Atmosphere** An inert or reducing atmosphere provides improved solderability by preventing or slowing atmospheric oxidation of the lead finishes and solder alloy.
- **Peak Temperature** The higher the peak temperature, the more the solder paste wets the land and wicks up to the lead, provided that the paste vehicle system remains active and fluid.
- **Profile Length** A longer time above liquidus normally results in better wetting as long as the paste flux is not

consumed during the preheat and soak processes. The preheat ramp rate and/or soak time of the profile affects the total amount of time the flux has to act on the substrate, lead and solder powder. If this time is too short, the flux does not have enough time to clean the surfaces to be soldered. However, if the time is too long, the flux may be used up before it has time to remove all of the oxidation. In addition, an extensive time above liquidus can lead to excessive intermetallic compound growth.

3.4.4 Solder Paste The composition of the solder paste has a large impact on wetting. Selection needs to consider flux type, metal alloy type, and the size of the solder powder.

3.4.4.1 Flux J-STD-004 is the standard used to classify fluxes. The activity of the flux used in the solder paste determines how well the paste will solder.

The flux used in the solder paste needs to be compatible with the alloys being used in the board finish, lead metalization, and solder alloy. For example:

- Metals such as Cu, Au, Ag, Pd, Sn and Sn-Pb can be soldered using most available flux types.
- Cu alloys, Kovar, stainless steel and Zn are normally soldered with an inorganic flux.
- Aluminum alloys require a very specialized flux. These fluxes contain inorganic salts, such as chlorides and fluorides of zinc, tin, potassium and ammonium.

3.4.4.2 Solder Alloy The selection of a solder alloy to be used in solder paste is based on the substrate materials, final solder connection properties and operational temperature of the finished assembly. Eutectic alloys Sn63Pb37 and Sn62Pb36Ag2 are the most commonly used solder alloys. They have the following useful properties:

- Good wetting due to the affinity between tin and many other metals.
- The solder alloy itself has no brittle intermetallic compounds.
- Melting temperature of the eutectic alloy is below the temperature that would damage components present in common assemblies, yet above the service temperature of the completed assembly.

The composition of the solder alloy will also affect solderability. It has been shown that varying the composition of a Pb-Sn solder alloy affects the area of spread when applied to a clean copper surface.

Figure 3-2 shows that the addition of Sn to Pb (up to a certain composition) decreases the surface tension between the solder alloy and substrate material.

3.4.4.3 Powder Particle Size Smaller diameter solder powder means larger surface area that is available for wetting.

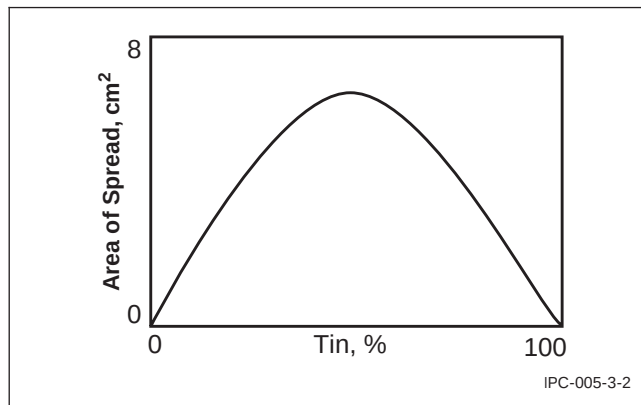


Figure 3-2 Effect of Alloy Composition on Area of Spread

the flux. This can result in reduced wetting if the amount of flux is insufficient to completely remove all of the oxidation from the solder powder.

3.4.5 Summary Wetting of a solder paste is dependent on the following factors: board surface finish, component metallization, reflow profile, solder alloy and flux.

3.5 Solderability Testing The purpose of solderability testing as it applies to solder paste involves analyzing the wetting ability of the paste. There are other factors that affect solderability such as the metal substrates, component leads and terminations. To evaluate these materials the user is referred to J-STD-002 and J-STD-003.

3.5.1 Solder Paste Wetting Tests The wetting ability of solder paste is determined using IPC-TM-650 Method 2.4.45 and the evaluation criteria as given in J-STD-005. This test evaluates the effective wetting of the solder paste on a solderable surface.

3.5.2 Solderability Test Documents The measurement techniques and systems that can be used for solderability evaluations are listed in J-STD-005, J-STD-002, and J-STD-003. Table 3-2 provides a listing of commonly used solderability test methods.

3.5.2.1 Special Solderability Test Methods The following are several other solderability test methods that users may find of interest:

- **Sequential Electrochemical Reduction Analysis (SERA)** This is a chronopotentiometric method that involves the reduction of surface oxides in sequence according to their electromotive reduction potentials. This method can determine the type of oxide on the surface and its thickness. While this is yet to be recognized in the industry as a standard solderability test tool it has shown to be of value in some instances.
- **Ceramic Plate Test** (A modification of IPC test method TM 2.4.43) The ceramic plate test is another test that can be used to evaluate the wetting of a solder paste. This test

Table 3-2 Common Solderability Test Methods

Name of the Test	Application	References	Comments
Edge Dip Test	PCB, Lead	J-STD-003 MIL-STD-203 MIL-STD-883 IPC-S-803 IEC-68-2-20	Visual Rating; most common in the industry; least expensive method.
Wetting Balance	Lead	J-STD-003 MIL-STD-883 IEC-68-2-20	Quantitative and graphs used, expensive.
Globule Test	Lead	J-STD-003 IEC-68-2-20	Numerical rating for flux, solder, etc.
Rotary Dip	PCB	J-STD-003	Visual Rating
Solder Float	PCB	J-STD-003	Visual Rating
Wave Solder	PCB	J-STD-003	Visual Rating
Spread Test	Solder Paste	J-STD-005	Visual and quantitative test

involves printing a brick of solder paste onto a non-wettable surface, such as a ceramic plate. Then a component with leads of known-good solderability, e.g., SOIC or QFP, is placed on the solder brick and reflowed. The wetting of the solder paste onto the component leads is then evaluated visually for evidence of de-wetting or non-wetting after reflow. This test should be performed with ramp and dwell temperatures and times that closely resemble the actual production process conditions. If there is evidence of de-wetting or non-wetting, this may indicate that there is a problem with either the solder paste or the processing conditions.

3.5.3 Solderability Test Method Selection This section lists some of the variables that should be considered when applying the tests listed in this guide. The results of each test are dependent on the interaction of these parameters. Controlling the following parameters is mandatory to produce reliable results:

- **Method** Acceptable test methods are listed in IPC-TM-650.
- **Equipment** Equipment to be used in testing is recommended in the applicable standards, other acceptable equipment may be acceptable in some instances. When using any equipment for evaluation purposes, it is recommended that the equipment is calibrated and a known or accepted standard is included in the evaluation. As with all testing, repeatability and reproducibility are to be considered prior to the acceptance of the data.
- **Material** This section may be considered the most critical area of an evaluation. Material interactions, preparations, storage, handling and reactivity may introduce uncontrolled variables into the evaluation. Specific issues are noted in the Environment section of this guide.

- **Manpower** Important consideration should be given to this area. The key to obtain accurate evaluation data is to understand how the following issues may affect an evaluation. Training, information, communication, cooperation and motivation can be sources of variation. Everyone involved with evaluations needs to address and understand these issues prior to the evaluation.
- **Environment** As mentioned previously the environment may contribute to the variability of results in an evaluation. Most methods will specify these conditions. When the conditions are not specified, recording them for the evaluation is suggested. These include temperature, humidity, atmosphere and sources of contamination, each of which may greatly affect chemical, mechanical and electrical testing.

4 PRINTING SOLDER PASTE

Printing is probably the most complex aspect of solder paste performance. The intention of this section of the handbook is to provide an understanding of the primary characteristics controlling solder paste deposition.

The printing process is governed by two solder paste parameters:

- Rheology
- Characteristics of the solvent system

The first is usually the most critical factor, and even today, little headway has been made in correlating the rheological properties of solder paste (which exhibits a combination of pseudoplastic, thixotropic and viscoelastic characteristics) to printing. The paste thixotropy is the most troublesome aspect, as the relaxation and retardation of the paste breakdown and build-up in viscosity are frequently on a similar timescale to the print cycle.

Characteristics of the solvent system address both loss of solvent to the atmosphere (volatility), and absorption of moisture by the solder paste. This absorption is, of course, most critical to the performance of water-washable pastes, although even no-clean pastes can exhibit concretion (hardening) effects in high-humidity conditions. Over the last five years, “enclosed print-head” printing innovations by some screen printer manufacturers have eliminated much of the variability associated with solvent loss and absorption.

The size of the solder powder also plays a role in finer pitch printing, since particles close in size to the aperture width either may or may not pass through, leading to increased variability.

4.1 Printing Needs The primary performance needs for a printing process are:

- A range of print speeds
- Capable of both fine and coarse pitch simultaneously
- Invariant with time

This last aspect is crucial for preventing the need for time-consuming, wasteful and possibly stencil-damaging paste clean-up and replenishment. The time-insensitivity has several aspects:

- **Open Time** Ideally, the print volume of even the smallest deposits should not vary with time, even after lengthy (30 minutes or more) pauses in the printing process. This aspect of solder paste printing is typically called “open time,” “print after pause” or “abandon time.”
- **Slump** The stencil may need wiping if the paste begins to drop to a low viscosity and begins to bleed onto the underside of the stencil. The need for wiping every few print cycles leads to variations in the print volume.
- **Stencil-Life** How long paste can be left on a stencil or screen is primarily a function of the solvent trends.

4.2 Printing Variables The solder paste manufacturer should provide recommended print parameters for benchmarking their materials. These may include:

- Recommended printer setup (squeegee angle, squeegee pressure, etc.)
- A range of print speeds
- Various lengths of abandon time
- Stencil design including aperture size, aperture shape, stencil thickness, etc.
- Squeegee type
- Underside stencil wipe frequency
- Humidity and temperature ranges

4.3 Primary Control Variables These are essentially the same as those for paste tack (see subsequent Section 5) - the ‘ability of solder paste to retain components’ (ASPaRC). During printing “raw” solder paste is exposed to the atmosphere. The major difference is the variation in paste rheology due to the material either rolling across the stencil or screen during the print cycle, or sitting motionless.

4.4 Printing This section describes the printability of a solder paste material using parameters recommended from the paste vendors. Room conditions should be within the range specified by the paste manufacturer. Minor parameters changes may be required for optimum printing.

4.4.1 Apparatus

- A solder paste printer
- A stencil, usually made of stainless steel, 0.15 mm [0.0059 in] thick, containing 0.4 mm [0.0157 in], 0.5 mm [0.0197 in] and 0.65 mm [0.0256 in] pitch QFP patterns (stencil to be designed and aperture dimensions defined)
- Flat panel substrate and/or matching boards (Note: For end users, the actual stencil and matching boards for production may be used, if desired.)

4.4.2 Procedures

- a. Record the room conditions (temperature and humidity) at the beginning of the test and at each interval a print test is initiated to define the print environment conditions. Ideally the room is temperature and humidity controlled to about $25^{\circ}\text{C} \pm 2^{\circ}\text{C}$ [$77.0^{\circ}\text{F} \pm 3.6^{\circ}\text{F}$] and $50\% \text{ RH} \pm 10\%$ or within the range specified by the paste manufacturer or agreed upon between two parties. Exercise care to ensure that the paste is not positioned directly in the draft of any room or cabinet environmental control equipment.
- b. Before testing, stabilize the solder paste to room temperature by either placing the sample in a constant temperature water bath or by leaving the sample overnight at room temperature. Stir the paste by hand for 30 seconds (about 30 turns) to obtain a uniform consistency. Record the temperature of the paste.
- c. Set the print parameters of the printer as recommended by the solder paste vendor.
- d. Transfer an appropriate amount of the material to be tested onto the stencil in front of the squeegee in the direction it prints. The amount should be adjusted to form approximately a 1-2 cm wide roll when printing is initiated. Record the paste temperature and room conditions (temperature and humidity).
- e. Print continuously (on flat panel substrates), adjusting the parameters as needed. Wipe (cleaning the underside of the stencil) if necessary until the optimum printing performance is obtained.
- f. When the print performance is at optimum level, replenish the solder paste to form an approximately a 1-2 cm wide roll. Thereafter, do not add more paste if performing the first part of step g (intervals printing). For continuous printing, add paste as required.
- g. With these optimum print parameters, print 10 prints initially and then at 2 and 4 hours later (leaving paste on the stencil exposed to ambient conditions) after standing at the ambient temperature and humidity (other time intervals may be printed if desired). Record the temperature of the paste, the temperature and humidity in the printer chamber. This practice will enable one to determine the sensitivity of the paste to environmental conditions, the stencil-life and the paste's "Response to Printing Pause," at these conditions.
- h. A similar observation can also be obtained from continuous printing. For the best Response-to-Printing-Pause characteristic, the print should be idle for about 60 minutes. The first few prints after idle time indicate the Response-to-Printing-Pause characteristics of the paste.

4.4.3 Evaluation

- a. While printing, carefully examine the rolling of the paste as it moves across the stencil. Generally, a good printing paste rolls as the squeegee is shearing it across the stencil.
- b. At the end of the print cycle, observe the release of the paste from the squeegee blade as it lifts up. Most of the paste should stay on the stencil when the squeegee lifts up ready for the next cycle to print. If the squeegee lift is small, a curtain of paste hanging at the end of the print cycle is acceptable.
- c. Periodically after a few cycles and a few hours, observe the stencil apertures. There should be no clogging with paste, as evidenced by blinding of the apertures, and incomplete to no transfer of the paste onto the substrate.
- d. All prints should be examined a few minutes after printing. Selective prints should be examined after 20 minutes standing at room conditions and there should not be much deviation from the first examination. The following print defects are to be examined for each print in each of the 16, 20 and 25 mil pitch QFP patterns: bridging, slumping, incomplete print, light prints, missing prints, wedge-shaped prints, print tailing, particles around prints and frequency of wipes.
- e. Select a few sites and measure the height of the printed fillet. The paste height should be within 20% (or other set percent) of the stencil thickness or within the acceptable ranges.
- f. If an automated solder paste inspection instrument is available, the pass/fail criteria should be set to 70 - 80% for passing.
- g. After each print interval, the first few prints indicate the Response to Printing Pause characteristic of the paste. A good Response to Printing Pause solder paste material gives a full print with good definition immediately after idle time.
- h. The length of time solder paste can be continuously printed in one shift with acceptable results, indicates the stencil-life of the paste.
- i. Periodically, observe the paste on the stencil after extended exposure to the environment. There should be no drying or wetting of the paste due to humidity and/or temperature.
- j. Record type of printer used (make and model), stencil (chem-etched, laser cut, etc.), and print parameters.

4.5 Solder Paste Print Quality Control Variables

4.5.1 PCB Variables

- **Board Warpage and Planarity** May impact stencil/board gasketing leading to inconsistent paste volume transfer and solder paste bleed-out under stencil.

- **Solder Mask Height** May impact stencil/board gasketing and solder paste volume transfer.
- **Tooling Holes** Impact board and stencil alignment.
- **Plugged Vias** Impact gasketing by raising stencil.
- **Surface Finish** HASL finish can affect gasketing of apertures and tenting (of the stencil) near large plated areas due to excessive domed surface of the coating. Poor flatness can also throw off vision alignment systems due to poor reflective characteristics.

4.5.2 Solder Paste Variables

- **Powder Size and Distribution** Excessive fines may increase viscosity resulting in poor aperture fill and release and overall poor print quality. Large particles may clog fine pitch apertures.
- **Paste Tackiness** Excessive paste tack may lead to squeegee blade hang-up and aperture clogging. Insufficient tack may result in placement defects.
- **Paste Stencil Life** Short stencil life requires printer parameter adjustments to compensate for paste variations and ultimately result in paste dry out or shear thinning.
- **Paste Rheology** Effects paste roll, aperture fill and release. Fine pitch printing requires shear sensitive material.

4.5.3 Stencil Variables

- **Aperture Formation Method** Whether chemically etched, laser cut, or electroformed, impacts paste release quality and deposition volume consistency.
- **Stencil Thickness** Impacts paste release and deposition height and volume. May lead to bridging or insufficient solder paste.
- **Stretch During Stencil Assembly** Impacts paste deposition accuracy.
- **Trapezoidal Shape and Aperture Wall Smoothness** Impacts paste release, deposition quality, bridging, and insufficient solder paste.
- **Stencil Material** Several options are available for stencil manufacture. Stainless steel, nickel, brass and Kapton all have unique characteristics that can enhance the print process.

4.5.4 Screen Printer Variables

- **Squeegee Type** Metal vs. Poly may affect paste volume. Poly blades can scoop paste resulting in decreased volume.
- **Squeegee Speed** May impact paste shear, paste roll characteristics, aperture fill and overall print deposition quality.
- **Squeegee Pressure** May affect gasketing, print deposition quantity, blade wear, and blade angle.
- **Squeegee Angle** Impacts paste roll characteristics and aperture fill quality.

- **Underside Wipe Frequency** Affects on aperture clogging, print quality, bleed-out, bridging, and solder balling will vary, depending on whether the wiping is done dry, wet or with vacuum.
- **PCB Release Speed and Distance** May impact aperture release efficiency, deposition quality and morphology, and clogging.

4.5.5 Environmental and Operator Variables

- **Temperature** High temp leads to paste slump. Low temp may cause overall poor printability.
- **Humidity** High leads to moisture pick-up, paste shear, paste slump. Low leads to paste dry out and poor printability.
- **Paste Handling** Temperature of paste at time of application may impact roll quality, fill, and release. Amount of pre-mixing before application can impact paste viscosity and printability.

5 ABILITY OF SOLDER PASTE TO RETAIN COMPONENTS (TACK)

The word “tack” has become synonymous with how well solder paste can hold a component in position during all operations prior to the formation of the reflowed connection. However, the variable commonly referred to as “tack” (the peak tack force established by use of IPC-TM-650, Method 2.4.44) has increasingly been seen as a poor indicator of a factor that may be referred to simply as the ‘ability of solder paste to retain components’ (ASPaRC). It is important to differentiate between these factors.

5.1 Background The IPC-TM-650, Method 2.4.44 “tack test” was developed at the end of the 1980s, at a time when component placement was a comparatively slow process. The primary reason that a solder paste deposit could not hold a termination in place was the rapid upward movement of the placement head. The test method chosen was therefore one that gives as a measure of tack, a peak tension force, as the result of a rate-controlled extension.

5.2 Tack Test Shortcomings The current tack test makes several assumptions, the most important of these being:

- The peak extensional force during probe removal is a valid indication of ASPaRC in an SMT production process (see Figure 5-1).
- The test uses a 0.25 mm [0.0098 in] thick deposit, which is unrealistic in today’s manufacturing environment.
- The test uses a 300-gram insertion force, which is unrealistically high.
- The test is extremely slow, favoring viscous dissipation of the applied probe-force, rather than the elastic “bounce” response sometimes seen during ultrasonic placement.

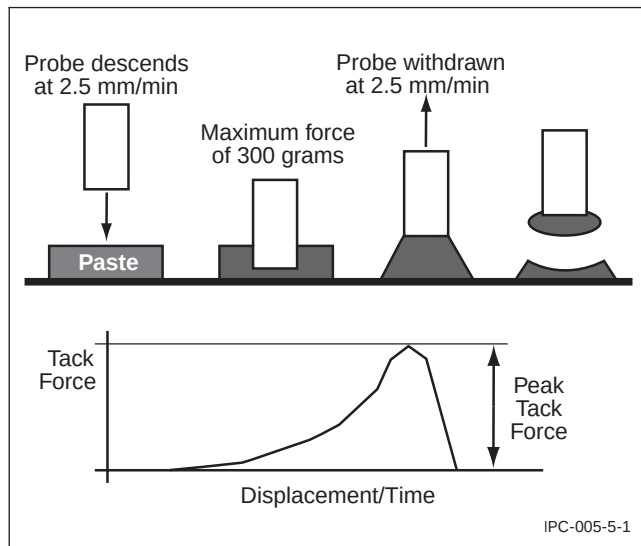


Figure 5-1 The Extensional Nature of "Tack"

- The "tack life" data can be reported in three ways, which eliminates the ability to compare data from different manufacturers.

5.3 Tack Life Although ASPaRC is used as a general term, it is probably best to use the name "tack life" to describe the length of time after printing, during which a paste is able to retain the placed parts when subjected to normal operational procedures. This may include high-speed pick-and-place equipment ("chip-shooters"), the manual handling and population of a board, and/or the movement of boards on conveyors or in board-stackers. Changes in solder paste rheology are almost always deleterious to the performance of the paste. The total useful working-life of a paste can be seen to be a function of four basic "life" parameters that we will call A, B, C and D; see Figure 5-2 and Table 5-1. This means that if a paste has been stored incorrectly, or has spent many hours exposed to adverse conditions on a stencil, then there will be a resultant shortening of the tack life of the paste.

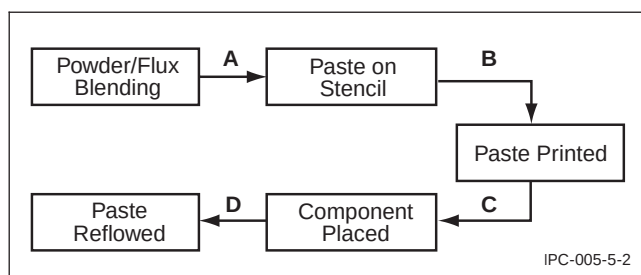


Figure 5-2 The Interaction of Various Factors Affecting Solder Paste 'Working Life'

"Storage" (A) and "Time on Stencil" (B) are discussed in other sections of this document. "Open Tack" (C) and "Retention Time" (D) however, are germane to this section, and can be pooled together under the general term "tack life." Therefore, there are two kinds of tack life:

Table 5-1 Main Control Variables Affecting Solder Paste Working Life

	Parameter	Control Variables
A	Storage	Time, temperature, amount of stirring, packaging
B	Time on Stencil	Time, temperature, humidity, gas velocity over paste, print speed, prints per hour
C	Open Tack	Time, temperature, humidity, gas velocity over paste, deposit thickness
D	Retention Time	Time, temperature, humidity, gas velocity over paste, deposit thickness, reflow preheat

- **Open Tack (C)** The length of time after printing on a circuit board, during which parts can still be placed in the solder paste deposits without either falling off, or causing an 'open connection' on subsequent reflow.
- **Retention-Life (D)** The length of time after placement during which a part remains in place prior to formation of the final reflowed connection.

D is usually greater than C: that is, most solder pastes retain the part, once placed, for a much longer period than the time over which they allow parts to be placed. The adhesion force of some pastes may even increase as the deposit dries around the leads. In addition, most operations have a longer time between printing and placing than between placing and reflow. Therefore, open tack is the more important factor.

5.4 Increased Tack Strategies Methods used to increase tack (as tested to IPC-TM-650, Method 2.4.44) may not necessarily give increases in ASPaRC due to the discrepancy between the two types of parameter.

5.5 Increased Tack Life Strategies Solder paste formulators can use a variety of means to give an increased solder paste life. The following lists potential drawbacks:

- **Change in Metal Loading** Reduction of the metal loading may give a small increase in the open-tack of the solder paste, but there may also be a tradeoff in slump.
- **Low Volatility Solvents** High boiling point (low vapor pressure) solvents may also be used as a means of improving the open-tack life. However, this can sometimes increase the amount of flux residue that may accumulate in the reflow oven as either solids (causing increasingly frequent maintenance) or liquids that may drip onto the finished assemblies. The reflow oven manufacturers have responded by devising a variety of different means of removing flux vapors from the oven.

5.6 Control Variables The initial ASPaRC is a function primarily of the solder paste, and most particularly, the flux formulation. However, several variables impact on the tack life (most particularly on the Open-Tack). The most important of these are: