IPC-HDBK-001F
Handbook and Guide to Supplement J-STD-001

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0.1 GENERAL

0.1.1 Scope This Handbook is a companion reference to the J-STD-001 *Requirements for Soldered Electrical and Electronic Assemblies* and is intended to provide supporting information.

Additional detailed information can be found in documents referenced within the Standard (and this Handbook). Users are encouraged to reference those documents to better understand the applicable subject areas.

Although this Handbook uses mandatory terminology (e.g., **shall**, must, etc.), nothing within this Handbook is considered mandatory unless this document is specified as a mandatory requirement in the contract documentation.

The intent of this Handbook is to capture “how and why” information and give more background for the specification limits and how they were derived. In addition, other supporting information is provided to give a broader understanding of the process considerations needed for the production of acceptable hardware. The target user of this Handbook is a process or manufacturing engineer.

0.1.2 Purpose The Handbook describes materials, methods, and verification criteria that, when applied as recommended or required, will produce quality soldered electrical and electronic assemblies. The intent of the Handbook is to explain the “how-to”, the “why”, and fundamentals for these processes, in addition to implementing control over processes rather than depending on end-item inspection to determine product quality.

The J-STD-001 and the IPC-HDBK-001 do not exclude any acceptable process used to make the electrical connections, as long as the methods used will produce completed solder joints conforming to the acceptability requirements of the Standard.

0.2 FORMAT (Using This Handbook)

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This Handbook provides guidance on the J-STD-001F requirements. The section and paragraph numbers in this Handbook refer and correspond to the section and paragraph numbers in J-STD-001F. However, the information provided in this Handbook is applicable to Users of any previous version of J-STD-001.

The text of J-STD-001F no longer includes a space shuttle symbol or any other visual cue where the requirements are different in J-STD-001FS *Space Applications Electronic Hardware Addendum to IPC J-STD-001F Requirements for Soldered Electrical and Electronic Assemblies.* It has also been removed from the text of this Handbook. Although this document will not provide discussion on each of the differences between J-STD-001F and J-STD-001FS, it may provide information on certain topics addressed in J-STD-001FS, i.e., lead-free mitigation, that may need to be considered in a general soldering process. This information will be included in the applicable section of this Handbook and not highlighted in any manner.

A cross reference listing, provided as Appendix C to this Handbook, will assist Users with identifying related paragraphs in previous revisions of J-STD-001. This cross reference listing includes identification of the associated Space Applications Electronic Hardware Addendum paragraphs for revisions E (ES) and D (DS).

Information concerning the appendices in J-STD-001 is either addressed in the body of this Handbook or covered more thoroughly in another document. An appendices guide is included at the end of Section 13 that links the topics discussed in the appendices of J-STD-001 to the appropriate supplemental information.

Where used verbatim, text that is directly quoted from a standard is italicized. In this Handbook, the word “Standard” refers specifically to J-STD-001 Revision F.

Note: References in the text of this Handbook (not text quoted from a Standard) refer only to sections, tables, and Figures in this Handbook and will be followed by “of the Standard” unless otherwise noted (see Example 1). If the reference is to a Section, Table, or Figure, a designator of the revision being referenced will follow it (see Example 2).

Example 1: For more information on lead trimming, see 5.2.0.5.
Example 2: For more information on surface mount components, see Table 7-2 of the Standard.

Endnotes are included in some sections to acknowledge references included in that section. Acronyms are used throughout this Handbook and are defined in an Acronym Index at the end of this Handbook.

All following Clause numbers align to the Clause numbers in the published J-STD-001F.

Clause numbers preceded by * are additional content for this Handbook. There is no related Clause in the Standard.

1.1 SCOPE

This Standard prescribes practices and requirements for the manufacture of soldered electrical and electronic assemblies. Historically, electronic assembly (soldering) standards contained a more comprehensive tutorial addressing principles and techniques. This Standard does not provide comprehensive tutorials on principals and techniques, but may direct the reader to other documents that may. For a more complete understanding of the J-STD-001F recommendations and requirements, the Standard suggests using this document and the IPC-A-610, Acceptability of Electronic Assemblies.

As stated in 1.13.2 of the Standard, it is an industry consensus document, meaning that additions, deletions and modifications to the Standard are made and agreed upon via consensus vote by the Standard Development Committee responsible for that document. The Standard Development Committee is made up of User and Manufacturer representatives from across the industry. IPC provides a Staff Liaison.

The Standard content is dependent upon industry submissions of requests for change. At the back of each Standard there is a Standard Improvement Form and instruction on how to submit the form. Whenever possible these criteria should be submitted to the IPC Technical Committee/Standards Development Committee to be considered for inclusion in upcoming revisions of this standard.
As materials, products and processes evolve in our industry, it is expected that there will be submissions requesting improvements or addition of new criteria related to new technologies and/or component configurations and possible changes to material requirements as chemistries evolve. All submissions should be accompanied by supporting data. Submissions are reviewed, discussed, evaluated and dispositioned via consensus vote at Standard Development Committee meetings, which anyone can attend. (Contact IPC for more information on Standards development Committees)

1.2 Purpose This Standard describes materials, methods and acceptance criteria for producing soldered electrical and electronic assemblies. The intent of this document is to rely on process control methodology to ensure consistent quality levels during the manufacture of products. It is not the intent of this Standard to exclude any procedure for component placement or for applying flux and solder used to make the electrical connection.
As described in 1.1 of this Handbook, there is a process in place for submitting requests for changes to the Standard.

1.3 Classification The User (the individual, organization, company, or agency responsible for the procurement of electrical/electronic hardware, having the authority to define the class of equipment and any variation or restrictions to the requirements of this Standard).

It is important to understand that decision about the Class of acceptance criteria is not related to any specific product or product category. The decisions need to be based on criticality of need (continued operation) and the operating environment. The User is responsible for defining the product class.

Class 1 General Electronic Products: Includes products suitable for applications where the major requirement is function of the completed assembly.

Class 2 Dedicated Service Electronic Products: Includes products where continued performance and extended life is required, and for which uninterrupted service is desired but not critical. Typically the end-use environment would not cause failures.

Class 3 High Performance Electronic Products: Includes products where continued high performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support or other critical systems.

1.4 Measurement Units and Applications

Table 1-1 in this handbook is a list of common Metric (SI) prefixes. Engineering drawings or other process documents may not provide measurements in SI units. For those instances where dimensions, temperatures, or other process parameters are provided in English units, conversion formulae are provided in Table 1-2 in this handbook. Non-critical features should be rounded to the first decimal place using standard rounding techniques (use the hundredths value: zero to four rounds down, five to nine rounds up). Critical features should be converted to the appropriate accuracy as required by engineering documentation.

Table 1-1 Metric Prefixes

Prefix	**Symbol**	**Meaning (multiply by)**	
atto-	a	0.000,000,000,000,000,001	10^{-18}
femto-	f	0.000,000,000,000,001	10^{-15}
pico-	p	0.000,000,000,001	10^{-12}
nano-	n	0.000,000,001	10^{-9}
micro-	µ	0.000,001	10^{-6}
milli-	m	0.001	10^{-3}
centi-	c	0.01	10^{-2}
deci-	d	0.1	10^{-1}
deka-	D	10	10
hecto-	H	100	10^{2}
kilo-	K	1,000	10^{3}
mega-	M	1,000,000	10^{6}
giga-	G	1,000,000,000	10^{9}
tera-	T	1,000,000,000,000	10^{12}
peta-	P	1,000,000,000,000,000	10^{15}
exa-	E	1,000,000,000,000,000,000	10^{18}

Table 1-2 Conversion Formulae

Units to be converted	**Formula**
degrees Fahrenheit (F) to degrees centigrade (C)	(F-32)/1.8 = C
inch (in) to centimeter (cm)	2.54 x in = cm
inch (in) to millimeter (mm)	25.4 x in = mm
mil to microinch (µin)	1 mil = 1000 µin
mil (.001″) to micrometer (micron) (µm)	25.4 x mils = µm
square inch (in^2) to square centimeter (cm^2)	6.452 x in^2 = cm^2
ounce (oz) to gram (g)	28.35 x oz = g
pound (lb) to kilogram (kg)	0.4536 x lb = kg
fluid ounce (fl oz) to milliliter (ml)	29.573 x fl oz = ml
foot candles (fc) to lumens per square meter (lm/m^2)	10.76 x fc = lm/m^2

1.4.1 Verification of Dimensions The dimensions provided in the Standard are targets for a Manufacturer to use in establishing a process control system. It is not the intent of the Standard to require actual measurements for determining compliance to each of the various part mounting, solder fillet dimensions, or other requirements listed. They are provided as reference measurements to be used by the Manufacturer
Manufacturer for reference purposes (to disposition borderline conditions), or in order to resolve internal process problems.

The Manufacturer should evaluate assemblies that are not clearly rejectable, using 1.4.1 for guidance. Reworking a product simply because it does not exhibit the preferred conditions described in the Standard will not necessarily result in a more reliable product and may actually induce premature failure. Excessive or unnecessary rework can damage parts, the printed wiring substrate, or internal connections of PTHs and vias, not to mention the impact on schedules and profitability.

Because of this, the recommended practice is: If the inspector feels the need to evaluate the suspected anomaly from several angles for more than a few seconds, or increase magnification above that listed in the standard, the suspected anomaly should be accepted. If a condition is not clearly rejectable, it should be accepted. After a defect has been identified, magnification may be increased to determine its features.

1.5 Definition of Requirements The user needs to be aware that some of the content within the Standard are recommendations only, and are typically based on industry best practice. This content will contain wording other than "**Shall**" or "**Shall Not**". When there is a statement that uses "Should" for example, that is a recommendation and not a requirement.

The Figures and Tables in the Standard are used to clarify the written requirements. Where the text refers to a table with data the table is providing the requirements, e.g., SMT tables.

It is critical to remember that text always takes precedence over Figures. Some Figures may show conditions that are not referenced in the text or table. Those Figures are not intended to be used for the acceptance or rejection of the product.
The Standard contains requirements for three classes of requirements, as identified in 1.3. for this reason, each requirement has beside it a designation of which informs the user of what the disposition should be for each specific class of product, (1, 2, and 3). The requirements can be different for each product class. The user first must know what product class their product is being built and accepted to. When they read a requirement in the standard, the user should only be looking at the designation for their applicable product class, and ignoring the rest.

As an Example: Let's assume your product is Class 2 and we are looking at the requirement in 3.8.2.

3.8.2 Coating Meniscus *Component coating meniscus **shall not [N1D2D3]** be trimmed.*
The "**shall**" means there is a requirement. Then look for the Class 2 requirement, next to it, in the brackets.
For each product class there is a letter followed by the class number.
*"N" means there is No **requirement** established for that Class*
"A" means the condition is Acceptable for the class
"P" means the condition is a Process Indicator for that class, which means it is acceptable but should be monitored to see if the process can be improved to produce a better result, closer to a target condition.
A "D" in front of the product Class number means that the condition is a defect for that product class.

The 3.8.2 requirement states that the component meniscus that can extend from the body of a component, down the lead, **shall not** be trimmed. The designator inside the bracket for Class 2 is "D" (D2). That means that for Class 2 it is a defect. Classes 1 and 3 have their own designators, which may or may not be the same. In this case, Class 3 is also a defect if the meniscus is trimmed. If the meniscus is trimmed on Class 1 product, the designator inside the brackets is "N", which means there is no criteria established, so there is no criteria to reject the condition, and it would be acceptable unless separate criteria was established by the manufacturer or their user.

1.5.1 Hardware Defects and Process Indicators Hardware defects and process indicators are identified throughout J-STD-001. This paragraph defines both "Defect" and "Process Indicator" The main difference is that defects must be documented and dispositioned. Process indicators are NOT defects but typically are an indication that something in your process has shifted. Process indicators should be monitored.

1.5.2 Material and Process Nonconformance This paragraph in the J-STD-001 is intended to ensure that products manufactured with nonconforming materials (i.e. solder, flux) or processes such as soldering temperatures or solder contamination levels outside of the specification limits, would be considered defective. If these nonconforming conditions are present, the product must be identified and evaluated to determine if it is useable. As an example, section 3.3 states that type H or M fluxes **shall not** be used for tinning of stranded wires, for all three product classes. If it is determined after the product has been built that either one of these fluxes was used to tin stranded wire, it would be a material nonconformance, as well as a violation of section 3.3. Tests that simulate the product life expectancy and environments should be performed so that the resulting data may be used to support the disposition. This is particularly important to support a use-as-is disposition.

1.6 General Requirements This section discusses use of the Standard and establishment of product classes. It also provides a list of design and fabrication specifications that these requirements are meant to align with or support.
When a Contract invokes this standard on a product, any product feature not addressed with requirements in this Standard should be identified by the manufacturer if not already identified by the user. Acceptability requirements for those features should be established, documented, and agreed upon.

1.7 Order of Precedence
The order of Precedence should look like this:

Contract
User approved assembly drawings and documentation
J-STD-001
Documents cited within the J-STD-001
Assembly drawings and documentation that are NOT User approved

1.7.1 Conflict The Order of Precedence (1.7) specifies only a portion of the order. Conflict adds the remaining information to complete the order of precedence. As noted above, the Order of Precedence should look like the following:

Contract
User approved assembly drawings and documentation
J-STD-001
Documents cited within the J-STD-001
Assembly drawings and documentation that are NOT User approved

1.7.2 Clause Reference When the document refers to a "Clause" it is referring to the beginning of a subject section..
1.7 is a Clause. Any other paragraphs that begin with 1.7 are subordinate clauses. 1.8 would be the next clause.

1.7.3 Appendices At the back of the Standard, there are three Appendices. This clause clarifies for the user of the Standard that the Appendices do not contain requirements unless the contract, assembly drawing(s), documentation or purchase order identifies them as being required.

1.8 Terms and Definitions Terms and Definitions used in the Standard, other than those found in 1.8.1 through 1.8.14, should align with IPC-T-50, Terms and Definitions. J-STD-001 and IPC-T-50 revision dates may not align, which could affect whether or not a new term is defined in the IPC-T-50.

1.8.1 Disposition is Defines how a defect should be treated once it has been identified as a defect. It lists four possible dispositions. The Standard does not limit the disposition to only those four examples provided.

1.8.3 Electrical Clearance This clause defines electrical clearance and gives examples of what non-common conductors might be. The Standard does not identify one specific distance as the minimum electrical clearance requirement that must be met.

1.8.4 High Voltage The definition does not specify what is considered "high voltage", but points out that it can be different based on design and application. It is important to note that an assembler or inspector typically has no way of knowing if high voltage processing and/or criteria need to be applied unless the drawing or documentation specifies it.

1.8.5 Manufacturer (Assembler) As seen in the Standard, "Manufacturer" could mean an individual, company, or organization, Ultimately the manufacturer could be any of these that are responsible for the assembly process and verification of compliance to the requirements of the Standard

1.8.6 Objective Evidence This definition is referring to data that supports the existence of or the verity (truth) about a procedure, process, material, inspection or test result. The data may have been obtained through observation, measurement, test or other means. There are several instances cited in the Standard where objective evidence would be required. Personnel proficiency, Solder, Flux application, Removal of component surface finishes, SMT Area array packages, Bottom termination components, Conformal coating materials, and statistical process control sections all have some reference or requirement referencing the need for objective evidence. Objective evidence is also mentioned in the Appendices at the end of the Standard.

1.8.7 Process Control Product quality is dependent on process control. The philosophy of process control is to establish and control each process involved in the manufacture of a product with an ultimate goal of achieving a 100% acceptable product yield. The process is monitored and adjustments are made to ensure that the process remains in control and that minimal defective products is produced. Process parameters and product output are monitored to provide feedback of performance and assist in identifying the necessary corrective action.

Manual / nonautomated processes inject variations, which are not as repeatable as an automated processes and therefore are much more difficult to control. Results of manual processes employing the same equipment, such as a soldering iron, with the same setting, soldering the exact same materials, may produce different results. Manual processes are operator dependent. Outfitting operators with the same tools to control a process may yield little, or no change. The way a tool is used is operator dependent. With a soldering iron, for example, how, where, and with how much pressure a soldering iron tip is placed on a connection to be soldered are all individual factors which contribute to the resulting solder connection. How fast an operator feeds the wire solder and the diameter of that solder are also factors, as is the application of external liquid flux. Outfitting an assembly area with the same soldering tool cannot remove the human factor and may or may not help to control the process and yield better process results. Additional hands-on training when tools are changed may help reduce variation in results.

Effective corrective action systems usually begin with documenting the discrepancy and identifying the discrepant hardware. The discrepancy is then evaluated against the process and end product requirements to determine if the product is useable, requires rework, or cannot be used. If the fault is attributable to the Manufacturer’s internal processes, corrective action to eliminate the cause is usually prescribed. Where faults are attributable to external causes, such as purchased parts or assemblies, the supplier is usually asked to provide root cause analysis and corrective action. All actions in the corrective action system should be recorded for reference. Trends and overall activity levels are typically monitored to allow management of the procurement and assembly processes.

Continuous improvement means constantly looking for ways to improve the yield of a process and reduce production costs and cycle time. There is a point where the cost of improving the process exceeds the benefits from the improvement. Care must be taken to recognize that gains may occur outside of the traditional manufacturing cost environment, such as product life, costs, and customer satisfaction.

Clause 12.3 provides in-depth details on applying process controls.

1.8.8 Proficiency The Standard requires proficiency for anyone performing tasks or verifications (inspections) of requirements in accordance with the Standard. Additional detail relating to Personnel proficiency is found in 1.10

1.8.9 Solder Destination Side When soldering a plated through-hole, the solder is applied on one side of the CCA and flows through the hole to form a solder fillet on the opposite side of the CCA. Which side of a CCA is the solder destination side depends on where the solder is applied. The side where the solder is applied is NOT the destination side. The side that the solder flows onto after it goes through the plated through hole IS the solder destination side.

1.8.10 Solder Source Side When soldering a plated through-hole the solder is applied on one side of the CCA and flows through the hole towards the opposite side of the CCA. Which side of a CCA is the solder source side depends on where the solder if applied. The side where the solder is applied IS the solder source side.

1.8.11 Supplier The supplier as stated in the Standard is the individual, organization or company that provides parts and or materials to the individual, organization or company that is manufacturing the product..

1.8.12 User The user is defined in the Standard as the individual, organization, company, contractually designated authority, or agency responsible for the procurement or design of electrical/electronic hardware, and having the authority to define the class of equipment and any variation or restrictions to the requirements of this standard (i.e., the originator/custodian of the contract detailing these requirements)..The User may also be the manufacturer.

1.8.13 Wire Overwrap An overwrap is wrapped around a terminal for more than 360 degrees and remains in contact with the terminal or post. This would not be a defective condition unless the maximum degree of wrap was designated.

1.8.14 Wire Overlap This definition is in reference to a wire overlapping itself when wrapped on a terminal. It is not in reference to wires that overlap each other in any other application, such as inside a heat shrinkable soldering device. An overlap occurs when a wire is wrapped around a terminal for more than 360 degrees, and at any point within the wrapped area the wire is not in contact with the post and crosses over itself. This would be a defective condition for two of the three product classes, unless specifically allowed via approved design or documentation.

1.9 Requirements Flowdown When a User requires that their product be manufactured to the requirements of this standard and specifies the product Class, they expect to receive exactly that. When the prime manufacturer outsources a portion of the manufacturing process, it is critical that those same requirements are placed upon the subcontractor and any of their subcontractors that are contracted to build or supply portions of the end item. This is a critical process control. Just as the compatibility between processes within a manufacturing facility can impact the product, any incompatible materials or processes used by a subcontractor can have the same result.

The intent of this paragraph is to ensure that when the requirements of the base document are invoked by contract that the prime contractor flows down the same obligations to all of their subcontractor and vendors. This clause does not include commercial off-the-shelf items unless they are required to meet the end item requirements.

The second paragraph deals with parts that are already defined by another specification or requirement that meets or exceeds the requirements of the base document.

The third paragraph is addresses items that are procured with the intent of attaching them to your assembly. An example would be procurement of a daughter board to be attached to a motherboard that was manufactured to requirements of this Standard. It is recommended that the procured daughter board also meet the same acceptability requirements. The only parts that must meet the requirements of the base document are the solder connections that attach the daughter board to the motherboard when invoked by contract.

1.10 Personnel Proficiency In 1995, IPC responded to member requests for a formal industry traceable training and certification program for electronic assembly acceptance. U.S. Department of Defense (DoD) cancelled their certification programs, which focused on relatively small users groups. Companies needed a course that would allow them to easily train many workers on the document's requirements. Rather than develop a course internally, companies requested that IPC development of the course. IPC worked with a consortium of experienced academia and training companies in the now defunct DoD programs to develop the first program. Credibility of the program was considered paramount and required industry involvement. A committee of industry (user) representatives directed and formally approved the technical content and another committee (also comprised of industry representatives) established administrative policies and procedures. The IPC training and certifications program is revision specific due to content changes as the base document is revised. The process for developing the training program remains the same. A committee of industry (user) representatives directs and formally approves the technical content.

A good training program reinforces both discrimination and workmanship skills—see it, hear it, read it, write it and apply it. These programs include a critical element not available from online, video or computer-based training—full interaction with a knowledgeable, credible instructor to immediately resolve comprehension issues. While no IPC document requires participation in an IPC Certification Training program to use the Standard, customers frequently require that vendors have completed a certification program to ensure their products have gone through rigorous quality control. Use of industry traceable training also greatly facilitates ISO certification, which has become important in international trading. Any training program that is based on the requirements of the Standard, but is created by a source other than the IPC Industry Committee, is considered a Qualification training program. Operators should be issued a qualification to the requirements, or an internal Company certification that qualifies them to the requirements of the standard. Operators completing those training programs may be qualified to the requirements, but are not Industry Certified to the Standard requirements. Only the industry created and approved IPC Training program can issue a true IPC Certification to the requirements of this Standard. The distinction between being qualified to the Standard and Certified to the Standard is critical to the integrity of the training program. We must distinguish between the two. To some customers this is an important distinction because of the credibility and high standards the industry approved IPC Training program is held to.

The impact of formal training like IPC Training and Certification Programs on the electronics manufacturing industry cannot be overestimated. Literally hundreds of thousands of people involved in the production of circuit boards and assemblies have benefited significantly from these programs. Major OEMs and EMS companies have become leaders in the program, with impressive results.

Electronics assembly has always involved a large component of manual work, such as hand soldering and rework and repair techniques. Even at present, much of an assembly's quality and reliability is dependent upon the ability and consistency of skilled operators.

1.11 Acceptance Requirements are adequately defined in the Standard.

1.12 General Assembly Requirements are adequately defined in the Standard.

1.13 Miscellaneous Requirements are adequately defined in the Standard.

1.13.1 Health and Safety Health and safety are paramount. Occupational Safety and Health Administration (OSHA) regulations and any other local or governmental regulations are put in place to ensure the health and safety of workers. Access to those regulations should be available to everyone. It is good practice to flow applicable cautions into company rules and regulations or even into the manufacturing documentation when it is related to a process that will be performed, or when there will be a known exposure. Think of personal safety first and always wear required personal protective equipment.

1.13.2 Procedures for Specialized Technologies Technologies improve and change on a regular basis. New technologies emerge as well. In order for the Standard to keep up with these technologies, IPC and the industry Standard committee must rely on Users, Suppliers, and Manufacturers to provide proposed criteria and supporting data to the IPC for consideration of addition to the Standard. There is a Standard Improvement Form at the back of the standard, which should be used for this purpose.

2 Applicable Documents This clause in the Standard provides a summary of documents that are referenced. These documents are constantly being revised, new documents developed, and others made obsolete.

The extent that referenced documents are requirements depends on the wording of the reference in the Standard.

Following is a listing of documents referenced in this Handbook that are in addition to those listed in the Standard.

2.1 EIA

GEIA-STD-0005-1	Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder
GEIA-STD-0005-2	Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems
GEIA-HB-0005-1	Program Management/Systems Engineering Guidelines for Managing the Transition to Lead-Free Electronics
GEIA-HB-0005-2	Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-free Solder and Finishes
GEIA-STD-0006	Requirements for Using Solder Dip to Replace the Finish on Electronic Piece Parts

2.2 IPC

IPC-TR-580	Cleaning and Cleanliness Test Program Phase 1 Test Results
IPC-TR-581	IPC Phase 3 Controlled Atmosphere Soldering Study
IPC-TR-582	Cleaning and Cleanliness Testing Program Test Results for: Phase 3 - Low Solids Fluxes and Pastes Processed in Ambient Air
IPC-TR-583	An In-Depth Look at Ionic Cleanliness Testing
IPC-TP-1043	IPC Cleaning and Cleanliness Test Program Phase 3 Water Soluble Fluxes Part 1: B-24 Interactions of Water Soluble Fluxes with Printed Wiring Board Substrates/ Metallizations (IPC TP-1043 and TP-1044 Replace TR-581)
IPC-TP-1044	IPC Cleaning and Cleanliness Test Program Phase 3 Water Soluble Fluxes Part 2: B-36 Comparison to Phase 1 Rosin Benchmark (IPC TP-1043 and TP-1044 Replace TR-581)
IPC-HDBK-830	Guidelines for Design, Selection and Application of Conformal Coatings
IPC-9292	Material and Process Characterization. Qualification Test Protocol for Assessing Electrochemical Performance

2.3 Electrostatic Discharge Association

ESD TR 20.20	ESD Handbook

2.4 ASTM

ASTM D3359	Standard Test Methods for Measuring Adhesion by Tape Test

3 MATERIAL, COMPONENTS, AND EQUIPMENT REQUIREMENTS

3.1 Materials Selected materials in combination with the equipment establish a baseline process; therefore a material and process validation of the initially selected materials and equipment should be performed.

The manufacturer of a product must evaluate internal manufacturing processes, as well as those of subcontractors or suppliers. This is done in order to determine how the materials and processes used to create the product will interact with each other at each step in the manufacturing process, as well as storage and its end use environment. The material and process compatibility evaluation must consider such things as the expected manufacturing processes, including temperature limits and rates of change; chemistry of fluxes, solvents, parts, and-coatings; and coefficients of thermal expansion.

Re-evaluation to this requirement should be performed and documented whenever major elements of proven processes are changed. This is another area where proper communication between manufacturers and their subcontractors or suppliers is critical. Any change by a subcontractor (e.g., plating alloys, solder mask materials, cleaning methods, etc.) should be communicated to the manufacturer to ensure that the proposed changes will not have a detrimental impact on subsequent processes or acceptability of the product.

Samples of process changes:

Major Process Changes
- Fabrication houses
- Laminates (FR-4 to CEM-1)
- Metallization (HASL tin-lead to palladium flash)
- Solder masks (dry film to an LPI)
- Fluxes, type and/or formulation (RMA to water soluble)
- Cleaning, method and/or chemistry (Freon TMS to aqueous saponifier)
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Minor Process Changes

- Bake or cure cycles
- Minor process variations in fabrication
- Change from a 6% solids flux to a 2% flux of the same formulation
- Equipment or tooling where the output satisfies the requirements of the Standard (lead bending dies or wire strippers)

NOTE: The previous lists attempt to separate changes into major and minor categories for guidance, but the reader must use caution. Depending upon the combination of processes and materials, what might be a minor change for one supplier could be considered a major change to another.

Objective evidence of this compatibility evaluation **shall** be maintained and available for review. The manufacturer's process procedures or its user's requirements determine the format for the objective evidence and for how long it will be maintained.

In previous versions of J-STD-001 there was an appendix with guidance on material and process compatibility. This guidance has been updated and is now available as IPC-9202. In addition, IPC-CH-65 (Guidelines for Cleaning of Printed Boards and Assemblies) Section 6 (Process Development and Verification) contains additional guidance for material compatibility testing and includes sample test plan guidelines and test method considerations.

3.2 Solder This clause covers many of the materials considerations of the items used in electronics manufacture. Such information is useful when trying to understand the materials in use and their properties. Later clauses cover how these materials are used or processed.

Solder, an alloy used for joining metals, solidifies below 221°C [430°F]. It is generally accepted that the joining of metals above 221° C [430°F] is referred to as brazing. The most common alloy is tin and lead. Other alloys used in soldering include tin-silver, tin-antimony, tin-zinc, and indium-based solders. The melting point of the solder depends on the metals in the alloy and the percentage of each. Solder alloys, which change directly from liquid to solid and solid to liquid without any intermediate plastic states, are eutectic solders. The various solder types and their compositions and melting points can be found in J-STD-006.

Tin/lead solders used for electronics soldering are typically eutectic or near eutectic alloys. The eutectic composition, as shown in Figure 3-1(B), shows the tin/lead eutectic at 63% tin by weight and 37% lead by weight and is referred to as Sn63Pb37. In this diagram, the area above line A-B-C is always liquid (this line being referred to as the liquidous), and the area below line A-D-E-C is always solid (this line being the solidus). The area between these two lines is a mixture of solid and liquid phases, often referred to as the “pasty” region. The selection of the near eutectic condition is to promote rapid solidification of the solder connection, which minimizes grain growth during solidification, yielding a “shinier” solder joint.

Another common alloy used in electronics soldering is 60% tin/40% lead, referred to as Sn60Pb40. This alloy is often preferred in commercial applications due to its lower cost and similar properties to Sn63Pb37. The trade-off between Sn60Pb40 and Sn63Pb37 is the longer solidification time when the solder solidification process passes through the “pasty” region in Figure 3-1. This can result in duller appearing (although no less reliable) solder joints and an increased occurrence of disturbed solder connections (which move during solidification, resulting in a rough surface and dewetting).

The metallurgy of solder is a mixture of tin-rich crystals, referred to as the beta β phase, with a composition of 97.5% tin/2.5% lead and lead rich crystals, referred to as the alpha α phase, with a composition of 19% tin/81% lead. The as-cooled appearance of the eutectic solder microstructure is seen in Figure 3-2 and Figure 3-3 as a two phase structure containing a dispersion of darker platelets, being the lead-rich α phase, mixed in with larger crystals of the tin-rich β phase.

NOTE: When viewing solder using a Scanning Electron Microscope (SEM), the solder matrix appears like a photographic negative of the optical appearance due to the relationship between apparent “brightness” in an SEM view and atomic weight.

A number of diffusion reactions, which can occur while the solder is molten, as well as after solidification, can affect solder morphology. These reactions change the appearance of the solder microstructure and can be summarized as:

- Leaching: The dissolution of substrate metallization(s) into the molten solder during soldering.
- Coarsening: A solid state diffusion reaction which causes the individual phases to coalesce in order to reduce total free energy of the system by minimizing the interfacial area of the separate phases. The solder joints will appear “dull.” Either temperature or applied stress/plastic deformation can drive this process.
- Aging: The growth of intermetallic layers between the bulk solder and the substrate or component, which is driven primarily by time and temperature.

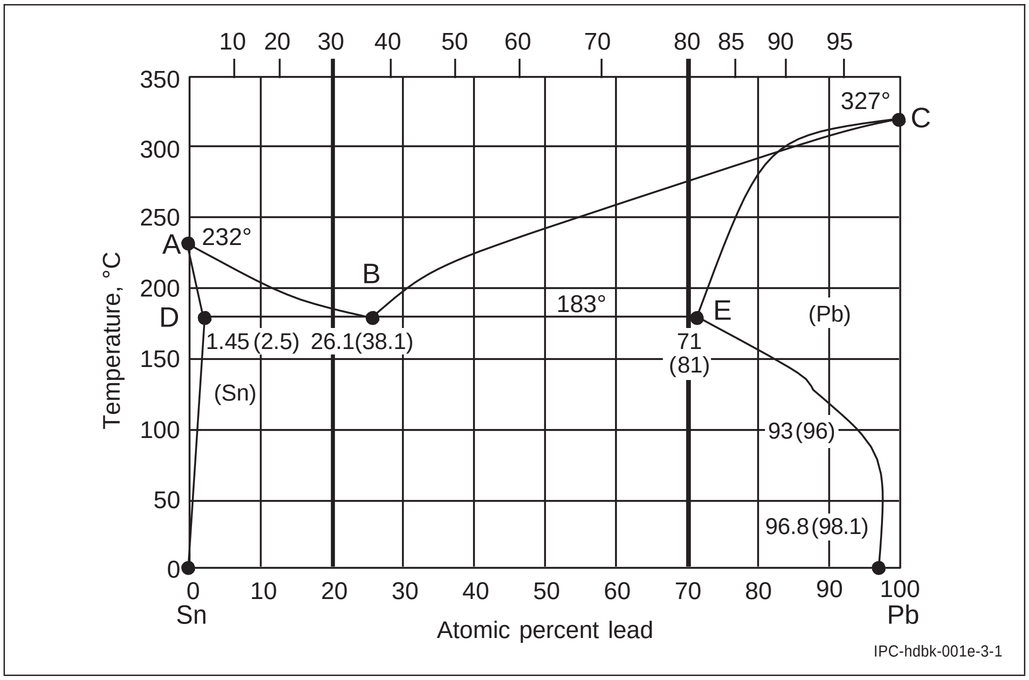

Figure 3-1 Phase Diagram for Eutectic Solder

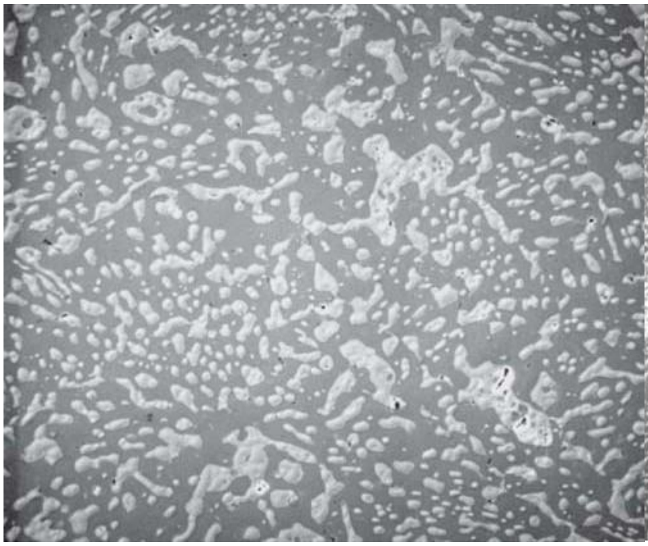

Figure 3-2 Eutectic Solder Microstructure

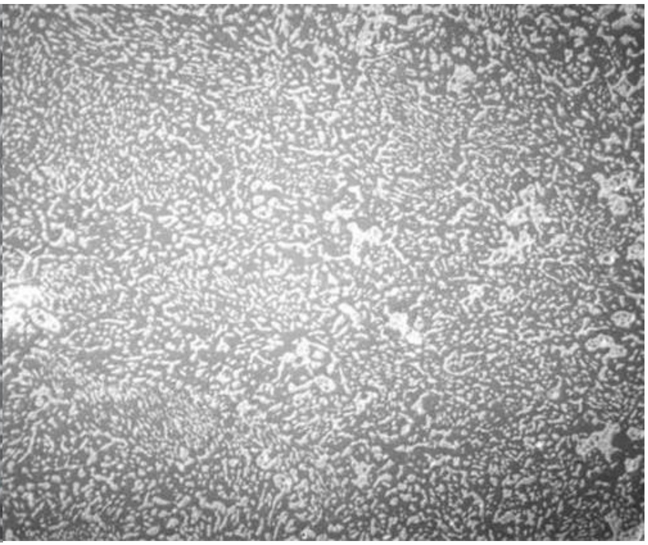

Figure 3-3 Eutectic Solder Microstructure

Physical Properties of Solder Alloys The properties of these solder alloys are sensitive to temperature, strain rate, cyclic loading frequency, and grain size. A listing of common physical properties of solder is given in Table 3-1.

Table 3-1: Common Physical Property Values for Eutectic or Near Eutectic Tin/Lead Solder

Physical Property (Alloy)	**Value**
Surface Tension (Sn60Pb40)	0.41 J/m^2 @ 250°C in air
Elasticity - (Sn63Pb37)	32 x 10^3 N/mm 2 @ 25°C
Viscosity - (Sn63Pb37 & Sn60Pb40))	2 centipoise (N·s/m^2)
Density (Sn63Pb37) (Sn63Pb37) (Sn60Pb40)	8400 kg/m^3 at 20°C 8000 kg/m^3 at 250°C 8500 kg/m^3 at 20°C
Coefficient of Thermal Expansion (Sn63Pb37)	24.5 x 10^{-6}/K
Heat of fusion (Sn60Pb40)	4600 J/kg
Specific heat (Sn60Pb40)	176 J/(kg-K)
Electrical Resistivity (Sn60Pb40)	0.17 milliohm·m @ 25°C 0.32 milliohm·m @ 100°C
Thermal Conductivity (Sn60Pb40)	51 J/(m·s·K) @ 25°C 49 J/(m·s·K) @ 100°C
Thermal Diffusivity (Sn63Pb37)	3.4 * 10^{-5} m^2/s

Solder Lead Free Solder alloys less than 0.1% lead by weight not listed by J-STD-006 may be used when such use is agreed upon by the manufacturer and the user.

Environmental legislation has had an enormous impact on the solder alloys used for electronics assembly. The European Union Restriction of Hazardous Substances (RoHS) directive officially went into effect on July 1, 2006 but a significant portion of the electronics supply chain began a wide variety of transition actions in the years prior to that implementation deadline in an effort to understand material issues and fabrication concerns. The RoHS directive contained a requirement that the maximum concentration of lead in a solder alloy was 0.1% which effectively resulted in the extinction of lead bearing solder alloys except for specialized applications. The electronics industry has initially focused on one non-lead solder alloy family, Tin (Sn)/ Silver (Ag)/ Copper (Cu) – (SAC), for a variety of criteria which includes (but not limited to) cost, metallurgical complexity, melting point, surface tension, availability and process-ability. Three solder alloys – SAC405, SAC305, and SAC105 – have received the most industry attention. Further industry resources have been expended in the characterization of Tin (Sn)/ Copper (Cu) "modified" solder alloys such as Sn/Cu/Ni/Ge or Sn/Cu/Ni/Bi. The rationale for considering the Sn/Cu "modified solder alloys is improvements in drop shock properties, lower copper dissolution properties and alloy cost. Table 3-2 illustrates a variety of lead-free solder alloys and their elemental compositions. Table 3-3 lists a variety of lead-free solder alloys and their melting temperatures.

Table 3-2: Lead-free Solder Alloys *(from G. Hen**shall** et al, “iNEMI Pb-Free Alloy Alternatives Project Report: State of the Industry” SMTAI 2008 Conference Proceedings)*

Alloys	**Investigators**	**Reference**
Sn4.0Ag0.05Cu (SAC4O5)	Pandher (Cookson), H. Kim & D. Kim (Intel), Kobayashi (Nippon Steel), Darveaux (Amkor/ASU)	ECTC 2007
Sn3.0Ag0.55Cu (SAC305)	Pandher (Cookson), Syed (Amkor), Kobayashi (Nippon Steel), Darveaux (Amkor/ASU)	ECTC 2007
Sn1.0Ag0.5Cu (SAC105)	Pandher (Cookson), H. Kim & D. Kim (Intel), Kobayashi (Nippon Steel)	ECTC 2007
Sn0.3Ag0.7Cu+Bi (SACX0307)	Pandher (Cookson)	ECTC 2007
Sn0.3Ag0.7Cu+Bi+Ni+Cr	Pandher (Cookson)	ECTC 2007
SAC3O5+0.05Ni+0.5In	Syed (Amkor)	ECTC 2007
SAC255+0.5Co	Syed (Amkor)	ECTC 2007
SAC107+0.5Ge	Syed (Amkor)	ECTC 2007
SAC125+0.05-0.5Ni (LF35)	Syed (Amkor), D. Kim (Intel), Kobayashi (Nippon Steel), Darveaux (Amkor/ASU)	ECTC 2007
SAC101+0.02Ni+0.05In	Syed (Amkor)	ECTC 2007
Sn-3.5Ag	Cavasin (AMD), Darveaux (Amkor/ASU)	ECTC 2007
Sn-3.5Ag+0.05-0.25La	Pel & Qu (Ga Tech)	ECTC 2007
Sn-0.7Cu	Darveaux (Amkor/ASU)	ECTC 2007
Sn0-4Ag0.5Cu+Al+Ni	Huang (Indium)	ECTC 2007
Sn0.7Cu0.05Ni+Ge (SN1000)	Sweatman, Miyaoka, Seki, Suenaga, Nislumura (Nihon Superior)	ICS&R Toronto 2008

Table 3-3: Lead-free Solder Alloys and Their Melting Temperatures

Composition (Percent)					Solidus (ºC)	Liquidus (ºC)
Sn	Ag	Cu	Bi	Sb		
95.5	3.8	0.7			217	220
95.5	4.0	0.5			217	225
95.5	3.9	0.6			217	225
96.5	4.7	1.7			217	244
91.8	3.4		4.8		211	213
96.5	3.5				221[1]	
99.3		0.7			227[1]	
99				1	232	235
97				3	232	238
95				5	235	240
65	25			10	233[2]	

[1] Eutectic composition

[2] Melting point

The use of lead-free solder alloys result in the soldering process engineer having to address two primary issues due to the differences from the traditional tin/lead solder alloys: (1) solder alloy initial melting point; (2) solder alloy solidification characteristics. The traditional tin/lead solders have melting points beginning at 183°C [361°F]. The melting point of the SAC solder alloy family is 217°C [423°F], 34°C [93°F] higher. This increase in solder alloy temperature causes a domino effect as the soldering flux, the printed wiring laminate, the components and the soldering process equipment must all be compatible for the higher temperature. Several industry studies have shown that a small increase in the amount of flux contained in a solder wire core, as shown in Figure 3-4, can be beneficial due to the increased soldering process temperatures caused by the lead-free solder alloy melting point.

Figure 3-4 Solder Wire Core Flux Comparison

Secondly, relatively few of the lead-free soldering alloys have eutectic alloys as described in clause 3.2. A eutectic solder alloy solidification behavior of changing from a liquid to a solid at a specific temperature provides the soldering process engineer a number of process control advantages in comparison to the non-eutectic solidification behavior of changing from a liquid + solid to a solid.

Caution should be exercised in selecting a lead-free solder alloy for a soldering process as these new alloys constitute a change in the form/fit/function of an electronic assembly. The diverse compositional ranges of the lead-free solder alloys combine with product functional requirements and product use environment interactions, results in a wide range of solder alloy thermal and mechanical characteristic responses. Figure 3-5 illustrates how a sampling of lead-free solder alloys compares to the traditional tin/lead solder alloys in fracture toughness testing. Figure 3-6 shows a similar response for drop shock testing.

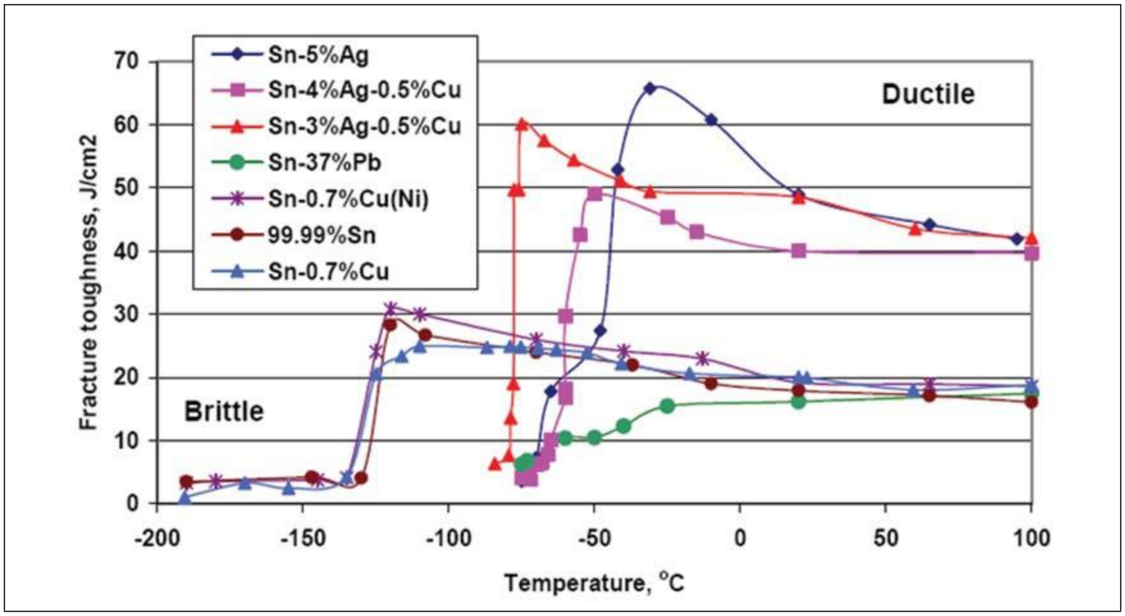

Figure 3-5 Solder Alloy Fracture Toughness Testing Results *(Graph from P. Ratchev et al, ''A Study of Ductile to Brittle Fracture Transition Temperatures in Bulk Pbfree Solder Alloys,'' EMPC 2005, Brugge, Belgium)*

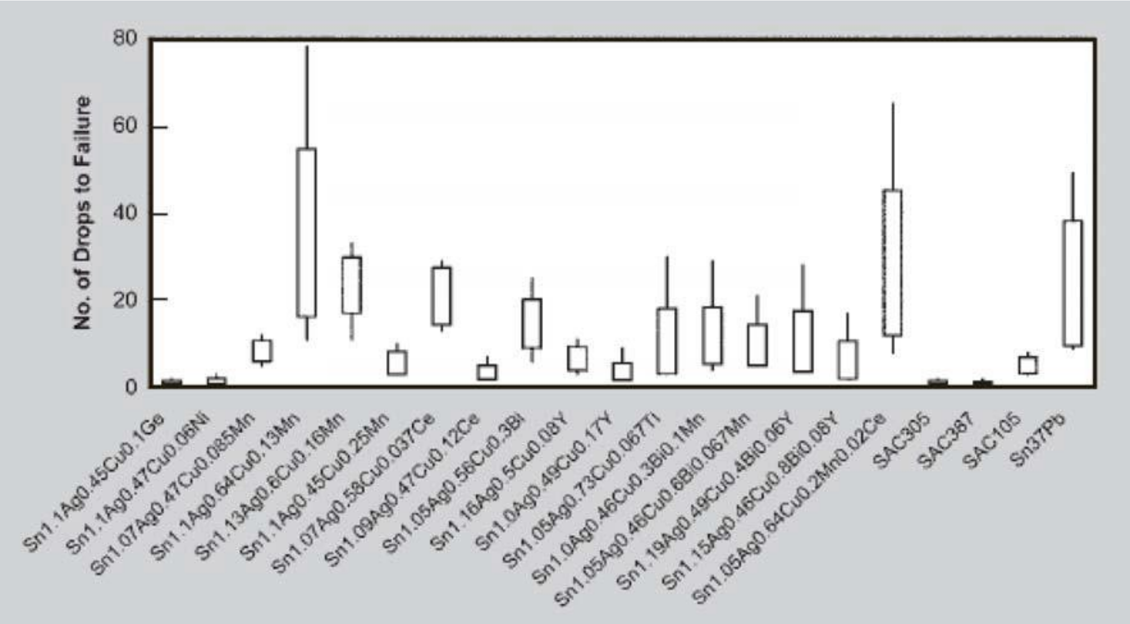

Figure 3-6 Solder Alloy Drop Shock Testing Results *(Graph from Lee et al, July JOM 2007)*

Lead-free Soldering: Process Considerations

Background The use of conventional tin-lead (Sn/Pb) solder in circuit board manufacturing is under ever-increasing political scrutiny due to environmental issues and new regulations concerning lead, such as the Waste Electrical and Electronic Equipment (WEEE) and the Restriction on Hazardous Substances (RoHS) Directives in Europe. In response to this, global commercial electronics manufacturers are initiating efforts to transition to lead-free assembly. Tin/lead soldering processes and lead-free soldering process are similar in many respects; however, there are a number of significant differences that need to be addressed insure product integrity.

Mixed Metallurgy The implementation of the European Restriction of Hazardous Substances (RoHS) Directive has initiated an electronics industry materials evolution. Printed wiring board laminate suppliers, component fabricators, and printed wiring assembly operations are engaged in numerous investigations to determine what lead-free (Pb free) material choices best fit their needs. The complexities of Pb free soldering process implementation insures a transition period in which Pb free and tin/lead solder finishes will be present on printed wiring assemblies. The use of lead-free components in a tin/lead soldering process is not a new topic for the electronics industry. Texas Instruments introduced a nickel/palladium/gold component surface finish in 1990 and the electronics industry has successfully processed that finish with few issues. The introduction of lead-free finishes such as tin, gold, silver and bismuth requires due diligence by the soldering process engineer to insure that any potential incompatibilities, such as gold embrittlement, are addressed. Figure 3-7 illustrates the incompatibility of a lead free bismuth solder alloy with a tin/lead component finish. The reduction in solder joint thermal cycle fatigue life is clearly evident for a tin/lead surface finish and a tin/copper surface finish with a SnAgCuBi solder alloy.

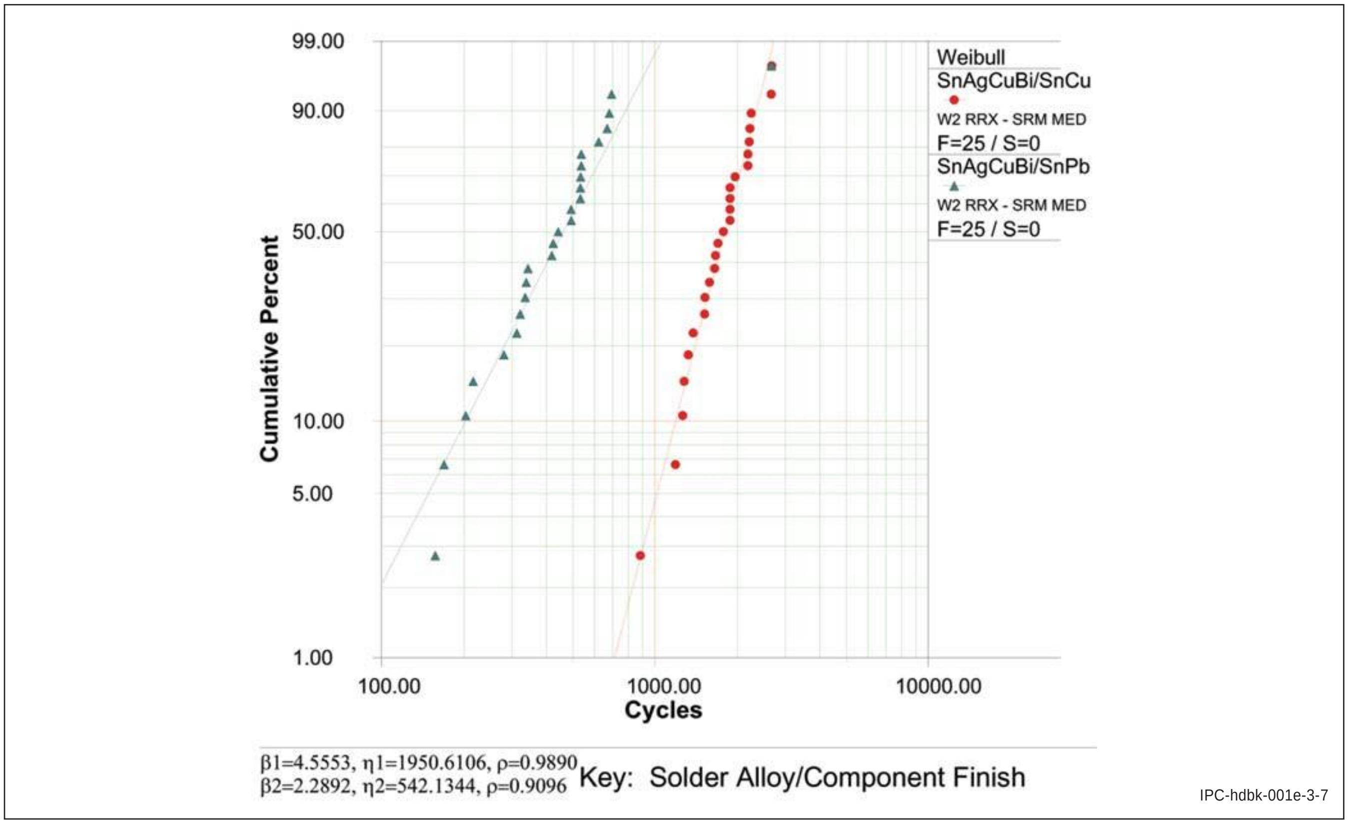

Figure 3-7 Lead-Free Solder Alloy/Component Surface Finish Incompatibility Example *(D. Hillman and R. Wilcoxon, ''JCAA/JG-PP Lead-free Solder Testing for High Reliability Applications: -55 °C to +125 °C Thermal Cycle Testing'' SMTAI Conference, 2006)*

A second mixed metallurgy topic of concern is the soldering of area array component styles such as ball grid arrays (BGAs), chip scale packages (CSPs), and flip chips (FCs). The contribution of the solder ball metallurgy to the overall solder joint volume for an area array package is significantly greater than for standard surface mount package technologies. Combine the solder ball contribution to the higher melting point of a lead-free solder alloy and the resulting solder joint has the potential for the creation of a non-uniform solder joint microstructure or an incomplete solder joint reflow. Figure 3-8 illustrates these two effects.

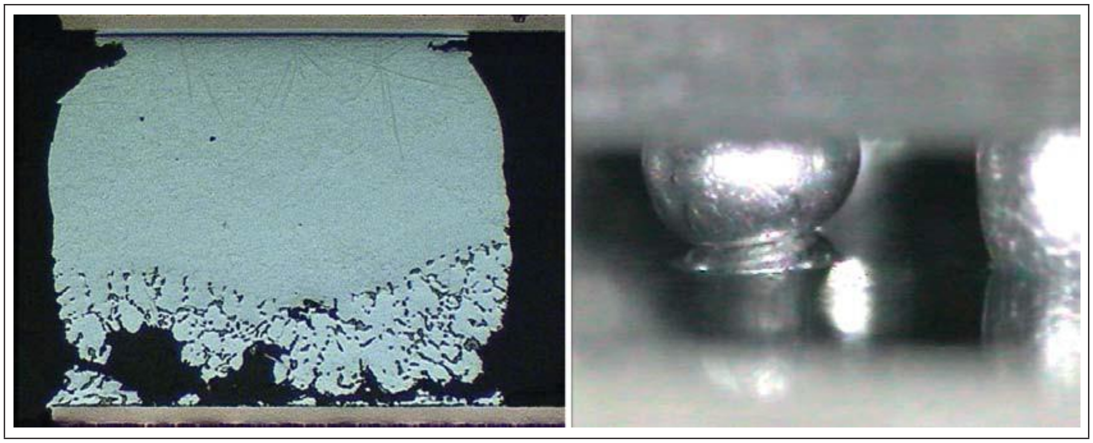

Figure 3-8 left: Non-uniform Solder Joint Microstructure, right: Incomplete Solder Joint Reflow (Head-on-Pillow) *(Photo courtesy Rockwell-Collins, used by permission)*

Temperature Compatibility The introduction of lead-free soldering processes has resulted in an increase in soldering process temperatures. The using of SAC solder alloy family increases the soldering process temperature from 183°C [361°F] (Sn63Pb37 solder alloy) to 217°C [423°F], a 34°C [93°F] increase without accounting for the thermal thieving effects of the printed wiring laminate! A review of the component and laminate temperature compatibility is necessary. Laminate materials will delaminate and warp if they cannot withstand the lead-free soldering process temperatures. A components moisture sensitivity level (MSL) is a function of temperature and some component materials will degrade if exposed to lead-free soldering processes. Figure 3-9 illustrates component incompatibility examples.

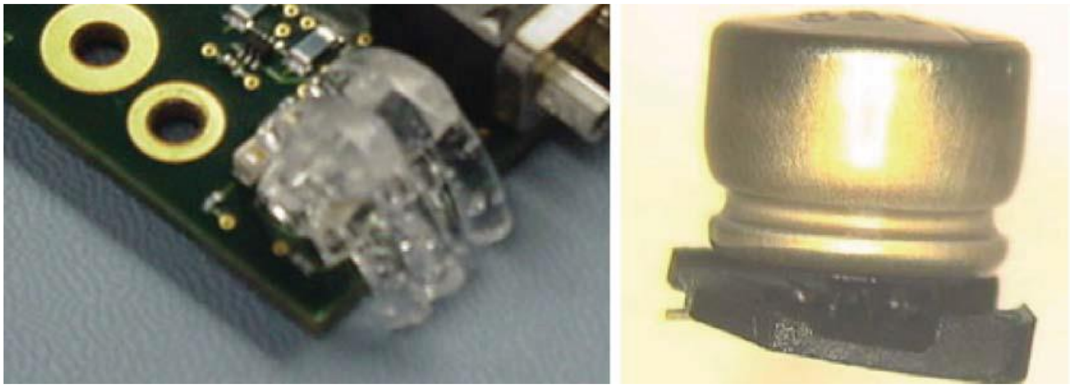

Figure 3-9 Component Degradation Due to Lead-free Soldering Process Incompatibility *(Courtesy of Rockwell Collins (left) and Bob Willis Electronic Presentation Service (right))*

Soldering Process Equipment Compatibility The tin content of lead-free soldering alloys is significantly **greater** than the traditional eutectic tin/lead solder alloys. Molten tin is an aggressive element in terms of the dissolution and erosion of other metals. The implementation of lead-free soldering processes requires a review of lead-free solder alloy compatibility with any process equipment that will come in contact with the molten alloys. Wave solder pots and static solder pots are two primary areas of concern. Figure 3-10 illustrates the attack of wave solder process equipment by a lead-free solder alloy.

Figure 3-10 Lead-free Solder Alloy Attack of Wave Solder Equipment Lead-free Solder Alloy Attack of Wave Solder Equipment *("Pb-free Technology and the Necessary Changes in Soldering Process and Machine Technology," H. Schlessmann, APEX 2002 Conference Proceedings)*

Copper Dissolution Concerns The discussion of molten lead-free solder alloy damage of soldering process equipment also has lead-free soldering process implications. The dissolution of copper plating on surface mount pads and in plated thru holes is significantly increased for lead-free soldering processes. Figure 3-11 shows the accumulative effect of repeated soldering process exposures for various lead-free soldering alloys. The copper dissolution issue is of critical importance for plated thru hole rework processes, especially those utilizing mini-wave or selective solder equipment.

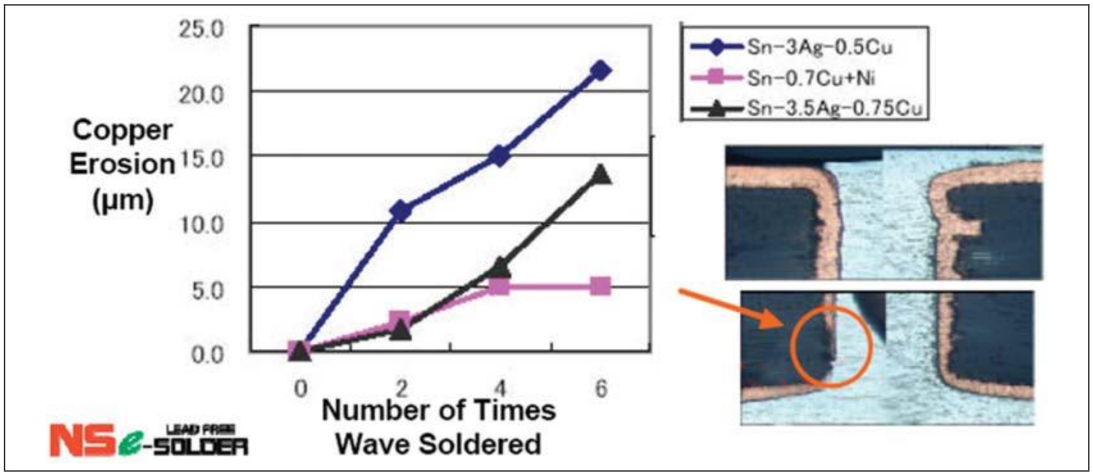

Figure 3-11 Copper Erosion Due to Lead-Free Soldering Processes *(Courtesy of Nihon Superior)*

Lead-free Finishes: Mitigation Strategies Several mitigation strategies currently exist within industry which can be used to minimize the risk of tin-whisker growth and subsequent problems. Until the growth mechanism for tin whiskers is fully understood and there is an accepted test method for tin whiskers propensity, there is currently no one known mitigation strategy that can be used to completely eliminate the risk of tin whisker growth. However, there are several mitigation strategies used in industry today that have been proven to reduce the risk of tin whisker growth. GEIA-STD-0005-2, “Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems”, provides detailed information on how to assess the level of risk associated with a particular product group and provides mitigation strategies which correspond to the level of mitigation required. These mitigation techniques focus primarily on processes that can be utilized after the component has been manufactured and subsequently assembled to the board. Mitigation strategies which can be used earlier in the design process such as; procuring parts that do not have a pure tin finish, board layout, spacing and plating options are discussed in GEIA-STD-0005-2, but are not discussed in this document.

Following is a short summary of a few commonly used industry mitigation strategies discussed in the GEIA-STD-0005-2:

1. Conformal Coating. If components with lead-free solder finishes must be used, government and industry subject matter experts strongly encourage utilizing conformal coating as a mitigation strategy. Conformal coat reduces the risk of a tin whisker failure by slowing down the growth of the tin whisker and/or containing whisker growth within the coating. However, depending on the type of coating and coating thickness, tin whiskers have been found to grow through conformal coatings. While most known coatings eventually allow growth through the coating over time there is no known case of a tin whisker re-entering or puncturing back into and penetrating the coating on an adjacent surface. However, this fact does not eliminate the possibility that two whiskers from adjacent surfaces couldn’t still intersect in free space and thereby create a short circuit condition. Coating materials and processes should be carefully reviewed to ensure their compatibility with the hardware design and application. For spray-on conformal coatings, the effectiveness of the mitigation depends on how well the coating is applied at various angles to avoid shadowing from high profile components. Conformal coating is difficult, if not impossible, to get underneath components with under-mounted connections, such as BTCs, BGAs, CSPs and PGAs. Also, coefficient of thermal expansion (CTE) mismatches become a serious concern when coatings are applied underneath components. For a conformal coating to be an effective lead-free mitigation strategy, the quality and thickness of the conformal coat must be controlled. Testing has shown acrylic conformal coatings are the least effective in mitigating tin whisker growth. Urethane coatings generally tend to retard whisker growth better than acrylic, but tests have also shown whiskers break through urethane coatings as well, but usually at a slower rate. Experiments and tests indicates Paraxylylene coatings provide the most effective coverage due to its vacuum deposition process and is more effective than other coatings in mitigating tin whisker growth. Unfortunately there is a perceived upfront cost increase and level of difficulty associated when utilizing this type of coating and therefore a lot of push back from industry against using it. However, the argument can be made that the increased cost of applying and reworking this type of coating can be offset with its resulting performance over time and

the resulting savings incurred over the life of a system utilizing this type of coating. Additionally, new coatings such as Atomic Layer Deposition (ALD) and others are routinely being developed and evaluated for their effectiveness concerning tin whisker mitigation.

2. Embedment/Encapsulation. In order for an embedment or encapsulation material to be an effective tin whisker mitigation, the material should fully wet and cover all surfaces of the components and areas specified for coverage. The cured material should be compatible with the hardware and product environment and should not adversely affect hardware performance or reliability. Other issues, such as CTE mismatch between the encapsulant and the surface, to which it is bound, should be addressed before using this form of mitigation. Rework may also be impossible when employing this type of mitigation, depending on the specific application.
3. Solder Dip Tin-finished Surfaces. Hot solder dipping of tin-finished leads and surfaces using a Sn-Pb based solder will help reduce whisker formation by relieving stress in the tin. It is important to note that solder dipping for mitigation purposes is different from traditional solder dipping because the lead must be coated over its entire length, right up to the package interface. The solder dipping process exposes components to higher temperatures than they would see during normal assembly processes, which could reduce the reliability of the component. To avoid these reliability issues, the solder dip process must be qualified and carefully controlled. This can be accomplished by using Scanning Acoustical Microscopy (SAM) before and after dipping along with other analytical techniques. Components with glass to metal seals can be damaged through thermal shock during the dipping process and it is recommended these parts not be solder dipped if possible.
4. Pb Over-plating. Pb over-plating involves plating Pb on the surface of the tin and then baking the component to promote complete interdiffusion of the Pb through the tin. This method is probably the most suitable for use on small chip-style passive devices.

Additional guidance and technical information on lead-free mitigation strategies can be found in the following documents and are an excellent resource for developing and implementing lead-free control plans.

- GEIA-STD-0005-1, Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder
- GEIA-STD-0005-2, Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems
- GEIA-HB-0005-1, Program Management/Systems Engineering Guidelines for Managing the Transition to Lead-Free Electronics
- GEIA-HB-0005-2, Technical Guidelines for Aerospace and High Performance Electronic Systems Containing Lead-free Solder and Finishes
- GEIA-STD-0006, Requirements for Using Solder Dip to Replace the Finish on Electronic Piece Parts

3.2.2 Solder Purity Maintenance Testing of a solder bath is a preventative measure. It is easier to test the solder bath and correct the composition than to disposition non-conforming hardware.

Testing Frequency How often the solder is tested is up to the individual user. To establish a baseline, the solder pot should be tested at a set frequency (i.e., monthly) established by the user, based on production levels, etc. Based on these results and how much product is being assembled using the solder pot, the frequency of testing can then be increased or decreased appropriately. Another option, once a baseline history has been established, is to replace the solder bath periodically rather than test and replenish it.

A summary of the recommended levels of solder impurities for eutectic (Sn63Pb37) and near eutectic (Sn60Pb40) solder and their effects is shown in Table 3-4. If an alternative alloy is used, the user must develop a table comparable to Table 3-4 with the guidance from the solder supplier.

Contamination Sources Some materials that may be found in solder baths, some of the reasons they are there, and issues to be aware of are outlined below. In small amounts, these materials are acceptable, but in higher levels, these materials are considered contaminants. It is noted that the addition of a certain amount of bismuth, nickel, and copper to the eutectic tin-lead solder alloy improves the wetting ability of the solder, whereas the addition of cadmium and zinc decreases the wetting power of the eutectic solders.

Copper Copper has negligible solubility in both tin and lead. Two intermetallic compounds: Cu3Sn and Cu6Sn5, are formed between copper and tin. As the copper content of the molten solder increases, higher temperatures are needed to overcome sluggishness and grittiness of the liquid metal. This increases the rate of solution of additional copper from the surfaces to be soldered, rapidly degrading the soldering conditions.

Gold The solubility of gold in tin-lead at room temperature is negligible. Several intermetallic compounds are formed between tin (Au6Sn, AuSn, AuSn2 and AuSn4) and lead (Au2 Pb and AuPb2). Unless the soldering is rapidly completed, the gold intermetallics will rise to the surface of the connection, causing an extremely dull gray, grainy surface. Above 0.340% gold contamination in the solder pot may cause embrittlement of the solder connection.

Cadmium The solubility of cadmium in both tin and lead is negligible. There is an intermetallic phase at elevated temperature. Cadmium surfaces can deteriorate rapidly and cause spotty connections with poor adhesion (poor wetting). Practically speaking, this problem does not often surface.

Cadmium is considered the plating of choice for resistance to salt-laden environments, but there are concerns with some of the carcinogenic properties of the materials in the cadmium plating process. Cadmium wastes also constitute hazardous materials with all of the attendant environmental regulations. The cadmium metal, itself, is not carcinogenic.
The most common source for cadmium metals being transferred to solder baths is the back shells on connectors, which are often cadmium plated to increase environmental resistance.

Table 3-4[1] Levels of Allowable Solder Impurities for Sn60Pb40 and Sn63Pb37 Solders (Weight %)

Material	**Preconditioning (Lead/Wire Tinning)**	**Assembly soldering (Pot, Wave, etc.)**	**Effect on solder joint if maximum allowable level is exceeded during usage**
Copper (Cu)	0.750%	0.300%[2]	Solder begins “sticking” to insulation materials, above 0.3% viscosity increases and solder becomes gritty.
Gold (Au)	0.500%	0.200%[2]	Solder becomes sluggish and grainy; above 4% solder becomes brittle.
Cadmium (Cd)	0.010%	0.005%[2]	Oxidation rate increases, above 0.15% area of spread decreased by 25%.
Zinc (Zn)	0.008%	0.005%[2]	Finish becomes dull, dewetting, oxidation rate increases.
Aluminum (Al)	0.008%	0.006%[2]	Solder becomes sluggish, frosty and porous; oxidation rate increases.
Antimony (Sb)	0.500%	0.500%	Increased dewetting.
Iron (Fe)[3]	0.020%	0.020%	Forms FeSn2 which is unsolderable.
Arsenic (As)	0.030%	0.030%	Grainy/pitted appearance, edge dewetting and reduction in area-of-spread.
Bismuth (Bi)	0.250%	0.250%	Dulling of surface, may reduce ability of solder to wet brass & steel.
Silver (Ag)	0.750%	0.100%	Solder surface finish becomes gritty.
Nickel (Ni)[3]	0.025%	0.010%	Blisters, formation of hard insoluble compounds.

Note 1: Data from J-STD-006, for Class 3 (critical) use solders.
Note 2: The total of copper, gold cadmium, zinc, and aluminum **shall not** exceed 0.4%.
Note 3: The solubility of these materials in solder at temperatures <260°C [500°F] is very low and problems only arise as a result of prolonged exposure.

Zinc Zinc has little solid solubility in tin and none in lead. No intermetallic compounds are formed with either tin or lead. Zinc is detrimental to the solder alloy. As little as 0.005% of zinc is reported to cause a lack of adhesion, grittiness, and susceptibility to grain boundary weakening.

Aluminum Aluminum does not have any solid solubility in either tin or lead at room temperatures, and only a small amount of aluminum is dissolved in liquid tin at an elevated temperature. Aluminum in molten solder usually causes sluggishness in the melt, with a considerable amount of grittiness and lack of adhesion. Very little aluminum is used in electronic soldering because of the large galvanic potential present between aluminum and the tin-lead alloy (1.53V). Aluminum surfaces that must be exposed to molten solder, even for a short time, should be hard anodized.

Antimony The solubility of antimony in tin at room temperature is about 6-8%, while little antimony is dissolved in lead at room temperature. In some specifications, the presence of 0.2-0.5% antimony is mandatory to retard the transformation of tin into its gray state (tin-pest). Excessive antimony may cause a spread reduction in lead termination.

Iron Iron has some solubility in tin at elevated temperatures, forming two intermetallic compounds, FeSn and FeSn2, manifesting themselves as needle-shaped crystals. The presence of iron in solder is detrimental and causes grittiness.

Arsenic No solubility of arsenic in either tin or lead has been observed. Two intermetallic compounds: Sn3As2 and SnAs, appear as a long needle in the microstructure. Arsenic may cause poor wetting.

Bismuth At room temperature, bismuth has solubility in lead of up to 18% and solubility in tin of about 1%. A concentration of less than 0.25% will cause a reduction in the working temperature. Bismuth causes a gray appearance.

Silver There is no solid solubility in either tin or lead, but tin and silver form the intermetallics Ag6Sn and Ag3Sn. When silver content rises over 2.0%, the silver-tin intermetallics will segregate upon cooling.

Nickel Nickel shows no solubility in either tin or lead. Intermetallics formed with tin are Ni3Sn, Ni3Sn2, and Ni3Sn4.

Solder Pot Contamination Copper, iron, gold, and nickel may be found in solder baths as a result of lead clippings, PCB pieces, or components falling into solder baths. In addition to these known causes of contamination, there are other ways that contaminants can get into the solder pot, such as a piece of jewelry falling into the solder pot.

Effect of Contamination on Solder Process Contamination can have adverse effects on the soldering process. It can result in brittle or grainy joints and lower the reliability of the product.

Resolving Contamination Problems If there are contamination problems, several options are available. By removing calculated amounts of contaminated solder and adding amounts of “virgin”solder to the solder bath, the relative level of contamination will be reduced. This can also be done if all of the contaminants are within limits as a process control measure.

If the user needs to add a large amount of “virgin”solder to the solder pot to bring the contamination limits to acceptable limits, the user may want to consider replacing the entire solder bath.

Reducing pot temperature will allow some contaminants to come out of the solution. This can happen through solidification of impurities or the creation of immiscible liquids. Either way provides relatively easy removal of the contamination.

In addition, if the solder bath is exceeding the limits, the possible cause of the contamination should be investigated:

- Has the solder bath been heavily used?
- Was there a one-time isolated incident that might explain the condition?

If the contamination is above the acceptable levels, increasing the frequency of analysis should also be considered.

Tin Depletion A product of wave soldering is the formation of dross on the static portion of the wave solder pot. The dross is primarily composed of solder, encapsulated by tin oxide. Additionally, a fine, black powder, which is found in tin oxide, will often form near the impeller shaft. It should be noted that this formation of tin oxides gradually diminishes the tin available in the solder and the tin level needs to be frequently monitored and the tin replaced.

Shown below are two formulas for determining the amount of tin to be added to a solder pot to adjust the tin content. Two cases are shown, depending on whether or not the amount of solder in the pot remains constant or not.

Case 1: Solder pot mass constant; i.e., solder is removed and replaced by new solder/tin.

$$M\ T\_A = \frac{M_P\,(Sn\%\ D - Sn\%\ C)}{(Sn\%\ A - Sn\%\ C)} \qquad \textbf{Eq. 3-1}$$

Case 2: Solder pot mass increases with added solder or tin.

$$M_{T\_A} = \frac{M_P\,(Sn\%\,D - Sn\%\,C)}{(Sn\%\,A - Sn\%\,D)} \qquad \text{Eq. 3-2}$$

Where:
M*T_A* = The mass of tin to be added to the solder pot.
M *P* = The mass of solder pot (prior to addition).
Sn%*D* = The tin content desired in the solder pot (% by weight).
Sn%*C* = The tin content currently in solder pot (% by weight).
Sn%*A* = The tin content in solder or tin bar used for addition (e.g., 100 for pure tin bar).

3.3. Flux

3.3 Unless otherwise specified on the design or assembly drawing or instructed by the User, the fluxes references by this document **shall** conform to IPC J-STD-004.

Flux **shall** [N1D2N2D3] conform to flux activity levels L0 and L1 of flux materials rosin (RO), resin (RE), or organic (OR), except ORL1 **shall not** [N1D2N2D3] be used for no-clean soldering Class 2 in this revision imposes the same flux activity levels as Class 3. L0 and L1 flux level is specified because they are low flux activity and present a reduced risk of corrosion and damage to the finished assembly. OR based fluxes have an increased tendency for creep corrosion (Reference Alcatel/Lucent paper). L1 has a higher halide content but has < 0.5% verses < 0.05% for L0.

Soldering flux provides the environment in which molten solder must work; it prepares the surface to be soldered by removing contamination and preventing oxidation. Fluxing is only a part of the total soldering operation, but the choice of the proper flux and the correct use of that flux can directly determine the reliability of the completed assembly. Solder is not glue and does not simply fill up a gap between parts or stick to a surface. Molten solder will only flow out and bond to a clean surface. Flux facilitates the surface preparation by providing a clean metal contact.

When solder is melted on a tarnished or oxidized surface, the internal, cohesive forces in the solder cause it to pull into a ball, much as water balls up on a waxed surface. Only when the surface is clean (free from oxide and dirt) will the bonding forces between the solder and metallic surface overcome the solder cohesive force and flow out over the surface.

Techniques such as mechanical abrasion, soldering with ultrasonics, using reducing gases such as hydrogen, using inert gases such as nitrogen or soldering in a vacuum, have all been effective means for preparing the surfaces for solder. However, the use of soldering flux is preferred, because of easy application, low cost, and reliability.

A material will only flow freely over a surface if in doing so, the total free energy of the system is reduced. In the case of soldering, the free energy of a clean surface is higher than a dirty one, making it more likely to promote solder flow.

The major purposes of a flux are:

1. Chemical: Reduces the oxides from the surface to be soldered and protects this surface (by covering it) from reoxidation.
2. Thermal: Assists in heat transfer from the heat source to the item being soldered (especially critical for hand and pulse soldering).
3. Physical: Transports the oxides and other reaction products away from the area being soldered.

In use, fluxes have two general criteria:

1. Flux activity: The ability of the flux to reduce oxides and protect the surfaces from reoxidizing.
2. Flux corrosivity: The impact of the flux residues on the long-term reliability of the assembly or device being soldered.

These two criteria typically oppose one another, as active fluxes tend to be highly corrosive, and fluxes that are not corrosive over the long term are also generally not very active in the short term. Obviously, one method of overcoming this problem is to remove the flux residue using some cleaning method. There is always some potential for residue remaining (due to inadequate processing); therefore, extremely active fluxes are rarely used in electronics.

For the fluxes to be useful, it is necessary that these materials be evaluated for corrosivity and insulation resistance of the residue when exposed to life cycle type environments. It has been noted that in many cases, "No Clean" fluxes are not compatible with cleaning attempts or other "No Clean" fluxes. The impact of materials used in subsequent processes (fluxes, solvents, and conformal coatings) needs to be evaluated in combination with the flux and soldering process under evaluation.

The following lists the requirements for choosing the correct soldering flux:

- Must remove oxide and penetrate films
- Must be thermally stable.
- Prevent oxidation at soldering temperatures;
- Lower interfacial surface tension;
- Be easily displaced by the molten solder;
- Be non-injurious to components;
- Be easily removed, if desired;
- Not affect performance if left on assembly

Flux should at the very least remove oxide. The secondary task of flux is to prevent oxidation of the surfaces during heating and to promote wetting and spreading of the solder by reducing the surface tension. Reducing oxidation is the only type of “cleaning” that a flux is designed to do. Too often the flux is expected to remove other types of contamination such as oil, grease, dirt and fingerprints.

Especially with the very low solids content fluxes, heat stability is a critical factor as the thin film of flux has to withstand whatever part of the entire heating process required.

3.3.0.1 Choosing the Proper Flux Sometimes the scientific approach is totally neglected and there are attempts to try every flux made, hoping to find that one magic formula which accomplishes the ideal soldered connection. The proper method to approach any soldering application, whether the heating is done with an iron, pot, flame, wave solder machine or air reflow is to consider the entire soldering system.

The temperature and types of heating methods, time of soldering, and the condition of the surfaces being soldered all determine the type of flux which must be used. The amount of oxide reduction required by a flux determines the strength or activity necessary, and therefore, the type of flux.

The solderability of plated metal coatings is affected also by the bath purity and processing conditions. The nature of the oxide coating is dependent not only on the metal selected, but also on the environmental and thermal history.

3.3.0.2 Flux Types There are basically only two types of fluxes: organic and inorganic. Each of these types has many variations. Fluxes of all types are available as liquids, pastes, or in cored wire solder. Flux within flux-cored solder wire and external flux must be compatible. With very few exceptions, fluxes are acids. Acids reduce oxides on metals. The acids can be water soluble, such as the inorganic and most organic fluxes, or non-water soluble, such as rosin or certain other carboxylic acids, or only solvent soluble, such as the RA (rosin activated) type fluxes. The IPC-JSTD-004 Requirements for Soldering Fluxes specification defines the industry classification system used distinguish the different flux chemistries available for industry use (See Tables 3-5 and 3-6 and J-STD-004B w/ Amendment 1, paragraph 3.3.1.2.2).

Table 3-5 Test Requirements for Flux Classifications (from J-STD-004B w/ Amendment 1)

Flux	Copper	Corrosion	Quantitative	Conditions for Passing 100 M☐ ☐ SIR	Conditions for Passing ECM
			(Cl^-,Br^-,F^-,I^-) (by weight)		

L0	No evidence of mirror breakthrough	No evidence of corrosion	<0.05%[3]	No-clean state	No-clean state
L1			□0.05 and		
M0	Breakthrough in less than 50% of test area	Minor corrosion acceptable	<0.05%[3]	Cleaned or No-clean state[4]	Cleaned or No-clean state[4]
M1			□0.5 and <2.0%		
H0	Breakthrough in more than 50% of test area	Major corrosion acceptable	<0.05%[3]	Cleaned	Cleaned
H1			>2.0%		

1. This method determines the amount of halide present (see Appendix B-10).
2. If a printed circuit board is assembled using a no-clean flux and it is subsequently cleaned, the user should verify the SIR and ECM values after cleaning. J-STD-001 may be used for process characterization.
3. Fluxes with halide measuring <0.05% by weight in flux solids may be known as halide-free. If the M0 or M1 flux passes SIR when cleaned, but fails when not cleaned, this flux **shall** always be cleaned.
4. Fluxes that are not meant to be removed require testing only in the no-clean state.

Table 3-6 Flux Identification System (from J-STD-004B w/ Amendment 1)

Flux	**Flux/Flux Residue Activit**	**% Halide[1] (b**	**Flux Type[2]**	**Flux Designator**
Rosin (RO)	Low	<0.05%	L0	ROL0
		<0.5%	L1	ROL1
	Moderate	<0.05%	M0	ROM0
		0.5-2.0%	M1	ROM1
	High	<0.05%	H0	ROH0
		>2.0%	H1	ROH1
Resin (RE)	Low	<0.05%	L0	REL0
		<0.5%	L1	REL1
	Moderate	<0.05%	M0	REM0
		0.5-2.0%	M1	REM1
	High	<0.05%	H0	REH0
		>2.0%	H1	REH1
Organic (OR)	Low	<0.05%	L0	ORL0
		<0.5%	L1	ORL1
	Moderate	<0.05%	M0	ORM0
		0.5-2.0%	M1	ORM1
	High	<0.05%	H0	ORH0
		>2.0%	H1	ORH1
Inorganic (IN)	Low	<0.05%	L0	INL0
		<0.5%	L1	INL1
	Moderate	<0.05%	M0	INM0
		0.5-2.0%	M1	INM1
	High	<0.05%	H0	INH0
		>2.0%	H1	INH1

1. Halide measuring <0.05% by weight in flux solids may be known as halide-free. This method determines the amount of halide present (see Appendix B-10).
2. The 0 and 1 indicate the absence or presence of halides, respectively. See paragraph 3.3.1.2.2 for flux type nomenclature.

The historic flux classifications of R (rosin), RMA (rosin mildly activated), and RA (rosin activated) have been replaced by a class system that provides a more detailed characterization of the flux material in terms of base chemistry, flux activity level, and halide content. The following chapter clauses provide further detail of the different base flux chemistries.

3.3.0.2.1 "No Clean" Fluxes Theses are used to eliminate the cleaning process and cleaning due to materials is not an option. It should be noted that the term "no clean" fluxes is an industry process descriptive term and does not necessarily reflect the flux chemistry character – IPC J-STD-004 provides the appropriate flux identification and characterization.

3.3.0.2.2 Rosin/Resin Fluxes (RO or RE classification) The mildest fluxes are those derived from rosin. Rosin is a mixture of resin acids which occur naturally in the oleoresin or sap of pine trees. The resin acids are three-ring, isomeric monocarboxylic acids with a hydrophenanthrene nucleus. Consisting of primarily abietic, pimaric acids and other similar acids, rosin was long acclaimed as the best flux for electronics soldering because of its neutral insulating nature at room temperature.

With the introduction of automated methods for soldering printed board assemblies came the increased use of liquid activated rosin fluxes. IPC J-STD-004 details specific tests for distinguishing between the various types of rosin fluxes.

3.3.0.2.3 Organic Fluxes (OR classification) Though this type of flux has been used for several decades, only in the 1980s did the general use of organic flux dramatically increase.

The organic water soluble fluxes are complex mixtures of organic acids, halide salts of organics acids and amines, wetting agents and solvents. All this salt has an effect on the insulation resistance of porous printed boards, such as paper-base phenolic. Glass/epoxy printed boards have been used successfully with or without plated-through holes. The assembly must be designed for water removal of the flux residue. Any areas where flux can be trapped should be avoided, such as stranded wiring, porous components, open relays or transformers.

One of the most dangerous properties of these organic fluxes is the ability of the residue to absorb water from the environment, greatly increasing its quantity and mobility. There is no such thing as self-neutralizing flux since neutralization requires heating to soldering temperature-a feat which is never completely accomplished.

The advantages for organic water soluble fluxes center on efficiency and ease of cleaning. Since the organic fluxes are very active, very little pre-cleaning is necessary, except to remove oil and dirt other than oxide. Reliability is greatly increased with the decrease in expensive rework. The time and temperature of the soldering process can be reduced since less heat is required to activate the flux. Post cleaning in a water solution also removes other ionic residues which may be on the printed board assembly from previous handling during processing.

This advantage of cleaning with water can also be a disadvantage. The very active fluxes contain hydrochloric acid which can attack copper and lead resulting in rinse water which can be an environmental problem. The solderability of assemblies has improved to the point where milder organic fluxes can be used. Either neutral pH or halide-free fluxes are available to avoid the dissolution of metal in the rinse water. Soldering activity is reduced, but so also is the attack on metals, laminates, and solder mask.

3.3.0.2.4 Inorganic Fluxes (IN classification) These flux materials find very limited use for electrical connections, this type of flux consists of metal chloride salts, primarily zinc and stannous chlorides. The strongest fluxes, the so-called stainless steel fluxes, usually contain a considerable amount of hydrochloric or phosphoric acids. These fluxes are highly corrosive and not completely removable with a water rinse.

3.3.1 Flux Application

All fluxes applied to a single assembly must be compatible. This implies that the flux used in solder paste, wave solder and rework material must be compatible from a chemical and cleaning process standpoint. Objective evidence is explained in Appendix C. If you are able the use the same flux material in a processes (e.g., compatible data is not required using the exact same flux material in the solder paste and rework material).

3.4 Solder Paste

Solder paste is a suspension of pre-alloyed solder powder particles in a flux vehicle to which special agents have been added to enable the solder powder to remain in stable suspension. Solder pastes are non-Newtonian fluids (comprised of more than one phase) and are also thixotropic (a material that viscosity decreases asymptotically over time under constant shear). The materials used to control viscosity and the thixotropic nature of the solder pastes are generally proprietary.

Most solder pastes contain 75-92 mass percent of solder metal (equivalent to approximately 24-45 percent by volume). The agents which are added to prevent the separation of the metal from the light flux vehicle also provide certain rheological properties which are necessary for the methods of application.

3.4.1 Solder Powder The solder powder used to make the solder paste should be controlled to give a consistent material. The mixture of the flux and thixotropic control materials are referred to as the “flux binder.”

Occasionally, solder powders are mixed such that the “bulk” composition is a common solder (e.g., Sn63Pb37) but is in fact a mix of particles of other compositions. An example of this is the solder powder sometimes used for leaded SMD soldering, which is Sn63Pb37 when analyzed in bulk, but is in fact a mix of pure tin and Sn10Pb90 powders. This mixture is used to slow the reflow of the joint during vapor phase soldering, thus reducing the number of open solder connections sometimes produced. Although the melting points of both materials are above the typical vapor phase reflow temperature of 215°C, solder reflow is accomplished initially by solid state diffusion between the individual particles, creating a meltable alloy at the interface. In this manner, complete reflow is achieved.

3.4.2 Particle Shape Effects The shape of the solder powder affects a number of paste characteristics.

- Oxide formation on the surface of the powder. The larger the surface-to-volume ratio, the larger the amount of oxides can be formed on the solder paste. These oxides will inhibit reflow and increase the formation of solder balls (which can lead to a reduction in overall volume of solder in the completed joint).
- Large variations in particle size and shape. This will increase both the wear on the dispensing equipment (e.g., stencil, screen, or syringe) and the probability of small openings becoming blocked by solder particle “log jams.”

3.4.3 Solder Particle Size Effects Solder particle sizes are a result of the solder powder process combined with post process sorting of the powder using mesh screens to sort the powder by size. Typically, solder powder sizes are categorized by a mesh value, which indicates whether the powder in question passed through the screen (-) or is retained on top of the screen (+). This value sign will precede the mesh value. A summary of common mesh sizes used for solder powders is shown in Table 3-6.

Table 3-6 Mesh Size vs. Particle size for Solder Powders Used in Solder Paste

Mesh Size	**Particle Sizes (mm)**
–325	Less than 45 mm
–270	Less than 55 mm
–200	Less than 75 mm
–200, +325	Between 45 mm and 75 mm

The choice of appropriate solder paste size is a tradeoff between the ease with which the solder paste can be printed, stenciled, or dispensed vs. the amount of solder balling. The smaller the particle size the more likely solder balling is to occur. Large number of solder balls is referred to a solder fines and depending on size may be washed away during the post solder cleaning process. By requiring both an upper and lower boundary for particle size (e.g., – 200, +325) may reduce solder fines.

3.4.4 Oxide Content in Solder Paste Oxides are formed by the exposure of the solder powder to air either during the powder fabrication or the addition of the binder materials. Solder powders typically contain some oxides, but new manufacturing techniques have made it possible to fabricate the solder paste (from powder through mixing with the binder) with an oxide content <0.03% by weight. When the oxide content increases to above 0.15% by weight, solder balling may result, especially with less active (ROL0/ROL1) fluxes. Solder oxides are less dense than solder (typically 6500 kg/m3) and will float to the surface of the molten solder.

Two quick qualitative tests for oxide content are:

- Reflow a small amount of paste on a substrate (typically 200 microns thick, with a 5.5 mm diameter) and look for the presence of solder balls. The size and number of solder balls are an indication of oxide content.
- Reflow about 10g of solder paste under a reflow fluid (typically peanut oil) at 215°C. Allow to cool under the oil, then remove and examine. The oxides will float to the surface and appear as a bumpy/dull area on the top surface

of the solder "button."

3.4.5 Metals Content Typically, the metals content of solder pastes is expressed as a percentage by weight. For most electronics applications, the solder paste used is 80 - 95% metal by weight. As the solder paste metal content decreases, the viscosity of the paste typically becomes more dependent on thixotropic control materials. These materials typically lose effectiveness with increasing temperature; therefore, pastes with lower metal contents have an increased tendency toward slump. Typical metal contents as a function of paste application method are shown in Table 3-7.

Table 3-7 Recommended Viscosities of Solder Pastes (@25°C; 1 Pazs = 1000 centipoise)

Application Method	**Metal Content (% by weight)**	**Viscosity (Pa*)**
Stencil Print	90%	600-1000
Screen Print	85%-90%	400-700
Syringe Dispenser	80%-85%	200-450
Pin Transfer	75%	50-250

3.4.6 Paste Viscosity The viscosity of the solder paste is highly dependent on:

- Temperature: in curves of viscosity vs. temperature, breaks in the curve can be caused by a phase change in the binder material.
  - ~~1)~~ Applied shear stress.
  - ~~2)~~ The "work history" of the solder paste: a result of the fact that as a solder paste is exposed to shear stresses, the viscosity drops and doesn't recover immediately.
  - ~~3)~~ The shear velocity at which the viscosity is measured.

A demonstration of these effects is shown in Table 3-8.

Table 3-8 Effects of Parameters on Viscosity (Shear rate is 1.5/sec unless otherwise noted)

Parameter	**Change**	**Viscosity Change (Pa)**
Particle Size	1-45 mm to 40-80 mm	From 250 to 390
Metal Content	86% to 90% (mass)	From 280 to 400
Temperature	From 18°C to 28°C	From 320 to 220
Shear Rate	From 0.1/sec to 50/sec	From 2000 to 50

As a result, all of the preceding items must be tightly controlled in order to get repeatable results between various test sites. Two types of viscosity measurement equipment are typically used for solder pastes: a rotating concentric cylinder method and a rotating helipath with a paddle.

In each case, it is essential to ensure that the solder paste stabilizes at a specified temperature (23°C - 25°C) prior to measurement. Any mixing done in order to prepare the sample (e.g., moving a sample from one container to the test container) should be controlled and/or done well before the measurement is taken. Typically eight to 24 hours are needed to allow for a sample of solder paste to achieve a stable and uniform temperature. This would also be adequate time to allow for any "mixing" effects to subside.

As viscosity changes with velocity, a measure of viscosity at 2 or more points in the paste's operating range (as determined from squeegee print speed) is the most informative. This information can be used to develop a VSI, which can be used to characterize solder pastes for printability. It has been suggested that a VSI of 3-6 is acceptable, with VSIs as high as 8 being available and providing superior printability.

3.4.3 Determination of Correct Paste Volume The use of solder paste allows for a unique control of the volume of solder deposited for a given solder joint. In this fashion, the volume of solder deposited can be tailored to reduce defects and compensate for other restraints (e.g., need for common thickness of a stencil or pad-to-pad spacing).

Models for determining the volume of solder paste required for a specific solder joint vary from simple geometric models to more complex functions, which take into account such features as surface tension, solder density, gravity, and wetting angle.

In general, the geometric models perform well enough for most purposes and are readily adaptable to spreadsheet type “what if” models.

Items that the model will need to take into effect are:

- Lead shape (including lead-to-lead coplanarity and potential spacing of lead from pad).
- Proposed solder fillet shape.
- Solder volume required for acceptable fillet.
- Solder already present in the form of pretinned pads and leads.
- Variability in lead and pad dimensions.

It should be stressed that this model is only an approximation based on nominal conditions. Allowances should be made for normal and expected process variations.

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- Lead shape (including lead-to-lead coplanarity and potential spacing of lead from pad).
- Proposed solder fillet shape.Solder volume required for acceptable fillet.
- Solder already present in the form of pretinned pads and leads.
- Variability in lead and pad dimensions.

It should be stressed that this model is only an approximation based on nominal conditions. Allowances should be made fornormal and expected process variations.

3.5 Solder Preforms Solder can be manufactured into specific, preformed shapes for use in automated assembly and soldering applications, or when precise amounts of solder and flux are required. Solder preforms are stamped from flat ribbon, formed from wire, cast from melted metal, or made with compacted powdered solder.

Advantages of using solder preforms include:
- Precise amounts of solder and flux for each solder joint.
- Placement can be automated, eliminating the need for manual assembly, inspection and touchup.
- Inaccessible soldered joints can be made.

Disadvantages of using solder preforms include:
- Solder preforms are sometimes viewed as a custom made, non-stock part because of small quantities, limited geometries, and minimum sources of supply. Short run quantities of special shapes may preclude recouping tooling costs.

Selection of solder preforms includes considerations of the solder alloy. In the case of performs containing flux, a determination of the proper flux and percentage required and choosing dimensions which deliver the correct amount of solder to the solder joint. Solder preforms should meet the same requirements for solder and flux.

Flux solvents used in solder preforms should not be harmful to the work piece or solder connection and should be easily removed after the soldering operation. If solder performs are used in surface mount applications, the ability of the fluxes and other constituents to be cleaned from under the part is an important factor in the selection of the flux and the cleaning system.

Solder preforms may contain flux in some form. The fluxes in the creams, pastes, and preforms are under the same restrictions as the liquid fluxes outlined in 3.3 (i.e., L0 or L1 activity, RO, RE, OR bases). Not all solder preforms contain flux.
When a solder preform contains flux that is totally encapsulated, it is called a heat-shrinkable, controlled solder device, which is covered in 4.19.

When the flux is either absent or non-encapsulated, devices can be categorized into the following types:

- **Solder Tapes** These controlled soldering devices are used to deliver the correct amount of solder to multiple wire or lead terminations. The solder tape device consists of a strip of solder and a slotted, high-temperature polymer tape with a pressure-sensitive adhesive on one surface.
- **Solder Columns** These controlled soldering devices are used to provide leadless ceramic chip carriers with conductive mounting columns consisting of a copper helix and solder. The mounting columns serve as compliant, conductive interfaces between the chip carrier and the board.

3.5 Adhesives Several types of adhesives are used in the fabrication of electronic products and provide an electrical, thermal or mechanical function depending on the adhesive properties of each formulation. Selection of an appropriate adhesive should identify the securing properties required, the application and curing method, and the service life of the material in the intended environment. Curing of the adhesive material is to be performed as defined by the Manufacturer and can typically include thermally activated, ultraviolet (UV) light cured, two-part epoxies and ambient cured. Adhesive applications exist for temporary adhesives intended to remain in place until a process operation is completed and the material can then be removed as directed by the Manufacturer.

The location of the adhesive prior to and after curing should not degrade the ability of solder to form an acceptable interconnection. The selection of adhesive materials should consider all subsequent processing of the soldered assembly, i.e., cleaning processes, additional thermal cycles for soldering other devices, or any electrical, environmental or mechanical testing, so as not to degrade the attachment characteristics.

3.5.1 Chemical Strippers Chemical stripping is appropriate for solid, single conductor wire only. Chemical stripping of small gauge ((<28 AWG) is used to prevent stretching of the wire and to prevent surface damage caused by mechanical stripping.

When the chemical stripping process is completed, it is necessary to totally remove/neutralize the stripping agent per the Manufacturer’s recommendation. Stripping chemical left on the conductor surface or allowed to wick under the remaining insulation will continue to attack both the insulation and wire surface creating a long term reliability concern.

The chemical stripping chemistry must be selected and processed in a documented manner that does not degrade (i.e. oxidize) the surface of the conductor inhibiting solderability. The stripping agent and process selected for chemical insulation removal should be repeatable. Precautions should be taken relative to health and safety concerns as directed by the Manufacturer of the chemistry used.

If a chemical stripping agent is applied for removal of conformal coating, the surface must be neutralized and cleaned after the conformal coating has been removed, resulting in a solderable surface for subsequent operations.

Temporary maskant materials, applied to protect specific surface areas during production activities, must be completely removed after processing, leaving no detrimental residue or degradation to solderable surfaces.

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Temporary maskant materials, applied to protect specific surface areas during production activities, must be completely removed after processing, leaving no detrimental residue or degradation to solderable surfaces.

3.7 **Components** is adequately defined in the Standard.

3.8.1 Component and Seal Damage

Typically component specification limits for allowable component and seal damage are not readily available on the production floor. Engineering should provide guidelines of component specification requirements for commonly occurring anomalies to component bodies and seals. This guidance can be in the form of visual images and written guidelines clearly detailing acceptable and defective limits of damage for specific components.

3.7.1 **Component and Lead Seal** is adequately defined in the Standard.

3.7.2 **Coating Meniscus** The coating meniscus should never be trimmed as such would violate the integrity of the component body. If trimmed post-solder, the coating meniscus is typically trimmed so the connection technically complies with the requirement that the component body not enter a solder connection. This is a very short-sighted approach to the problem and should not be done. On a lead with a coating meniscus the first 0.040" of the lead adjacent to the meniscus should be considered non-solderable due to outgassing and contamination propagated from the meniscus coating during its curing. (See Figure 3-12)

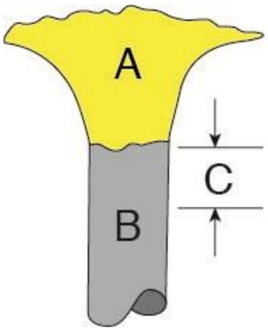


Figure 3-12 Coating Meniscus on a Lead

3.9 Soldering Tools and Equipment Appendix A of the Standard addresses the criteria for selection of hand soldering systems identifying the requirements for temperature control, tip to ground resistance, and system capability to provide controlled and sustainable heat to the connection area. Appendix A also addresses machine soldering system criteria for preheating of assemblies, temperature control and utilization of documented process controls. Specific hand solder system or machine solder system product details from the Manufacturer should be reviewed prior to purchase of equipment insuring production needs are met and component integrity is preserved during processing.

Note: The following will focus on hand soldering tools and associated information.

Regardless of the soldering iron type being used, successful hand soldering depends on the following conditions:

- Thermal contact is maintained between the soldering tip and the item to be soldered.
- Tip size and shape is thermally matched to the component.
- Tip is to be clean and free of oxides with an intact plating finish.
- The operator’s technique creates a thermal "bridge" of molten solder between the tinned tip of the soldering iron and the item to be soldered.
- Flux (typically from cored solder wire or applied liquid flux) is allowed to flow over the area to be soldered in advance of the molten solder, increasing the ability of the surface to accept solder (wetting) and providing a thermal transfer medium to aid in heating.
- Solder volume (amount) is controlled to form an acceptable solder connection.
- Contact time of the tip to the area to be soldered is controlled to create an acceptable solder connection without inducing thermal damage to the component or PCB.

A hand soldering tool can be defined by reducing it to its simplest terms: a heating source and a soldering tip. The heating source (element) provides heat to the tip, and the tip transfers heat from the element to the area and component being soldered. The amount of heat required is determined by the thermal mass of the component and the thermal mass of the laminate material. The mass and physical shapes of the soldering tip are considered when selecting an appropriate tip for a specific solder operation. Many variations of tip design are available to accomplish acceptable solder connections.

Control of the systems heat source (element) is provided by internal sensor technology designed to monitor and provide a constant temperature at the tip, matching the thermal demands of the solder connection being formed. Sensor technology varies from each Manufacturer, with each design focusing on temperature stability, rapid thermal recovery time, low tip resistance to ground, and no risk of ESD damage to electronic products being soldered. IPC – TM – 650 defines various test methods that can be used to evaluate soldering system performance using a common test protocol.

The physical configuration of the PCB laminate structure, which includes the number of circuit trace layers, ground planes and quantity of interconnect locations, will affect the amount of heat required from the heating element. The thermal load of the location to be soldered may require the use of an external auxiliary heat source to elevate the entire assembly to a temperature close to the required reflow point to minimize the risk of laminate damage due to prolonged tip contact time.

Soldering iron tips are typically created by shaping a core material from a copper alloy mixture and applying a plated finish, typically iron, to provide maximum thermal transfer via the copper alloy and surface finish stability with resistance to oxidation. As the plated surface deteriorates or wears over time, oxidation of the exposed copper base layer decreases the ability of the tip to transfer the needed heat during soldering, ultimately resulting in the need to replace the tip.
Tip selection, specifically the length, physical shape and thermal mass, should primarily be capable of providing rapid transfer of heat to the solder connection being formed without thermal damage to the component or PCB surface area. Minimizing the contact dwell time of the heated tip to the solder connection is accomplished by controlling the tip size and shape.

Raising the tip operating temperature significantly above the solder melt temperature to reduce contact dwell time by inducing rapid heat transfer to the connection point can cause thermal damage and poor quality solder connections. Modern heating element sensor technology and low mass tip designs have established the performance required to utilize the tip as a thermal transfer vehicle rather than a thermal storage medium.

When a tip becomes excessively oxidized (plating breakdown) or contaminated with flux residues or other foreign matter, the ability of the tip to transfer heat is greatly reduced. Tips should be kept clean and coated (tinned) with clean solder at all times to reduce oxidation. Replace or recondition tips in accordance with the tip Manufacturer’s instructions. Tip life can be maximized by:

- Using the lowest operating temperature that produces an acceptable solder connection.
- Avoiding physical damage to the plating surface from excessive pressure when soldering.
- Using the tip as a prying tool.
- Minimizing idle time with a hot tip resting in the holder.

Lead Free Concerns When processing requires the use of Lead-Free (Pb Free) alloys, the soldering systems, especially tips, should not be used to process Lead alloy solders to avoid cross contamination. Segregation of soldering equipment for Pb Free processes includes tips, sponges, tip cleaning tools, wire solder and solder paste, wave soldering systems and any supporting tooling that cannot be effectively cleaned of all residual solder.

Hand soldering equipment used for Pb Free soldering is no different than equipment used for traditional SnPb soldering. The same equipment can be used for either application requiring only a tip change to prevent cross-contamination of alloys and adjustment of the tip temperature. Once a tip is used for Pb-free soldering, it should not be used with other solder alloys.

Tip life will be substantially reduced with Pb-free solders. Pb Free alloys have a higher melting temperature and the required operating temperature for Pb Free processing causes the tip to oxidize quicker. Additionally, Tin based alloys (Pb-Free) interact more aggressively with the iron based plating finish on the tips causing the iron to leach into the Pb Free alloys eroding the plating finish. Manufacturers have introduced tips with increased iron plating thickness for tips used in Pb Free processing. Any soldering tip that shows plating cracks, wear areas, or exposed copper core material must be discarded.

4 General Soldering and Assembly Requirements

4.1 Electrostatic Discharge (ESD) Anyone involved in the assembly or handling of electronic hardware must be aware of and mitigate the potential for latent and/or immediate damage to sensitive electrical/electronic components by ESD. The Manufacturer must have a documented ESD control program that provides sufficient protection at the sensitivity level of the most electro-static discharge sensitive (ESDS) device(s) used in the product. This documentation must be available for review by the User.

ANSI/ESD-S20.20 (or equivalent) and ESD-TR20.20 ESD Handbook provide valuable information on establishing an ESD control program, proper handling and storage procedures, as well as how to set up and maintain an ESD-safe facility.

4.2 Facilities A facilities environment can have a substantial impact on the output of a production line. A few considerations are:

- Environmental factors can impair the proper function of solder paste and fluxes, resulting in significant rework.
- Humidity can have a substantial impact on electrostatic charge generation, solder paste and flux performance and many other process parameters.
- .
- Eating, drinking and the use of tobacco production the workplace has the potential to:
  - Subject personnel to possible health risks through the inhalation or ingestion of toxic chemicals or materials.
  - Contaminate the work area and surfaces to be processed, e.g., reducing solderability, adhesion of coatings, etc.

4.2.1 Environmental Controls The intent of this Clause is to ensure that the assembly area is isolated from external process or environmental conditions that may damage or degrade printed circuit boards and components, or adversely impact the solder assembly processes or overall product quality.

A positive pressure air conditioning system ensures that the uncontrolled external environment (humidity, temperature, air drafts, air pollution, contaminating chemicals, etc.) do not enter the soldering facility.

4.2.2 Temperature and Humidity The limits given in this Clause have been accepted as the minimum-maximum range for temperature and humidity in which most solder pastes, fluxes, or other solvents will perform as expected while maintaining considerations for control of electrostatic charges and operator comfort. Process control procedures should include modified limits where special materials or processes dictate.

Enhanced ESD control procedures may be required if humidity levels drop below 30% RH or if ESD Level 0 components are being used.

For more information on electrostatic discharge (ESD) control, see ANSI/ESD-S20.20 (or equivalent).

4.2.3 Lighting The intent of this requirement is to ensure that the work surface is properly illuminated to facilitate component identification, reduce assembly errors, establish a uniform level of illumination between workstations, and to reduce operator fatigue.

The illumination level was reduced to a “should” recommendation in the base document after concern was raised that requiring a minimum illumination level would be cost prohibitive for some assembly houses, because even if they currently met the illumination level of 1,000 lm/m^2 they would be required to verify the illumination level if it was a requirement .

The illumination level was elevated to a mandatory requirement in the Space Addendum.

A note was added to advise Users that the color of the light is useful in assisting the operator in discerning materials and contaminants with increased clarity. Metals such as copper and Kovar® or Alloy42® look the same at color temperatures under 3000° K. However, under higher color temperatures (4500 to 5000° K are best), these metals have very different appearance.

An illumination level of 1,000 lm/m^2 at the work surface is the accepted practice for the minimum level of illumination in which operators and inspectors should be expected to perform their tasks. 1,000 lm/m^2 is approximately equivalent to 93 foot-candles when measured using a photographic light meter.

Storage cabinets/shelving, workbench risers, test equipment, and personnel frequently obscure light from overhead fixtures. Even without obstacles, overhead (ceiling mounted) lighting rarely supplies the necessary illumination and will not meet the specification without supplemental lighting installed directly above the workstation. Before placing a light meter on the surface to be measured, the workstation should be set up the same as it will be for production with personnel in place. This will assure that the value indicated on the light meter reflects actual working conditions.

Lamps with a combination of a light fixture and a magnifying lens are often used because they not only provide illumination but are a useful assembly and inspection tool as well.

4.2.4 Field Assembly Operations The intent of this requirement is to ensure that the effects of exposure to uncontrolled environmental conditions during field assembly operations are understood and mitigated to ensure reliable solder joints and to minimize the introduction of defects in Class 3 products.

4.3 Solderability Solderability may be defined as the ease with which a surface can be wetted by liquid solder under a given set of conditions.

It is the ability that a surface has to form an intermetallic connection with solder. The phenomenon is similar to the water wetting on some surfaces such as paper and because of that, solderability and solder wetting are related terms. One of the main factors that diminish wetting is the level of oxidation on the surfaces. We refer as level of oxidation to the thickness, the distribution, and the type of oxide or corrosion products on the surface. Because it is hard to get an evaluation of the level of oxidation (for example, in some cases a tin oxide thickness of 100 A can prevent wetting from happening), other indirect methods are used which simulate the soldering processes. There are several methods to evaluate solderability and solder processes: therefore, the method to evaluate the solderability of certain element/surfaces **shall** be defined between the manufacturer and the user. In the J-STD-002 & J-STD-003 describe the standard methods to measure it such as wetting balance test in which the attraction force and time to wet the surface are measured.

4.4 Solderability Maintenance
In order to have stable results, the parameters and materials used **shall** be defined and control. The frequency of evaluation **shall** be defined according to quality control requirements or as an agreement between manufacturer and user.
The control of materials used to perform the tests **shall** be kept under control, monitoring the shelve life and their expiration time at any moment and maintaining adequate handling to avoid variation in the results.

4.5 Removal of Component Surface Finishes Many different materials and combinations of materials are applied as surface finishes to component leads and PCB terminations to improve electrical conductivity in high-frequency applications, to provide resistance to oxidation in high heat applications, to preserve solderability during storage and assembly, and to improve contact planarity.

While these finishes are provided to mitigate specific problems, their presence on the surfaces to be soldered may adversely affect proper wetting and overall strength of the solder joint.

4.5.1 Gold Removal Gold is applied to component leads for several reasons:

- It has a low contact (electrical) resistance, and can withstand multiple insertion and removal cycles (when used on PCBs, pin and socket contacts, and edge card connectors).
- It is used by many electrical component Manufacturers because of its compatibility with component fabrication temperatures and its ability to not oxidize, thus maintaining solderability.
- It is often used in microwave applications to enhance surface electrical conductivity and surface wave effects
- It is used on ceramic components to withstand high temperature firings.

Component Leads. The reliability of a solder joint can be degraded due to the formation of a gold-tin intermetallic layer during soldering. Investigations have shown that a gold-tin intermetallic layer forms under normal soldering process parameters. When the weight percent of gold in the solder joint reaches the 3-4% range, this gold-tin intermetallic layer is very brittle. This condition is referred to as gold embrittlement. Shock, vibration, and or thermal environments may cause brittle solder connections to fracture.

Prevention of gold embrittlement of solder joints is possible, provided the following two conditions are met.

1. There is enough solder volume present to allow dissolution of the gold so that the overall weight percentage of gold in the solder joint is below the 3-4% range.
2. The soldering process parameters allow for the solder joint to stay molten (183°C [361°F] minimum) for a sufficient time to allow the gold dissolution to reach equilibrium throughout the solder joint.

Industry testing has shown that the major source of gold embrittlement has been:

- Improper design of gold finishes for soldering, such that the gold finish is so thick (>2.54 microns) that gold dissolution provides a high percentage of gold in the solder joint (>3-4%).
- The soldering process parameters used resulted in a segregated zone of gold-tin intermetallic phase, which cracked.

Either solder tinning the gold finished components with a dynamic solder wave or a double-tinning process can remove the gold.

Gold is used as a PCB surface finish for planarity reasons and to provide a surface for wire bonding. In soldering to a gold PCB surface finish, removal of the gold on the PCB is not necessary, provided the thickness of the gold PCB finish is <2.54 microns, there is enough solder volume present to allow dissolution of the gold so that the overall weight percentage of the gold in the solder joint is below the 3-4% range, and the soldering process parameters allow for the solder joint to stay molten (183°C [361°F] minimum) for a sufficient time to allow the gold dissolution to reach equilibrium throughout the solder joint.

4.5.2 Other Metallic Surface Finishes Removal Many different materials and combinations of materials are applied as surface finishes to component leads and PCB terminations to improve electrical conductivity in high-frequency applications, provide resistance to oxidation in high heat applications, preserve solderability during storage and assembly, and to improve contact planarity.

While these finishes are provided to mitigate specific problems, their presence on the surfaces to be soldered may adversely affect proper wetting and overall strength of the solder joint.

4.6 Thermal Protection

Any processing of assemblies that requires application of heat could potentially damage thermally sensitive components. Heat can damage acomponent when applied directly to a component, or when heat is applied to an adjacent component that is being processed. Soldering and desoldering processes can expose components to temperatures that may cause damage to the electrical characteristics of the component being soldered into place. Some component designs contain external or internal elements that can be damaged. These elements may change the value or be damaged such that the device does not function per the electrical requirements of the circuit design. Heat exposure may also cause latent damage to some thermally sensitive components. This type of damage may or may not be detectable during test. Thermal sensitivity limitations for each component type can typically be found in the component manufacturers' data sheets. Recommended soldering processes can also be found on the component manufacture’s data sheets or in their application notes. Data sheets should be consulted to validate sensitivity levels.

When thermally sensitive components are identified, heat sinks should be used to isolate and prevent the induction of heat into the component body and internal elements. Thermal protection for surface mount components may take several different forms. A controlled preheat method or a hot air pencil soldering process may be needed to prevent thermal shock to some components. A masking method may be needed to shield adjacent components that are thermally sensitive.

Heat sinks are typically used to prevent the heat from damaging through-hole components during the soldering operation. They can range from simple alligator types of clips to reverse tweezers, which are typically attached to the lead between the component body and the area where the solder joint is made.

Component materials, such as those used for plastic body microcircuits, have other problems associated with processing temperatures.

One component of particular concern is the Multi-Layer Ceramic Chip Capacitor (MLCC.) Due to their complex mechanical structure, MLCC's are susceptible to damage caused by thermal and mechanical stresses. Micro cracks can form under end terminations, inside the component body. These cracks are undetectable during visual inspection, product test, or x-ray, and can result in latent field failures. Destructive analysis of the component is needed to verify this internal damage. Unless you produce Space Flight or Class 3 hardware, chances are you would not analyze failures to the component level, therefore, not knowing if failures are attributed to thermal shock of MLCC's. We, as manufacturing and quality professionals, can and should question attachment/assembly methods if we know there is risk associated with a specified or unspecified process.

Identification of MLCC's is critical. They are chip style capacitors that can come in a variety of sizes. Their reference designator, usually screen printed on the board, will begin with a "C". (C1, C2, etc.) Work instructions and drawings may not identify which components are MLCC's. An MLCC body is made of a ceramic material. The most common MLCC's are yellow, gold or tan in color, but may come in other colors. MLCC ceramic body color is consistent (homogeneous) around the entire chip body. MLCC's have end termination metallization that is 5 sided; top, bottom, two sides and the end of the chip. Although this is not visible from the outside of the component, internally, they have layers of metal electrodes.

Typically, MLCC's are automatically attached to the CCA and soldered as part of an automated reflow soldering process. This reflow process includes temperature ramp up and cool down rates which do not damage MLCC's unless the profile was not correct. Thermal shock to MLCC's usually occurs during hand solder operations where a soldering iron is used. This would include solder touchup, component replacement, or special modifications such as hand soldering wires or component leads to the same pad an MLCC is seated on and soldered to. Thermal shock to MLCC's may also occur during rework of adjacent components if precautions are not taken to prevent thermal stress to surrounding components.

Component manufacturers do not recommend hand soldering of MLCC's, however, they do provide strict guidelines for cases where hand soldering is unavoidable. Recommended soldering processes can typically be found on the component manufacture's data sheets or in their application notes. It is critical to be familiar with the approved soldering process so we can recognize a process issue when processing instructions are incorrect or if proper instructions are not being followed.

Operator awareness is critical. If there is no MLCC hand soldering process in place, assembly personnel should know that if they are asked to use a soldering iron to hand solder chip capacitors, or if they are presented with rework/modification instructions that include hand soldering of chip capacitors with a soldering iron, they should verify if these components are MLCC's before proceeding

Additional information and specifics can be found in "*Reliability of Multilayer Ceramic Capacitors"* By Michael H. Azarian, Ph.D., CALCE Electronic Products and Systems Center, University of Maryland August 9, 2005

4.7 Rework of Nonsolderable Parts Parts that are not solderable can sometimes be reworked. Before reworking the parts, they should be visually examined for obvious damage.

Typically, there are three ways to rework non-solderable parts: cleaning, chemically treating, and re-tinning.

Parts will sometimes not solder properly because they are dirty or contaminated. Contamination, such as skin oil or hand cream, can prevent the flux from reaching the lead surface or inhibit the flux's cleaning function.

Note: If the parts are to be re-tinned or chemically treated, they should first be cleaned to remove all grease, oil, dirt, flux, and other debris, and then properly demoisturized. Solvents or aqueous cleaners should be selected for their ability to remove both ionic and nonionic contamination, and must not degrade the materials or parts being cleaned.

Chemical treating requires specialized solutions. Part leads are usually immersed in a solution to deoxidize the finish or strip and re-plate the finish. The solution is then removed and the parts dried.

If parts are not solderable upon receipt, the supplier should be contacted and corrective action should be requested (even if parts are reworked in-house). If possible, the parts should be returned to the supplier instead of trying to restore the solderability in-house.

Tinning is not a guarantee of restoring solderability, especially in instances where the component has been subjected to sufficient thermal cycling tests to induce intermetallic formation. All tin-lead coated leads will contain a very thin intermetallic layer between the tin-lead coating and the copper from the lead.

4.8 Preprocessing Cleanliness Requirements The most common cause of solderability problems and poor solder joint quality is contamination.

Prior to any soldering operation, the components to be soldered must be clean and free of any contaminants that would interfere with the soldering process. Clean components should be handled in a manner that prevents transfer of contaminants onto the solderable surfaces of the component leads or terminations.

Contaminated components should be cleaned with a process that adequately removes the contamination but does not damage the component bodies, leads, or terminations.

Cleaning is covered in greater detail in Clause 8.

4.9 General Part Mounting Requirements

Some components are sensitive to heat and some soldering processes impose more thermal stress than others. Heat sensitive components should be identified and documented per process, to manually install and solder using a thermal shunt or heat sink where applicable.

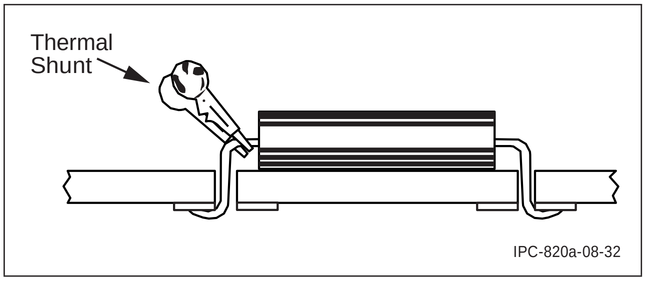


Figure 4-1 Thermal Shunt

Component Cleanliness Prior to any soldering operation, the components to be soldered must be clean and free of any contaminants that would interfere with the soldering process. Clean components should be handled in a manner that prevents transfer of contaminants onto the solderable surfaces of the component leads or terminations. Contaminated components should be cleaned with a process that adequately removes the contamination but does not damage the component bodies, leads, or terminations.

The assembly process should also address the need for interim cleaning. This is especially important in instances where:

- Subsequent assembly may be adversely impacted by contamination from previous soldering operations,
- Subsequent assembly may prevent removal of contamination from previous soldering operations, or
- The assembly sequence may be interrupted for periods of time that would allow contaminants to oxidize/harden (making removal at a later time difficult).

Cleaning is covered in greater detail in Clause 8.

4.9.1 Stress Relief Stress relief for wires and components is the gradual bend of the attaching wire/lead to the terminal post or solder connection. The gradual bend alleviates stress to the component seal and solder connection during heating and cooling cycles by electrical operation or environmental operating environment. When installing wires or components ensure that the attaching wire or lead has a gradual bend prior to soldering the connection. The bend should not be made after soldering so no stress is induced into the completed solder connection.

4.10 Hole Obstruction Hole obstruction usually occurs when components are mounted flush to the topside of a circuit board, or when spacers/mounts are installed improperly. The component body rests on the top of the board while the leads extend through the PTH. Topside hole obstruction can result in solder defects on the opposite side of the board. The component "caps off" the hole, which traps air and flux during the soldering process, resulting in a partially filled hole. The entrapped air and flux sometimes "outgas" during soldering and solidification resulting in blow holes.

Whenever possible, the component should be spaced up off the circuit board surface to allow an escape route for the air and flux during the soldering process by using a component with stand-off features on the component body structure, by using temporary spacers under the component or by installing the components using permanent "footed" spacers. The use of permanent spacers is normally only allowed if documented on the assembly drawing.

4.11 Metal-Cased Component Isolation Parts or metal cased components mounted over electronic circuitry should be adequately separated or insulated from conductive elements to prevent an electrical short. The clearance between components with metal cases and other conductive paths should not violate minimum electrical clearance. The assembly drawing should specify the insulative material required.

Permanent solder mask generally does not constitute an acceptable insulator for this purpose. The dielectric properties of the solder mask should be determined for acceptable values if it is to be used beyond intended material requirements (i.e., insulation).

4.12 Adhesive Coverage Limits Adhesives are frequently used to tack down wires and component bodies on electronic assemblies and can be applied prior to the soldering process. If applied prior to the soldering process, adhesives should not be applied to surfaces that will subsequently be soldered. Adhesives over solderable surfaces render the surface unsolderable. The application of the adhesive should be performed using the appropriate application device.

The selection of the adhesive material should be made carefully. Adhesives selected should be those that are designed for use on electronic assemblies that do not produce undesirable outgassing. The adhesive curing mechanism can potentially outgas detrimental materials, which can result in electrical leakage, corrosion, and metal migration.

4.13 Mounting of Parts on Parts (Stacking of Components) Unless specified on the assembly drawing, the stacking of components is not allowed. When stacking is allowed, the component assembly must not violate minimum electrical clearances between other parts or components.

Stacking may involve the soldering of surface mount chip components on top or alongside of each other. Stacking usually occurs when the existing design must be modified to incorporate additional components on the assembly and the PCB does not permit proper mounting of the device. Stacking should be documented on the assembly drawing. Stacking of resistors on top of each other is not recommended because the resistance of the bottom resistor could be changed by the presence of solder on the deposited element. When resistors are mounted on their sides, the deposited element(s) should be positioned towards the outside. Bridging components across other components is not recommended, as shown in Figure 4-2.

Figure 4-2 Component Bridging

4.14 Connectors and Contact Areas The presence of foreign material on a connector-mating surface is a serious defect and must be prevented. Foreign material may result in increased electrical resistance through the connector, fretting/abrasion/corrosion of the mating surface, or other mechanical damage to the mating surfaces.

4.15 Handling of Parts Devices are often handled by a variety of personnel between initial fabrication and final acceptance. Care must be taken during assembly and acceptability inspections to ensure product integrity at all times. A sample inspection of devices for physical damage (lead seal cracks, deformed device leads, case cracking, etc.) is often desired. This is especially true in the case of fine pitch devices, where small variations in coplanarity between leads can lead to solder defects (open solder connections) downstream. Ensure that soldered boards are allowed to cool sufficiently prior to cleaning as immediately immersing in cleaning solvent can cause thermal shock to the boards, components and soldered connections.

Recommended Practices for Handling Electronic Assemblies

1. Keep workstations clean and neat. There must not be any eating, drinking, or use of tobacco products in the work area.
2. Minimize the handling of electronic assemblies and components to prevent damage.
3. When gloves are used, they need to be changed as frequently as necessary to prevent contamination from dirty gloves.
4. Solderable surfaces are not to be handled with bare hands or fingers. Body oils and salts reduce solderability, promote corrosion and dendritic growth. They can also cause poor adhesion of subsequent coatings or encapsulants.
5. Do not use hand creams or lotions containing silicone since they can cause solderability and conformal coating adhesion problems.
6. Never stack electronic assemblies or physical damage may occur. Special racks need to be provided in assembly areas for temporary storage.
7. Always assume the items are ESDS even if they are not marked.
8. Personnel must be trained and follow appropriate ESD practices and procedures.
9. Never transport ESDS devices unless proper packaging is applied.

4.15.1 Preheating This clause deals primarily with preheating of the product prior to soldering operations.

This process should heat the boards to the point of eliminating the volatiles in the flux, preparing the board for soldering by raising its temperature to reduce thermal shock and improve solder flow in automated soldering processes (i.e. wave solder, selective solder or reflow). The preheat temperature should also be sufficient to raise a flux to its minimum activation temperature, especially under thermally shadowed areas. Preheating can be achieved through various means including hot plates, radiant heaters, forced hot air, infrared reflectors, etc. Whatever method is used, it is necessary to have efficient preheating temperature control.

4.15.2 Controlled Cooling A basic principle in metallurgy is that the physical properties of an alloy are highly dependent on the microstructure that develops as the metal is “frozen”. One of the most common processes used to control the microstructure is controlled cooling, often referred to by metallurgists as “quenching”.

The primary benefit behind the use of controlled cooling in electronics assembly is to reduce the temperature of the just-soldered assembly at a controlled rate to control the grain size in the solder joint microstructure, while also preventing thermal shock and stress on the components and circuit board to prevent damage (e.g.: component damage, solder joint cracking, excessive bow/ twist).

The secondary benefit is increased production through-put rates as the time between solder assembly and cleaning is reduced because the time delay necessary to allow the assembly to cool to a safe handling temperature is reduced.

Rapid cooling promotes fine grain growth in the microstructure, contributing to a stronger interconnection, and reduced liquidous dwell, which minimizes intermetallic growth, excessive oxidation and exposure of the assembly to high temperatures. However, rapid cooling also subjects the components and the circuit board to uneven mechanical stress that could promote both immediate (cracked component bodies or solder joints) and/or latent damage (micro-fractures in the intra-layer interconnects).

Reducing (slowing) the cooling rate produces a larger/coarser grain size, resulting in a solder joint with increased yield strength and tensile strength, but reduced fatigue resistance. A slower cooling rate may subject the assembly to increased dwell at elevated temperatures, resulting in intermetallic growth, oxidation, and aging.

The generally recommended maximum cooling rate for the most sensitive components on a printed wiring assembly is not greater than -6°C / sec. (-10.8°F / sec.). For most surface mount assemblies, the cooling rate is often controlled by the presence of chip capacitors on the board, but other components may have unique thermal sensitivities that must be accommodated to prevent damage. It is therefore recommended that the component datasheets be reviewed before implementing controlled cooling.

4.15.3 Drying/Degassing The base document recommends that the assembly (components and PCB) be treated to reduce detrimental moisture or other volatiles.

During fabrication and storage, both components and PCBs will often absorb moisture. This absorption of moisture can create defects during the soldering process. When heat is applied to the PCB and components, pressure from the entrapped moisture builds up and can lead to PCBs or component delamination (cracking), soldering voids (especially in PTHs), and device cracking.

To prevent damage from moisture exposure bare PCBs should not be left in the open ambient air for and extended amount of time. They should be placed in a nitrogen environment/dry cabinet or used within a limited period of time after being removed from a vacuum bag. If the level of moisture is unknown, bare PCB cards should be baked to remove any moisture from them.

For PCBs, the bakeout removes moisture accumulated during the fabrication process and absorbed during storage. Recommended baking times and temperatures are given in Table 4-1. Longer bakeout times and higher temperatures are not recommended, as they can degrade PCB and component solderability. See IPC-1601 for additional PCB storage and handling information.

Table 4-1 Baking Times and Temperatures (Bare/Unpopulated PCB)

Temperature, °C (°F)	Time (Hrs)
120 (248)	3.5 to 7
100 (212)	8 to 16
80 (176)	18 to 48

Moisture reabsorption begins immediately upon removal of the PCB from the oven and is linearly related to RH. For a storage environment of 20°C and 30% RH, a maximum interval of two to three days is recommended with the interval decreasing with increasing humidity.

Moisture or process sensitive components (as classified by IPC/JEDEC J-STD-020, ECA/IPC/JEDEC J-STD-075 or other documented classification procedure) should be handled in a manner consistent with IPC/JEDEC J-STD-033 or other documented procedure.

4.15.4 Holding Devices and Materials Sometimes it is necessary to utilize additional positioning devices, fixtures, or materials to hold down the components or the board during the soldering operation. These materials typically are not solderable and do not contaminate any of the surfaces being soldered, nor do they prevent any solder wetting and fillet formation.

Space Addendums (ES/DS): The Space Addendums modified the requirement to ensure that the use of holding devices and/or materials does not pre-load component leads or conductors with stress (spring-back force) during the solder solidification phase.

4.16 Machine (Nonreflow) Soldering

4.16.1 Machine Controls The intent of this requirement is to ensure that documented procedures are available at the machine describing the operation and sequence for starting, operating, adjusting, and shutting down the equipment. This helps ensure the process is repeatable and controlled.

These controls are implemented for wave solder machines and fountains to allow solder to flow through the Plated Thru-Hole (PTH) barrel and create an intermetallic bond between the solder and the lead, and the solder and the barrel.

Some of the conditions that can be controlled within these processes include (but are not limited to), solder level (in both bath and fountain), solder temperature, atmosphere conditions (i.e. air or inert gas), flux amount and coverage area, solder wave contact time, conveyer speed, and pre-heat temperature (if applicable).

Varying any of these conditions may have an impact on the solder's ability to wet to the surfaces being joined. Any impact on the ability to form an intermetallic bond with the surfaces being joined and will impact joint reliability. This is why changes or adjustments must be identified!

Topping Oils

Many wave soldering machines are set up to incorporate oil either on top of the solder in the pot or injected into the wave to assist soldering. Essentially, these proprietary oils are an extension of the flux system. With the purpose of lowering interfacial surface tensions between the solder and metal surface being soldered, the topping oil also reduces oxides on the solder pot. Most oils are composed of mineral oil, fatty acid, and anti-oxidizing agents.

This type of oil is compatible with the rosin flux and solvent removal system. Organic water soluble fluxes require a water soluble type of topping oil such as glycols, wetting agents, or other high temperature water soluble liquids.

4.16.2 Solder Bath Sn60Pb40 and Sn63Pb37 solders are typically used in solder pots with soldering temperatures of 260°C ± 5°C. Wave solder temperature set-points may be varied from 232°C to 287°C, with higher temperatures being used for more massive PCAs and lower temperatures for thermally sensitive devices (with Sn/Pb/Bi solders being used for cases of extreme thermal sensitivity).

Excessive solder temperature may adversely affect the performance of WOA activated low residue fluxes. The User should always refer to the product data sheet of a specific flux for guidance on recommended processing temperatures. Once the temperature of the solder pot has been determined and set, it should not be changed to accommodate various board sizes or configurations. These changes should be factored into the proper conveyor speed and preheat dwell time. Change in the solder pot temperature is both time consuming and delays manufacturing time. The major point in not changing solder pot temperature with various boards is the change that will occur in the viscosity of the solder, which will impact the fluidity of the solder and quality of the solder joints. Another element related to the solder pot temperature is the relationship of tin/lead solder temperature to the dissolving rate of the metals being soldered. This is one way to change the concentration of dissolution of copper in the solder pot, which will affect the results of the soldering operation.

Dwell time of a single point on a PCA on the surface of the solder pot is generally limited to three to six seconds to prevent part and PCB damage due to overheating. Dwell time is a function of conveyor speed, wave configuration, and immersion depth (the latter two defining the contact length of the PCA on the wave).

Molten solder is forced (generally by a mechanical impeller) from a sump (solder pot) through a channel and a series of baffles up through a nozzle where it forms a standing wave of molten solder. The molten solder then falls away on either side of the wave back into the solder pot. The configuration of the solder wave varies considerably, but essentially its purpose is to present a constantly renewed (oxide free) source of solder to the bottom surface of the PCB. A thin, static oxide film does form on the wave, but is broken and skimmed away by the advancing PCA during soldering (Lea, C., *"A Scientific Guide to Surface Mount Technology"* Electrochemical Publications, 1988, pg. 133.

The preheated assembly receives the balance of the heat required to raise the joint areas to the soldering temperature, causing the liquid solder to wet those areas to be joined.

The assembly is conveyed, usually up a 4° to 12° slope, until its bottom surface contacts the crest of the solder wave, where the pads, protruding leads, plated holes, and bottom side surface mounted components are soldered.

The solder only wets to, or forms joints on, solderable metallic surfaces. Consequently, no soldering takes place on the board surface, which is non-metallic. Poor soldering can occur on any metallic surfaces that are contaminated or have poor solderability

A common wave for soldering traditional boards with leads in PTHs is the asymmetrical wave used with an inclined conveyor. The majority of the solder flowing from the nozzle flows against the travel direction of the boards. The remaining portion of the solder flows as a smooth laminar stream of solder in the same direction as the board. This small amount of solder flows over a weir, often adjustable in a vertical position, so that the speed of the solder flowing towards the exit weir is moving at the same speed as the board and the conveyor. With the boards and the solder moving in the same direction and at the same speed, the drainage conditions where the assembly separates from the wave are ideal for optimum soldering results.

Various wave configurations have been used, including the narrow parabolic wave, the wide wave, the adjustable wide wave, and the hollow jet wave. Some are operated with horizontal conveyors and others with inclined types. To eliminate solder bridges sometimes formed as a board separates from a solder wave, some wave solder machines may have an air knife fed with hot air. This sweeps any bridges from the joint areas before the solder has had a chance to solidify.

When used in a nitrogen wave soldering system, nitrogen is supplied to the hot knife.

For wave soldering of surface mount assemblies where, in addition to the usual leaded components, small chip components have been glued to the bottom of the board, two solder waves are sometimes used. The first solder wave is usually a high, rather narrow wave made turbulent by some mechanical means. This is achieved by pumping the solder through rows of small fixed or moving holes at the outlet of the nozzle or by means of a unidirectional hollow jet wave. The jet wave’s flow trajectory is usually aimed in the same direction as the board’s travel direction. This first turbulent wave is followed by an asymmetrical laminar wave as previously described.

The turbulent action of the first wave causes the solder to move in and around all the chip components to help ensure that all solder joints get soldered. Those that are still not soldered will most likely be soldered when contacting the second wave. In some designs, a vibrating device is added to produce additional mechanical pressure in the second laminar wave to promote hole filling and further reduce solder skips. With double wave systems, a separate pump (usually found in the same solder pot) for independent wave height control drives each wave. Some machines have the two waves in separate solder tanks, in which case it is possible to control the solder waves at different temperatures.

A number of wave configurations are currently in use. In order to evaluate them, it is necessary to understand that the solder wave in contact with a PCA can be divided into three regions:

- The wave entrance, or wetting region, is where initial contact with the solder is made. The final evaporation and dispersion of the flux and the initial wetting (especially to bottom side SMDs) is done here. Solder wetting and “skips” are generally related to this region. Low frequency vibrations are often set up in this region (or a separate oscillating wave is used) to both “scrub” the solderable surfaces and aid in the fluxing action. This is also done to achieve a degree of initial flux distribution and solder wetting on bottom side SMDs to reduce shadowing or skipping of these connections.

  A similar effect is accomplished by using a “dual wave” system, combining a “rough” and a “smooth” wave. Skipping of bottom side SMD connections is aggravated by both increasing part size vs. spacing between parts and the placement of the to-be soldered lead too close to the part body.
- The middle, or “heat transfer,” region, where the bulk of the heating and solder wetting and spreading occurs.
- The exit, or “break away,” region, where the PCA exits the wave. This region is the final formation of the solder joints and where solder defects occur. Up until this point, all the solder has been fluid and subject to change and no “joints,” per se, have existed.

The rate at which the solder falls away from the PCA is a function of the inclination of the conveyor (typically tilted at 4° to 12° from the horizontal) and the wave shape. The rate of “break away” in the exit region impacts the formation of solder bridges and icicles. Too slow a rate can lead to solder ball and dross formation and retention on the PCB and associated bridging. Too abrupt a change can leave the solder “stranded.” The rate of “break away” is controlled by conveyor speed and conveyor angle.

Hot air knives directly after the solder wave are also sometimes used to control/reduce solder bridges (cold or room temperature air should not be used, due to possible thermal shock damage to components, especially chip capacitors).

4.16.2.1 Solder Bath Maintenance In order to keep the solder alloy free of foreign elements it is recommended to define the frequency of solder bath analysis. This can be done by atomic absorption or performing elemental analysis of a sample.

Maintenance includes the removal and discarding of the dross from the solder pot. Dust can be inhaled, so precautions should be taken by using filter masks while performing the operation. If oils are not re-used in the wave, they have to be disposed of according to the regulations of the local community, state, and federal/national governments.

4.17 Reflow Process

Ovens used in this process are generally divided into two parts: heating and cooling zones. The total number of zones in an oven can range from three zones to eight or more. When utilizing Lead-free processes it is recommended that a minimum of five zones be employed (although some manufacturers have had success with fewer).

The heating zones are generally comprised of heating elements that increase the air (or inert gas) temperature, and then force the gas over the PCB or assembly to be soldered. The temperatures and air pressure are regulated within the zone to control the transfer of heat to the assembly in order to reach the reflow temperature of the alloy being used. In order to obtain a reliable connection the temperature must remain above the liquidous temperature of the alloy being used long enough to allow for good wetting and the establishment of a good intermetallic bond between the solder and the surfaces being joined. This is referred to as the Time Above Liquidous or TAL. This reflow process is known as convective due to the characteristic of using moving air (or gas) to heat the materials. On the other hand, the cooling zones are dedicated to reducing the temperature by using a ramp down appropriate for the process. In some cases, the air is replaced with Nitrogen in order to diminish the oxidation during the soldering process. This type of configuration should be used when low levels of oxidation are desired. It should be noted that the use of Nitrogen in this process may increase the occurrence of tombstoning.

The process should be set up in accordance with the following variables: the characteristics of the solder paste, the size & thickness of PCB and the component manufacturer’s recommendations (if utilizing process sensitive parts).

In this type of process, solder is applied to the PCB in the form of solder paste, which contains flux and other chemistries that control the behavior of the paste.

A thermocouple or other temperature monitoring device should be used to establish the profile and check it periodically. Profile verification should be done weekly, monthly, or every maintenance period.

For profile acquisition, the position of the sensors or thermocouples on the assembly should provide data at the locations containing the highest thermal mass (i.e. lowest peak temperature) and lowest thermal mass (i.e. highest peak temperature). This will provide data indicating the highest and lowest peak temperatures and allow the profiler to establish set points between them that are at (or slightly above) the reflow temperature of the alloy being used. Areas to consider include the location of critical components, temperature sensitive components, heat sinks and small components in hot areas such as PCB edge, just to name a few.

The parameters to control include (but are not limited to); zone temperature, conveyer speed, and fan speed. It should be noted that once established the conveyer speed should not be changed as such a change will effect heat exchange in all of the oven zones and require an adjustment accordingly.

Solder Paste Solder paste is a mixture of solder particles with flux and materials used to control viscosity and flow/print characteristics.

Solder pastes are non-Newtonian fluids (comprised of more than one phase), as well as thixotropic (a material that viscosity decreases asymptotically over time under constant shear). The materials used to control viscosity and the thixotropic nature of the solder paste are generally proprietary.

Paste Selection Criteria The first step in selecting a solder paste is the selection of the solder alloy to be used (based on soldering temperatures and metallization(s) to be soldered). The flux is then selected as a trade-off between activity required and cleanability. The viscosity and metal content are then selected, based on the deposition process selected, and then the process is optimized to ensure repeatable results. Important parameters to be optimized include solder paste tackiness (the ability of the paste to hold parts in place prior to reflow), slump, and working life.

Another variable to be considered during selection is the ability of the paste supplier to consistently produce and deliver the material with consistent quality. In order to ensure that this quality is maintained, the User needs to control both the storage and use of the paste. This includes ensuring that refrigerated materials have adequate time to reach room temperature prior to use (typically 8 to 24 hours). This avoids condensation in the solder paste. Temperature control during storage and use of the paste is also important.

Care is needed to ensure that “used” solder paste (e.g., material left on screens or stencils after printing) is disposed of properly and not re-used. The viscosity and deposition characteristics of the pastes are often irrevocably changed as a result of prolonged exposure to factory environments due to non-uniform evaporation rates for the constituents of the solder paste binder.

Application Methods Solder pastes can be applied using a variety of application techniques depending on process and manufacturing constraints.

Screen Printing In screen printing, the solder is forced through a mesh screen (typically made from polyester or stainless steel) over which a thin emulsion is spread and cured. Holes are left in the emulsion by imaging of the desired pattern onto the emulsion using UV light, which cures the emulsion in all exposed areas.

Solvent or water washing removes the uncured emulsion, and the final screen is inspected for uniformity of openings, edge definition, and thickness. For fine pitch printing (<1.27 mm patterns), the orientation of the mesh should be at a 45° angle to the orientation of the pads to reduce the shadowing effect of the mesh.

Also, thinner mesh screens are used to produce more uniform results. Mesh size is determined primarily by paste particle size. Generally, the particle size should be z1/3 the minimum opening size.

Parameters for some commonly available screens are given in Table 4-2. The height of the wet print can be calculated as follows:

Table 4-2 Common Screen Parameters

Material	Mesh Count	Thread Diam. mm	Mesh Opening mm	% Open Area
Stainless Steel	60	0.11	0.310	58.3
Stainless Steel	80	0.094	0.224	49.5
Stainless Steel	105	0.076	0.165	46.9
Stainless Steel	200	0.041	0.086	46.2
Polyester	83	0.099	0.201	44
Polyester	137	0.064	0.114	42

hw= (hm z A0) + he

Where
hw = Height of the wet print
hm= Mesh Thickness (~2X mesh diameter)
A0= Percent of open area
he = Emulsion thickness (height)

The wet print height can be combined with the area printed to yield a volume of paste printed. This solder volume is then compared to the required solder volume and the parameters are adjusted until the optimum solder volume is achieved. Modifications can be made in either overall thickness of the emulsion or individual hole sizes (e.g., micro modifications) to optimize print volumes for a mix of component types.

The advantages of screen printing are a relatively fast throughput of product, reasonably inexpensive tooling, and good print definition.

Important parameters in the success of screen printing are:

- Screen fabrication parameters (mesh, material, emulsion thickness).

- Squeegee durometer and angle of attack (typically z80-90 durometer).
- Squeegee pressure (low enough to minimize squeegee deformation).
- Screen snap off (z1/100 distance from edge of screen to start of printing area12).
- Printing speed (speed of squeegee across the printing surface, generally z5 cm/sec).

For fine pitch printing, the variables of squeegee durometer, print speed, and snap-off distance are especially important. Metal-bladed squeegees are especially effective in printing fine pitch connections. Some common screening problems and solutions are listed in Table 4-3.

Table 4-3 Common Screening Problems and Solutions

Problem	Result	Solution
Misregistration due to misalignment of substrate	Bridging and/or voids Increase in solder balls	Use Mylar sheet over substrate to check and correct alignment
Scavenging of paste	Insufficient solder printed	Reduce squeegee pressure Change to higher durometer squeegee Raise snap off height Use thicker stencil Use stencil with larger aperture
Smearing of print	Solder bridges Solder balls	Screen is contaminated. Wipe off bottom of screen periodically.
Clogged screen	Poor or non-existent print	Clean screen by wiping off bottom. Check paste viscosity (may be too high due to evaporation of solvents)
Print thickness too low	Insufficient paste printed	Increase emulsion thickness use harder durometer squeegee increase metal load in paste.
Areas of print with no solder deposited	Insufficient/no solder paste	Distribute paste evenly across screen prior to printing

Stencil Printing Stencil printing is done in a fashion similar to screen printing, except that rather than a mesh screen being used, a metal sheet (typically 0.2 mm thick) is etched to form the printing pattern. The advantages in stencil printing are that the mesh is not present (thus the percent-open area in Equation 7-1 would be 100%) and it is capable of producing finer depositions with a greater paste height than screen printing.

For fine pitch printing, the method of etching the stencil and the smoothness of the sides of the stencil aperture are critical. Techniques like nickel plating, the use of molybdenum foil, laser etching, and electro-polishing are offered to ensure a smooth aperture wall that will then maximize paste transfer from the stencil to the screen.

Syringe Dispensing Syringe application of solder paste is often used where the substrate surface is not flat (thus making screen or stencil printing impossible) or when the number of paste locations are few and/or widely scattered. Syringe application offers a flexible mode of depositing paste, but at the cost of a lower throughput (in terms of printed pads/minute). The volume dispensed depends on pressure, pulse time, needle ID, paste particle size, and paste viscosity.

Pastes viscosities must be adjusted to allow for syringe dispensing. Pastes are often available packaged by the paste supplier in the required viscosities. Carefully controlled air pressure or a mechanical auger generally supplies pressure. The auger system offers the advantage of being less effected by the inclusion of air pockets in the solder paste.

Pin Transfer Pin transfer is often used to deposit an array of solder paste onto substrates or in areas where screen printing is not practical (e.g., substrate is not flat). The volume of paste deposited is a function of paste viscosity, shape and size of pin, and contact time during paste acquisition and deposition.

Solder Paste Bakeout Many solder pastes require a prebake prior to reflow to allow for some of the solvents used to control viscosity to escape prior to exposure to solder reflow temperatures. This step reduces solder balling (caused by “spitting” of the evolving solvents during sudden heating) and internal voiding of solder joints but can increase slump. Over-baking will also lead to solder balling, due to an increase in surface oxidation on the solder particles.

Typically, paste bakeout temperatures are in the range of 70°C to 80°C for periods of five to 30 minutes.

Vapor Phase Soldering Vapor phase soldering uses the condensation of vapor from a boiling fluid to heat the PCA and components up to solder reflow temperatures. In principle, the PCA is lowered into the vapor over the boiling fluid using either an elevator or conveyor, where it dwells until reflow is achieved and is then removed. Vapor phase soldering is used for both surface mount and plated-through hole assembly and was originally developed for the soldering of backplane PCAs using solder preforms.

The vapor used is generated by boiling “primary” or “reflow” fluids, which are generally organic compounds in which the carbon-bound hydrogen atoms are replaced with fluorine atoms. These materials are colorless, odorless, non-flammable, chemically inert, and non-toxic.

Due to the expense of the reflow fluid, a variety of methods are used to keep the vapor contained in the system (vapor loss constitutes one of the largest operating expenses). These methods include cooling coils, long, enclosed tunnels (inline systems), automated covers, and sacrificial vapor blankets (batch systems). The sacrificial vapor blanket (“dual phase”) system uses a secondary vapor blanket, which is usually added over the boiling fluid and contained with a secondary set of cooling coils. The product generally dwells in this zone on the way out of the system to allow for the primary vapor to drain back into the reflow sump preventing/reducing drag out losses. Due to the restrictions being placed on CFC materials such as Freon TF, non-CFC substitutes are available, but most new systems rely on increased cooling coils and a system of tunnels and/or covers to control fluid loss. Some physical properties of common reflow fluids are given in Table 4-4.

Table 4-4 Physical Properties of Vapor Phase Reflow Fluids

Property	**R113**	**LS 230 (Galden)**	**FC 5312 (3M)**
Boiling Point, °C	47.6	230 ±5	215
Molecular weight	187	z650	821
Pour Point, °C	–	–80	–13
Density @ 25°C, g/cm^3	–	1.82	1.93
Density of saturated vapor @ boiling point, mg/cm3	7.38	19.5	20.3
Viscosity of liquid @25°C, centipoise	0.7	8	30
Surface Tension of liquid @25°C, 1000 * (N/meter)			
Specific heat of liquid @25°C, J/(g z K)	0.95	1.00	1.05
Thermal conductivity at 25°C, 1000 * (W/(m z K))	74	70	70
Electrical Resistivity, W z cm	–	2 x 10^{15}	1 x 10^{15}
Heat of Vaporization @ boiling point, J/g	–	63	67
Heat Transfer Coefficient, Horizontal plate @200°C, W/(m^2	–	280	z300

The advantages and disadvantages of vapor phase soldering are summarized in Table 4-5.

Table 4-5 Advantages and Disadvantages of Vapor Phase Soldering

Advantages	**Disadvantages**
Simplicity of control and easy to adapt to new designs - solders both SMT and PTH connections.	Process more likely to induce solder wicking.
Absolute control of maximum temperature, regardless of design/thermal load.	More expensive to purchase and maintain than other mass reflow systems.
Rapid heat-up rate with uniform application of heat for all sides.	Increased intermetallic thickness and a “dull” finish.
Small, unbonded devices are “self centering.”	More likely to induce “tombstoning” of chip devices.

The heat-up rate for a solid body in a vapor phase system can be modeled using the following equation17:

$T_S = ((T_F – T_O) * (1 – e^{(–t/to)})) + T_O$

When $t_O = (\delta * c * V)/(h * A)$

Where:
T_S = Temperature of solid at time t, °C
t = Time, seconds
T_0 = Starting temp, °C
c = Specific heat, J/(kg * K)
h = Heat transfer coefficient, W/(m^2 * K)
T_F = Boiling/Vapor point of reflow fluid, °C
t_o = Characteristic time where TS is = 63% of T_F, seconds
δ = Density of solid, kg/m^3
V = Volume, m^3
A = Area of body, m^2

A listing of some specific heat and density data for materials used in electronics soldering is shown in Table 4-6.

Table 4-6 Thermal Data for Electronic Materials

Material	Specific Heat (J/kg z K)	Density (kg/m3)
Aluminum (Al)	1000	4020
Copper (Cu)	390	8920
Electroless Nickel/Electroless Palladium/Immersion Gold (ENIPIG)	Note 1	Note 1
Electroless Nickel/Immersion Gold (ENIG)	Note 1	Note 1
Electrolytic Gold over Electrolytic Nickel	Note 1	Note 1
Epoxy	1500	1350
Glass	630	2250
Gold (Au)	130	19320
Immersion silver (i-Ag)	230	10490
Immersion tin (i-Sn)	210	7280
Kovar®	460	8360
Nickel	540	8800
Solder (Sn/Pb)	180	8155

Note 1: Each layer will have a different value.

It should be noted that when soldering is involved, the heat-up profile predicted by this equation would also have a delay at approximately the melting point. The length of the melting point is proportional to the difference between the melting point of the solder and the boiling point of the fluid.

This delay is predicted by the equation: $t_L = (\lambda_S * \delta * V)/(h * A\ (T_F - T_S))$

Where:
t_L = Time for solder to change phase from solid to liquid, seconds
δ = Density of solid, kg/m^3
h = Heat transfer coefficient, W/(m^2 * K)
T_S = Temperature of solid at melting point of solder, °C
λ_S = Heat of fusion of solder, J/kg
V = Volume, m^3
A = Area of body, m^2
T_F = Boiling/Vapor point of reflow fluid, °C

Troubleshooting Typically, problems in vapor phase soldering take three forms:

- Dissolution of termination materials (especially on chip devices and gold leaded parts), leading to poor solderability and lowered solder joint strength.
- Open solder connections caused by the solder not staying in the pad area but flowing up the lead (also known as solder wicking/thieving).
- Lifting of one end of chip devices, creating an open circuit (tombstoning).

Typical solutions to these problems are shown in Table 4-7.

Table 4-7 Problems and Solutions in Vapor Phase Soldering

Problem	**Probable Cause(s)**	**Typical Solutions**
Poor wetting/fillet formation	• Contamination • Poor solderability • Excessive dissolution of termination material (plating) into solder	• Ensure components are clean and meet solderability requirements • Use parts with barrier layer (typically Ni or NiPdAu) between termination material and solder joint. • Reduce dwell time after achieving reflow
Cold Solder Lack of solder paste reflow (Crusting)	• Excessive thermal mass • Insufficient preheat	• Use/Increase amount of preheat • Lower mass of work piece (e.g., remove/reduce tooling). • Change to a reflow fluid with lower rosin solubility.
Tombstoning or tipping up of chip devices.	• Solder reflows at one end of device before the other end and wetting force tips part.	• Use/Increase amount of preheat • Revise pad size to reduce pad extension and thus tipping force.
Open connections on leaded SMD devices	• Dissolution/washing of flux and paste by condensing reflow fluid. • Coplanarity - Leads not in contact with paste or pad • Insufficient solder quantity • Solder Thieving - solder flows preferentially to traces or vias	• Improve coplanarity of device leads • Adjust amount of preheat

Critical Parameters for Vapor Phase Process Control By its very nature, the vapor phase process has few critical process parameters, with the exception of the preheat and heat-up rates. Both of these parameters are used to overcome the thermal mass of the board assembly (size, layer count, layer metallization density, laminate material, etc.) and the complexity of the design. Preheat is controlled by the process, while the heat-up rate is a function of the design In setting up the parameters for a new assembly, the operator only controls the speed at which the hardware is introduced to the vapor and the time it dwells during reflow and cool-down.

The dwell time to achieve reflow should be kept as short as possible while achieving complete reflow (usually monitored either by visually monitoring the progress of reflow or by installing thermocouples on the test PCA). The dwell time in the system after reflow (out of the reflow vapor zone) is critical to ensure that the assembly is not inadvertently shaken prior to solder solidification.

Most of the fluids also break down to some degree under thermal loading (use), releasing Perfluoroisobutene (PFIB), a pulmonary irritant with an accumulated lethal concentration of 0.5 ppm over six hours[19]. Vapor phase systems incorporate venting systems to control PFIB release but overheating can increase the rate of PFIB generation. The heating elements in the vapor phase system should be run at an “idle” system when product is not actually being soldered to reduce PFIB generation.

Rosin contamination can build up on heater surfaces, causing localized “hot spots,” and should be monitored and controlled.

Contaminated fluid can usually be reprocessed by the fluid vendor or locally by distillation/filtration to control rosin accumulation.

Fluid loss is also critical, both as an operating cost and a safety hazard. Reflow fluids are typically slippery, and condensation on surfaces, like floors around the system, can be dangerous. Fluid loss is generally caused by drag-out (a function of conveyor speed) or excessive venting.

IR Soldering IR soldering relies on the absorption of infrared radiation into the substrate, components, solder, and flux to heat the assembly to soldering temperatures. IR radiation is sometimes broken down in classes by wavelength, as shown in Table 4-8. For practical purposes, IR wavelengths greater than 100 µm are not used.

Table 4-8 IR Radiation

Class	**Wavelength (µm)**
Near	IR 0.72 - 1.5
Middle	IR 1.5 - 5.6
Far	IR 5.6 – 1000

A summary of the advantages and disadvantages are shown in Table 4-9.

Table 4-9 Advantage and Disadvantages of IR Soldering

Advantages	**Disadvantages**
Low equipment maintenance costs	Peak temperatures are not limited
Less likely to create “tombstoning” and open connections than vapor phase	More likely to cause discoloration of the PCB
Can be run with a variety of processing atmospheres, including inert gas	Can be used to solder only SMD devices (no PTH, unless Intrusive Soldering process is used)

The principle of operation of IR soldering systems is that a surface at temperature T will emit radiation. The Stefan-Boltzman law gives the heat flux generated by this radiation: $q = aT_4$

Where:
q = Heat flux density, W/m^2
a = Constant (for “black body”), 5.7 X 10^{-8} W/(m^2 * °K^4)
T_4 = Temperature of source, °K

The energy transfer between this source and another body (assuming both are “black bodies” or perfect absorbers of IR) is given by: $Q = F_{1,2} * A_1 * \sigma * (T_1^4 * T_2^4)$

Where:
Q = Thermal energy, W
$F_{1,2}$ = View factor, unitless
A_1 = Area absorbing the IR energy
σ = Constant (for “black body”), 5.7 X 10^{-8}W/(m^2 * °K^4)
T_1 = Temperature of source #1 (emitter), °K
T_2 = Temperature of source #2 (recipient), °K

The absorption factor varies as a function of surface texture (rougher surfaces absorb more energy), material, and wavelength of IR radiation.

Infrared sources for SMT soldering and their characteristics are shown in Table 4-10. The first three sources rely on filaments wrapped in a tube directly irradiating the item to be heated. The last type (area source secondary emitter) uses a filament buried in a thermally conductive material and backed (on the side away from items to be soldered) with a refractory material to provide a more uniform emitter pattern.

Table 4-10 Characteristics of Infrared Sources for SMT Soldering

Emitter Type	IR Class	Wattage (W/cm)	Suitability
Focused tungsten tube filament lamps	Near IR	300	Not suitable; problems occur with shadowing and sensitivity to color; overheating likely.
Diffuse array of tungsten filaments	Near IR	50-100	May be used, but heating rate is sensitive to the color of components.
Diffuse array of nichrome tubes filament lamps	Near to middle IR	15-50	Better source; little sensitivity to color and less sensitive to shadowing.
Area source secondary emitter	Middle to Far IR	1-4	Best type; no shadowing or color sensitivity.

The use of an inert atmosphere, such as nitrogen for soldering using IR has been shown to increase production rates and solder joint quality while reducing rework. The benefits derived are:

- Lower oxidation of surfaces (improved solderability and wetting)
- Use of less active fluxes
- Reduced flux spread (across the assembly surfaces), thus decreasing the area needing to be cleaned.
- Reduced solder balling, bridging, and opens (higher solder assembly quality with reduced rework)
- Higher processing temperatures (up to 300°C with <5 ppm O2), as the combustibility of the fluxes are reduced in a nitrogen atmosphere.
- Reduced discoloration of component and board surfaces (improved product appearance).

Critical Parameters for IR Process Control In the establishment of the solder schedule, the main issues are to create a solder schedule with an effective trade-off between rapid heating rates to reduce oxidation and affect reflow on all device types, and the need to protect substrates and parts.

Once a solder schedule or thermal profile has been established for an oven, the main concerns are to ensure that the air (or gas) flow rate and heater efficiencies remain constant to ensure repeatable processing. If gas mixtures are used, they also could be monitored.

Hot Gas Soldering Soldering by hot gas can be done in a number of atmospheres (typically air or nitrogen), with the hot air applied either locally for rework or limited assembly or generally (as in a convection oven). Hot air soldering can be used for either PTH or surface mount soldering.

An advantage of hot gas soldering over IR soldering is that hot gas soldering can approach vapor phase soldering heating rates while avoiding the problems associated with variations in the heating rates of different parts of the assembly, due to variations in IR absorption by different materials.

Process control typically consists of creating solder schedules (relating set points within the oven zones) and monitoring the repeatability of the oven control zones. Repeatability is measured both over time and across the chain in the direction perpendicular to the direction of travel.

Resistance/Hot Bar/Pulse soldering In this process, an electric current is passed through the device leads or a “heater bar”. The resistance of the leads (generally of the material or the contact resistance) is then used to produce the heat required for soldering.

This method can be applied to either individual joints (called “single point soldering”) or multiple joints along one or multiple sides of a leaded component. A thermocouple is generally attached to the heater bar (or thermode) near where the leads will be soldered and a “feedback” control system is used to control temperature. Having the heater bar too hot will burn the flux, making removal difficult.

Resistance soldering is almost exclusively used for the soldering of leaded surface mount devices, with the leads typically extending away from the device body (i.e.: gull wing).

In general, there are two types of resistance soldering systems:

- Single point soldering systems are designed to solder one lead at a time. These use either the heater bar or a "parallel gap" soldering system, where the current passes through the device leads.
- Multiple lead soldering systems, which are similar in method to the resistance bar system, except that the bar extends across a number of leads on one side of a part. Some systems allow for soldering all four sides, typically using four independently operated bars.

Solder is supplied by either pretinning the device or pad, or is added by using solder paste or preforms. Already reflowed materials (solder from tinning or preforms) are typically preferred over paste, due to the lower outgassing and lower volume required.

Critical Parameters for Resistance Soldering Process Control Resistance solder schedules typically have three stages: heat-up, solder reflow, and cool-down. The optimum schedule is one in which the time and force on the pads is minimized.

A summary of the characteristics of these three stages is shown below:

- The heat-up stage is when the heat and pressure are initially applied to the lead and solder. Heat-up rates can run up to 300°C/sec (as measured on the heater bar) for FR-4 material. Due to the thermal mass of the device being soldered, the actual lead/laminate temperature may lag the heater bar by 35°C to 80°C. The heat-up stage should typically last one to two seconds (with one second being preferable).
- The degree of lag is a function of [21]:
  - Heater bar-to-lead contact area (higher areas yield lower thermal lags).
  - Heater bar-to-lead contact force (higher force will reduce thermal lag, but too much force will cause delamination of the PCB and lead misalignment). Typical hold down forces are in the range of 4.2 N/mm [22].
  - The relative location of the heater bar control thermocouple to the leads being reflowed (smaller distances result in lower lags).
- Reflow, or time-at-temperature, is the stage when actual solder flow and solder wetting occur and generally runs four to six seconds. A good measure of adequate reflow time is to look for the "reflow line" or demarcation between the solder reflowed onto the lead and the solder of the pad, which remains un-reflowed. When this line is consistently well away from the leads, the time at temperature is sufficient[23].
- Cool-down is the stage when the solder solidifies. The thermode should be removed from the joint prior to solder solidification to prevent excessive residual stresses from causing solder joint failures.

Hold down (contact) force is also critical to the quality of the solder joint. For best results, it is recommended that low pressure be used initially, increased to a maximum after solder reflow, then rapidly tapered off during cool-down. However, using the thermode to hold down leads badly out of alignment is not recommended, as it may result in residual mechanical stress in the solder joint, leading to creep rupture failures in the solder connection.

Laser Soldering Laser soldering is used for the soldering of surface mount solder joints of both the leaded and leadless varieties. The main advantage to laser soldering is its rapid heating rate (lasers typically produce about 100kW/m^2), without any applied thermal mass (e.g., a soldering tip), or thermal flashover to adjacent areas. This leads to very rapid heating and cooling combined with the ability to only reflow small, highly selected areas, while leaving the balance of the assembly at essentially ambient temperatures.

Typically, the laser is directed either onto the lead or the pad near the lead/metallization. Solder is supplied either by pretinning the lead/metallization or pad or by the use of solder preforms. Solder paste should not be used because solder balls will be produced due to rapid solvent evaporation during soldering.

While lasers have been successfully used for soldering leadless chip and leaded SMT devices, the use of laser soldering of inward facing lead designs (i.e.: J-Lead, L-Lead) may result in PCB damage caused by the excessive beam duration times and power settings needed to achieve solder reflow.

Intrusive Soldering Intrusive soldering may also be known as "paste-in-hole", "pin-in-hole", or "pin-in-paste" soldering.

This is a solder assembly process commonly used for reflow solder assembly of mixed technology boards (SMT and through-hole). Solder paste is applied to the board using a stencil, SMT components are placed on the board, through-hole components are then inserted and the entire assembly is reflow-soldered.

The objective of stencil printing of solder paste for the intrusive reflow process is to provide enough solder volume after reflow to fill the hole and create acceptable solder fillets around the pins.

For recommendations on stencil design for Intrusive Soldering, please refer to IPC-7525, "Stencil Design Guidelines".

4.18 Solder Connection The most important aspect of solder joint quality is wetting.

Wetting is the free flow and spreading of solder on a metallic surface to form an adherent bond. The ideal solder connection has a smooth, concave fillet, the full circumference of the connection, and which extends to the edge of the termination pad. The acceptable solder connection is characterized by good wetting, evidenced by smooth feathering of the fillet onto the connection elements, and by the formation of a small contact angle between the solder fillet and the elements being joined. Contact angles of 90° or less are considered acceptable, although there can be instances where contact angles in excess of 90° are acceptable.

In some solder connections, there will be a line of demarcation, or abrupt transition zone, where the applied solder blends with the solder coating, plating, or other surface material. The line of demarcation is an indication that something interfered with the smooth feathering of the fillet to the connection surface. If there is evidence that the connection is fully wetted, the solder connection is considered acceptable.

There are solder alloy compositions, lead or terminal coatings, and PCB plating and solder processes that tend to produce dull, gray, or grainy solder connections and larger wetting angles.

High temperature and lead-free solder alloys typically produce dull and slightly grainy finishes. Large mass solder connections tend to cool slowly and generally do not produce shiny solder connections. Solder connections with these attributes are acceptable.

4.18.1 Exposed Surfaces Exposed basis metal generally occurs on the ends of pre-tinned or solder-coated leads that are formed and trimmed to length/shape prior to installation. Depending on storage conditions and the amount of time between the trimming and soldering operations, oxides will build up on the exposed basis metal, sometimes interfering with wetting and solderability (especially if low activity rosin (RO) or resin (RE) flux is used).

However, as long as the rest of the solder connection exhibits good wetting, exposed basis metal on lead ends does not affect solder connection integrity and is usually considered acceptable. This also applies to the edges of the PCB circuitry, which may not have been coated with solder or other metal plating, depending upon the PCB fabrication and plating process.

Rational Exposed ferrous metal surfaces may corrode and rust when exposed to high humidity or salt fog environments. The formation of corrosion by-products/debris can interfere with operation of electro-mechanical and optical equipment, can serve as a host for collection of other contaminants, and can pose a Foreign Object Debris (FOD) risk.

4.18.2 Solder Connection Defects

The conditions listed here are considered defects for all three classes because of their negative effect on the form, fit and/or function of the assembly. Solder connection defects and possible causes are detailed as follows:

a. Fractured Solder Connection
   Movement of the connection elements may cause this defect after the solder has solidified. As the name indicates, the solder connection will show evidence of fractures or cracks in the fillet. Fractured solder is an indication of a serious processing or handling problem.
b. Disturbed Solder Connection
   Disturbed solder connections generally occur when one or both of the elements being soldered move during the solidification of the solder connection. Stress lines characterize the connection along with localized granular zones, which may include minute fractures. This may also impact the intermetallic bond.
c. Cold/Rosin Solder Connection
   A cold solder connection is a connection in which the solder has not properly flowed and wetted the surface and the solder does not feather out on the connection elements. A cold solder joint is typically formed in hand soldering operations, not mass soldering. Rosin connections have visual signs of rosin that has not been burned off or activated, and usually congregates between the connection points of the joint.
d. Solder that violates minimum electrical clearance

e. Fails to comply with wetting criteria of 4.18. Solder joints that exceed a 90° angle (except those special cases mentioned in 4.18) are usually a sign that the wetting action has been interfered with (either by contamination, oxidation, plating anomaly, or some other root cause).
f. Solder bridging between connections except when path is present by design. When there is a connection between two points by design, they are electrically common and the circuit function is not negatively affected.

The below defects are only applicable to the space addendum:
g. Overheated solder connection.
h. Blowholes and pinholes (where the bottom and all sides are not visible).
i. Excessive Solder
Solder in the bend radius of axial leaded parts in PTHs is not cause for rejection provided the lead is properly formed, the topside bend radius is discernible, and the solder does not extend to within 1 lead diameter of the part body or end seal.
j. Insufficient solder.
k. Contamination (e.g., lint, flux, dirt, extraneous solder/metal).
l. Solder that contacts the component body (except as noted in 7.5.7 and 7.5.8).
This defect generally applies to through-hole mounted components. By design, some SMDs may have exceptions to this requirement.

If a trend in solder connection defects is identified, it should be noted as a reflection of a possible unstable process, or undocumented change in material, or the improper use of equipment.

4.18.3 Partially Visible or Hidden Solder Connections Partially visible or hidden solder connections are often present in today’s electronics assemblies as circuit complexity and component interconnect density increases. As visual inspection is often the preferred inspection technique used to positively verify that the solder terminations are properly wetted and compliant with the drawing/requirements, the presence of partially visible or hidden solder connections presents a possible conflict with compliance to J-STD-001 [1.11].

Where visual inspection is not possible, and a sampling inspection plan is not part of a documented process in the control plan approved by the User, other nondestructive evaluation/inspection techniques (e.g., laminography, microfocus X-ray, fiberscope optics, etc.) may be used - provided the NDE inspection technique does not damage or degrade the hardware.

BGAs and BTCs are sensitive to reflow conditions; variations in the process, or in the materials could cause solder anomalies and thus NDE inspection can be employed to identify inadequacies in thermal profiling. These types of components will require continuous process control in order to assure the effectiveness of the assembly process.

4.19 Heat Shrinkable Soldering Devices A controlled soldering device (e.g., heat-shrinkable soldering devices) consists of some form of carrier, which delivers controlled amounts of solder and flux to an interface where a solder joint is to be made. There are two classes of controlled soldering devices: encapsulated and non-encapsulated.

Encapsulated devices are those in which the solder and flux are contained within a shaped carrier, formed of insulating material. The carrier changes shape during the soldering process and conforms to the contours of the items being soldered together, encapsulating them and providing environmental protection. The degree of environmental protection provided by this type of controlled soldering device depends on several factors in both the controlled soldering device and items being soldered. In the controlled soldering device, the carrier material and presence or absence of sealant materials affect the ability to provide environmental protection. The number of conductors being soldered, their shapes and sizes, and the insulation material are all factors that affect the degree of environment protection obtained. This protection can be as minimal as electrical insulation coupled with mechanical protection and resistance to gross contamination, as is provided by devices not containing sealant. At the other extreme, devices containing sealant and using materials formulated and configured appropriately can provide sealing against altitude immersion, fluid exposure, corrosive gases, and immersion under conditions of pressure. Because the encapsulated types of controlled soldering devices are already insulated and self-encapsulating, post-installation cleaning is not required.

5 WIRES AND TERMINAL CONNECTIONS

5.1 Wire and Cable Preparation

There are two main methods of removing (stripping) wire insulation to expose the wire conductor: 1) mechanical and 2) chemical. Mechanical insulation stripping can be performed either by manual or automated machine. Manual insulation removal can be accomplished by mechanical or thermal wire strippers.

Automatic Machine Wire Stripping: Automated machine wire strippers are too numerous to cover. Automated wire strippers should be setup operated and maintained per the manufacturer's instructions.

Manual Mechanical Wire Stripping: To avoid damage to wire strands it is suggested to use compound wire strippers (Figure 5-1) which provides precise control of the wire stripping operation. Compound wire strippers are designed for a specific type of insulation (e.g. Teflon, polyethylene, etc.). Compound wire strippers have a series of cavities for specific wire gauges. The user must match the wire gauge to the appropriate cavity. As the handles are squeezed together, the gripper will compress against the wire retaining it in place. Continuing to squeeze, the blades will close around the wire and move in opposing directions from the grippers cutting the insulation and separating the insulation from the wire. After severing the insulation, the insulation "slug" should be removed by twisting it in the direction of the lay of the wire strands. It is recommended that this type of striper be checked periodically for blade alignment and blade sharpness.

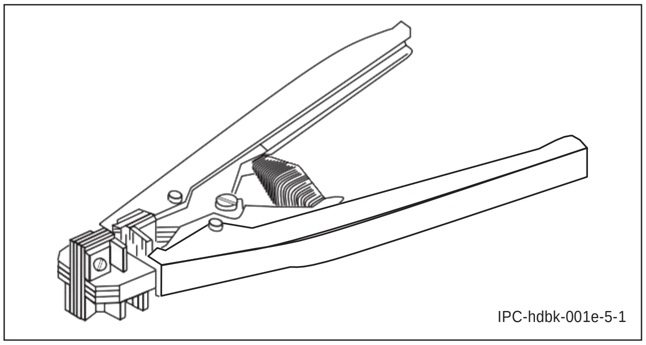


Figure 5-1 Compound Wire Stripper

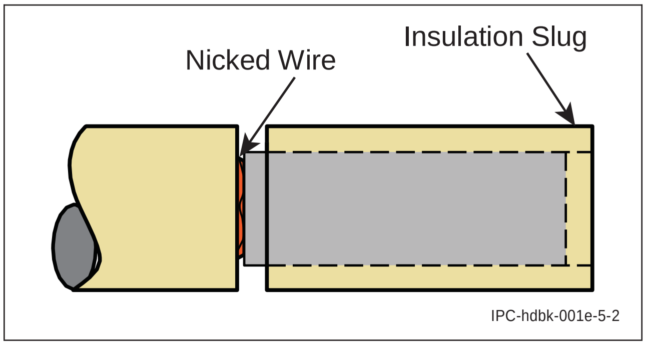


Figure 5-2 Stripped Wire

There are types of mechanical wire strippers that do not provide precise control of the insulation removal process. Users must exercise extreme care to ensure that the V-shaped cutters do not damage wire strands or cut during the insulation removal process as there is no specific wire gauge cavity and wire damage may easily occur at the cut end of the insulation (see Figure 5-2). It should be noted that the use this type of stripper is not allowed for class three products.

Thermal Wire Strippers: Thermal wire stripping is generally performed using “hot tweezers” which strips the wire insulation by melting the insulation down to the wire conductor. Temperature settings should be matched to the type of wire insulation to be removed and set per the hot tweezers manufacturer’s instructions. After severing the insulation, the insulation “slug” should be removed by twisting it in the direction of the lay of the wire strands. To avoid smearing melted insulation into the wire strands the insulation slug should not be removed by the hot tweezers.

Chemical Wire Stripping: Chemical stripping agents (e.g., solution, paste or cream) can only be used with solid conductor wires, such as magnet or enameled wire. The wire is dipped into the chemical stripping agent to dissolve the insulating coating. Only the portion of the insulation immersed in the stripping agent will be removed. Chemical stripping agents must be used in accordance with the manufacturer’s instructions. Chemical stripping agents should be matched: 1) to the type of insulation to be removed, and 2) to ensure maintenance of the wire conductor solderability. Failure to properly remove or neutralize the chemical stripping agent will result in continued degradation of the insulation and wire conductor. The chemical stripping process should be documented to ensure good process control for the use, removal/neutralization, and disposal of the chemical stripping agent.

5.1.1 Insulation Damage Insulation damage can occur throughout the manufacturing process. Examples include mishandling, improper insulation removal process, wire prep operation, or during the final assembly process. When using thermal insulation removal process, slight discoloration is permissible however the insulation **shall not** be charred (burned black). There are some insulation materials that are more susceptible to discoloring when removed by the thermal heating process. At no time during the soldering process can insulation be melted into the wire strands (including the tinning of the wire).

5.1.2 Strand Damage Strand damage is caused by the stripping operation or mishandling. Table 5-1 identifies damage limits for stranded wire. Clause 6.1.2 has criteria for solid conductor damage.

Table 5-1 Allowable Strand Damage[1,2,3]

Number of Strands	Maximum Allowable Strands, Scraped, Nicked or Severed for	Maximum Allowable Strands, Scraped, Nicked or Severed for Class 3 for Wires that will not be	Maximum Allowable Strands, Scraped, Nicked or Severed for Class 3 for Wires that will be Tinned
1 (solid conductor)	No damage in excess of 10% of conductor diameter.		
2-6	0	0	0
7-15	1	0	1
16-25	3	0	2
26-40	4	3	3
41-60	5	4	4
61-120	6	5	5
121 or more	6% of strands	5% of strands	5% of strands

Note 1: No damaged strands for wires used at a potential for 6 kV or greater or otherwise designated as high voltage. **Note 2:** For plated wires, a visual anomaly that does not expose basis metal is not considered to be strand damage. **Note 3:** A strand is considered damaged if nicks or scrapes exceed 10% of strand diameter.

5.1.3 Tinning of Stranded Wire

Wires need to be tinned before they are formed for attaching to solder terminals or formed into splices (other than mesh).

Wires must not be tinned when used in crimp terminations, threaded fasteners, or used in forming mesh splices.. Tinning of stranded wires will not allow a good connection between the wire and crimp terminal. Tinning of threaded fasteners will not allow it to be sufficiently tightened and torqued, if required. Tinning of mesh will not allow the wires to be meshed together so that the strands will interlace evenly.

Tinning of stranded wire is performed following insulation removal. Tinning is primarily performed to assure that the wire/lead conductor to be soldered has a uniform and readily solderable surface. Tinning of stranded wire has the added benefit of bonding the individual wire strands together, thereby allowing the wire to be formed to terminals or attachment points without separation of the individual strands. Limited solder wicking during tinning or soldering of wire is permissible as long as the solder does not extend to a portion of the wire that is required to remain flexible.

Tinning can be accomplished by dipping the bare conductor end into flux and then into a molten solder pot or by using wire solder and a soldering iron. The dwell time in either the molten solder or the application of heat from an iron should be minimized so heat damage to the wire insulation is avoided. The result of either tinning method should leave the wire conductor with a smooth coating of solder with the outline of the strands being visible.

5.2 Solder Terminals The size of the wire and the size of the terminal should match. The integrity of the solder connection is determined by the appropriate installation of the wire into the terminal cup. A full depth insertion gives the maximum amount of surface for both the wire and the cup to form a strong solder joint. The modification of any terminal solder cup, wire or lead is not allowed to accommodate an oversized wire/lead Wire strand deformation or removal weakens the wire and may result in a less reliable solder connection.
NOTE: Gold-plated cups require gold removal if the gold thickness is greater than 2.54 micrometers (see Clause XXX). You can do this by filling the cup with solder and wicking it out.

1. Insert a predetermined number of cut slugs of flux-cored solder wire in the cup. Fill the cup with sufficient solder to ensure solder will not overflow when the user inserts the conductor.

2. Hold the cup approximately at a 45^0 angle to prevent entrapment of gases and flux.

3. Using a soldering iron or resistance-soldering unit, apply heat to the side of the cup until reaching the flow temperature of the solder.

4. If required, place insulation tubing on the wire and slide it back out of the way.

5. Place the stripped and tinned wire in the cup, bottoming the wire in the cup. Maintain heat until it forms a good fillet to the cup and wire. Do not heat longer than necessary to form an acceptable connection. Excessive heat can cause wicking under the wire insulation. “Burp” the connection by moving the wire toward the operator and seating it against back wall of cup. Ensure that the wire does not move while the solder is solidifying.

5.3 Bifurcated, Turret and Slotted Terminal Installation

5.3.1 Shank Damage Damage in the shank can include perforations, splits, cracks, or other conditions that allow liquid processing materials such as flux and cleaning solvents to enter the space between the terminal shank and the mounting hole. Circumferential cracks or splits are those that run parallel to the terminal base. When such damage is present the subsequent soldering process may result in solder entrapment, blow holes, or other solder defects. Circumferential cracks in shanks can continue to propagate allowing a complete separation of the terminal shank from its base.

5.3.2 Flange Damage Flange damage is similar to shank damage, except that it occurs in the swaged or rolled area of the terminal. These types of damage typically are not as serious as shank discontinuities; therefore, some damage is allowed. However, be careful to ensure that any damage does not subsequently result in solder entrapment, blow holes or other solder defects. The process to roll or flare the flange during the installation of the terminal must be controlled, such that radial cracks and splits do not exceed the allowed requirements (see Figure 5-3).

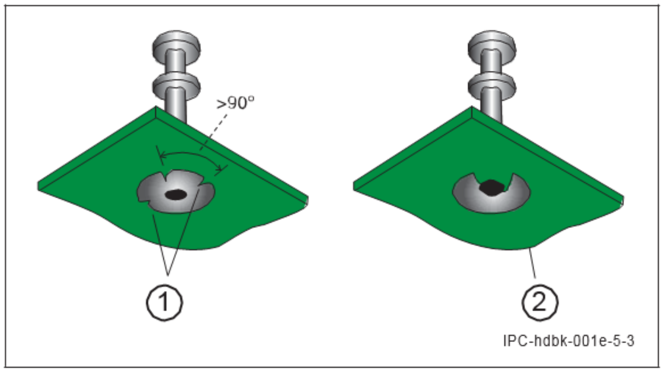


Figure 5-3 Flange Damage

1. **Radial split (3 max)**
2. **Split extends into barrel**

5.3.3 Flared Flange Angles

Flared flange angle is the distortion of the straight terminal shanks outward used to hold/retain the terminal to the PCB prior to soldering. The mechanical fit of the terminal after flaring should be tight, such that the terminal does not tilt, but is loose enough to be hand rotated. The flare is for mechanical retention prior to and during the soldering operation. If the flare is too tight, it may cause crazing around the hole and may prevent solder flow upwards into the mounting hole and may result in laminate damage because of the resulting air gap and the thermal expansion during the soldering process. If the flare is too loose, the terminal could tilt during soldering. The terminal swaging tool should be adjusted to produce a flare within the specification requirements. It is difficult to inspect for the appropriate flared angle and, as such, the tooling must be controlled to ensure that consistent forming of the flare is accomplished (see Figure 5-4).

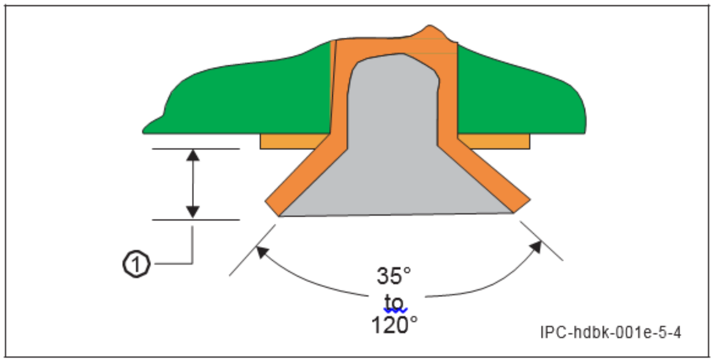


Figure 5-4 Flare Angles
1. 0.4 mm [0.015 in] min. to 1.5 mm [0.06 in] max

5.3.4 Terminal Mounting – Mechanical Terminals not requiring electrical connection to the PCB are mechanically mounted using a rolled flange. The rolled flange should terminate against bare board laminate. If the rolled flange is terminated against printed wiring foil, the foil area of termination should not be part of an active electrical circuit or ground plane. The rolled flange is used when the flange is to only provide a mechanical attachment (see Figure 5-5).

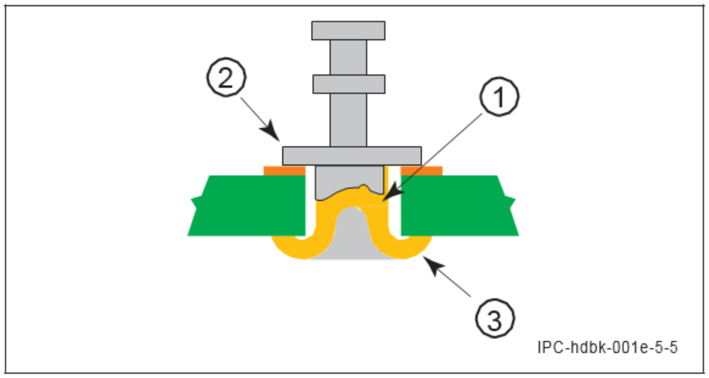


FIGURE 5-5 Terminal Mounting – Mechanical
1. Shank2. Terminal base
3. Rolled flange

5.3.5 Terminal Mounting – Electrical Terminals requiring electrical connection to the PCB are normally mounted using a flared flange in a PTH which may have active circuitry on the flared side of the PCB. Typically the flared flange will not be used for an interfacial connection (e.g., connecting the top, bottom and internal layers of the PCB). Since there is a possibility that using flared terminals in plated-through holes may break the plating in the hole and cause electrical discontinuity during thermal cycling, interfacial connections are discouraged. The flared flange is used in lieu of a rolled flange to prevent trapping of fluxes and/or cleaning solutions in the rolled area during soldering/cleaning processes See Figure 5-6).

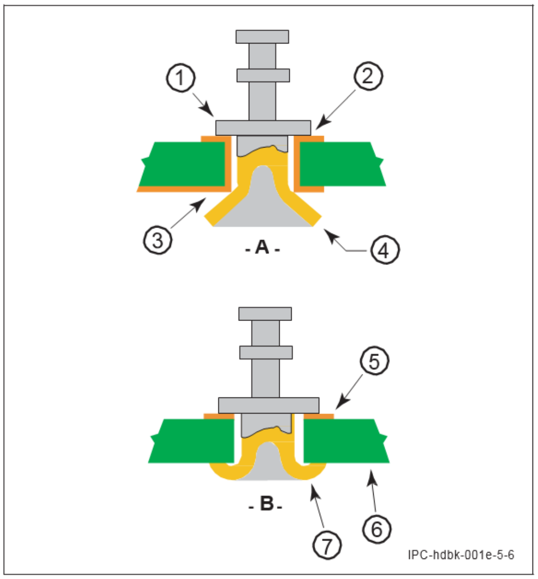


Figure 5.6 Terminal Mounting – Electrical

1. Flat shoulder
2. Nonfunctional land
3. Plated-through hole
4. Flared flange
5. Conductor
6. Board
7. Rolled flange

Rolling the flange against bare board laminate should be used if:

- The hole is not plated through.
- The connecting circuitry is on the side opposite the termination.
- The rolled area does not get soldered or come in contact with solder/fluxes.

5.3.6 Terminal Soldering This section covers soldering the terminal into the board, not leads to the terminal. See 5.4 or wire and component lead mounting/attachment and soldering criteria.

5.4 Mounting to Terminals This section covers wires and component leads mounted (e.g., wrapped or inserted) and soldered to terminals**.**

5.4.1 General Requirements

5.4.1.1 Insulation Clearance Insulation, which interferes with the formation of the solder connection, can weaken the connection or hide defects from visual inspection and detection. Clearances that are too large can expose bare wire or pose a shorting problem between two non-common conductors adjacent to the terminal. The combination of an improperly tinned wire and excessive insulation clearance will most likely result in a birdcaged wire. The wire should be stripped and tinned long enough to be wrapped around (or through) the attaching terminal, such that, when trimmed, the insulation neither touches the terminal, nor is further than the maximum distance allowed away from the terminal.

5.4.1.2 Service Loops Service loops are the extra length in the wire provided during installation of the wire to terminals; therefore, the wire is longer than required to reach the attaching terminal. When repairs are required in the field (i.e., the removal of the attached wire), enough wire should be present to allow the service technician to cut, re-strip, and reattach the wire following the repair. The wire is usually precut to a documented length prior to assembly, per assembly instructions.

5.4.1.3 Stress Relief Stress relief for wires and components is the gradual bend of the attaching wire/lead to the terminal post or solder connection. The gradual bend of the wire as it is attached to the terminal post or solder connection alleviates the stress to the component seal and solder connection. During heating and cooling cycles that electronics experience, either by electrical operation or environments the electronics must operate in, the components expand and contract, exerting mechanical stress on the components and solder connections. As shown in Figure 5-7, when installing wires or components, ensure that the attaching wire/lead has a gradual bend in the same direction as the wire/lead is wrapped on the terminal before soldering the connection. The bend should never be made after soldering.

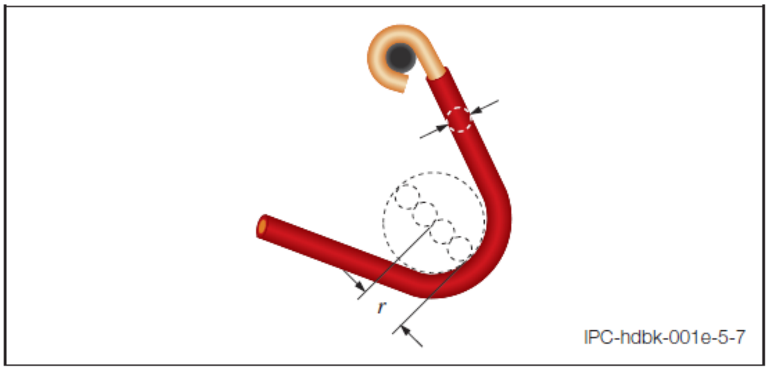


FIGURE 5-7 Stress Relief

5.4.1.4 Orientation of Lead or Wire Wrap The orientation or position of the wire as it enters the terminal should be in the same direction as the wire is wrapped around the terminal, as shown in Figure 5-7. When wrapped in this manner, the wire exerts no stress into the solder connection. When wrapped improperly, the wire stress can "peel" the wire away from the terminal. Examples of this are shown in Figure 5-8 and Figure 5-9. When wrapping wire around or through terminal posts/slots, make sure that the wire is oriented in the same direction as the mechanical wrap to the post. (Add figures XXX)

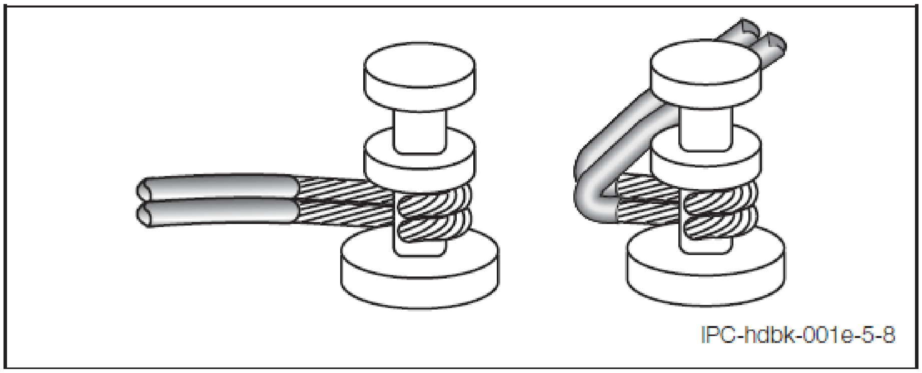


FIGURE 5-8 Wire Wrap

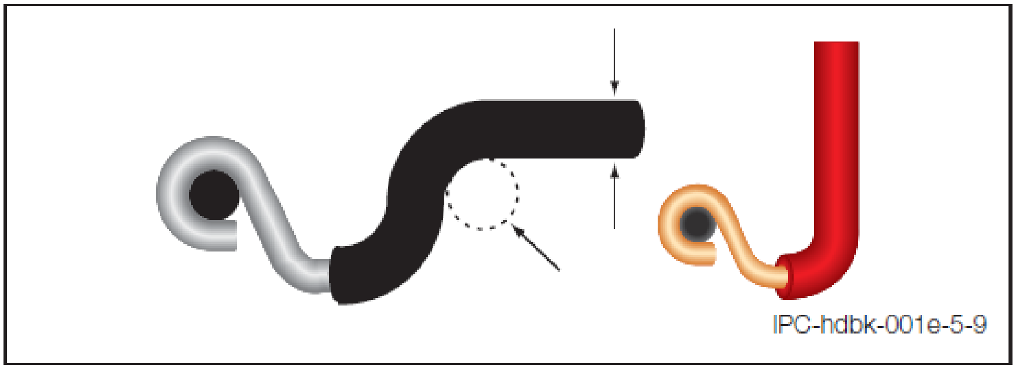


FIGURE 5-9 Wire Wrap Around Terminal Post

5.4.1.5 Continuous Runs Continuous runs are used to connect multiple adjacent terminals together using one wire length instead of individual pieces of wire between each shank or post. The wire attachments for the first and last attachment must meet the minimum wrap requirements for the terminal type. Continuous runs are used for routing a bus wire between terminals Wires routed in this manner have mechanical strength in the first and last wrap and sufficient strength in between by making contact with terminal posts prior to soldering Continuous runs are more economical than using individual wires wrapped to each terminal. Start at the first post with a wrap as if it were a turret terminal, weave the wire through the succession of terminals as required, terminating the last wrap again as if it were a turret terminal. This process is shown in Figure 5-10

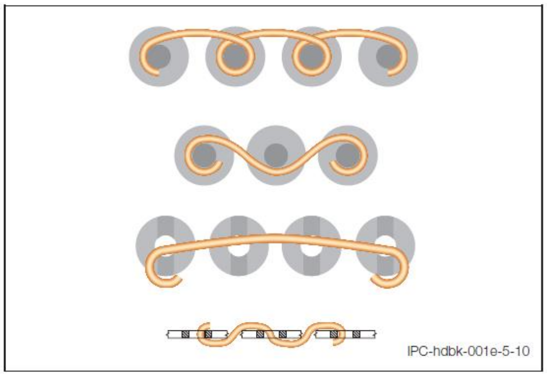


Figure 5-10 Continuous Runs

5.4.1.6 Insulation Sleeving (Wires Soldered to Pierced, Hook and Cup Terminals) The purpose of the sleeving is to cover the soldered connection to provide electrical isolation and mechanical strength for the connection.

5.4.1.7 Lead and Wire End Extensions Violating minimum electrical clearance is always a defect. If the wire ends extension is more than one lead diameter beyond the terminal it may interfere with other parts of the assembly or cause an electrical short.

5.4.2 Bifurcated and Turret Terminals

5.4.2.1 Wire and Lead Wrap-Around – Turret and Straight Pin A 180° wrap to the terminal shank provides sufficient mechanical support to prevent movement of the wire during the soldering and cooling phases of the soldering connection. The amount of wrap (180°) determines the strength of the finished solder joint. Overlapping serves no purpose, takes up more space leaving less room for additional wire attachments and can recreate problems if rework is necessary. The wire/lead should be held firmly against the terminal while the wire/lead is wrapped around the terminal shank using an appropriate tool. The lead end is then trimmed off to the desired length using lead cutters. Using an appropriate tool, gently form the wire or lead end to the terminal shaft and in contact with the flange base (or previously installed wire wrap), as shown in Figure 5-11.

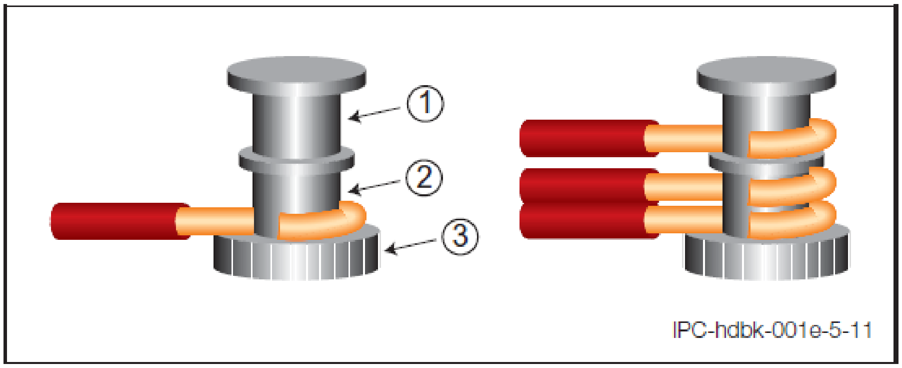


Figure 5-11 Wire and Lead Wrap Around

1. Upper guide slot
2. Lower guide slot

3. Base

5.4.2.2 Termination of Small Gauge Wire (AWG 30 and Smaller) Small gauge wire (magnet wire is usually AWG 30 and smaller) should be wrapped more than one time around the terminal depending on the class requirement. The exception to requirements for wire larger than AWG 30 is based on the need to assure that the wire is mechanically stabilized during the soldering operation. Multiple wires will assist in stabilizing the wire during the soldering operation. Caution should be exercised to assure that the insulation material has been removed from that portion of the wire that is to be wrapped around the terminal and soldered.

5.4.2.3 Side Route Connection – Bifurcated Terminals Side route wires to bifurcated terminals require a90° minimum wrap and should be mounted to the terminal post in ascending order with the largest wire on the bottom. The wire is dressed through the slot and wrapped around either terminal post, assuring positive contact with the base of the terminal and at least one corner of the post. The wires should not overlap. When required by approved designs, wires or component leads may be routed straight through the tines without wrapping.

Due to electrical spacing constraints, some designs require straight-through routing with no wrap, as shown in Figure 5-12. When the wrap requirements are not met, staking is used to provide mechanical stabilization to the resulting solder connection.

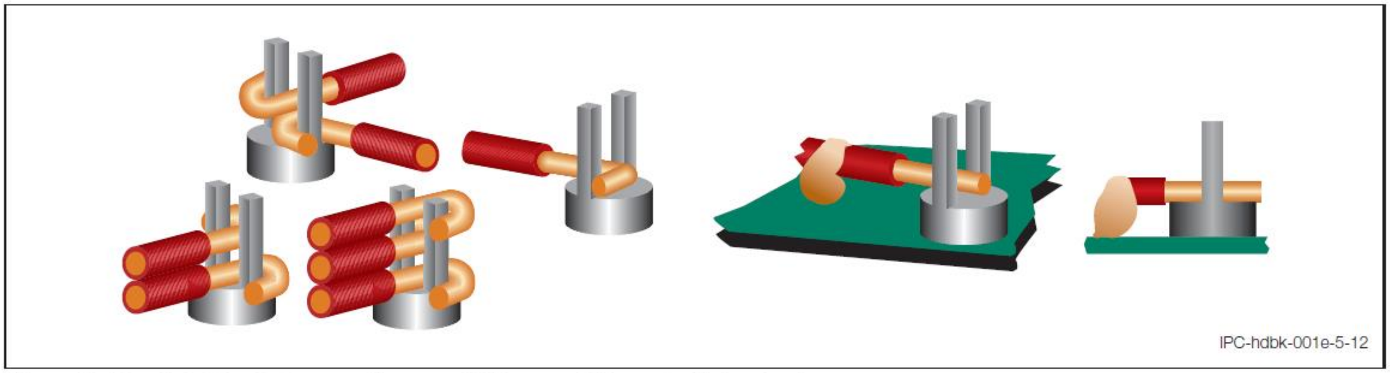


Figure 5-12 Side Route Connections and Wrap on Bifurcated Terminal

5.4.2.4 Top and Bottom Route Connections. Bottom routed wires should feed (positioned) through the terminal with no insulation entering the base of the terminal. The wire should have a minimum 90° bend and be in contact with the terminal base as shown in Figure 5-13. Top-routed wires need to fill the gap between the terminal tines (or posts). This is accomplished by using two wire diameters in the space between the terminal tines. The user should pre-form the wire (double) prior to insertion between the tines. If a second wire is used, insert both the wire and the wire piece into the space between the tines, using friction fit to hold in place prior to soldering, as shown in Figure 5-14.

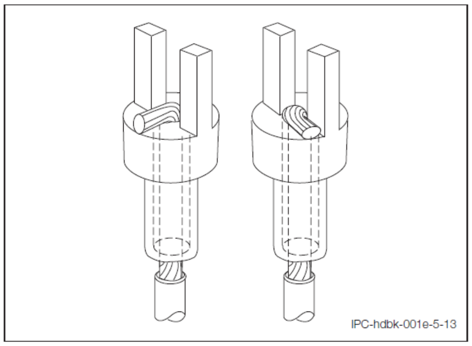


Figure 5-13 Bottom Route Terminal Connection

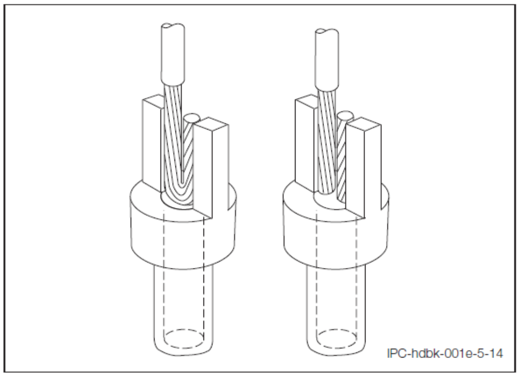


Figure 5-14 Top Route Terminal Connection

5.4.3 Slotted Terminals Slotted terminals have the wire/lead extending straight through the opening of the terminal. The wire/lead is not required to be wrapped. Solder should wet 100% of the portion of the lead/wire that is in contact with the terminal. Solder may completely fill the slot. You should be able to see the wire/lead on the exit side of the terminal; however, it should not violate minimum electrical clearance.

5.4.4 Hook Terminals A 180° wrap to the terminal provides sufficient mechanical support to prevent movement of the wire during the soldering and cooling phases of the soldering connection. No more wires than can fit on the hook should be attached. This is shown in Figure 5-15.

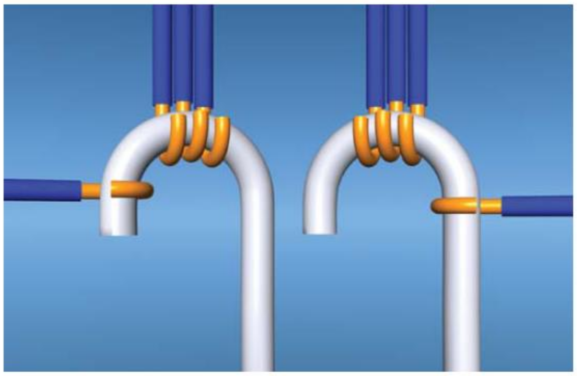
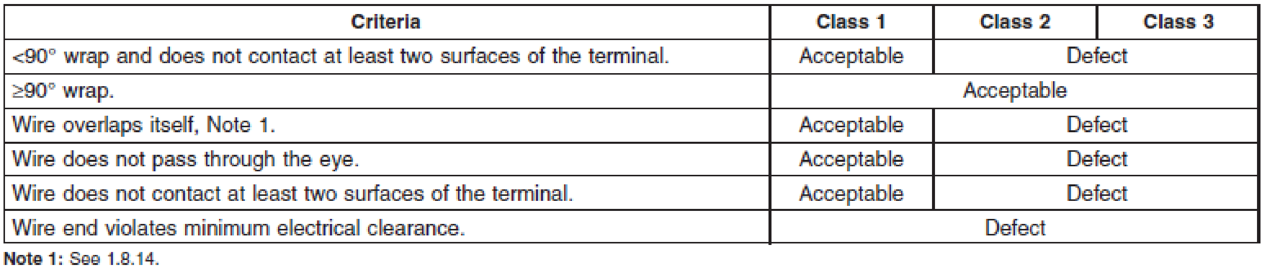


Figure 5-15 Hook Terminal Connections

5.4.5 Pierced or Perforated Terminals A minimum 90° wrap through the terminal slot provides sufficient mechanical support to prevent movement of the wire during the soldering and cooling phases of the soldering connection. See Table 5-2 for wire placement requirements and Figure 5-16.

Table 5-2 Pierced or Perforated Terminal Wire Placement



Criteria	Class 1	Class 2	Class 3
<90° wrap and does not contact at least two surfaces of the terminal.	Acceptable	Defect	
≥90° wrap.	Acceptable		
Wire overlaps itself, Note 1.	Acceptable	Defect	
Wire does not pass through the eye.	Acceptable	Defect	
Wire does not contact at least two surfaces of the terminal.	Acceptable	Defect	
Wire end violates minimum electrical clearance.	Defect		

Note 1: See 1.8.14.

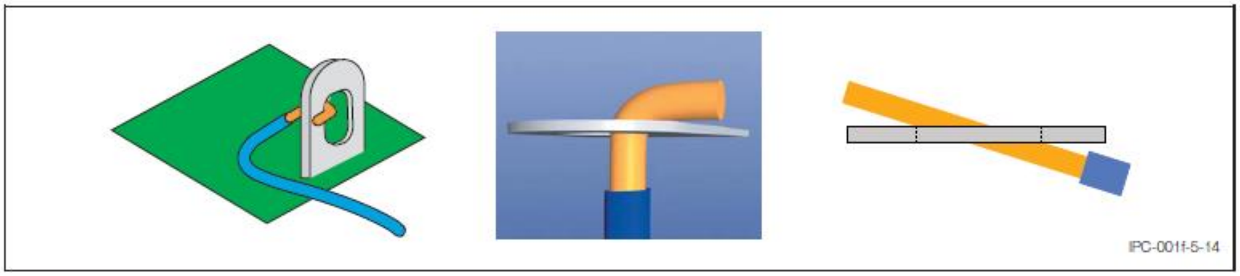


Figure 5-16 Pierced or Perforated Terminal Wire Placement

5.5 Soldering to Terminals The solder coverage requirements are intended to apply to all terminal types covered by the J-STD-001.

When a wire/lead is soldered to a terminal, solder flows around the wire/lead and the terminal post to create the finished soldered connection. The solder will typically wet to the wire/lead first and then build into the interface between the wire/lead and the post. The space between the wire/lead and the terminal will be filled with solder; however, it may have a slight depression between the two as shown in Figure 5-17.

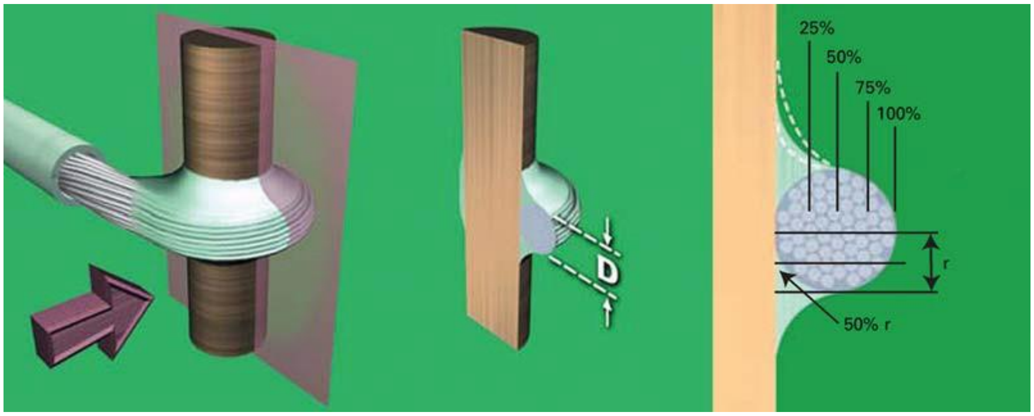


Figure 5-17 Solder Height

5.5.1 Cup and Hollow Cylindrical Terminals The integrity of the solder connection is determined by the amount of the wire inserted into the terminal cup. A full depth insertion and placing a wire in contact with the back wall of the cup or other wires gives the maximum amount of surface for both the wire and the cup to form a strong solder joint. Wire strand deformation or removal weakens the wire and may result in a less reliable solder connection.

5.6 Jumper Wires (See Figure 5-18)

Jumper wires are used to complete electrical continuity between two points on a PC board assembly. They fall into three (3) categories

1. Those that are considered wires and are installed during assembly. The routing, termination, and bonding of these jumper wires are documented by engineering instructions or drawing notations.
2. Those that are added after assembly to effect a change or modification. The routing, termination, and bonding of these jumper wires are documented by engineering change notice instructions or drawing notations.
3. Those that are added to correct a defect (i.e. repair a damaged conductor).

They may be terminated in plated holes, and/or to terminal standoffs, conductor lands, and component leads.

Jumper wires are considered components and should be covered by an engineering instruction document for routing, termination and wire type.

General Rules

Select the smallest diameter wire that will carry the required current needs.

Keep jumper wires as short as practical and unless otherwise documented do not route over or under other replaceable components. Design constraints such as real estate availability and minimum electrical clearance need to be taken into consideration when routing or staking wires. A jumper wire 25 mm [0.984 in] maximum in length whose path does not pass over conductive areas and do not violate the designed spacing requirements may be uninsulated. Wire is insulated if greater than 25 mm [0.984 in] in length or is liable to short between lands or component leads.

Insulation, when required on the jumper wires, should be selected so it is compatible with conformal coating, should withstand soldering temperatures, have some resistance to abrasion, and have a dielectric resistance equal to or better than the board insulation material.

Silver plated stranded wire should be avoided whenever possible. Under some conditions corrosion of the wire can occur. However, there are instances where silver-plated wire is appropriate to use because of other desirable characteristics.

> ***Silver Plated Wire –*** *Silver is typically not used as a lead finish because of a condition known as silver migration. Silver on the leads migrates to create an intermetallic layer of Ag 3 Sn and Ag 5 Sn with the solder. Intermetallic compounds such as these are known to be a leading cause of solder joint failure. Silver is used as over plate for fasteners in some high temperature applications.*
>
> *Silver plated wire, in addition to contributing to solder connection failure due to intermetallic formation, precipitates dendritic growth under certain conditions. Dendrites, upon bridging two circuit paths, create a short circuit.*

Recommended wire is solid, insulated, plated copper wire, 22 to 32 AWG with a heat-resistant insulation. **Note:** Wire with tin-lead plating may be restricted due to environmental laws.

Chemical solutions, pastes, and creams used to strip solid wires should not cause degradation to the wire. Ensure cleaning product and process are compatible.

Wire Preparation

Cut the jumper wires approximately 12.7 mm [0.50 in] longer than the estimated length needed. **Note:** The length and gauge of the jumper wire may be critical. All wires have an electrical resistance (impedance) to the flow of electricity. This impedance is important to electronic circuitry. Always refer to wiring lists for specific jumper wire requirements.

Strip insulation from each end of the jumper wire. Strip length is dependent on the termination style.

If required, tin the stripped ends with solder. Clean if necessary.

5.6.1 Insulation Clearance

Minimum: The insulation is in contact with the solder but does not interfere with formation of an acceptable connection. If the insulation is in contact it may interfere with the formation of the solder connection. If the insulation is embedded it may cause a weak solder connection.

Maximum: The insulation clearance is two wire diameters or less including insulation or 1.5mm [0.0591 in], whichever is greater and does not permit violation of minimum electrical clearance to adjacent non-common conductors.

5.6.2 Wire Routing

Unless otherwise specified by high speed/high frequency requirements, route jumper wires the shortest route in straight legs as possible, avoiding test points, to points of termination. Allow enough length for routing, stripping and attachment.

Jumper wire routing on assemblies having the same part number should be the same pattern

Routing should be documented for each part number and followed without deviation. This will aid in inspection of wire. When changing the routing it may affect form, fit and function.

Do not allow jumper wires to pass over or under any component, however, they may pass over parts such as thermal mounting plates, brackets and components that are bonded to the PWB.

> *Take in consideration the trapping of contaminants when wires are routed under components. When routed over components consider the implications of wires coming in contact with heat sinks or hot components and electrical interference in RF applications*.

Jumpers may pass over solder lands if sufficient slack is provided so they can be moved away from the solder land for component replacement.

Contact with heat sinks specific to high temperature generating components **shall** be avoided.

Except for connectors at the edge of the board, do not pass jumpers through component foot prints unless the layout of the

5.6.3 Wire Staking

Jumper wires may be staked to the base material (or integral thermal mounting plate or hardware) by adhesive or tape (dots or strips).

When adhesive is used, it is to be mixed and cured in accordance with the manufacturer's instructions. All adhesive must be fully cured before acceptance.

Consider the end-use product environment as well as subsequent process compatibility when selecting the appropriate staking method.

Spot bond so that the stake fillet is sufficient to secure the wire with no excessive spillover onto adjacent lands or components.

Staking is not to be on a removable or socketed component. Where design constraints are an obstacle, staking is to be discussed with the customer.

Jumper wires are not to be staked to, or allowed to touch, any moving parts. It is recommended that wires be staked within the radius of each bend for each change of direction, however it is sometimes recommended that wires be staked on either side of the bend. Either should be acceptable so follow your instructions

Wires and staking tape/adhesive do not overhang the board edge.

> *Adhesives are frequently used to tack down wires and component bodies on electronic assemblies. The application of the adhesive should be performed using the appropriate application device. In areas where adhesive flow could spread to areas to be soldered, a controlled applicator (i.e., syringe) should be used to carefully apply the material to just the surfaces requiring staking. The viscosity of the adhesive can be controlled to preclude spreading of the material during application.*
>
> *The selection of the adhesive material is important as, depending on the curing mechanism, they can outgas harmful materials, which can result in electrical leakage, corrosion, and metal migration.*
>
> *Unreacted or uncured adhesive components may be harmful to electronics.*

Some jumper wires are manufactured with a special thermo-set adhesive coating and are thermally bonded to the board surface with a special bonding tool/iron.

5.6.4 Land

When attaching a jumper wire to a vacant land the wire is position parallel to the longest dimension of the land.

For a land width of 6 mm (0.236 in) or larger, the wetted wire to land interface is at least 2 wire diameters.

For a land width less than 6 mm (0.236 in) the wetted wire to land interface is at least 50% of the land width or 2 wire diameter, whichever is less.

The wire or wire end should be discernible in solder.

5.6.5 Supported Holes

Jumper wires may be attached by any of the following methods:

- Soldered into a PTH/Via Hole (5.6.5.1)

This section provides requirements fo jumper wire practices that arerequired by engineering/documentation. See IPC-7711/7721 for additional jumper wire information

For jumper wires attached to components other than axial leaded, lap solder the wire to the component lead.

Assure the solder connection length and insulation clearance meet the minimum/maximum acceptability requirement.

5.6.5.1 Lead in Hole

Wires can be soldered to a PTH or via hole. If the wire is soldered to a PTH that has a component lead that will be acceptable for Class 1 and Class 2 only.

For Class 3 the wire should be wrapped or lap soldered to component lead.

5.6.5.2 Wrapped attachment

Wrapped attachments should be mechanically secure.

The jumper wire ends are attached to component lead projections by wrapping the wire.

The jumper wire is wrapped a minimum of 90° on a flat lead (e.g. DIP and SIP components) and 180°on a round lead (e.g. axial and radial components).

Wire overhang of component lead or land, should not violate minimum electrical clearance.

5.6.6 SMT

Jumper wires may be lap soldered to leads, end termination or lands.

The following conditions are to be taken in consideration when attaching wires to SMT connections:

- Insulation clearance does not permit shorting to non-common conductors or violate minimum electrical clearance.
- Evidence of wetting of jumper wire to the lead or the land.
- Wire contour or end is discernible in the solder connection.
- No fractures in solder connection.
- Wire overhang does not violate minimum electrical clearance.

Note: For applications of high frequency, i.e., RF, leads extending above the knee of the component could present problems. There should be no adhesive on component bodies, leads or lands. Adhesive deposit should not obscure or interfere with solder connections.

5.6.6.1 Chip and Cylindrical End Cap Component

Wire is lap soldered to the pad with the wire positioned parallel to longest dimension of the land.
Wire to component termination-land solder connection length is at least 50% of land width, or twice the conductor diameter, whichever is greater.
The wire should not be soldered on top of the termination.

Note: Lap joints on Gull, J, and castellated connections provides maximum contact/interface area

5.6.6.2 Gull Wing

Lap solder wire on top of lead
Jumper attached to Gull Wing uses a lap soldered wire where the wire length and solder wetting extends a minimum of 75% of the distance measured from the edge of the land to the knee of the Gull Wing lead.
The end of the wire should not extend past the knee bend.
The wire should not violate electrical clearance.

5.6.6.3 J Lead

Just like the Gull Wing the wire enters straight at the lead across the land and up the lead Wire length and solder wetting extends a minimum of 75% of the height of the J lead.
The end of the wire should not extend past the knee bend.
The wire should not violate electrical clearance.

5.6.6.4 Castellation

Wire enters straight at the Castellation across the land and up the Castellation
Wire length and solder wetting extends a minimum of 75% of the distance measured from the top of the land to the top of the castellation.
The end of the wire should not extend past the top of the castellation.
The wire should not violate electrical clearance.

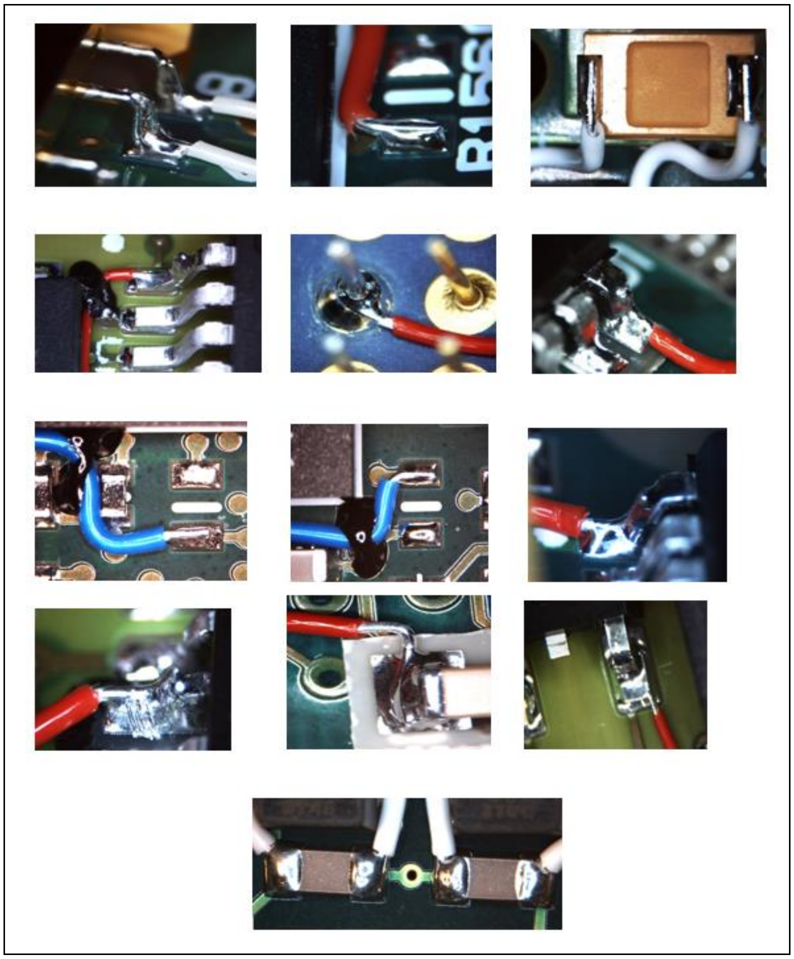


Figure 5-18 Jumper Wires

5.5.1 Cup and Hollow Cylindrical Terminals The integrity of the solder connection is determined by the amount of the wire inserted into the terminal cup. A full depth insertion and placing a wire in contact with the back wall of the cup or other wires gives the maximum amount of surface for both the wire and the cup to form a strong solder joint. Wire strand deformation or removal weakens the wire and may result in a less reliable solder connection. A minimum of 75% solder fill of the terminal is required and if there is an inspection hole present on the terminal cup, solder **shall** be visible. Buildup of solder on the outside of the cup that affects form, fit or function is cause for rejection but a thin film is not a defect.

A typical process for soldering wires into cups and hollow cylindrical terminals is as follows:

1. Prior to adding any solder to the cup terminal, measure the cut length of the stripped and tinned wire conductor so that it can be inserted to the full depth of the cup.
2. If required, place insulation tubing on the wire and slide it back out of the way.
3. If the cup terminal is gold plated and is required to have the gold removed (see Section 4.5.1) heat the terminal and add solder until the cup is filled. Reheat the terminal and remove all the solder in the cup with either solder braid or an un-tinned stranded wire. This process should be repeated twice.
4. Insert a predetermined number of cut slugs of flux-cored solder wire in the cup. Fill the cup with sufficient solder to ensure solder will not overflow when the user inserts the conductor.
5. Hold the cup at approximately a 45° angle to prevent entrapment of gases and flux.
6. Using a soldering iron or resistance-soldering unit, apply heat to the side of the cup until reaching the flow temperature of the solder.
7. Place the stripped and tinned wire in the solder filled cup, bottoming the wire in the cup. Maintain heat until you see good solder fillet form to the cup and wire. Do not over heat the terminal as too much heat can cause excessive wicking under the wire insulation. “Burp” the connection by moving the wire toward the operator and seating it against back wall of cup. Ensure that the wire does not move while the solder is solidifying.

NOTE: Gold-plated cups require gold removal if the gold thickness is 2.5 micrometers or more (4.5.1 of J-STD-001).

6 THROUGH-HOLE MOUNTING AND TERMINATIONS

6.1 Through-Hole Terminations – General

6.1.0.1 Axial-Leaded Components Axial-leaded parts are to be mounted as specified on the approved assembly drawing. Components should be mounted approximately parallel to the board surface, approximately centered between the two holes, and should be in contact with the board. The furthest distance between the component body and the board should not be more than 0.7 mm for Class 3.

If components are specified to be mounted off the board, they need to be elevated at least 1.5 mm [0.059 in] to provide for heat dissipation and ensure that heat generated by the component does not damage the PCB. If these components are mounted in unsupported holes, there needs to be lead forms at the board surface or other mechanical support since the unsupported holes will not provide adequate support for the component.

For axial leaded components, at least one component lead needs to have stress relief provided the component is not clip or adhesive mounted, or otherwise constrained. (See Figure 6-1). All axial leads need to have stress relief when the component is clipped or adhesive mounted or otherwise constrained.

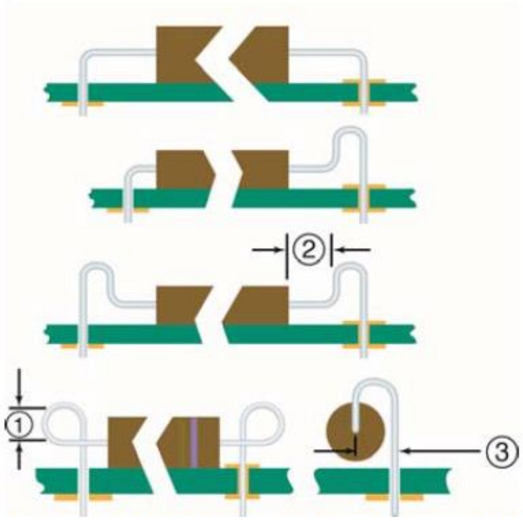


Figure 6-1 Component Lead Stress Relief Examples

Axial lead components mounted vertically in supported holes need to have component height in accordance with the design. Components should be mounted with the larger side perpendicular to the board surface (approximately ±15°) and clearance from the board to the body or weld bead are to meet the requirements of Table 6-1.

Table 6-1 Component to Land

	Class1	Class 2	Class 3
C (min)	0.1 mm [0.0039 in]	0.4 mm [0.016 in]	0.8 mm [0.031 in]
C (max)	6 mm [.24 in]	3 mm [0.12 in]	1.5 mm [0.059 in]

Axial leaded components mounted vertically in unsupported holes need to be mounted with lead forms or other mechanical support to prevent lifting of the solder land.

Because of vibration and shock concerns, for Class 3 products, axial-leaded parts should not be surface mounted vertically (perpendicular to the board).

6.1.0.2 Radial-Leaded Components

6.1.0.2.1 Side Mounted Side-mounted radial-leaded components should be mounted parallel to the surface of the printed board. The side or surface of the body, or at least one point of any irregularly configured component (such as certain pocketbook capacitors), should be in full contact with the printed board. The body should also be bonded or otherwise retained to the board (as shown in Figure 6-2) to prevent damage when vibrational and shock forces are applied.

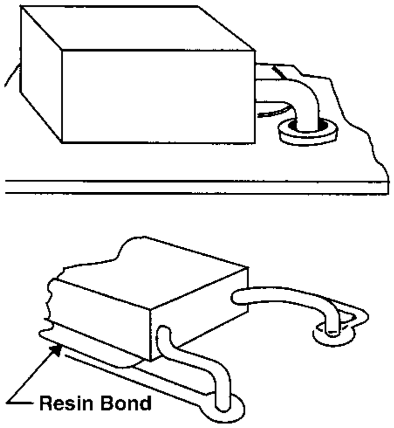


Figure 6-2 Side Mounting

6.1.0.2.2 Freestanding Unless otherwise noted on the assembly drawing, the minimum clearance for freestanding (supported by leads only) vertical mounted parts should be 0.3 mm [0.012 in] between the component body (measured from the seal or lead weld) and the board. The maximum clearance should be 2.0 mm. See Figures 6-3 and 6-4. Excessive clearance and component tilt are not considered defects unless they violate the minimum electrical clearance.

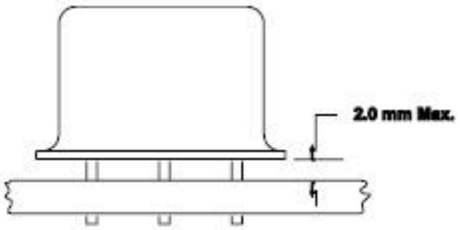


Figure 6-3 Vertical Mounting of Freestanding Components

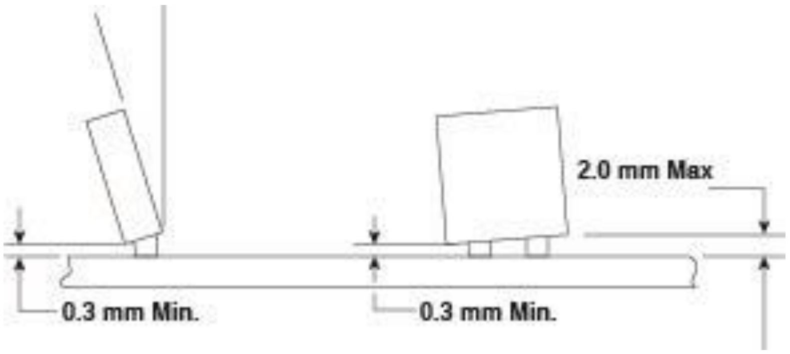


Figure 6-4 Mounting of Components with Dual Non-Axial Leads

Radial-leaded components should be mounted parallel to the board. Non-parallelism should not result in nonconformance with the minimum/maximum spacing limits (Figure 6-3 and 6-4 above). When dual leaded components (Figure 6-4) are mounted freestanding, the larger sides should be perpendicular to the board surface (approximately ± 15°), as shown in Figure 6-5.

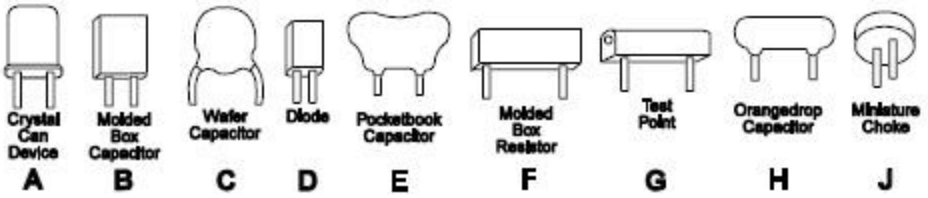


Figure 6-5 Typical Configuration of Components with Dual Non-Axial Leads HDBK 001-6-27 (IPC-001-033)

6.1.02.3 End Mounting When documented on an approved assembly drawing, a radial-leaded component may be end mounted, as shown in Figure 6-6. The end surface of the body should be in full contact with the printed board, and the body should be bonded or otherwise retained to the board to prevent damage when vibrational shock forces are applied. Also, lead-bend clearance and lead-bend radius requirements apply.

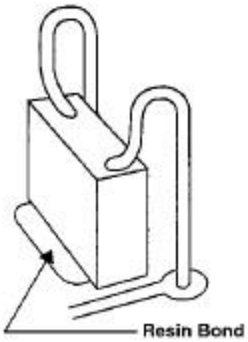


Figure 6-6 End Mounting 6.1.0.2.4 Integral Standoffs

When a component with resilient integral feet or a resilient integral standoff is mounted to a printed board, the component should be seated with each foot in contact with the surface of the board. For this application, a button standoff, as shown in Figure 6-7B, is deemed a foot, and the mating surface of each button should be flat on the board (or circuitry thereof).

Footed standoffs, as illustrated in Figure 6-7 C and D, should have a minimum foot height of 0.25 mm. Standoffs should never be inverted.

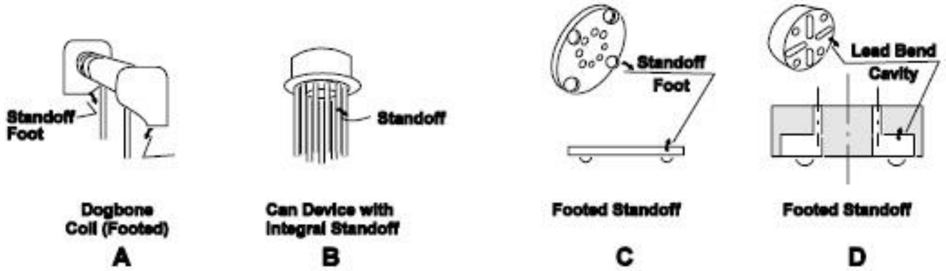
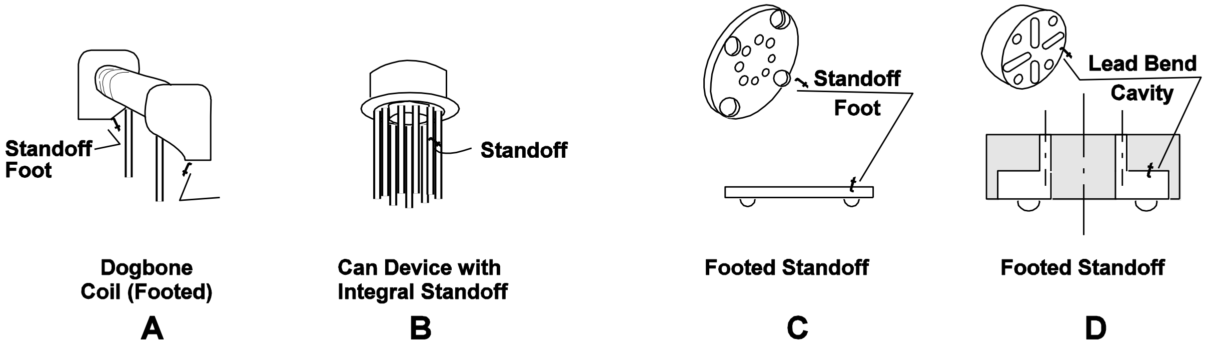


Figure 6-7 Mounting with Feet on Standoffs

6.1.0.2.5 Non-Resilient Footed Standoffs When specially configured non-resilient standoffs are used, that portion of the lead in the lead bend cavity (see Figure 6-8) should conform to an angular line. This line should extend from the lead insertion hole in the standoff device to the land attachment hole in the printed board.



Dogbone Coil (Footed)

Can Device with Integral Standoff

Footed Standoff

Footed Standoff

Figure 6-8 Mounting with Feet on Standoffs

6.1.0.2.5 Non-Resilient Footed Standoffs When specially configured non-resilient standoffs are used, that portion of the lead in the lead bend cavity (see Figure 6-8) should conform to an angular line. This line should extend from the lead insertion hole in the standoff device to the land attachment hole in the printed board.

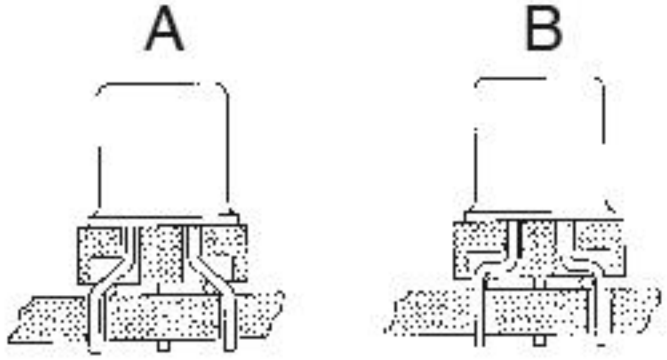


Figure 6-8 Non-Resilient Footed Standoffs
A - Acceptable - Lead is properly formed in the bend cavity.
B - Not Acceptable - The lead is improperly formed in the bend cavity.

Note: Depends on Standoff configuration chosen by design activity and how the lead reacts when mounted in the standoff.

[Note: Depends on Standoff configuration chosen by design activity and how the lead reacts when mounted in the standoff]

The component and spacer mounting need to comply with the requirements of Table 6-2.

Table 6-2 Components with Spacers

Criteria	Class 1	Class 2	Class 3
Supported holes with spacer in full contact with both the board and the component.	Accept	Accept	Accept
Supported holes with spacer touching both the board and the component but not in full contact.	Accept	Accept	Process Indicator
Supported holes with spacer not touching either the board or the component.	Accept	Process Indicator	Defect
Un-supported holes with spacer in full contact with both the board and the component.	Accept	Accept	Accept
Un-supported holes with spacer not in full contact.	Defect	Defect	Defect
Spacer is inverted	No	Defect	Defect

	Requirement		

6.1.1 Lead Forming

The lead forming process may be manual or part of an automated forming and insertion operation. The mechanism for bending the leads must not impart stress to the component lead-to-body seal or the component's internal electrical element connection. The tools used should not damage the lead being formed (e.g. pliers with serrated or sharp edges). The component leads need to be mechanically supported prior to the forming action, and so the lead to body seal is isolated from the force used to bend the lead over. The critical elements of lead forming are support at the lead exit from the component body, the lead forming action, and lead end trimming. See Figure 6-9.

To control the lead forming process, it is important to recognize when the forming action causes damage to the component.

Each component should have an associated specification to which the part is procured. Table 6-3 shows the bend radius requirements for component leads to ensure there is no damage to the lead during the bending process, and assure stress relief.

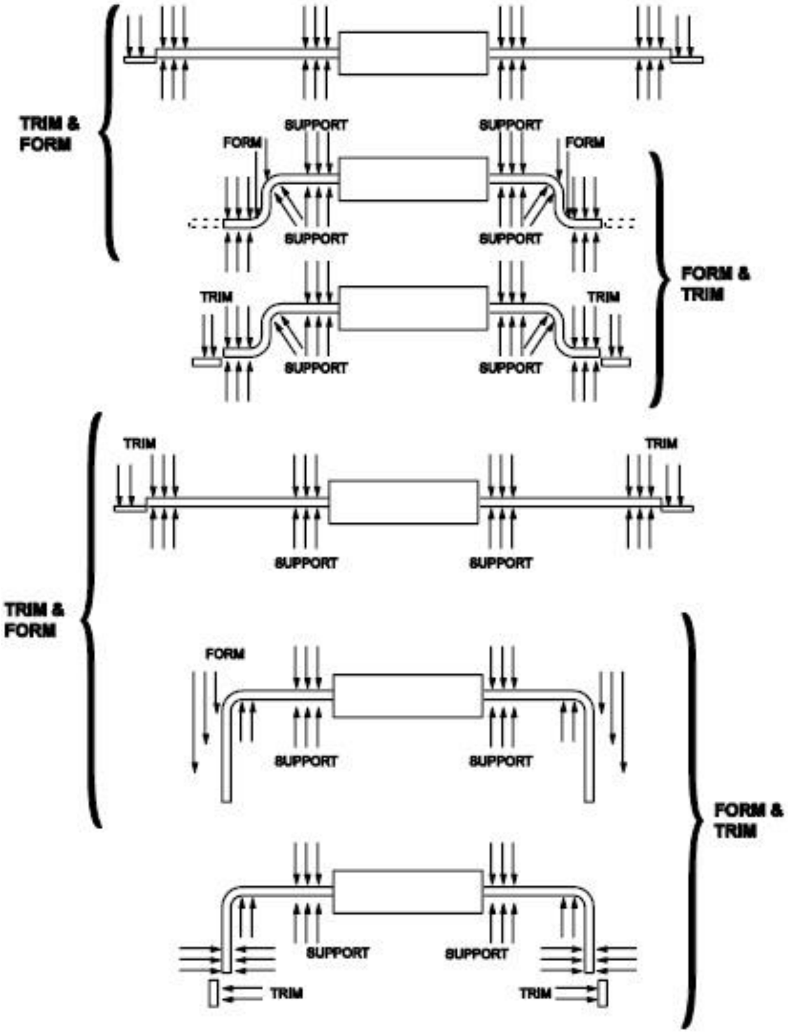
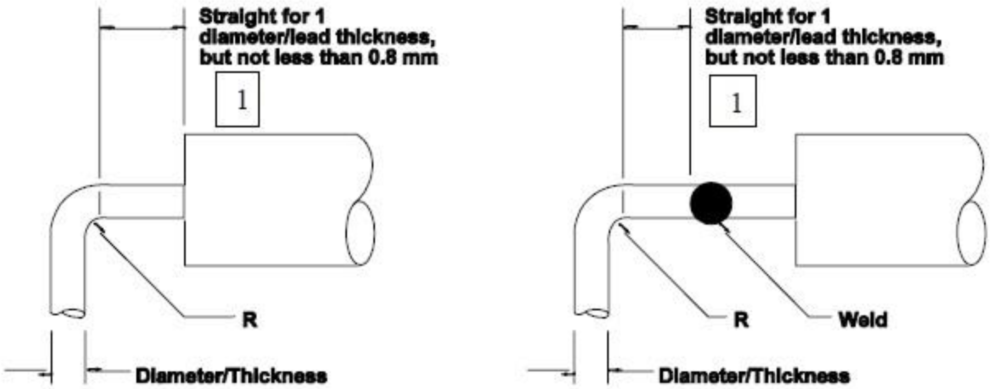


Figure 6-9 Lead Forming Forces

6.1.1.0.2 Lead Forming Requirements The distance from the component body, or weld, or bead to the start of the bend is known as the lead bend clearance. By forming the lead at least one lead diameter (0.8 mm) away from the component body, the chance of damaging the lead to-body interface is lessened. This includes the distance away from the welded bead 63 on some component (e.g., tantalum capacitors) types. Most automatic lead forming equipment is capable of performing this lead forming operation within these requirement allowances.

When hand forming, the assembler should be instructed to perform the operation in a manner that isolates the stress to the component end seal and bends the component lead within these requirements, see Figure 6-10.



A. Standard Bend

B. Welded Bend

(Lead Bend Clearance)

Figure 6-10 Lead Bends

1. Lead is straight for 1 diameter/lead thickness, but not less than 0.8 mm. Measurement is made from the end of the part. The end of the part is defined to include any coating meniscus, solder seal, solder or weld bend, or any other extension. (The span for components mounted with a conventional lead form is 7.6 mm minimum, and 33 mm maximum.)

Table 6-3 Lead Forming Guide

Max. Lead Diameter	Minimum Bend Radius (R)
<0.8 mm	1 diameter/thickness
0.8 to 1.2 mm	1.5 diameters/thickness
>1.2 mm	2 diameters/thickness

6.1.2 Termination Requirements Three typical through hole mounting methods (see Figure 6-11) are:

- Straight-through (stud) mounting, in which the component lead is inserted through the hole and is not clinched,
- Partially-clinched mounting, in which the lead is inserted through the hole and is then bent over slightly for retention on the board, and
- Clinched (full clinch), where the lead is inserted through the hole and is then bent fully over to the board/circuitry surface for retention to the board.

[Note: Straight-through and partial clinch terminations are easier to Rework]

The lead clinch should be sufficient to provide mechanical strength during the soldering process. The orientation of the clinch is optional provided it does not violate minimum electrical clearance between the end of the lead and a non-common conductor. DIP leads should have diagonally opposing leads partially clinched outwards.

Lead terminations in unsupported holes should be clinched at least 45° for Class 3 assemblies. If a lead or wire is clinched, it should be wetted with solder in the clinched area and the outline of the lead should be discernable in the solder joint.

Tempered leads should never be fully clinched as this may cause damage to the lead or component.

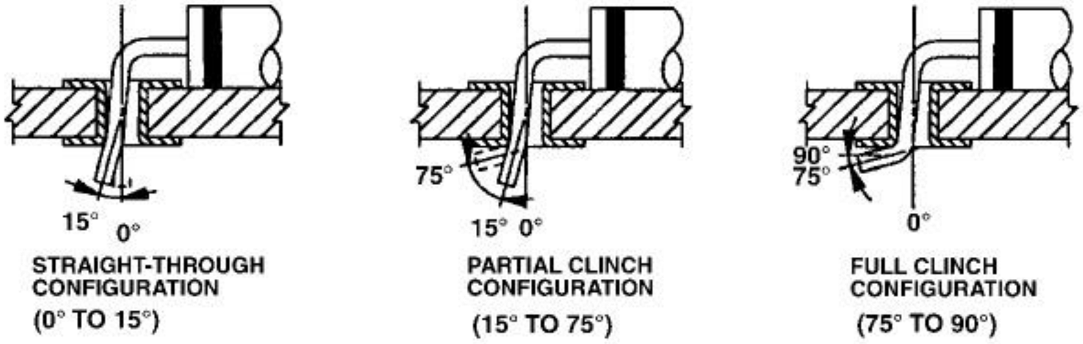


Figure 6-11 Through-Hole Mounting Methods Axial-leaded components should never be mounted with the spacing between the body and the board surface more than 2.0 mm. If the component requires spacing beyond 2.0 mm, the component should be mechanically secured or attached to the board surface using adhesives. When the component spacing is too high (above 2.0 mm), there is not sufficient strength within the solder connection to ensure the appropriate level of reliability unless other means (mechanical attachment or adhesives) are used. The component leads should be formed using equipment with form/cut dies that determine the final lead form and assure proper spacing. The use of mechanical holding devices or adhesives is usually a design requirement and should be included on the assembly drawing.

Lead protrusion needs to be small enough to prevent violation of minimum electrical clearance requirements. See Table 6-4 for supported holes or Table 6-5 for unsupported holes.
Connector leads, relay leads, tempered leads and leads greater than 1.3 mm [0.051 in] diameter are exempt from the maximum length requirement provided that they do not violate minimum electrical spacing as trimming of these leads may damage the components.

Table 6-4 Protrusion of Leads in Supported Holes

	Class 1	**Class 2**	**Class 3**
(L) min	End is discernible in solder1		
(L) max.	No danger of shorts	2.5 mm [0.0984 in]	1.5 mm [0.0591 in]

Note 1: For boards greater than 2.3 mm [0.0906 in] thick, with components having pre-established lead lengths, e.g., DIPs, sockets, connectors, as a minimum have the component or lead shoulder flush to the board surface, but the lead end may not be discernible in the subsequent solder connection. For components having manufacturer's pre-established lead lengths that are less than board thickness, and the components or lead shoulders are flush to the board surface, the lead end is not required to be visible in the subsequent solder connection.

Table 6-5 Protrusion of Leads in Unsupported Holes

	Class 1	**Class 2**	**Class 3**
(L) min.	End is discernible in solder		Sufficient to clinch
(L) max1	No danger of shorts		

Note 1: Lead protrusion should not exceed 2.5 mm [0.0984 in] if there is a possibility of violation of minimum electrical spacing, damage to soldered connections due to lead deflection or penetration of static protective packaging during subsequent handling or operating environments.

6.1.3 Lead Trimming Leads may be trimmed after soldering, provided the cutters do not damage the component or solder connection due to physical shock. This requirement is not intended to apply to components that are designed so a portion of the lead can be removed after soldering (e.g., break-away tie bars). Any lead trimming after soldering that cuts into the solder fillet needs to be reflowed to eliminate any fracture of the soldering joint. If the solder connection is reflowed this is considered part of the soldering process and not rework.

6.1.3.0.1 Lead Cutting Tools used to trim lead ends must be designed so as not to impart shock to the component lead seals or internal connections within the component body. Detrimental shock is any impact force during lead trimming that induces fractures in the seal of hermetically sealed components or damages internal electrical connections within components. Shock from lead trimming can damage the sealing properties of the component and allow contaminants (i.e., cleaning fluids) to enter the internal cavities of the component. Shock during lead trimming can also fracture internal solder or weld connections within the component. Lead trimming should be performed using tools that isolate the shock when cutting off the lead end. Typical tooling used captures the lead in the area towards the component body prior to the shearing action of the cutter.

6.1.4 Interfacial Connections (Vias) Plated through holes without leads used for interfacial connections need not be filled with solder. However, since partially-filled PTHs may contain contaminants, they are best left either completely empty or completely filled. One effective technique for precluding solder in narrow aspect ratio PTHs is to permanently tent these holes with permanent solder mask. Tenting is the use of permanent solder mask as a covering over PTH vias. Unfilled narrow aspect ratio* holes will require the least strength from the solder mask tent. Tenting is generally ineffective on holes larger than 0.64 mm. Many solder masks are also not well suited for tenting and should be evaluated for this.

Evaluation of various solder masks may require trials of different manufacturers and materials until one is found that suits the design application. These holes may be used in lieu of blind via holes, which may also become a collection point for contaminants. Temporary solder masking is another effective method for precluding solder from plated-through holes. The drawback is that the masking must be removed following soldering. See Figure 6-12 for acceptable interfacial hole fill examples.

*Hole Ratio refers to the diameter of the PTH compared to the thickness of the PWB. Narrow aspect holes have a relatively small PTH in respect to the thickness of the PWB.

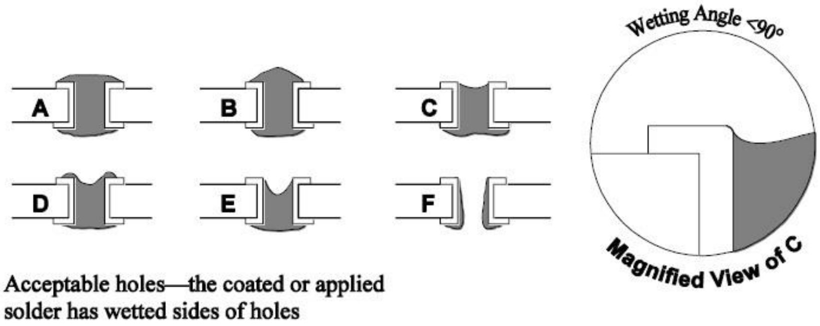


Figure 6-12 Via Fill

6.1.5 Coating Meniscus in Solder is adequately defined in the Standard.

6.2 Supported Holes is adequately defined in the Standard.

6.2.1 Solder Application Solder wire is typically used for hand soldering. The type, form, and weight percent of flux in the wire (if applicable) identify the solder wire. Solder preforms are generally either solder wire or solder sheets formed to a specific shape (typically a toroid or washer) for use in reflow soldering (oven, vapor phase, or IR) of PTH devices. Preforms may contain flux but are typically either flux-free or coated with a mild rosin flux, used both for soldering and to prevent oxidation on the preform surface (see 3.5).

The use of an operator in the soldering process increases the variability of the process. A well trained soldering operator can produce consistent and reliable quality hardware. The process engineer can provide support by making a careful hand soldering tool selection, which is properly matched to the connections being soldered. A description of generic hand soldering tools is provided in 3.9.

Regardless of the soldering iron type, successful hand soldering depends on the following conditions:

- Good thermal contact between the soldering iron tip and the item to be soldered. This includes ensuring that the tip is clean and free of oxides and creating a thermal “bridge” of molten solder from the tinned tip of the soldering iron to the items to be soldered.
- Allow the flux (typically from cored solder wire or liquid flux) to flow over the area to be soldered in advance of the molten solder. The flux will both increase the ability of the surface to accept solder and act as a thermal transfer medium to aid in heating.
- Apply adequate solder to form an acceptable solder connection from one side only. Application of solder from both sides can trap contaminates inside the solder joint.
- Maintain thermal contact until good solder spread is obtained (but do not stay too long).

- Remove the soldering iron but do not disturb parts until solder solidification is complete.

6.2.2 Through-Hole Component Lead Soldering While the solder in a through hole connection must show evidence of wetting, a minimum amount of solder fill is also required for connection strength. The goal of a through hole solder connection is 100% hole fill with good wetting to the lands, leads and barrel top and bottom. The unfilled height allowed in the requirements includes the total from both the top and the bottom sides. Less than 100% solder fill may not be acceptable in some applications, e.g., thermal shock, electrical performance. The user is responsible for identifying these situations to the manufacturer.

6.3 Unsupported Holes

6.3.1 Lead Termination Requirements for Unsupported Holes is adequately defined in the Standard.

7 SURFACE MOUNTING OF COMPONENTS

7.1 Surface Mount Device Lead In Revision F, common criteria or design considerations were pulled out of the individual sections of Section 7 Surface Mount Components and centralized into one section here.
When via in pad exists, there is a likelihood that fillet height criteria will not be met, and if needed, alternate criteria needs to be agreed to between User and Manufacturer (based on classification and end item requirements).
Where applicable, solder fillet may extend through the top bend, but should not extend under the bodies of SMT components whose leads are made of Alloy 42 (or similar).

7.1.1 Plastic Components In Revision F, exceptions to solder touching the component body (of a plastic device) were pulled out of the individual sections of Section 7 Surface Mount Components and centralized into one section here. Additional exceptions were added where by design and under normal processing conditions, solder contacting the component body might be expected (Inward L-Shaped Ribbon Leads, SMT Connectors [with the caveat that solder cannot go into the connector cavity], Leadless Components where the land extends up to or underneath the component body).

7.1.2 Forming Prior to soldering surface mounted components; the leads must be configured appropriately. The forming activity (which includes bend radii and contact length) must not damage or degrade the lead-to-body component seal. Forming surface mounted component leads prior to soldering allows for proper fit on the surface of the board. It also allows the component to be formed without exerting any stress on the lead-to-body seals of the components. Most surface mount lead forming is performed using die-equipped forming machines, which capture the leads firmly before bending and trimming the lead ends. This prevents damage to the lead-to-body end seals.

7.1.3 Unintentional Bending (formerly Lead Deformation Limits) After forming, component leads may be deformed up to 10% of the diameter, width, or thickness, and still be acceptable for use. Lead deformation beyond 10%, with or without exposed basis metal, indicates improvement of the lead forming process is required. Such damage may compromise component performance or reliability. (Note exposed basis metal is now governed by section 4.18.1, while lead deformation limits can be found in section 4.9).

7.1.4 Flat Pack Parallelism Flat pack parallelism refers to the relationship between the base surface of the component body and the lead surfaces, which mount to the printed wiring, as shown in Figure 7-1. Some canting (tilting) of the component is permissible, but the maximum clearance between the component base and the PCB surface should not exceed 2.0 mm, nor can the component exceed max height requirements. Canting may cause improper distribution of stresses on the solder connections. Most surface mount lead forming is performed using die-equipped forming machines, which are tooled to form the parts with the appropriate parallelism and lead spacing.

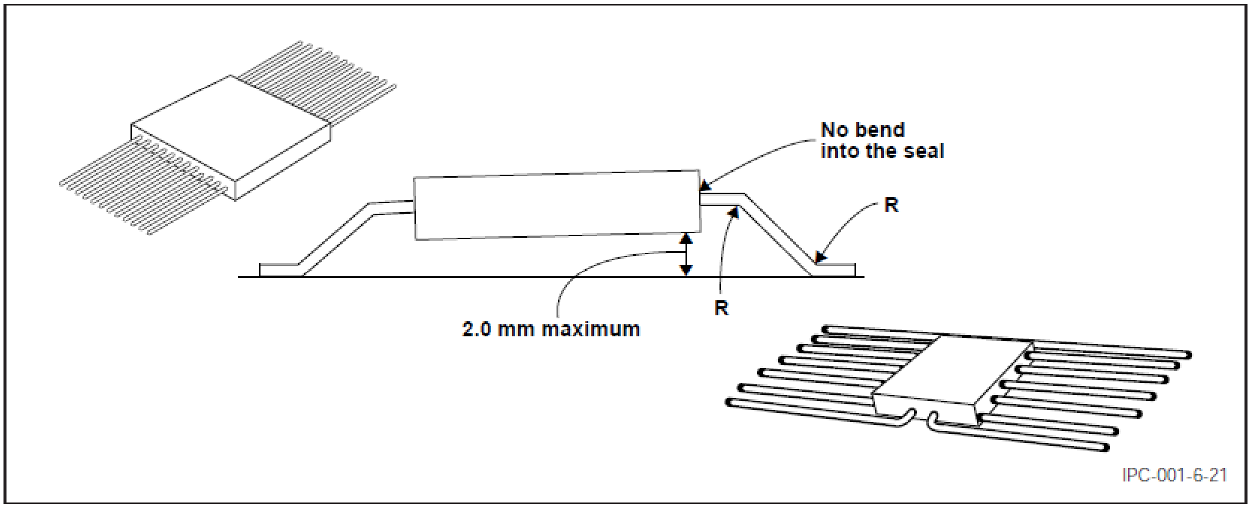


Figure 7-1 Surface Mount Device Lead

7.1.5 Surface Mount Device Lead Bends Any damage at the lead to-body seal can expose the internal elements of the component to processing solvents or environmental contaminants, which may cause corrosion and latent component failure. The minimum radius requirement ensures that the lead bend does not induce a latent fracture caused by work hardening of the lead material. Forming and trimming equipment is available with dies that meet the stated requirements. (Note Revision F corrected a typographical error in the required bend radius, was 1T, now ≥ 1T)

Note: Leaded DIPs may not withstand reflow soldering temperatures.

In some cases, the leads can be hand formed and trimmed. This approach is discouraged because it may damage component glass seals.

7.1.6 Flattened Leads Flattened, or ‘‘coined,’’ leads are axial, round leads that are formed to mount flat on surface mount circuitry, providing a stable and mechanically secure interface for soldering. The flattened portion of the lead **shall not** be less than 40% of the original lead diameter (for Class 3 hardware). Lead forming/trimming equipment is commercially available. Dies must form and coin the leads without damaging the component lead-to-body seals. Coining is generally not performed unless directed by the assembly drawing.

7.1.7 Parts Not Configured for Surface Mounting Components of the through-hole configuration (e.g., DIPs, transistors, metal power packages, and other nonaxial leaded components) **shall not** be surface mounted unless the leads are formed to meet the surface mount device lead forming requirements When used in a surface mount application(s), whenever possible, leads should be formed using die forming/cutting equipment, not with pliers, which will not bend the leads to consistent dimensions. Precision die cutting/forming equipment is commercially available to form all leads on the same geometric plane (proper coplanarity), ensuring that all leads contact the circuit pads.

Components with tempered leads **shall not** be formed for Class 3 hardware.

Note: Tempered leads are often heat treated leads to make the leads harder, but when bending are more susceptible to fracturing, due to increased brittleness. **Note:** Leaded DIPs may not withstand reflow soldering temperatures.

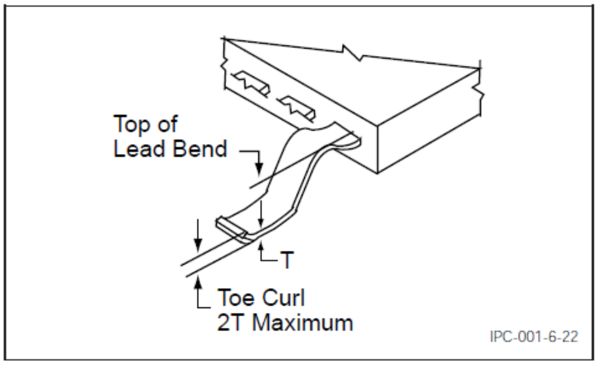


Figure 7-2 DIP Lead Forming

Butt/I Lead mounting (7.3 and Figure 7-3) is not considered a high reliability final soldered connection because there is little surface-to-surface interface between the lead and the circuit pad. Butt/I lead mounting is only permitted on Classes 1 and 2, and is not permitted for Class 3.

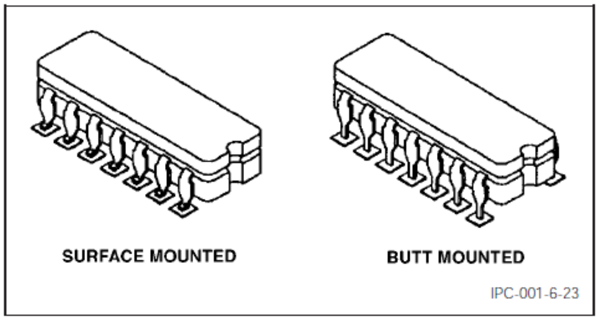


Figure 7-3 Surface Mounted and Butt/I Mounted DIPS

7.2 Leaded Component Body Clearance Uninsulated components must not contact exposed circuitry on the laminate surface. An insulating material, preferably a spacer or sleeving on the component body as directed by the assembly drawing, is required to isolate the component at the contact point. If the component is not insulated, component leads must be formed to elevate the device at least 0.25 mm [0.01 in] above the exposed circuitry. To minimize any vibration concerns, maximum clearance between the bottom of a leaded component body and the printed circuit surface should be 2 mm [0.08 in].

7.2.1 Axial-Leaded Components Surface mounted axial leaded components that are mounted more than 2 mm [0.08 in] above the surface should be secured to the substrate to reduce vibration effects. This can be accomplished with an adhesive (staking) or other mechanical means.

7.3 Parts Configured for Butt/I Lead Mounting Butt/I lead mounting is a method of mounting leaded components that were designed for through hole applications to surface lands. Component leads are trimmed to the appropriate length (as required to meet component standoff requirements), and then the component is positioned on the termination areas and soldered. Contact with the land pattern is perpendicular (no foot contact). Butt/I lead mounting is not considered a high reliability final soldered connection, because there is little surface-to-surface interface between the lead and the circuit pad. Butt/I lead mounting where a through-hole part has been modified is not permitted for Class 3. Components with solder charged terminations (i.e. a built in solder preform) are allowed for all three classes, and have the same criteria (see 7.5.10.2). As other styles of Butt/I leaded components gets introduced into the industry, use on Class 2 and 3 products is permitted, but only after acceptance criteria is agreed to between Manufacturer and User (again because of the less than ideal solder joint, it is critical that testing and/or criteria be established to ensure hardware produced will meet or exceed end item requirements).

7.4 Hold Down of Surface Mount Leads/Components A component’s leads that are held down during solder solidification will impart residual stress on the solder connection(s), which can cause early failure. This requirement must also apply when reworking soldered connections. As an example: if a lead has excessive side overhang, there is a potential that the rework operator may want to heat the solder, re-align the lead in the molten solder and hold it until the solder solidifies. The proper method sequence is to remove all of the solder, form the lead as necessary, realign the lead on the land and then re-solder. It is critical that the re-alignment of the lead not impart stress at the lead to body interface. Another consideration is if several leads are mispositioned on a multi-leaded device the operator should correct the alignment of the entire package not just the leads in question. This is usually accomplished by removing the package and re-aligning for resoldering.

Further, components should not be pressed down against the PCB land or other mating surface during the soldering operation or during solder solidification. The intention is not to eliminate the solder stand-off height (solder thickness “G”) which is a critical element of the soldered connection. It is understood that holding a component from the sides during soldering and solidification, may impart some downward force which is acceptable as long as the stand-off height (and corresponding solder thickness “G”) between the part and pad is not eliminated.

7.5 Soldering Requirements Solder connections for surface mounted components should have the same quality characteristics as through-hole solder connections. It is understood that components with surfaces and/or termination ends or sides that are not wettable by design are exempt from solder wetting requirements in those areas.

7.5.1 Misaligned Components A primary consideration for component surface mounting is alignment of the component terminations with the pad terminations on the PCB. Some components will tend to self-align (if not bonded down) during the solder reflow cycle, but some misalignment may remain (The tendency of components to self-align during reflow should not be considered a tool for correcting misaligned components). This Standard sets limits, based on the classification of the assembly, for various types of SMDs. The limits for misalignment are established based on the intended end-item classification use, which reflects the functional performance requirements for the assembly. Misalignment must not violate minimum electrical spacing requirements, even when compliant with the Standard’s mounting and placement requirements. Minimum design electrical clearance is a dimension that may vary with the voltages present on the circuit traces, and the environment in which the assembly is expected to operate. Fine pitch surface mount components may, in some cases, comply with the maximum side overhang requirement, but at the same time reduce the electrical clearance to adjacent termination areas to less than the minimum electrical spacing, and thus be a nonconformance, i.e., a defect for all classes. When these types of conditions exist, they should be identified on the corresponding assembly drawing and work instructions.

Misaligned components (tiled/raised…) cannot violate maximum component height requirements, nor impact form, fit or function. From a manufacturing perspective, when in doubt, ask the Design agency if form, fit or function comes into question.

Finally from an alignment perspective, as one reviews the individual Surface Mount sections and the dimensional requirements of say for example “allowable side overhang”, the reader should note that this is the total allowable overhang (i.e. both sides cumulatively). One should not assume that if in a design where for example side overhang exists on both sides of the lead in question that as long as the individual overhang on each side is less than say 25% (at least from a Class 3 perspective) then this is acceptable. This is not the case, again looking at an example, if there is 20% overhang on each side (40% total) this is not going to allow Manufacturing to meet the Maximum Side Overhang requirements (25% for Class 3) nor the Minimum End Joint With requirements (75% for Class 3).

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Misaligned components (tiled/raised…) cannot violate maximum component height requirements, nor impact form, fit or function. From a manufacturing perspective, when in doubt, ask the Design agency if form, fit or function comes into question.

7.5.2 Unspecified and Special Requirements Certain joint features are unspecified in size, and the only requirement is that a properly wetted fillet be visible. If a geometric dimension or other criterion is not specified, the feature is considered noncritical to the performance of the interconnections, and/or no criteria has been established.

Not all characteristics/attributes of a solder connection are essential for the mechanical and electrical integrity of the connection, and (in some cases) not all attributes are visually inspectable. If a solder connection meets the criteria listed by Tables 7.3 through 7.21 in the Standard and conforms to the solder connection criteria of 4.18, the connection is of sufficient quality to meet the requirements of the Standard. Note that a properly wetted fillet (with wetting evident to all elements being joined) must be present on every solder connection.

In cases where a minimum solder fillet requirement is not specified, the presence of a properly wetted fillet is sufficient to maintain the design reliability of the connection for the product application. In rare cases where the product will be subjected to significant thermal cycling, vibration or mechanical shock, it may be appropriate to specify solder fillet dimensions other than those included in the Standard. Note also there are certain types of components , typically J-Lead devices and Gull Wing devices, may use leads that are fabricated in a manner that renders one side of the lead non-solderable (i.e., that are not intended to be soldered).

Because approximately 75% of the volume and corresponding strength of a J-Lead or Gull Wing solder connection is in the heel fillet (“F”) and solder thickness (or Standoff fillet “G”), the absence of a side fillet is not considered detrimental to reliability.

7.5.3 Bottom Only Terminations Challenges with these style components include a lower standoff height leaving little room for visual inspection, and the low solder columns (Standoff solder Joints “G”) provide little compliancy for stress relief and thermal expansion. Because the only termination is between the bottom of the component and the land, minimum overlap is required (as defined by dimension “J”). Additional guidance can be found in IPC-7093, under general types, discrete components. From an overlap perspective there are some instances where the termination’s feature size is less than the component’s feature size (for example the component is wider than the metallization). In those instances, overlap criteria pertains to the size of the metalized feature (i.e., termination), not the size of the component body in question. Additionally, when the termination/metallization does not come to the component edge features such as “D” (Minimum Side Joint Length), “E” (Maximum Fillet Height) and “F” (Minimum Fillet Height) may not be visible, and one should defer to 4.18.3 for partially Visible or Hidden Solder Connections. For these style component, i.e., ones with hidden or partially hidden solder joint, it is recommended that the first article and subsequent production be validated via non-destructive means.

7.5.4 Rectangular or Square End Chip Components - 1, 3 or 5 Side Termination While overlap similar to bottom-only criteria is desirable, the Standard’s requirements for minimal overlap with at least the minimum end joint width and height requirements provides adequate connection reliability. Extremely harsh operating environments may require greater overlap. Revision F imposes additional overlap criteria (“J”) for Class 3 hardware, but would only be applicable for 3 and 5 sided termination devices.

Mounting a chip component upside-down may impart stresses that can crack the glass layer or resistive element, causing early failure. Additionally, solder coming in contact with the component body may impart stresses within the component and is not allowed.

7.5.5 Cylindrical End Cap Terminations This component is sometimes referred to as MELF (Metal Electrode Leadless Face). With their round cross-section, these components often feature less standoff (dimension “G”), than chip components, so the Standard includes a requirement for a minimum side fillet height to ensure structural strength and stress relief. The round shape may also lead to more misalignment than with chip components. Lands with cut-outs (i.e. u-shaped lands) may aid in component positioning, provided that an adequate solder fillet is formed.

7.5.6 Castellated Terminations Is adequately defined in the standard.

7.5.7 Flat Gull Wing Leads The heel fillet and solder stand-off, dimension “G”, provide approximately 75% or more of the strength of this type of connection, with the balance of the connection provided by the side joint length. The minimum 75% side joint length of long narrow leads may not be adequate in operating environments that have vibration, because the end of the lead may resonate and initiate cracking, which could grow along the bottom/side fillet area and ultimately lead to failure. A greater side joint fillet may be required, and if so, needs to be documented.

Depending on the lead material and the component manufacturing process, the sides of flat gull wing leads may not be wettable and there will not be any side joint height. Lack of side joint height should not impact connection reliability. However, if the side surfaces are known to be wettable and wetting isn't occurring, this could indicate a general wetting problem that may also be impacting wetting to the lead in the "G" and heel fillet areas. This should be investigated. Some gull wing lead forms are very close to the component body, and when PCB lands extend under the component, there is increased possibility of solder touching the component body. For low profile plastic bodied components (e.g. SOT or SOD), this is acceptable. For high profile components (QFP), filling the gap between the lead and component body with solder may be a reliability concern and needs to be investigated (see 7.1.1 for exceptions to solder touching the component body).
New Toe Overhang criteria (B) for Class 2 and Class 3 (Revision F), not permitted when the foot length (L) is less than three times the lead width (W), and is allowable when L≥3W, and minimum electrical clearance is maintained (and all the other dimensional requirements of Table 7-7 are met).

7.5.8 Round or Flattened (Coined) Gull Wing leads The heel fillet criteria for flat gull wing leads is in essence, also applicable to round or flattened gull wing leads. Conversely the solder thickness or stand-off fillet "G" is reduced on round leads, thus there is an additional side fillet height requirement.. Note in the case where acceptable side overhang exists on one side of the soldered connection, the minimum side fillet height would not apply there, but still be required on the opposing side. Toe overhang is acceptable per Note 1 of Table 7-8, and also provided that all other dimensional requirements of Table 7-8 are met.

7.5.9 J Lead Terminations J-leaded devices should be mounted to minimize side overhang and with the part positioned so that a minimum solder fillet can be formed. However, because approximately 75% of the strength of a J-Lead solder connection is in the heel fillet, the absence of a side fillet is not considered detrimental to reliability. Note, minimum heel fillet height applies in the heel fillet area only; there is no requirement/criteria for a toe fillet.

7.5.10 Butt/I Terminations

7.5.10.1 Butt/I Connections (Not Permitted for Class 3 Products) The limitations against Class 3 go back to early uses of SMT where through-hole component leads were sheared to make SMT terminations. Hermetically sealed components such as ceramic DIP packages with leads fabricated from Alloy42® or Kovar® are not wettable on the sheared ends, so there is no "G" wetting. The sheared leads were typically thin and narrow, and environmental stress screening proved that the minimal fillet that wets to the side surfaces of the leads is not adequate for harsh operating environments (high vibration and thermal cycles typical of Class 3). Because of evolving termination styles such as column grid arrays and butt terminations that are thicker and do have wettable surfaces, the Class 3 prohibition is creating some challenges to Users (see 7.5.10.2 below). IPC-9701 *Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments* will help Users qualify alternate acceptance criteria.>

7.5.10.2 Butt/I Connections – Solder Charged Terminations New criteria (Revision F) for components with hole(s) designed into the leads, and preloaded with solder (built in preform) to aide in the formation of the solder joint during reflow. This particular type of butt/I configured lead is acceptable for Class 3 use with the caveat that additional shock and vibe testing may be necessary, dependent on end use environment. Criteria are the same for all three classes. Figure 7-11 depicts a set of solder charged leads prior to reflow, note the leads, not the solder are centered on the mounting pads.

7.5.11 Flat Lug Leads the stiff leads provide little compliancy, and all of the strength of the solder connection is in the contact area between the lead and the land, no side or toe overhang is allowed for Class 3. This criteria has always been specific to leads of power dissipating components but with revision F criteria was added for any other flat unformed leads such as attachment of flex circuitry. Most of the criteria for flat unformed leads mirrors that for the flat lug lead criteria with the following exceptions: maximum side overhang for Class 3 has been established at 25%, and maximum gap for Class 3 has an added requirement to not violate minimum electrical clearance.

7.5.12 Tall Profile Components Having Bottom Only Terminations This termination style is similar to bottom-only chip terminations, but with greater stress on the solder connections (for Class 2 and Class 3 hardware) from the heavier and taller components. Revision F corrected the dimension to define the overlap criteria. ("R" to "S" for defining minimum side joint length). Note, there are instances where by component design, the termination does not extend to the component edge. In that case, the criteria here is applicable to the termination/metallization, not the component body itself.

7.5.13 Inward Formed L-Shaped Ribbon Leads and requirements for these components are similar to "J" Leads (see 7.5.9).

7.5.14 Surface Mount Area Array Packages The Standard does not require x-ray inspection, but it is recommended and may be necessary for effective process development and process control. Additional guidance can be found in IPC-7095. Revision E expanded these criteria to include non-collapsing balls and column grid array terminations.

7.5.14.1 Ball Grid Array Components with Collapsing Balls These criteria apply to conventional BGAs incorporating hemispherical terminations composed of leaded or lead-free solder that is designed to melt and reflow during reflow soldering. Additional guidance can be found in IPC-7095. Voiding within the limits imposed by the standard may be acceptable, but the incidence of voiding should be monitored. Changes in void size, incidence, or location within the solder connection may indicate process problems that require correction.

7.5.14.2 Ball Grid Array Components with Non-collapsing Balls These criteria apply to components with terminations that are not intended to collapse (melt and re-form) during reflow soldering. They may incorporate high-temperature alloys that resist soldering temperatures. Additional guidance can be found in IPC-7095.

7.5.14.3 Column Grid Array Components These components are similar to BGAs with non-collapsing balls, but incorporate metal structures that resist collapse during soldering. Standoff may be higher, and may be intended to provide for thermal mismatch between the substrate and the component body (which may be ceramic).

7.5.15 Bottom Termination Components (BTC) Guidance can be found in IPC-7093. Voiding criteria may need to be established as agreed between user and supplier, and consider the power dissipation and thermal characteristics of the device.

7.5.16 Components with Bottom Thermal Plane Terminations (D-Pak) It's important to separate the criteria for formed leads from criteria related to the thermal plane area. Users are referred to the criteria for the type of formed lead extending from the devices. While J-STD-001 primarily refers to soldered thermal planes of these components, there are some assembly operations that may use a thermally conductive adhesive instead of solder on some parts of the land.

7.5.17 Flattened Post Connections Criteria have not been established for Class 3 because no reliability studies have been submitted for committee review that would aid in establishing Class 3 criteria. In addition, these components share some of the same characteristics as with butt-style terminations which are not acceptable for use on Class 3 product. There is little compliancy in the leads, and little solder volume to provide stress relief or resist thermal expansion.

7.5.18 P-Style Terminations Criteria for the P-Style termination is based on test data submitted to the J-STD-001 committee. This is a new termination style with limited test data and history, therefore it is suggested that consideration for use should be accompanied by additional product specific testing to ensure the end product can withstand all applicable environments

7.6 Specialized SMT Terminations Component Manufacturers are continuously developing specialized termination styles that are unique to a particular component or are specially made for a limited number of Users. Often the components are fielded without adequate evaluation of the attaching solder connections. It isn't possible for documents such as J-STD-001 or this handbook to include criteria until there is significant User history, and testing using defined test methods such as IPC-9701. Users of this document are encouraged to submit such data and propose acceptance criteria to the IPC Technical Committee to be considered for inclusion in upcoming revisions of the Standard.

8 CLEANING PROCESS REQUIREMENTS

IPC J-STD-001F requires that items must be cleaned by a documented process. It could reasonably be asked why an assembler should be concerned about the "cleanliness" of a manufactured electronic assembly. The answer is that quality and reliability often depends on knowledge of what residues are present, and what impact those residues may have.

Fabrication processes for printed boards and the assembly processes for printed assemblies are a series of mechanical, chemical, and thermal operations, each of which can affect the cleanliness or residue content of the assembly. Some residues are benign, some are harmful, and others can cause catastrophic failures.

Electronic designs vary in their sensitivity to residues, depending on a wide range of factors. Ionic residues can cause corrosion, electrochemical migration, or electrical leakage under humid conditions. Non-ionic (organic) residues, such as oils or silicones, can interfere with adhesion or performance of adhesives or conformal coatings. Particulate residues, such as paper fibers, can absorb moisture in service, resulting in unintended electrical shorts. Paint will not adhere to a metal surface if it is coated with residual grease or oil. Dirt can interfere with transmission of data in electro-optic equipment.

In Figure 8-1, uncleaned and unreacted flux residues between high voltage pins of a power supply resulted in carbonizing of the board, destroying the assembly. In Figure 8-2, an inadequate cleaning process left flux residues, which when combined with humidity, resulted in electrochemical migration (dendritic growth) causing electrical shorts.

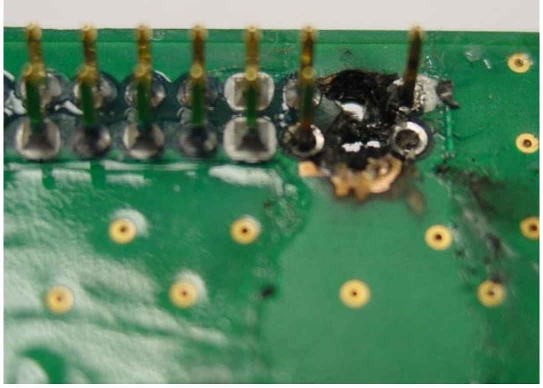

Figure 8-1 Burned PCB

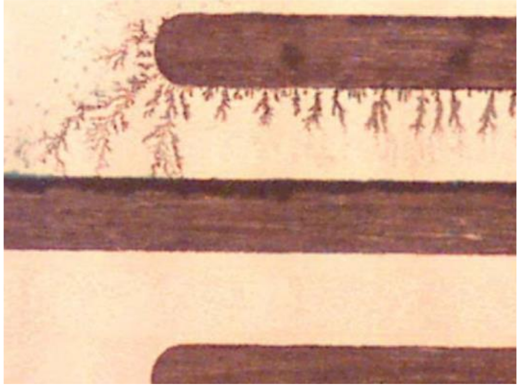

Figure 8-2 Dendrites

For more information on cleaning materials, equipment and processes, see IPC-CH-65 “Guidelines for Cleaning of Printed Boards and Assemblies”. This is an excellent reference covering aqueous, semi-aqueous, and solvent cleaning chemistries and processes. IPC-CH-65 also covers benchmarking and validating of cleaning processes, and includes how process residues affect reliability.

8.0.1 Process Residues and Their Impact on Product Reliability Product reliability represents the functionality of a device or assembly under environmental conditions for a given time period. The traditional view of quality assurance equated circuit board reliability with low visual residue and resistivity of solvent extract (ROSE test) measurements. As the industry progresses, higher circuit densities, larger footprints, smaller and stacked components, and lower component standoffs bring new risks. Other cleanliness tests may be needed to identify, extract, and measure the residues that correlate to product quality.

Other industry changes increasing the value of cleaning include:

- Increased circuit sensitivity with tighter spacing (a small amount of contamination can shift the circuit output).
- Newer flux formulations reduce the level of high solids rosin needed to seal and encapsulate fabrication residues, and use less resistant activators. Low solids fluxes, commonly formulated with weak organic acids, leave chemical residues that do not directly correlate with traditional ionic conductivity/resistivity measurements.
- Multiple assembly operations may bake residues onto surfaces prior to cleaning. It is not uncommon for one assembly to see SMT reflow for top and bottom components, wave soldering, selective soldering, underfill applications, rework, and localized brush cleaning that may deposit pockets of residue in critical areas.
- Residue sources include the bare board, components, and secondary processing.
- High-power devices may be designed to work in harsh environments.
- Non-ionic residues may be harmful, and appropriate test protocols have not been established.

8.0.2 Historical Perspective on Cleaning and Cleaning Processes For many years, printed boards finishes required relatively aggressive rosin-based fluxes to strip oxides from the surface metal to form a reliable solder connection. Because these fluxes were corrosive, residues had to be fully removed. The solvent of choice was one of the ozone depleting compounds (ODCs), which were not strong cleaning agents, but had other desirable properties. Flux residues were assessed by visual inspection, which is not always completely effective, so analytical tests were developed to measure ionic cleanliness of electronic assemblies and the effects of flux residues. Tests and acceptance limits were developed solely for the high-solids rosin fluxes in common use at that time.

In the 1970s, water-soluble (non-rosin) fluxes entered the commercial realm, while the military and medical manufacturers shied away from the unknown (for good reason). Decades later, when the Montreal Protocol and Clean Air Act dictated the elimination of ODCs, assemblers had to change methods. Flux suppliers began to provide a bewildering array of flux formulations, some tailored to specific applications. Suppliers of cleaning agents and equipment developed a wider variety of technologies, including solvent, semi-aqueous, and aqueous methods.

With this newfound choice of materials and processes, there was a new obligation to determine what constituted a clean assembly, whether the processes were compatible, and what effects the new materials had on reliability. The existing specifications for acceptability (chemical, electrical, and visual) continued to be based on rosin chemistry. Low solids fluxes were designed for a no-clean process and left visible residues. These residues were often benign, but the long-established rosin paradigm held that visible flux residues were harmful, so assemblies were often cleaned unnecessarily to remove (largely) cosmetic residues.

As research was conducted on the new fluxes, materials, and processes, it became apparent that there were no “golden” numbers or one-size-fits-all acceptability criteria. For this reason, specifications became based more on testing protocols to demonstrate reliability than on a single pass-fail test acceptance limit. The underlying philosophy of J-STD-001 now embodies this approach, putting responsibility for process demonstration on the manufacturer, and allowing the manufacturer and customer to agree on the test methods and acceptance criteria. However, to give adequate coverage to the issues of flux selection, cleaning dynamics, and materials compatibility is beyond the scope of this Handbook.

The IPC maintains a wealth of technical papers and handbooks illuminating the subtle but critical elements of process testing and process effects. In addition, as a volunteer organization, IPC maintains a network of experts in all aspects of electronics assembly technology. This network can be tapped electronically by subscribing (at no cost) to IPC TechNet, which is an active worldwide electronic forum with over a thousand engineers, chemists, and process professionals.

8.0.3 Magnification and Visual Inspection for Cleanliness In any discussion of cleanliness, it is important to discuss magnification power. At high enough magnification, even the most finely crafted assemblies can look contaminated. If the manufacturer inspects with the naked eye (no magnification), and the customer examines the same surface at 50X, there will be disputes.

J-STD-001 F 12.2.2 discusses inspection methodology and magnification aids. It is noted that for cleanliness inspection, magnification is not required, which implies examination with the naked eye, but allows for higher magnification. Unfortunately, the Standard does not give an upper limit for magnification in this case, but notes that “magnification may be needed to determine if contamination affects form, fit or function.” Engineering support may be needed to assess whether a residue affects form, fit, or function based on visual characteristics alone.

IPC-A-610 includes the following guidance:

- Contaminant is not only to be judged on cosmetic or functional attributes, but as a warning that something in the cleaning system may not be working properly.
- Every production facility should have a standard based on how much of each type of contaminant can be tolerated. Testing with ionic extract devices based on J-STD-001, insulation resistance tests under environmental conditions and other electrical parameter tests as described in IPC-TM-650 are recommended for setting a facility standard.

This recognizes that one cannot determine acceptable or unacceptable cleanliness of an assembly by visual aspects alone. If the cleaning process normally produces assemblies with no visible residues, but visual examination now shows visible residues, something in the cleaning process has changed and must be investigated. The second bullet point reinforces that the assembler must not only understand the materials used and the manufacturing process, but also how much residue can be tolerated before reliability is affected.

Examples:

In Figure 8-3, taken at a magnification exceeding 4X, an inspector saw the mottled surface of the solder mask, and believed it was flux residues. In fact, the appearance was related to the matte finish caused by the filler materials used in the solder mask, and had nothing to do with flux residues or cleanliness.

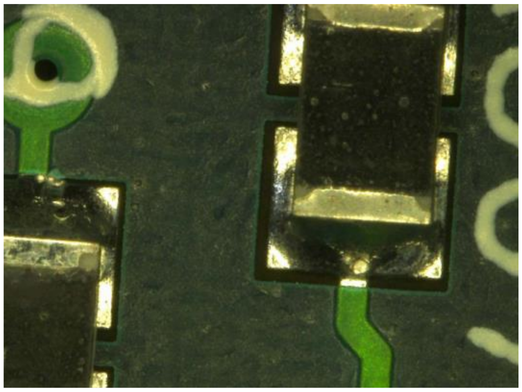

Figure 8-3 Solder Mask Surface Appearance

In Figure 8-4, an examination of 0603 capacitors showed faint white residues under the capacitors. In this case, the white residues were in fact flux residues (weak organic acids). The saponifier chemical in the aqueous cleaner had been running at a lower concentration than normal. Follow-up testing proved that the residues had no adverse effects on hardware reliability.

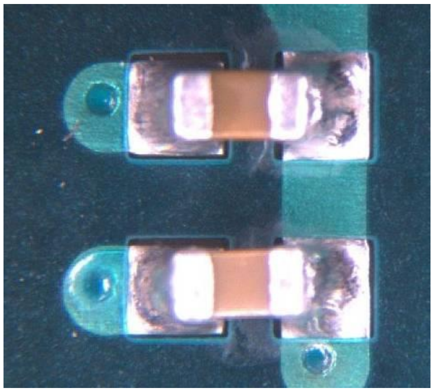

Figure 8-4 White Residue

In Figure 8-5, the inspector rejected the assembly for flux residue at the base of the gold pins, mistakenly believing that all solder joints should be bright and shiny, and that if the solder joints were not bright and shiny, it must be caused by flux residues. In this case, the frosted appearance of the solder joints was not harmful and had nothing to do with flux residues.

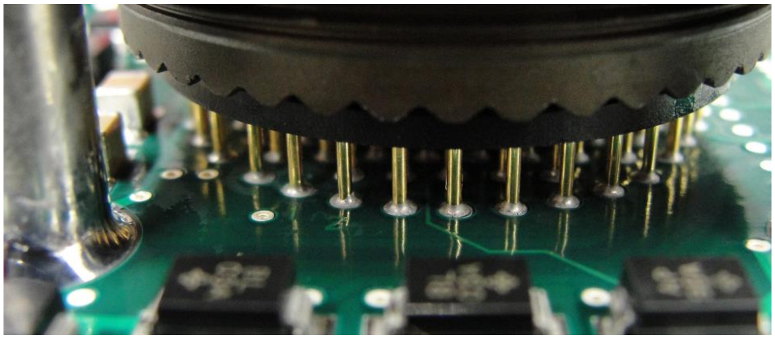

Figure 8-5 Frosted Solder Appearance

8.0.4 J-STD-001F Section 8 Demystified J-STD-001F requires
"*An item that is required to be cleaned* ***shall [N1N2D3]*** *be cleaned per a documented process to allow removal of all contaminants (especially flux residue).*"

If an assembly is required to be cleaned, then a documented cleaning process must remove all contaminants, especially flux residues. Although a documented cleaning process may be desirable for Class 1 and 2, it is not required. For Class 3 product, the removal of contaminants and the documented process are firm requirements.

In practice it is impossible to remove all residues from an assembly, so visual and analytical (test) criteria are established in the Standard. Some chemical tests, such as ion chromatography, are very sensitive and can determine low levels of residue.

When is an item "required to be cleaned?" Most often, the requirement is based on design or process considerations, and is included in the design, or is specified by the end item user or customer. If an assembler desires to use a no-clean assembly process, they should complete a materials and process compatibility study proving that the uncleaned hardware meets all requirements.

If a no-clean assembly is not required to be cleaned, is Section 8 applicable? Customers of no-clean hardware should be aware of the detrimental consequences of some residues. Even a no-clean assembly might require some form of chemical analysis/assay. Because a no-clean assembly process will not address any detrimental residues from bare board fabrication, component manufacture operations, or assembly processes, any no-clean assembler should understand the residues present on the manufactured assembly. The assembler should perform reliability studies identifying the residues present and their impact on reliability, and have that information documented and on file for review.

"The items cleaned ***shall [D1D2D3]*** *be capable of meeting the cleanliness requirement as specified herein."*

After an item is cleaned, if it does not meet the cleanliness requirements, this is a defect for all three classes, and must be dispositioned.

"All items to be cleaned ***shall [D1D2D3]*** *be cleaned in a manner that will prevent component degradation, e.g., thermal shock, and/or detrimental intrusion of cleaning media into components that are not totally sealed."*

Immediately after mass soldering (e.g. convection reflow or wave soldering) the components and laminate are still very hot. Immediately immersing an assembly in cooler cleaning solutions will result in thermal shock that could cause degradation in the laminate or the components.

8.1 Cleanliness Exemptions *"Terminations internal to self-sealing devices (e.g., heat shrinkable solder devices) are exempt from the cleaning requirements of this standard when the device encapsulates the solder connection."*

Encapsulated residues cannot be removed, but they are isolated and entrapped, and so cannot cause electrochemical problems.

8.2 Ultrasonic Cleaning Ultrasonic cleaning utilizes acoustic energy in combination with a cleaning solution. The ultrasonic energy may vary in terms of frequency and power level. Some early implementations of ultrasonic cleaning utilized combinations of frequency and power that damaged components by destroying gold wire bonds between the active silicon die and the package. Consequently, ultrasonic energy has historically been banned from high reliability electronics, especially in military hardware. Research by Dr. Peter Footner has shown that some combinations of frequency and power allow for good cleaning, but do not result in damage to wire bonds or other structures inside components.

Bare boards and assemblies with components that have no internal dies or wire bonds are not damaged by ultrasonic energy. For assemblies with delicate components, ultrasonic cleaning can be used if the manufacturer generates objective evidence that the documented ultrasonic cleaning process does not damage dies or wire bonds. The two IPC test methods referenced may be used to establish such objective evidence.

8.3 Post Solder Cleanliness Post solder cleanliness covers an assembly just prior to conformal coating, as coating will entrap any surface contaminants. If conformal coating is not used, then it refers to the condition of the assembly just prior to use, or incorporation into the next higher assembly. The manufacturer should be aware that assemblies can pick up undesirable residues from shipping materials or inadequate packaging. Visual inspection is required for both particulate contamination and flux residue, using inspection power defined in Table 12-2.

8.3.1 Foreign Object Debris (FOD) *"Assemblies **shall [D1D2D3]** be free of foreign particles that are loose, e.g., could be dislodged in the normal service environment of the product or violate minimum electrical clearance."*

Foreign object debris (FOD) and other unintentional remnants of the assembly process are signs of poor workmanship and may compromise circuit reliability. Electrically conductive (metallic) particles may cause electrical shorts, and nonconductive particles may migrate between electrical contacts and cause open circuits, or interfere with operation of moving parts like switches. Solder balls are more prevalent with some low residue fluxes, and loose solder balls or those that can come free with shock or vibration pose a risk of shorts. Solder balls that are firmly embedded into the solder mask or laminate are rejectable if they compromise electrical clearance between component pins or other conductors.

8.3.2 Flux Residue and Other Ionic or Organic Contaminates Flux chemistry has evolved from a few basic constituents in the 1970s to modern fluxes with multiple complex elements, ranging from halide-free, low activity (J-STD-004, class ROL0) to halide-bearing high activity (J-STD-004, class INH1). The activity level, and therefore the corrosivity of the flux residues can depend on many factors, including the individual chemicals used (from a list of hundreds); the amount applied flux, the thermal history of the flux, the degree of removal by the cleaning process, and potential interactions with cleaning chemicals.

A common misconception is that low activity fluxes (i.e. no-clean fluxes) are non-corrosive. The benign nature of low solids flux residues depends a great deal on thermal profiles. If the minimum activation temperature is not achieved, then the flux residues may still be corrosive or electrically conductive, leading to undesirable long term performance.

Some flux formulations, especially "low residue" or "no-clean" fluxes contain highly active and potentially corrosive chemicals that are designed to react with the heat of soldering. Solder heat causes chemical reactions that turn the residues benign. If these flux activators are not exposed to solder heat, or otherwise do not reach the minimum activation temperature, flux residues will remain highly corrosive. This is of special concern during hand soldering, where liquid flux may be applied from a squeeze bottle or other bulk dispenser. When flux is applied this way, the amount added is relatively uncontrolled, and can vary greatly depending on the skill and attention of the solder operator. Liquid flux may spread far from the local area around the solder connection, and could become entrapped under adjacent components. Because the soldering iron will be applied only to the small area around the soldering connection being formed, much of the flux will never be exposed to sufficient soldering heat.

Manual application of highly reactive liquid flux must be carefully controlled. The manufacturer should implement appropriate process controls that limit the amounts and areas where liquid flux is applied, including training operators to apply only the minimum amount of flux necessary to accomplish the task. Needle-tipped flux applicators should dispense liquid flux only a drop at a time. Foam-tipped applicators can be used to apply a thin coating of flux to the solder connection area. And if flux-cored solder wire is used, liquid flux might be eliminated entirely.

8.3.3 Post Soldering Cleanliness Designator The post soldering cleanliness designator classifies the manufacturing operation with respect to cleaning and methods for monitoring cleanliness. All manufacturers should understand what kinds of residues are on their electronic assembles, have objective evidence of the effects of those residues on reliability, and monitor residue levels for changes that can represent unacceptable impacts on quality and reliability.

If the assembler does not know any of these critical elements, then cleanliness designator C-22 applies by default, and requires that, at a minimum, circuit boards must be cleaned on both sides and tested for ionic cleanliness by Resistivity of Solvent Extract (ROSE).

Many manufacturers, especially those who build to IPC Class 3 products, have performed extensive research on the residues present on their assemblies, and the effects of those residues. J-STD-001 Appendix C provides extensive guidance for this (ref. Clause 3.1), and references IPC-9202 as one possible method. If such objective evidence is available for review, an assembler is allowed to choose a more appropriate cleanliness designator. The cleanliness designator relates more to the methods used for periodic monitoring for cleanliness than it does for initial process qualification.

As an example, suppose that an assembler has fully examined the residue assay of an assembly, including chemical characterization of the residues by ion chromatography, a correlation study between ion chromatography and ROSE for process control, and assessment of the residues on electrical performance by SIR testing, all for a no-clean assembly process. If the IC and SIR testing were used for process qualification only, with ROSE as the periodic monitor, the Cleanliness Designator would be C-02 (cleaning zero board sides, i.e. no-clean, and ROSE monitoring). If process monitoring were to be performed using both ROSE and ion chromatography, then the Cleanliness Designator would be C-025 (cleaning zero board sides, monitoring by ROSE and another documented test).

In this scenario, the data package may be used to help define ion cleanliness acceptability criteria, or more adequate process control parameters for ROSE, than is defined in the Standard.

8.3.4 Cleaning Option is well adequately defined in the Standard.

8.3.5 Test for Cleanliness is well adequately defined in the Standard.

8.3.6 Testing As described below, the appropriate cleanliness test will depend on the type of flux being used. The sampling plan and cleanliness limit will depend on the specific test and the end item requirements of the electronics being produced.

8.3.6.1 Rosin Flux Residue IPC-TM-650, method 2.3.27 is titled “Rosin Flux Residue Analysis – HPLC Method”. HPLC stands for High Pressure Liquid Chromatography. The origins of this test go back to the early 1990s, after. Circa 1990, the IPC conducted a study to benchmark the cleaning capabilities of ozone depleting substances on high solids rosin fluxes, summarized in IPC-TR-580. Later studies of other cleaning materials and processes were compared to this benchmark and summarized in IPC-TR-581, TR-582, IPC-TP-1043 and IPC-TP1044. Those tests included ionic cleanliness by resistivity of solvent extraction (ROSE), residual rosin by high pressure liquid chromatography (HPLC), and surface insulation resistance (SIR). IPC-TM-650 method 2.3.27 for residual rosin determination was developed as part of this research, as were the cleanliness criteria for Classes 1, 2, and 3.

It should be noted that these criteria were developed for rosin fluxes with solids content of approximately 35%. In addition, the cleaning methods used now-banned ozone depleting compounds (e.g. Freon TMS or 1,1,1 trichloroethane). In contrast, modern rosin fluxes are lower in rosin content, typically less than 15% solids. Modern cleaning processes, compared with 1990, are much more effective, and this test may be applicable only for rosin fluxes in excess of 25% solids.

8.3.6.2 Ionic Residues (Instrument Method) and **8.3.6.3 Ionic Residues (Manual Method)**

8.3.6.0.2 Resistivity of Solvent Extract Testing The resistivity of solvent extract (ROSE) test (sometimes called, the Solvent Extract Conductivity or (SEC) test) is often misused and misunderstood.

Back in the 1970s, there were no ionic cleanliness test methods available in the electronics industry. For many assemblers, cleanliness was judged by visual aspects only. Because many of the fluxes of that time could be corrosive and leave ionic residues if not adequately removed, electrochemical failures occurred in the field with regularity. Bill Hobson and Bob Denoon, Naval Avionics Center, Indianapolis, developed a quick and easy test for ionic cleanliness. That work was documented in NAC Material Research Report 3-72.

A solution of 75% isopropyl alcohol and 25% deionized water was run through mixed bed resin cartridges until the solution resistivity was high (>6 Megohm-cm), as measured by a temperature-compensated dip probe. Rosin alone is insoluble in water, so the test solution included isopropyl alcohol to dissolve some of the rosin and release the ionic constituents of the flux into solution so that they could be measured. The solution was poured over an assembly surface and captured into a beaker, and then the drop in solution resistivity of the extract solution was measured. Hobsen and Denoon decided to baseline this drop in solution resistivity against a common and easily ionizable salt, sodium chloride (NaCl). For example, if the change in resistivity was equivalent to adding 500 micrograms of sodium chloride, and the extracted surface area was 100 in^2, then the cleanliness would measure 5 micrograms sodium chloride equivalence per square inch.

This can be a source of confusion. The units for the ROSE test are in micrograms of sodium chloride equivalent per unit area (in^2 or cm^2). ROSE testing does not measure how much sodium, or chloride, or sodium chloride is on the assembly surface, itis not ion specific and cannot make such a determination. An ion specific test such as ion chromatography is needed to determine how much of a particular ion is present.

Hobsen and Denoon ALWAYS intended their test as a process control tool, not as an analytical tool or a metric for product acceptability. For example, if one's process typically measures 2.0 or less, but the most recent test measures 9.0, something in the process has changed and should be investigated. The IPC developed IPC-TM-650 method 2.3.25 (manual method) based on this test procedure.

The researchers continued their development work, correlating changes in extraction solution resistivity with surface insulation resistance under humid conditions, documented in NAC Materials Research Report MRR 3-78. They concluded that for ROSE values less than 10.06 micrograms of sodium chloride equivalence per square inch (1.56 µg/cm^2), risk of electrochemical failures were generally acceptable. Because this was the only ionic cleanliness data available to the industry at the time, this cleanliness limit was incorporated into military standards like WS6536 and MIL-STD-2000, and eventually into J-STD-001.

Hobson and Denoon then collaborated with Dr. Jack Brous, Alpha Metals to develop a machine to automate the ROSE process, which became the first Omegameter™. A test assembly would be immersed in a tank of freshly deionized isopropanol and water, and the change in resistivity of the solution was monitored over time. If the solution resistivity was stable after 10 minutes, the test concluded. Studies indicated that for this instrument, a value of 14.00 micrograms of sodium chloride equivalent per square inch correlated to the 10.06 micrograms equivalent for the original beaker test.

Military standards and military customers soon required assemblers to use such an instrument on samples during production, and many other versions of automated ROSE testers followed, such as the Ionograph™, Zero Ion™, Contaminometer™, etc. Some of the machines made resistivity measurements by keeping the extraction tank as a closed vessel, which became known as the "static method" (IPC-TM-650, method 2.3.26.1). Other machines treated the extraction tank as an open vessel, measuring resistivity of the solution as it exited the tank and integrating the results over time, and constantly circulating freshly deionized solution past the test sample. This became known as the "dynamic method" (IPC-TM-650, method 2.3.26.2). These machines allowed assemblers to monitor their processes for ionic residues, and field reliability issues from ionic contamination were greatly reduced.

One problem was that different test equipment designs yielded consistently differing results for identical test substrates. To address this, military standards incorporated "equivalency factors" for instruments on the market at the time. Table 8-1 shows the equivalency values from MIL-STD-2000.

Table 8-1 Equivalency Values from MIL-STD-2000

Instrument	**Equivalency Factor (µg NaCl eq./in^2)**	**Acceptance Limit (µg NaCl eq./in^2)**
Beckman	7.47	10
Markson	7.62	10
Omegameter 200	10.51	14
Ionograph	15.20	20
Ion Chaser	24.50	32
Zero Ion	25.17	37

Again, all of this work applied to the very limited material set in use at the time, i.e. high solids (>35%) rosin fluxes (e.g. RMA), followed by cleaning with solvents later identified as ozone depleting chemicals (e.g. Freon TMS, 1,1,1 trichloroethane).

In addition, some systems of the time were limited in precision, and readings from a machine at one supplier could differ from an identical model elsewhere, leading to accept/reject disagreements within the supply chain. In the early 1990s, the

IPC Ionic Cleanliness Task Group began a round robin experiment to examine the repeatability and reproducibility of ionic cleanliness instruments on the market at the time. This work was performed at the Electronics Manufacturing Productivity Facility (EMPF), then in Indianapolis, Indiana, and the resulting work was documented in IPC-TR-583 "An In-Depth Look At Ionic Cleanliness Testing". The overall conclusions of that study:

- The instruments studied were neither repeatable
- (precise) nor reproducible (accurate).
- Static and dynamic methods did not yield equivalent results.
- The type of flux greatly affected the results.
- Ionic residues were not removed effectively under some low standoff components (entrapment sites).
- Testers using heated and unheated extract solution produced different results.
- All machines had "dead band"; initial cleanliness of the extract solution differed from test to test.
- Exposure to carbon dioxide in the air had a significant impact on solution conductivity.

The study concluded that, despite their limitations, these instruments were still useful as process control tools (as they were originally intended), but should not be used for product acceptance.

In the late 1980s, the solvents commonly used for cleaning in the industry were identified as major contributors to the depletion of stratospheric ozone. The signing of the Montreal Protocol and US Clean Air Act of 1995 caused the industry to move to alternative flux materials and cleaning agents. Lower solids (15%) rosin fluxes, water soluble fluxes, synthetic fluxes, and low residue fluxes all began to be used, along with alternative cleaning chemistries and alternative materials.

The newer fluxes leave different residues than the high solids rosin fluxes for which the original ionic cleanliness standards were developed, and given the limitations documented in TR-583, why are automated ROSE testers still used today? Because these instruments were required for so long, many electronics manufacturers have one in house. The equipment is relatively easy to maintain and operate, and even a flawed cleanliness measure is preferable to none at all, at least until a better method can be developed. Properly maintained and used, these instruments are still valid process control tools.

Keep in mind that:

- All solvent extraction tests depend on time, temperature, and solvency.
    - If the flux residue will not dissolve in the chosen extract solution, then it will not be detectable in the test. Residues may be baked on or into the laminate or soldermask, and difficult to solubilize.
    - If flux residue is slow to dissolve in the extract solution, it may not be detectable in a short (e.g. 10 minute) test.
    - If residues require elevated temperature to dissolve (as many low-residue fluxes do), then testing with a room temperature solution may not be effective.
- Conversely, if the extraction methodology is too harsh, the materials of construction may be chemically attacked, adding residues or chemicals into the extract solution that have no bearing on the overall reliability of the assembly being studied. In addition, ROSE testing will not necessarily dissolve and clean all rosin-based flux residues from the assembly, and any remaining rosin may react with water in the test solution, creating hydrolyzed flux residues that are more difficult to remove than the original flux .ROSE testing measures contaminants only on surfaces that are exposed to the extract solution, not entrapped contamination. Concentrated contamination in localized areas may not dissolve completely during the test, and the readings will be "averaged out" over the entire surface area of the assembly. This is why electrochemical failures are still possible even when the ROSE test shows the assembly to be "clean".
- Assemblies that pass through ROSE testing should not be used for other residue characterization tests. If you test an assembly by ROSE and then do electrical testing on the assembly, it may do quite well, since the extract solution will have dissolved and removed any surface contaminants.
- Be aware of any trend that the instrument is showing. If, at the end of a 10 minute test, solution conductivity is still climbing steadily, the assembly may not be "clean" even if the test result is below the J-STD-001 limit for ionic cleanliness. In such a case, harmful residue may simply be slow to dissolve. Solder mask may be incompletely cured and is slowly releasing absorbed process chemicals. Poorly cured adhesive may be leaching contaminants. Continue the test until results stabilize; if solution conductivity continues to increase, stop the test and investigate.
- ROSE measures ionic contamination, not organic residues, including greases, oils, or silicones.
- For acceptance, a "one size fits all" cleanliness limit (e.g. 10.06 $\mu g/in^2$) is no longer appropriate. Modern assemblies are too dense and surface geometries too complex, and processes are too varied to use a 40 year old metric blindly for all products. "Low residue" or "no-clean" flux residues are qualitatively different from high solids rosin fluxes (e.g. RMA),

and present different risks of electrochemical or other failures in service, so using a cleanliness limit developed for RMA flux may not be valid. If ionic cleanliness testers are to be used for process control and product acceptance on anything other than low activity, high solids, rosin-based fluxes, then the user should perform correlation studies to determine adequate process control limits and acceptance values, considering their chosen material set and end-use requirements.

Ionic cleanliness testers can be valuable tools, but you must understand the outputs and use them intelligently.

8.3.6.4 Surface Insulation Resistance (SIR) If the cleanliness designator does not include SIR testing, it is not required, but default cleanliness designator C-22 does not prohibit the manufacturer from including SIR where it may be useful. As an example, if both sides of an assembly are cleaned and then verified by both ROSE and Belcore™ 24 hour SIR, then the cleanliness designator would be C-223. SIR may be an effective test for process qualification, as detailed in Clause 3.1 and Appendix C of J-STD-001F, as well as IPC-9202, or as agreed between User and Supplier.

8.3.6.5 Other Contamination “Other Contamination” goes beyond ionic contaminants, residual rosin, and flux residues, and can include outgassed silicone residues, polyglycols from solder masks, residual long chain alcohols from cleaning agents, etc. A variety of analytical chemical methods can be utilized, such as atomic absorption (AA), inductively coupled plasma (ICP), gas chromatography mass spectroscopy (GC-MS), and Karl Fischer titration. In most cases, IPC does not include vetted analytical test methods in IPC-TM-650, so the analytical methodology (or test method) and the acceptance limits must be agreed upon by the user and the manufacturer.

8.4 Frequently Asked Questions on Cleanliness

Question: Why would an assembler choose to clean a “no-clean” flux?

A Discussion of “No Clean” Terminology and Flux History, by Doug Pauls, Rockwell Collins and Bill Kenyon, Global Centre Consulting

If you examine the flux and solder paste markets of today, you would see product names containing phrases like “cleanable no-clean”, “water washable no-clean”, or “water rinsable no-cleans”. Such phrases seem to be oxymorons or conflicts in terms, leading to great confusion in the industry. If one looks at the flux classifications of J-STD-004, none of them are labeled as “no-clean”. A frequently asked question in the industry is “why would anyone clean a no-clean flux?”.

To better understand fluxes and flux terminology, a brief overview of fluxes and flux history in the electronics industry may be of benefit. Fluxes generally consist of a carrier, a diluent, an activator and some trace materials designed to optimize application and minimize soldering defects.

In the early stages of the modern electronics industry, the majority (if not all) of the fluxes employed rosin (from pine tree sap) as the carrier, 2-propanol (isopropyl alcohol or IPA) as the diluent and diethylamine hydrochloride or bromide as the activator. The trace ingredients included foaming agents and surfactants to minimize solder bridging and other defects. The carriers held the activator and related materials in place for optimum soldering results during the preheating and solder bath application steps. During preheating, the activator was designed to dissociate into the volatile free amine and acidic hydrohalide which removed any surface oxides to enhance solder joint quality. The organic parts of solder paste formulations were similar, except they had to have lower activator strength to prevent attack on the solder paste during storage. Such formulations also had to contain rheology control agents. These agents allowed solder pastes to drop in viscosity when a shear force was applied (e.g. just in front of the blade during solder paste printing, then immediately regain their original viscosity once the shear force is removed. Such agents thus prevent slumping and other soldering defects. Fluxes of that era had a 35% solids rosin content. Any activator residues had to be cleaned from the assembly after wave soldering or reflow operations, or severe corrosion would result.

The military specifications of that time (MIL-F-14256), which dominated the industry, classified these rosin (Type R) fluxes depending on how much of the active compound it contained. A Type R flux contained a very small level of activator. The more common RMA, or Rosin Mildly Activated, flux had a higher level of activator and was more aggressive. If an even higher activator level was used, for very hard to solder applications, the RA, or Rosin Activated, class flux was used. Most flux formulators provided “high solids” rosin fluxes that fit in one of these three rosin flux classes. Type RA-MIL contained less activator than a full RA, but allowed a path to military acceptance of fluxes with higher activator levels than RMA. Some commercial applications used Rosin Super Activated fluxes (RSA), which could contain activator levels 50% greater that RA. In the late 1970s/early 1980s one of the solvent cleaning agent suppliers developed the Synthetic Activated (SA) flux concept and shared it at no cost to all members of the flux and solder paste supplier sector. The resulting flux residues were easily cleaned in the preferred mild solvents without compatibility concerns, possessed high soldering power to cope with poor solderability and eliminated 'white residues'. Certain formulators found excellent results extending the concept to experimental fusing fluids for board fabrication, as well as in experimental solder pastes.

In the 1980s, the Department of Defense (DoD) mandated the adoption of industry specifications wherever practical. Flux experts from commercial and military backgrounds worked jointly on the development of J-STD-004, which often mirrored the requirements of the military flux standards. In 1995, the military cancelled MIL-F-14256 and directed users to J-STD-004.

J-STD-004, the predominant international specification on fluxes, classifies a flux based on the chemical nature of the flux, the activity level of the flux and its residues, and whether or not the flux contains a halide (fluoride, chloride, bromide, iodide). Flux and solder paste makers offer no clean formulations in compliance with an industry standard. The J-STD-004 flux identification system (J-STD-004, Revision B) is shown in Table 8-2.

Table 8-2 Flux Identification

Flux Composition	Flux/Flux Residue Activity Levels	% Halide[1] (by weight)	Flux Type[2]	Flux Designator
Rosin (RO)	Low	<0.05%	L0	ROL0
		<0.5%	L1	ROL1
	Moderate	<0.05%	M0	ROM0
		0.5-2.0%	M1	ROM1
	High	<0.05%	H0	ROH0
		>2.0%	H1	ROH1
Resin (RE)	Low	<0.05%	L0	REL0
		<0.5%	L1	REL1
	Moderate	<0.05%	M0	REM0
		0.5-2.0%	M1	REM1
	High	<0.05%	H0	REH0
		>2.0%	H1	REH1
Organic (OR)	Low	<0.05%	L0	ORL0
		<0.5%	L1	ORL1
	Moderate	<0.05%	M0	ORM0
		0.5-2.0%	M1	ORM1
	High	<0.05%	H0	ORH0
		>2.0%	H1	ORH1
Inorganic (IN)	Low	<0.05%	L0	INL0
		<0.5%	L1	INL1
	Moderate	<0.05%	M0	INM0
		0.5-2.0%	M1	INM1
	High	<0.05%	H0	INH0
		>2.0%	H1	INH1

[1] Halide measuring <0.05% by weight in flux solids and may be known as halide-free.
[2] The 0 and 1 indicate the absence or presence of halides, respectively. (Since some flux components may have naturally occurring halides, the absence of halides is taken to mean no halides were added deliberately by the flux formulator.)

So a ROM1 flux has a rosin chemistry, medium activity level, and containing halides. An INH1 flux was inorganic based, high activity, and halide containing (e.g. zinc chloride activated flux). So where do the “no cleans” come from?

In the late 1980s, the Montreal Protocol was enacted, which mandated the elimination of ozone depleting compounds (ODCs), which were the predominant cleaning materials for rosin-based fluxes. This dramatically opened up alternatives in the flux market to the rosin fluxes, and fluxes such as water soluble fluxes, low residue fluxes, and synthetic fluxes were placed on the market. Many manufacturers chose to examine new material sets and new manufacturing methods as alternatives to the high solids rosin fluxes and ODC cleaning. One of these avenues was to use low residue fluxes and to not clean the assemblies. These low residue fluxes were designed to have stable and benign residues after soldering processes, which was a stark contrast to the corrosive fluxes used previously. In this case, the manufacturer made a choice to use low residue fluxes in a no-clean assembly process. Flux marketers began selling the low residue fluxes as “no clean fluxes” per J-STD-004.

Which returns us to the question of why would any electronics assembler choose to clean a low residue (proper term) or no-clean (incorrect term) flux?

One of the biggest hurdles that the no-clean assemblers faced was bare board cleanliness. When everyone cleaned, this was not a major issue as fabrication residues were often addressed by the robust cleaning systems used. When the assembly cleaning processes were eliminated, the fabrication residues often resulted in electrochemical failures, such as dendritic growth, electrolytic corrosion, and electrical leakage currents in humid conditions. Often times during this era, the bare boards had passed the existing cleanliness specifications, based on resistivity of solvent extract testing, and yet still resulted in high failure rates for OEMs. Such failures could often be traced back to the non-ionic water soluble fusing and hot air solder leveling fluid residues from fabrication processes-(see IPC-TM-650 TM 2.3.38 & 2.3.39). Ion chromatography testing for electronics assemblies was adopted by our industry during this time period as well.

Today, bare board residues and their impact on electronic assemblies are better understood, and there are better tools for measuring bare board cleanliness, but the need to clean may still be required by OEMs. When an OEM chooses to implement a no-clean assembly process, they have not really eliminated the need for cleaning, but have moved the cleaning requirement upstream to the board fabricator and component makers. This may not be always understood by the OEM, the fabricator and especially the customer. In addition, with any profit squeezed out of the board fabrication sector, board fabricators and assemblers may no longer have technical staff members that understand the critical parameters for board cleanliness, or may shortcut bare board cleaning to get a lower price or better profit. OEMs may not understand how to specify or measure cleanliness in procurement contracts, and so cleaning in the OEM assembly process may remain in the process as a viable safety net for fabrication and ultimately assembly residue removal.

Using similar reasoning, OEMs may choose to clean because of residues that remain on components. At present, there are no industry standards for component cleanliness. This may be especially true where components have to be re-tinned as a solderability restoration. Such re-tinning may require a much more active flux whose residues cannot remain on the components.

Cleaning processes also have secondary benefits, such as removal of solder balls, allowing the use of water or solvent soluble masking agents, and changing surface energy of assemblies for conformal coating.

An OEM may also choose to clean because of assembly esthetics, especially in the high performance, medical or military realms. A defense contractor often has to deal with contractual language and boilerplate language that may be decades old, referring to specifications no longer in force, or with customers whose experience with fluxes was back in the “good old days” of high solids rosin fluxes. In those days, a visible flux residue was always potentially a bad flux residue. A popular misconception is that visible flux must be “contamination” and undesirable. That mentality carries through for many programs simply because so many military programs have been bitten by harmful effects of flux residues or lack of cleaning. It is not uncommon for an OEM to choose to continue to clean a low residue flux because it is far easier than changing the mindset of the customer. Without any quantitative measurement techniques and appropriate pass/fail limits, it was extremely difficult to convince anyone that the dreaded “white residues” were usually merely cosmetic or that the invisible but very damaging hydroscopic non-ionic residues were a source of real disaster, especially at elevated humidity levels.

This leads to perhaps the most subtle reason why an OEM may choose to clean a low residue flux; it is easy to change a material or process, compared to the effort needed to change a culture. Implementing a true no-clean assembly process involves dozens, if not hundreds of changes, each of which can have a detrimental effect on assembly reliability if not addressed. It involves placing controls on vendors, selection of new material sets and possibly new equipment, implementation of controls on storage and handling, and a massive retraining of personnel. One of the greatest “forgotten elements” of a successful “no clean” process is implementation of rigorous board and component solderability standards to cope with the very mild soldering materials used. Thus the “no clean” assembler lost the process flexibility of stepping up to more aggressive fluxes and pastes to compensate for marginal solderability, knowing any residues could be essentially completely removed in the cleaning process. No clean processes have remained in the assembly tool box, even as spacings become increasing smaller. Component makers are trying to cope with this by putting more and more active elements on fewer components to minimize component count and increase I/O spacing to ease cleaning when specified. BGAs are a good example of this approach. None of these factors are trivial or inexpensive, although the elimination of the cleaning process, cleaning agents, and personnel was often hastily implemented by management perception that it would automatically result in huge cost savings.

IPC J-STD-001 clearly places the burden of materials compatibility testing on the shoulders of the OEM. When a low residue flux or solder paste is chosen, the OEM must choose a flux/paste that is cleanable with a chosen cleaning chemistry. Not all low residue fluxes can be cleaned or at least, cleaned adequately to acceptable levels as assemblers demand more performance from smaller amounts of soldering chemistry.

So, there are many valid reasons why OEMs continue to implement cleaning processes, even when using low residue or “no clean” fluxes.

Question: How do I know that the area under a low standoff component (e.g. BGA) is clean?

One of the drawbacks of ROSE or ion chromatography testing, is that they are usually performed by immersing the entire assembly in test solution, and therefore yield an average ionic cleanliness level for the exposed surfaces of the assembly being tested. The total contamination found is averaged over the total surface area. While the resulting number may show “acceptable” levels, it may not find areas of localized high contamination, such as under BGAs or other areas where residue may be entrapped. There are methods available for performing local extractions to test for ionic residues, but some are proprietary, or may require consistent and expert technique. The IPC Ionic Conductivity Task Group is working to formalize some of these localized extraction techniques, including corner extractions, local irrigation and capture, cross sectioning and extraction, and dam and fill method. Ion chromatography of these localized extractions may characterize the particular residues found, but will not determine the potential effects of those residues. Long term accelerated life testing in a humid environment may be the most effective way to demonstrate that detrimental levels of residues do not exist under low standoff devices.

Question: Can flux residues flow or relocate?

Flux residues can vary dramatically in composition, and those with polymeric constituents (or that act like polymeric materials) do have softening temperatures. While actual flow of flux residues is very rare, it can occur. Flux residue under conformal coatings, potting compounds, or other encapsulants can soften and cause the overlying material to delaminate.

Question: How does hand cleaning or topical cleaning impact overall cleanliness?

Topical cleaning is often performed after hand soldering of a component, when flux residues are treated with a cleaning agent (often from a squeeze bottle or flip-top dispenser), and then scrubbed with a brush. If the combined flux/cleaner is not rinsed off or otherwise removed from the board, it remains a contaminant that may represent a reliability risk. Flux removers chemically combine with the flux to form a compound that is more easily rinsed, and if not completely removed from the assembly, all that has been accomplished is to create a new residue and smear it around a wider area on the surface.

Question: Can you explain what electrochemical failures are?

Many of us in the electronics industry understand the basics of electroplating. Metal ions, such as copper or gold, are dissolved in an electrolyte, usually acidic, and when an electrical potential is applied, the metal ions are deposited on the target and become solid, plated metal.

Electrochemical failures are simply this process, done in reverse. A soluble residue on the circuit board, when combined with a little water, can form an electrolyte. When an electric potential is applied between non-common conductors, for example during normal operation of the electronic circuit, an undesired electrical leakage current can flow through the electrolyte, causing erratic function in the circuit. If the residue contains strongly electronegative ions such as chloride or bromide, the electrolyte can become acidic and dissolve surface copper or other conductors. Dissolved metal ions then migrate under the influence of the driving electrical potential. On a microscopic scale, the acidity (pH) of the electrolyte changes between anode and cathode. As metal ions migrate, they drop out of solution as a metal filament. These metal-salt filaments are most often referred to as “dendrites”. Eventually, these metal filaments can grow and bridge the intervening space between cathode and anode, creating a short circuit. In this way, undesired low-resistance paths arise from ionic residues, when combined with moisture and electricity.

Question: Will wearing gloves make it easier to meet the ionic cleanliness requirements of J-STD-001?

While gloves may help minimize the transfer of finger salts and oils to an assembly surface, they all too often provide a false sense of security and can actually aid in the transfer of residues to an assembly. The general assumption is that the exterior surfaces of the glove are clean, but in practice, it does not take long for glove surfaces to become contaminated with flux, solvents, adhesive residues, skin or hair oils from incidental contact, etc. The constant changing of gloves takes considerable attention and discipline, and can result in a high consumables cost, so they may not be changed as often as they should. In addition, gloves with talc on the inner surfaces represent an ionic contaminant, as talc is loaded with undesirable ionic materials.

Gloves may also be viewed by operators not as a way to protect an assembly from their residues, but to protect their hands from process chemicals. While this may be true, it often leads to a subtly different use of gloves leading to more residue transfer to an assembly.

When used, gloves should be chosen for functionality and comfort. Uncomfortable gloves will not be worn as consistently. Disposable gloves are inexpensive but often act as vapor barriers, entrapping moisture from the skin. White cotton gloves breathe more, but are often treated with chlorine bleach for a bright white color, and chlorine residue is corrosive to electronics. As an alternative, cotton gloves with nitrile on the palms and fronts of the fingers are recommended. These gloves have the breathability of cotton gloves and the chemical resistance (and low electrostatic charging) of nitrile. The nitrile surfaces can be regularly cleaned with mild solvents.

Question: I know ionic residues are related to electrochemical failures, but do they have other negative impacts?

Research by Hillman and Snugovsky has shown that high ionic residues correlate with increased risk of tin whisker growth in pure tin surfaces, as shown in Figures 8-6 and 8-7.

Figure 8-6 Average Tin Whisker Density *D. Hillman, IPC/SMTA Cleaning and Conformal Coating Conference, 2010*

Figure 8-7 Average Tin Whisker Density *D. Hillman, IPC/SMTA Cleaning and Conformal Coating Conference, 2010*

9 PCB Requirements

9.1 Printed Circuit Board Damage

9.1.1 Blistering/Delamination: Blistering is a form of delamination. It is a localized swelling and separation between any of the layers of a laminated base material, or between base material and conductive foil, or protective coating (i.e., solder mask).

Delamination is a separation between plies within the base material, or between the base material and the conductive foil, or both.

Blistering and Delamination are considered to be major defects. Separation of any part of the board can lead to a reduction of the adhesion to occur and impact the insulation properties. The area of separation could house entrapped moisture, processing solutions, contamination, or electromigration and cause corrosion and other detrimental effects. Entrapped moisture, when subjected to soldering temperatures, can create steam that blows holes through the plated side walls, exposing the resin and glass of the plated through holes and creating large voids in the solder fillet.

9.1.2 Weave Exposure/Cut Fibers: Weave Exposure/Cut Fibers is a surface condition of base material in which the unbroken fibers of woven glass cloth are not completely covered by resin. Weave exposure is considered to be a major defect. The exposed glass fiber bundles allow wicking of moisture and entrapment of processing chemical residues. Weave exposure reduces the dielectric properties between conductive patterns to less than the minimum electrical clearance.

9.1.3 Haloing: The distance between the haloing penetration and the nearest conductive feature is defined to be less than the minimum lateral conductor spacing, or 100 µm [4 µin].

9.1.4 Edge Delamination: Edge delamination which reduces the physical spacing from the edge to the closest conductive pattern by more than 50% or more than 2.5 mm [0.1 in], whichever is less is not acceptable.

9.1.5 Land Conductor Separation: The outer, lower edge of land/conductor areas cannot be lifted or separated more than the thickness (height) of the land/conductor. For Class 3 assemblies, the land areas cannot be lifted when there is an unfilled via or via with no lead in the land. There cannot be any separation of circuit conductors from the base laminate by a length greater than one conductor width.

9.1.6 Land/Conductor Reduction in Size: This affects the electrical characteristics of the conductor. Reductions in cross-sectional area are incapable of carrying the designated current load and are susceptible to reduced reliability. Hence, the width of printed conductors or width/ length of lands cannot be reduced by more than 20% for Class 2 and 3 and 30% for Class 1

9.1.6 Flexible Circuitry Delamination: This is often caused by coverlayer wrinkles. Coverlayer wrinkles develop due to compression forces experienced when flexible circuits are bent sharply. The compression forces cause wrinkles in the coverlayer or covercoat on the inside of the bend. In turn, the cover wrinkles can lead to the delamination of the insulating materials. Delamination (separation) or bubbles in the coverlayer or covercoat of the flexible circuitry that span more than 25% of the distance between adjacent conductive patterns is not acceptable because.

9.1.8 Flexible Circuitry Damage: There can be no evidence of tearing, blistering, charring, or melting of the insulation.

- **Creases:** Ridges in a material caused by a fold or wrinkle being placed under pressure. Creases reduce the current carrying capability and reliability of the printed conductors and the bond integrity of the laminate. To prevent creases in flex circuits the utilization of a proper bend radius and strain relief is necessary.
- **Physical damage:** Cuts, nicks, gouges, tears or other physical damage that results in exposed circuitry or reduce electrical separation below minimum requirements are not acceptable such as

    - Nicks in the flexible portion of circuit cards that extend more than 50% of the distance from the edge to the nearest conductor or 2.5 mm [0.1 in], whichever is less.

    - Nicks or haloing along the rigid part of the edges of the rigid-flex printed circuitry, cutouts, and unsupported holes that exceed 50% of the distance from the edge to the nearest conductor or 2.5 mm [0.1 in], whichever is less. Dents in the surface coverlayer of the flexible material that expose circuitry below (Reduced thickness).

- **Foreign material in covercoat:** Foreign material under the covercoat represents a contamination and reliability concern.

NOTE: Mechanically created indentations caused by contact between the coverlayer of flexible printed circuit boards or assemblies and molten solder are not rejectable. Additionally, care should be taken to avoid bending or flexing conductors during inspection.

9.1.9 Burns: Burnt loactions are definedas being scorched, charred, or badly damage areas on a printed circuit board resulting from exposure to excessive heat. The depth of damage can range from slight discoloration, to melted conductors, to a hole through the entire printed circuit board. Discoloration is not rejectable – charring is rejectable.

9.1.10 Non-Soldered Edge Contacts: It is important that no solder or flux contamination is present on any of the gold contacts (including “no-clean” processed assemblies) in the critical contact area. Any solder present can have a long term detrimental effect on the gold plating. Solder and gold are dissimilar metals. When solder is present in the mating area of a gold contact this may induce galvanic corrosion on an electronic assembly.

9.1.11 Measles: Measles are defined as an internal condition occurring in laminated base material in which the glass fibers are separated from the resin at the weave intersection. For more information see IPC-A-600 IPC Blue ribbon committee information on measles. Measling is not a defect for Class 1, 2 and 3 printed board assemblies. Measling and Delamination are not the same condition. Measling is usually related to thermally induced stress, but can also be found in newly laminated materials.

Note: Measling is an internal condition which may not propagate under thermal stress and has not been conclusively shown to be a catalyst for conductive anodic filament (CAF) growth. Delamination is an internal condition which may propagate under thermal stress and may be a catalyst for CAF growth. The IPC-9691 user's guide for CAF resistance testing and IPCTM-650, Method 2.6.25, provide additional information for determining laminate performance regarding CAF growth.

9.1.12 Crazing: Crazing is an internal condition that occurs in reinforced laminate base material whereby glass fibers are separated from the resin at the weave intersections or along the length of the yarn. (This condition manifests itself in the form of connected white spots or crosses that are below the surface of the base material.) It is usually related to mechanically-induced stress, such as swaging terminals into PWBs..

- Crazing cannot exceed 50% of the physical spacing between non-common conductors.
- Crazing at the edge of the board cannot reduce the minimum electric clearance between board edge and conductive pattern. If the minimum electrical clearance is not specified, the spacing cannot be more than 50% or 2.5 mm [0.1 in], whichever is less.

Note: Visual aids can be found in IPC-A-610.

9.2 Marking: Marking is a method of identifying printed boards with part numbers, revision letter, Manufacturer's date code, etc. Marking provides both product identification and traceability, which aids in assembly, in-process control and field repairs. Marking must be readable, durable, compatible with the manufacturing processes, and should remain legible through the life of the product. Missing, incomplete or illegible characters in markings are unacceptable and could result in defective printed circuit assemblies Component part numbers may not be visible but assembly part number, serial number, etc. are critical and must remain legible; along with any specific identification on drawing or in assembly requirements – matched sets etc.

9.3 Bow and Twist Warpage: Bow is the deviation from flatness of a board characterized by a roughly cylindrical or spherical curvature such that, if the board is rectangular, its four corners are in the same plane. Twist is the deformation parallel to a diagonal of a rectangular sheet such that one of the corners is not in the plane containing the other three corners. Bow and/or twist on a board are detrimental when the board must fit in card guides or in packaging configurations in which space is limited.

9.4 Depanelization: Depanelization is the process of removing or separating individual printed circuit boards (PCBs) from a panel. Depaneling after soldering is to be done in a manner that does not impart damage to the assembly in excess of the following: Edges cannot be frayed; Nicks or routing cannot exceed 50% of the distance from the board edge to the nearest conductor or 2.5 mm [0.1 in], whichever is less; Loose burrs cannot affect form, or fit or function. Depaneling can be accomplished by using one of the following cutting techniques: Hand break; V-cut; Punch; Router; Saw; or Laser. Each of these cutting techniques has its own set of advantages/disadvantages ranging from: inexpensive versus expensive equipment costs; to inducing higher stresses versus lower stresses at the contours of the V-groove lines (or break-out tabs) which are used to help separate the individual PCBs from the panel; to higher accuracy and precision of using lasers versus the need of a metal fixture or jig during the cutting operations, as examples.

10 Coating and Encapsulation, Staking

10.1 Conformal Coating Conformal coating, for the purpose of this document, is defined as a thin, translucent, polymeric coating that is applied to the surfaces of PCAs to provide protection from the end-use environment. Typical coating thickness ranges from 12.5 μm [0.49 mil] to 200 μm [7.9 mil].For more information concerning conformal coating users of this document are recommended to refer to IPC-HDBK-830.

Processing characteristics and curing mechanisms are dependent on the coating chemistries used. The desired performance characteristics of a conformal coating depend on the application and must be considered when selecting coating materials and coating processes. Users are urged to consult the suppliers for detailed technical data.

This guide enables a User to select a conformal coating based on industry experience and pertinent considerations. It is the responsibility of the User to determine the suitability, via appropriate testing, of the selected coating and application method for a particular end use application.

A conformal coating may have several functions depending on the type of application. The most common are:

- To inhibit current leakage and short circuit due to humidity and contamination from service environment.
- To inhibit corrosion.
- To improve fatigue life of solder joints to leadless packages.

- To inhibit arcing and corona.
- To provide mechanical support for small parts that cannot be secured by mechanical means, to minimize damages due to mechanical shock and vibration.
- Limitations of some coatings are exposure to sulfur rich environments and tin whisker formation

The quality of the conformal coating is dependent upon the procedures used in both mixing (where applicable) and curing the coating. While some two-part systems are mixed by volume, other two-part systems are mixed by weight. Care must be exercised to ensure the correct basis for mix ratio is used, or else the physical characteristics of the resultant coating will suffer. Mixing in incorrect ratios can result in changes in the hardness, CTE, surface adhesion/bonding characteristics, elasticity, and shear strength.

If curing conditions are not optimized in accordance with the Manufacturer’s instructions, the same parameters listed prior may be affected. In addition, improper cure of some coatings will result in only a skin at the surface of the coating achieving cure. This false cure will trap uncured coating material between the coating surface and the PCB surface. Such uncured coatings can have a significant effect on SIR and affect the operation of the coated circuits. Documented process variations will allow traceability, should unexplained field failures later occur.

Most conformal coating systems are chemically complex systems, and for many, the Manufacturer will define or identify a shelf life or “pot life”. Shelf life is how long the User can store conformal coating systems on the shelf between the time the material is manufactured and the time it is used. Shelf life is usually rated in months and can be from three to twelve months, or more.

Pot life is how long the User has to use the conformal coatings after mixing or exposing them to room ambient conditions in an open container. Pot life is widely variable and may be from minutes (for some two-part epoxies) to hours.

Shelf life and pot life are usually rated as a function of environmentally optimum storage or use conditions. Actual usable life may be much shorter than the Manufacturer’s rating if storage/use environments are uncontrolled. The major contributing factors to chemical degradation during storage are temperature, humidity extremes, and in some cases, exposure to infrared (IR) or ultraviolet (UV) radiation (sunlight).

10.1.1 Types of Conformal Coatings Conformal coatings are polymeric materials used to protect electronic assemblies from a wide variety of life cycle contaminants. Conformal coatings provide a high degree of insulation protection and are usually resistant to many types of solvents and harsh environments encountered in the product life cycle. The coating materials also act to immobilize various types of particulates on the surface of the PCA and function as protective barriers to the various devices on the board.

They are resistant to moisture and humidity, but not typically sulfur or whisker formation which may reduce the potential of leakage currents, "cross talk", electrochemical migration, dendrite growth and arcing. These issues are becoming more critical with the reduction in component size, pitch, circuitry spacing, laminate thickness, and voltage plus the rise in speed (frequency) of signals.

Conformal coatings can be broken down into two liquid families; organic and silicone. The primary traditional classifications are acrylic (AR), epoxy (ER), silicone (SR), urethane (UR) and poly-paraxylylene (XY). These classifications based on basic resin chemistry type, which is further differentiated into subtypes based on cure mechanism. IPC-HDBK-830 provides a comparison of various coating types and application notes and provides an excellent guide for use of conformal coatings. See Figure 10-1.

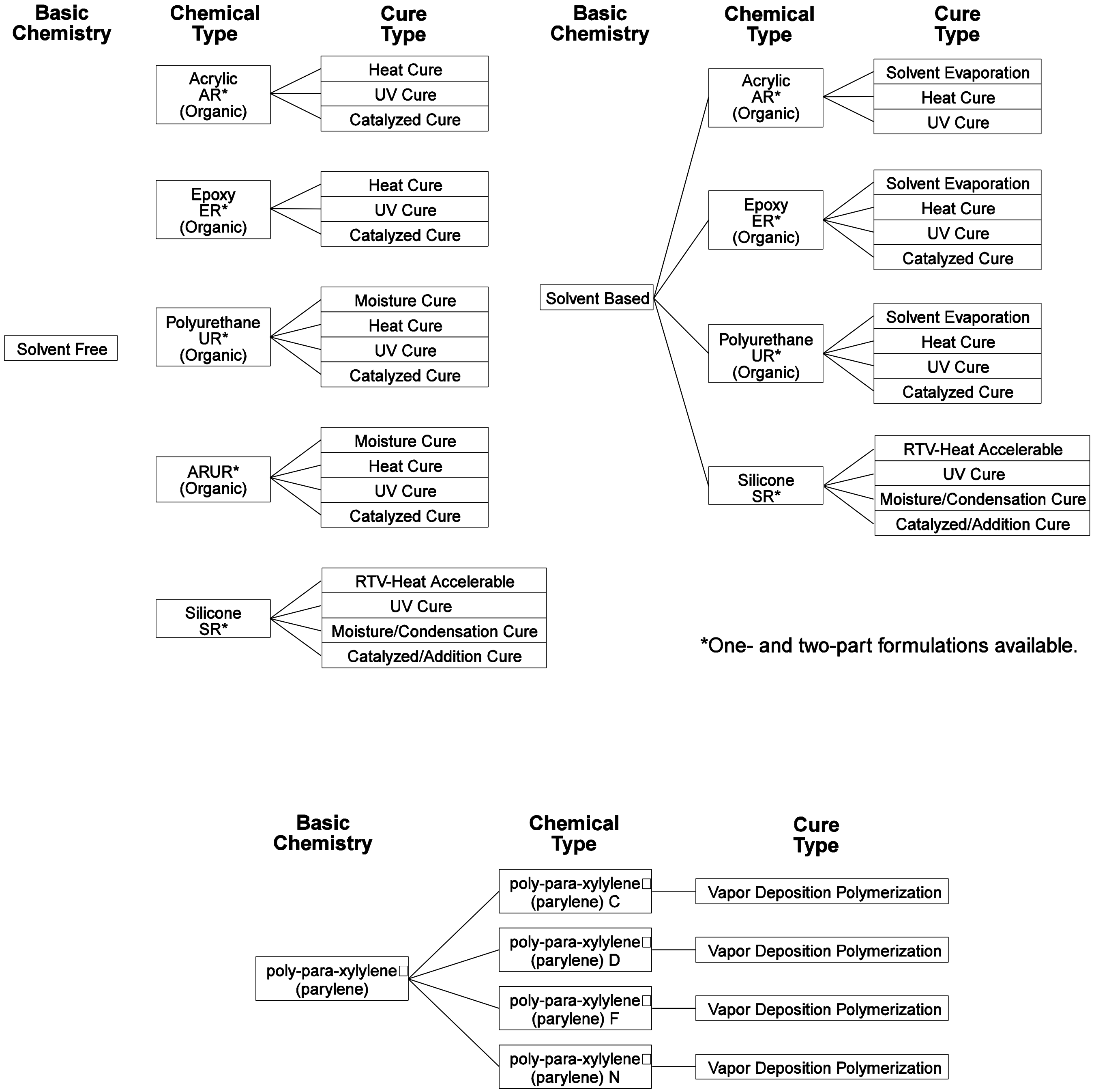

Figure 10-1 Conformal Coating Family Trees

These systems are primarily made up of monomers, oligomers, de-foaming agents, fillers, and wetting agents. Various combinations of each are added to the formulations to adjust the cured and uncured properties. Solvents may be added to adjust application viscosity. Prior to the start of curing process, solvents evaporate ("flash off"), leaving a resin matrix to initiate the cure. The VOC emissions associated with this type of cure created a need for more environmentally acceptable production chemistries and cure mechanisms. Presently solvent-based conformal coating chemistries exist which are exempt from environmental regulations. Refer to IPC-HDBK-830 for environmental, health and safety considerations.

All resins except for acrylic resins are cured by an irreversible polymerization reaction with varying degree of cross-linking (thermoset polymers). The cross-linking of the epoxy, urethane, and silicone polymers provide very good chemical resistance but also make it difficult to remove the coatings when performing repair work. No polymerization reaction is taking place when applying acrylic coatings. Therefore, it is misleading to say that acrylic coatings are cured. They are formed by drying a solution of already formed acrylic polymer chains dissolved in a solvent (thermoplastic polymer). Hence, acrylic coatings are easily dissolved in many organic solvents providing poor chemical resistance but facilitating repair work. Consequently, most acrylic materials are solvent-based.

All, except paraxylylene, have traditionally been solvent-based until environmental issues dictated a need to change. Now, many materials are solvent-free chemistries (100% solids). The ability to cure is commonplace. This new generation of conformal coating materials has also given birth to hybrid coatings that contain two or more systems to achieve superior properties, i.e. ARUR. See Section 10.1.11 for examples of two-part systems.

Raw materials as well as film properties need to be considered while selecting conformal coating materials. Due to variations in conformal coating chemistry, it is recommended to consult the coating Manufacturers or technical data sheet for more information.

Acrylic (AR) – Acrylics are easy to apply and the dried film can be removed using solvents. Spot removal of the coating to repair a solder joint or replace a component can be easily accomplished by localized solvent application.

Acrylics dry rapidly, reaching optimum physical properties in minutes, are fungus resistant and provide long pot life. Furthermore, acrylics give off little or no heat during cure, eliminating damage to heat-sensitive components, do not shrink during cure and have good humidity resistance. Acrylic coatings exhibit low glass transition temperatures (Tg), i.e. 100°F (37.78°C) or less. Above Tg, the large expansion can result in damaging effects.

Epoxy (ER) – Epoxy systems are usually available as two part compounds. They provide reasonable humidity resistance and good abrasive and chemical resistance. They are virtually impossible to remove chemically for re-work since any stripper that will remove the coating may vigorously attack epoxy-potted components as well as the epoxy-glass board itself. The only effective way to repair a board or replace a component is to burn through the epoxy coating with a knife or soldering iron.

Single part epoxy resin coatings with temperature-activated hardeners are also available. These coatings require curing at temperatures higher than 150°F. Single part UV curable coatings are available which eliminates curing at these elevated temperatures.

When most epoxies are applied, a ‘buffer’ material must be used around fragile components to prevent their damage from film shrinkage during polymerization. Curing at low temperature, if possible, is encouraged to reduce shrinkage.

Curing of epoxy systems takes place up to 3 hours at an elevated temperature or up to seven days at room temperature. Short pot life creates a limitation on their effective use.

Single part vinyl modified epoxy compounds are available for special applications.

Silicone (SR) - Silicone coatings are extremely useful materials when components must endure extreme temperature cycling environments such as automotive applications. The useful operating range of these materials is -55°C to +200°C. They provide high humidity resistance along with good thermal endurance, making them desirable for PCAs with heat dissipating components such as power resistors. For high impedance circuitry, silicones offer a very low dissipation factor. They are very forgiving materials in production because they coat over and adhere to most surfaces found on a PCB and offer good resistance to polar solvents. Cross contamination factors stemming from the use of silicones and the effects on other production processes are no longer a major concern with the solvent-free, nonvolatile chemistries that are easily handled with proper housekeeping practices. Secondary cure for the UV curable versions is accomplished with a very effective ambient moisture mechanism. It should also be considered that high temperature protection may generally demand that the silicone coating be cured at or near to the maximum temperature it is designed to withstand. Silicone coatings can be applied at large thickness (>0.01 inch), thus immobilizing wiring (jumpers etc.) on PCAs.

Polyurethane (UR) - Polyurethane coatings are available as either single or two-component formulations. Both provide good humidity and chemical resistance, plus higher sustained dielectric properties.

Their chemical resistance, however, can be a major drawback since rework can become difficult and costly. To rework, repair, or replace a component, refer to IPC-7711/7721.

Early polyurethane compounds exhibited instability or reversion of the cured film to a liquid under high humidity and temperature conditions. Newer formulations, however, eliminate this phenomenon.

While polyurethanes can be soldered through, this usually results in a brownish residue, which affects the aesthetics of the coating.

Single component polyurethane's, while easy to apply, sometimes require 3-30 days at room temperature for optimum cure. Two component formulations, on the other hand, reach optimum cure properties at elevated temperatures within 1-3 hours, but with pot lives of 30 minutes to 3 hours.

Paraxylylene (XY) – These are the vacuum deposited paraxylylene coatings. Both material characteristics and application technique yield XY conformal coatings that are uniquely different from the liquid applied coating types. The obtained coating film yields consistent thickness with true conformance to PCA contour and is pinhole and bubble free. The XY film is also characterized by properties such as good dielectric, low thermal expansion, good abrasion resistance and outstanding chemical resistance, among others. This makes XY coating a good choice for protecting circuits against effects from harsh environments, notably high humidity with condensation, intermittent immersion, salt fog, atmospheric pollutants and exposure to aggressive solvents. This type of coating is frequently used in FDA approved devices for medical and biomedical applications. Paraxylylene coating can be removed by abrasion, conventional surface mount techniques, excimer laser, heat softening, plasma etching and several other methods. Paraxylylene coatings are very effective in high voltage applications, owing to the capability of coating sharp edges.

A fluorinated version is also available that can maintain its properties at temperatures in excess of 400°C, has increased UV stability, and has a lower dielectric constant.

Two-Part Systems (Acrylic/Polyurethane & other combinations)

UV and Solvent Cure - A recently developed method of curing is to utilize ultra-violet light. This permits curing of the material in seconds rather than in minutes or hours. They have been specifically developed for use on flat bare substrates and are of particular benefit for fiber optic filament coating as curing can be effected at speeds of up to 400ft/min.

Their use on PCAs, however, is somewhat limited because of the shadowing effect produced by components. As a result of this, a catalyst is often required to ensure a chemical reaction to cure the compound in shaded areas. However, this produces the associated drawbacks of two-part systems such as short pot life and material blending for correct application. One-part materials have been developed, although they tend to be of an epoxy or polyurethane base.

Two-part products are difficult to repair as subsequently reapplied coatings do not etch into the existing material surface, but produce discrete lamination. The reliability of this type of coating is suspected at temperature ranges such as 55ºC or +130ºC as they become brittle and less flexible.

Other Types of Conformal Coatings

Amorphous Fluoropolymer-Polytetrafluoroethylene (PTFE) - is an amorphous thermoplastic polymer, similar to Teflon®, which does not crystallize with age. Because it has a very low surface energy, it is hydrophobic to water and also repels organic alcohols, ketones, ethers, acids, and amines. It is permeable to most common gases and hydrogen chloride vapor as well as aqueous hydrochloric acid and soluble inorganic chlorides. It can be deposited on substrates as vapor, and as solution by spin cast, dip and spray.

When fluoropolymer coatings are used in aerospace environments/applications, electrical properties may degrade due to radiation exposure. Caution should be used when selecting material with these electrical properties.

Fluorocarbon (FC) - Fluorochemical surface modifiers are hydrophobic-oleophobic coatings that reduce the surface energy of a substrate to 11-12 mN/m. This property allows water, solvents such as heptane, toluene and acetone, and lubricating oils to bead up and drain off a substrate. These coatings are applied as a thin fast drying layer that can be soldered through for rework, and frequently do not require masking. The coatings are typically supplied in fluorocarbon solvents which are non-flammable, low in toxicity and are not VOCs. The low viscosity and low surface tension of the coating allows it to flow into, and coat in-between, small gaps and layers. Fluorochemical surface modifier coatings are thin and not very resistant to abrasion, but insoluble to most organic solvents and as a fully reacted polymer in solution, has an indefinite pot life.

Perfluoroether - For certain applications involving extended exposure to fuels, hydrocarbon oils, hydraulic fluid, non-polar solvents, acids or bases, the use of perfluoroether type coatings could be considered. This polymer is based on a perfluoroether (fluorinated-carbon to oxygen) backbone combined with an addition-curing silicone crosslinker. One-part perfluoroether materials are processed (dispensed/sprayed and cured) in the same manner as heat-cured silicone type coatings. They can be sprayed or dispensed using typical existing equipment and heat cured at 150°C for 1 hour.

Perfluoroether elastomer provides improved low temperature properties, long-term heat resistance, self-priming adhesion, excellent electrical properties, and ionic purity. As a 100% solids (no-solvent) material, it offers processing advantages unmatched by other standard fluoroelastomers. The thermal resistance and low modulus are similar to silicone properties while providing protection from the harshest environments.
Low Pressure Mold (LPM) is the process of insert injection molding a full or partial circuit assembly. Thus encapsulation the desired circuitry and components

10.1.1 Application The continuity of coating in designated coating areas is essential to effective coating performance. Even a small pinhole size area of exposed PCB surface can invalidate the coating effectiveness by providing a point of entry for moisture penetration. The major culprit here is PCB and component cleanliness. Process residues on the PCB/component surface can cause a conformal coating to fail to wet or adhere to the contaminated surface.

Minimization of coating fillets (webbing) is desirable for two main reasons:

- To prevent the formation of moisture traps
- To avoid a coating configuration that would place undue mechanical stress on a component or connection when the assembly is exposed to thermal extremes during use.

Note: An excessive coating fillet is one where the coating bridges from components or, more frequently, wires and forms a concave depression that is capable of holding fluid. Such fillets may, under some conditions, exert undue mechanical force on the coated components due to differing CTEs.

The formation of fillets or webbing can frequently be inhibited or controlled by paying close attention to the viscosity of the coating material applied and the orientation of the PCB (with respect to gravity) during the cure cycle.

When masking the assembly prior to conformal coating, there are two areas of concern:
The method of masking (either application or removal) does not include the prospect of EOS/ESD damage to the assembly.
When masking materials are removed, no unacceptable residual contamination remains on the assembly.

In some cases, minor amounts of adhesive retained on the assembly may not be objectionable, while in other cases, a residual adhesive could degrade electrical operation, act as an anchor mechanism for foreign material, or inhibit mechanical interface of the assembly if present on card guides or bearing surfaces.

The requirement that the dimension of an area designated to be masked **shall not** be reduced in length, width, or diameter by more than 0.75 mm is telling the User that:

- The maskant or mask material must be within 0.75 mm of the designated location.
- Assuming the mask begins precisely at the perimeter of the area designated for masking, it is OK if the conformal coating wicks, creeps, or penetrates beneath the masking material as long as such penetration does not exceed 0.75 mm.

Many conformal coatings include constituents or materials that are toxic and/or flammable. Assure that personnel have reviewed the Material Safety Data Sheets (MSDS) for the coatings being used and that applicable safety practices are followed.

Compatibility should always be verified between the masking material and the coating material. Some masking materials contain a substance that is incompatible with the coating materials. For example, natural latex liquid mask contains alkaline which inhibits the cure of certain catalytic conformal coating products.

Maskants may leave some form of residue. It is important to evaluate whether this residue can be harmful to your process before implementation. An example of this would be tape residue left from the masking process during gold plating of contact points on the PCB. The supplier cleaned the PCBs after plating, but did not do a thorough job. When the PCBs arrived at the assembly plant, they were inspected as normal and sent to the assembly line. The components were added and at the end of the process was the conformal coat equipment. The conformal coat was applied with varying results. A lot of dewetting and bubbling occurred. All the PCBs had to be touched up by cleaning the surface of the masking residue and reapplying the conformal coat. To have a consistent and good quality coat, it is imperative that the PCB to be coated is clean.

Residues to be aware of:
- Adhesives
- Human agents – perspiration, acids and/or oils
- Lanolin from hands
- Mold release agents
- Oils
- Silicones - could be silicone backed adhesive tape
- Surfactants
- Flux residues of some fluxes
- Fabrication residue trapped in solder mask porosity
-

It is suggested that pre-production products be processed prior to the validation of actual production.

Liquid masking material is sometimes used to mask components free of conformal coating. This material is applied in a liquid form that subsequently hardens to a rubber-like consistency. This type of masking material, if it cannot be removed by cleaning subsequent to conformal coating, should not be used for masking any electrical connector and/or electrical socket contact since the material can become entrapped inside the electrical contact and attempting to remove the material using manual means may spread the contact fingers resulting in a potential intermittent electrical connection.

10.1.1.1 Components Required to be Uncoated The main thrust is that electrical operation or mechanical adjustment of electronic controls (potentiometers, rheostats, inductor tuning slugs, variable capacitors, trim-pots, test points, etc.) be left uncoated. In some cases (essentially high frequency), the operating characteristics of circuits will be affected by the application of conformal coating. In such cases, it may be necessary to "fine tune" the assembly after application of conformal coating. Subsequent to such final tuning, the adjustable mechanism will normally be "staked" or "locked" with a thread-locking adhesive to prevent change due to vibration/shock or unwarranted adjustment. The prohibition against coating screw threads or card guides and other bearing surfaces is a similar extension of common sense practices.

10.1.1.2 Conformal Coating on Connectors This paragraph from the Standard requires that the mating connector surfaces, meaning both the mating connector shells and the electrical contacts, not be covered with conformal coating. An electrical contact covered with a high dielectric constant conformal coating will obviously not function as an electrical contact. A connector shell, which is coated with the conformal coating, will probably not mate properly with the interfacing connector.

10.1.1.3 Conformal Coating on Brackets This requirement is intended to address both mechanical and electrical concerns. If the mating surfaces are coated and then assembled, there exists a high probability that the conformal coating will eventually cold-flow due to the sustained mechanical pressure and result in the assembly becoming mechanically loose. Another concern is that the mounting bracket of the device needed makes electrical and thermal contact with the PCB surface circuitry in order to function.

In some designs, the assemblies are designed for "plug-in" into a next-higher assembly (e.g., card cage or "bucket") and as such, captive or other types of fasteners are provided on the assembly. In other designs, the assembly is provided with mounting holes into which mounting hardware is added as part of the next-higher assembly process. It is important that both the fasteners, as well as the mounting hole areas be kept free of conformal coating, unless otherwise specified on the drawing as the presence of the coating may hamper installation of the assembly, or the coating material could flake off and cause an intermittent electrical connection in event it becomes trapped in an electrical contact.

10.1.2 Performance Requirements

10.1.2.1 Thickness The intent of the requirement is to ensure that the conformal coating is applied in sufficient quantity to achieve intended design goals. Such design goals may be sealing out moisture, protecting the circuit from particulate contamination expected to be present in the end-use environment, maintaining a high Surface Insulation Resistance (SIR), providing improved dielectric characteristics on the PCB surface, or providing mechanical reinforcement for components or wires. All conformal coatings are capable of absorbing moisture at various rates (depending upon the coating type).

Naturally, the thicker the coating (consistent with the limits listed in 10.1.2.1 of the Standard), the longer it will take moisture to penetrate through the coating to the surface of the PCB. Thermal conditions, coating weight, etc., also impact this process.

Conformal coating thickness can be determined using various acceptable methods. One method used measures the bare board thickness using a micrometer or caliper in a designated area on the board prior to applying the coating. After the coating is applied, the thickness is again measured (preferably in the same area). If the board is coated on both sides, the thickness is calculated by taking the difference between the before and after measured dimensions and dividing by a factor of 2. If only one side is coated, the result is not divided by 2. Another method uses a wet gage which is a gage having a series of notches. When the gage is placed on the wet surface of the coating, coating travels into some of the notches. The notches are identified with a numerical value which is read by the operator. This value is then compared to a table or graph which converts the wet reading to an equivalent dry film thickness reading. If this method is used, it is important to use the correct conversion information since it varies depending on the type of conformal coating used. For example, if one uses the conversion information for Type UR conformal coating for determining the thickness of Type AR coating, in may result in too thin a Type AR coating. Other methods of measuring coating thickness using X-Rays, etc. may also be used.

One of the performance characteristics of conformal coating is a known value of dielectric constant or electrical resistance, which is usually quite high. Some customers consider solder mask suitable/acceptable as an insulator between components and the PCB surface or conductors on the surface. The performance characteristics of solder mask DO NOT include an assessment of dielectric constant and that solder-mask MAY NOT be an acceptable insulator in all cases. Ensure that the requirements of the assembly drawing are followed.

10.1.2.2 Coating Coverage The coating should be completely cured from the surface of the coating, completely through to the surface of the PCB, and under all components. The coating should also be homogeneous (uniform in consistency, with particles equally distributed or mixed throughout the material).

Blisters or breaks must be avoided, because a blister or break is an area where the coating has not formed an intimate/protective bond with the surface of the PCB. This area is subject to fracture or break and can entrap moisture during field use and lead to short circuits. A blister or break is a defect that starts at an area on the surface of the PCB that is contaminated with some chemical or substance that keeps the conformal coating from adhering to it.

A void is an area where the conformal coating is not present. Voids leave the base material (component body or PCB surface) completely exposed and are normally caused by surface contaminates, which preclude adhesion of the coating material. The appearance of a void may remind the User of an area of ground plane with solder non-wetting. A void provides access to the unprotected PCB or component for any moisture or foreign material available.

A bubble is a bubble of air entrapped in the coating between the surface of the PCB and the surface of the coating (as contrasted to a blister, where the PCB surface is not sealed by the coating). A bubble, like a blister, is an area capable of entrapping and retaining moisture. This area is also mechanically weak and may be expected to break sooner or later.

Bubbles may be caused by:
- Improper mixing of two-part coatings, wherein air is entrained into the coating material.
- Improper cure, where the surface of the coating cures prematurely and inhibits the outgassing through the surface associated with a normal curing cycle.
- The method of application (brush coating is more prone to bubbling than dip or spray coating).

Crazing is also a defect since it is a network of fine cracks on the surface or within the coating which can result in the issues noted above.

Peeling or wrinkles in the coating are also considered defects since they can result in flaking off of the coating causing components or board areas to be vulnerable to absorbing moisture.

Mealing is considered a defect since it represents a separation at the interface between the conformal coating and the board base material or component that could cause the coating to eventually become dislodged or otherwise present the possibility of moisture entrapment.

Note: The presence of cracks, crazing, voids, bubbles, mealing, peeling, wrinkles or foreign material is not considered a defect unless it results in exposing the component conductors, printed circuit conductors, (including ground planes) or other conductors and/or violates design electrical clearance.

Foreign material should not be included in the conformal coating. Regardless of the type of foreign material (whether conductive or not), changes of both the dielectric constant of the material and the physical characteristics of the coating will result. A reduction of the dielectric constant may cause/contribute to a circuit failure, and a change in the physical characteristics of the coating will usually result in (long term) a crack or fracture due to the change in elasticity of the coating where the foreign material is entrapped. A small piece of lint from a glove or cleaning tissue can function as a “wick” and provide a ready path for moisture to penetrate the surface of the coating. Voids, bubbles, or foreign material are defects only if the minimum electrical clearance is violated or conductors are exposed.

The prohibition of mealing, peeling, or wrinkles (non-adherent areas) is intended to ensure that the conformal coating applied be firmly adhered to the surface.

***10.1.2.2.1 Conformal Coating Adhesion** Several factors affect the ability of a conformal coating to adhere to a PCA. These factors include, but are not limited to, cleanliness, compatibility between the coating and other interface materials, and degree of cure. Adhesion properties are important to the final product appearance and function. A conformal coating that does not adhere completely to the PCA is not protecting that PCA. Improper adhesion can lead to blistering, peeling, cracking, mealing, and popcorning of the conformal coating, especially during thermal cycling and heat/humidity treatment. The adhesion requirement is defined by the agreement between the applicator and the end User. The end User and applicator should determine what level of adhesion produces a functional PCA and what test(s), if any, **shall** be used to determine that sufficient adhesion has been achieved and maintained through any tests or environmental conditioning. The risk for adhesion failure is not only affected by the strength of adhesion but also by the elasticity of the conformal coating. A coating with high elasticity is less prone to adhesion failure when exposed to mechanical tension than a coating with low elasticity.

Adhesion of conformal coating can be tested using ASTM 3359 Method B. This test may not be applicable to certain coating types.

(a) Solder Mask/Substrate - Compatibility of the solder mask and substrate with the conformal coating of choice is essential in order to produce a high quality PCA. Adhesion of the conformal coating to the solder mask is central to the compatibility issue. The large number of solder mask, substrate, and conformal coating combinations make a detailed list here impractical. The end-Users should discuss the compatibility criteria of the conformal coating with the conformal coating supplier. Qualification of a given system including solder mask, coating materials and process parameters should be completed prior to the implementation of these materials.

(b) Components - Poor adhesion/de-wetting of conformal coatings to component and component leads can be a problem. In some cases the problem can be remedied with a change in application method, allowing better penetration of the conformal coating in between fine-pitch leads, etc. Some components may have material on their surface that can inhibit conformal coating adhesion, such as mold release agents, wax, polysiloxanes (silicones) and marking inks. Component cleanliness is also an important factor in conformal coating adhesion.

(c) Surface Finishes - One of the areas on a PCA that a conformal coating has to adhere to is the surface finish of the PCB. Surface finish is the material on metallized areas of the exterior PCB layer. Previous generations of these areas on a PCB were the remaining copper after etching and other PCB processing prior to reflowing tin/lead (Sn/Pb). Newer technologies have resulted in alternate materials to Sn/Pb being used as the finish on the PCB prior to assembly processing. These materials include, but are not limited to, bare copper, immersion tin, immersion silver, immersion gold, electrolytic or electroless nickel combined with gold and/or palladium, organic soldering preservative (OSP), and other similar types of alloys. It should be noted that if these materials are on areas of the PCB where a solder joint is formed, then the processing usually will modify these finish materials. Most of these modifications are the conventional assembly processing using hot air Sn63/Pb37 eutectic solder leveling or reflow methods. However, because the surface finish may contain a different metal or organic material prior to assembly processing, the resulting intermetallic in the solder joint may contain trace elements of the board surface finish. It is this type of condition and other areas of the PCB with finishes not changed by assembly processing that need to be evaluated for conformal coating compatibility. In many cases, these conditions may necessitate conducting a qualification test using a representative PCB sample before approving the intended conformal coating as “acceptable for use”.

(d) Cleanliness - The single most common deterrent to conformal coating adhesion is surface contamination. The presence of ionic residues, oily materials, and particulates on board surfaces and components can result in corrosion, insulation breakdown, poor adhesion and subsequently, failure of the conformal coating. Ionic contamination may cause mealing or vesication of the conformal coating. Oily materials and particulates will not allow most conformal coatings to adhere to the surface/substrate leading to peeling. A thorough cleaning and drying process is the best method available to minimize the adhesion problems due to residues. Even when using low-residue fluxes/no-clean processes it is very important that the assemblies do not exhibit any of the flux residues. Small traces of flux residues left on the PCA due to improper cleaning and volatilization of the flux chemistries can lead to poor adhesion of the conformal coating. The cleaning process is also a factor. When using alternative cleaning methods and chemistries, such as hydrocarbons, terpenes, esters, etc. caution must be observed with respect to residual solvents. These residual solvents can cause outgassing at elevated temperatures resulting in adhesion problems such as blisters and vesication. When using aqueous cleaning methodologies proper drying is essential. Conformal coatings may have poor adhesion due to the presence of any residual water on a PCA.

***10.1.2.2.2 Substrate Preparation** The preparation of the PCA prior to conformal coating is very critical to good wetting, adhesion and subsequent reliability of the PCA. The level and type of soldering residues, handling residues, ionic residues and component mold release agents all play key roles in the success achieved with any coating and/or coating process. The solder mask also has a great impact on how well the adhesion performance of a particular coating material will be.

With the advent of many low residue flux chemistries, (also known as no-clean), cleaning the PCA prior to conformal coating is not desirable but sometimes is still necessary. The level of visible and non-visible residues will vary on the type of PCA, physical mass of the components and the solder excursion profile. Base line ionic and corrosive species measurement and periodic confirmation are still recommended and should be within the IPC prescribed limits. Most low residue fluxes may turn "white" after solvent extraction testing for NaCl, as a result of the alcohol in the test solution drying and developing the clear/invisible residues into a white powder. This is an esthetics issue leading many assemblers not to test at all. The adhesion of conformal coating to these residues is generally very good with all conformal coatings. But, how well the residues are adhered to the solder joints should be considered, to reduce the potential for delamination of the cured coating material to the solder joint areas during the life cycle of the PCA.

Water-soluble flux processes require water washing and are generally good candidates for conformal coating because the assemblies are cleaned of many process residues. The critical factor to consider with this type of process is that the PCAs are completely dry, prior to conformal coating.

Vapor degreasing techniques prior to conformal coating operations have been outlawed in many countries due to environmental concerns. The cleanliness of the PCA must still be monitored to insure performance and reliability of the coating materials used. Compatibility of the coating with these process residues should be checked.

Priming Prior to Coating Substrates are typically cleaned to ensure reliability and the best adhesion. To further enhance adhesion, priming or adhesion promotion is a sometimes used technique after cleaning.

Priming for Silicones To obtain optimal adhesion performance of a silicone conformal coating, a priming step may be required. Optimal adhesion is normally obtained when only a very thin, uniform coat of primer is applied.

Three steps should be considered if priming is required:
1. *Preparing the surface* - to provide a clean, dry and in some cases reactive surface
2. *Applying the primer* - to provide a very thin and uniform surface coating
3. *Curing the primer* - to provide the ideal bonding surface for the silicone

Optimal adhesion is obtained only when the maximum surface area and surface reactivity are made available at the time of primer application. Organic and water-soluble contaminants and loose particulates can reduce the effective surface area available for bonding. Good adhesion can only be obtained when the substrate surface is strong enough to hold a bond.

The primer must evenly coat all available surface area to achieve optimal adhesion. Some surfaces may cause a primer to bead up. Poor surface wet-out like this will result in only spotty/localized adhesion. If the primer beads up when applied, solvents or other additives can be added to the primer to improve wet out. Consult the primer supplier for selection of such additives.

There is a common misconception that can cause considerable problems in the application of a primer; in nearly all cases "more" is definitely *not* better. Less is best. The best primer performance may be obtained with a cured primer thickness of 0.1 to 10 microns, with optimal adhesion at about 1 micron coverage. Often, this thin application can be best accomplished by wiping the primer on and then immediately wiping it right back off. When applying a primer by dipping or spraying, dilution may be recommended to decrease the primer coating thickness. Over application of most primers will be evidenced not only by poor adhesion, but also by white chalkiness or flakiness on the cured primed surface. Loose material should be brushed off; however, decreased adhesion performance may still be expected.

Maximum adhesion performance is directly related to the extent of the cure of the reactive species in the primer. Primers containing silane-coupling agents begin to react with atmospheric moisture as the solvent carrier evaporates. Ideal adhesion will be obtained during a "window" of extent of primer cure that will be unique to a particular adhesion system, i.e., a given surface, primer and silicone conformal coating. For a given primer, the choice of silicone to be used with it usually has a greater influence on the optimal extent-of-cure window than does the choice of the surface material (Figure 10-2).

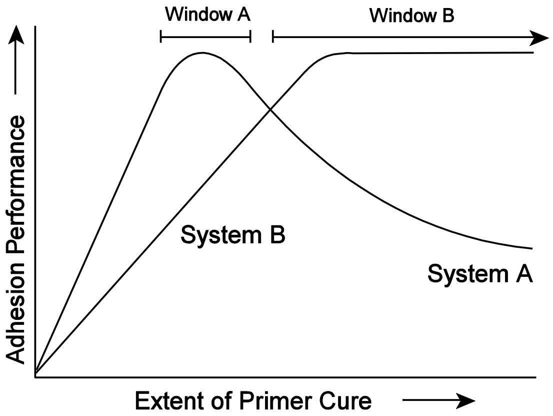

Figure 10-2 Cure Windows of Primer Cure

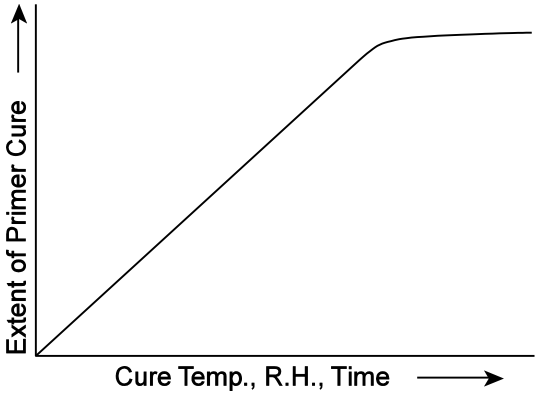

Figure 10-3 Conditions that Influence the Extent of Primer Cure

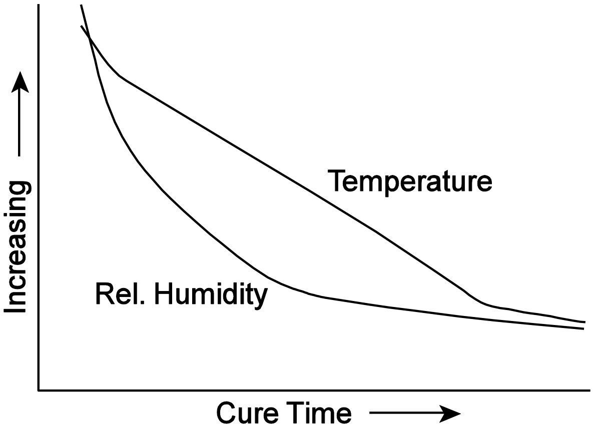

Figure 10-4 Influence of Temperature and Humidity

The extent of primer cure is controlled by three main cure conditions: temperature, relative humidity, and time (Figure 10-3). In most applications, the temperature at which the primer is cured either does not vary severely, or cannot be controlled, as is most often the case with relative humidity. The amount of time that a primer is allowed to cure, however, can usually be more carefully monitored. It is recommended that an evaluation of the effects of cure times on adhesion be carried out to maximize adhesion performance. This can be achieved by allowing the primer to cure at average or normal application conditions for 15, 30, 60, 120, and 240 minutes, and then continuing through the remainder of the normal bonding procedure. Alternatively, primers can be cured for 15 minutes at 72°F, 100°F, 125°F, and 150°F, if the normal primer cure is carried out at the elevated temperatures. Oven atmospheres can often be quite dry. This will slow the cure rate down unless precautions are taken to maintain an adequate relative humidity.

To increase the relative humidity in the primer curing area, suggestions include commercial humidifiers, open pans of water (large surface area of water) in the oven, and water misters. It should be noted that water condensed directly onto surfaces to be primed will degrade performance if not removed prior to the primer application.

The optimal cure time established by the above oven curing procedure will be influenced by changes in temperature and humidity (Figure 10-4). Two general “rules of thumb” are:

- Cure may be reduced by 50% per every 20°F increase in cure temperature given equal relative humidity (actually 18°F or 10°C = doubling of most reaction rates).
- Cure times should be approximately doubled per every halving of the relative humidity.

There are no sure predictive means to distinguish between adhesion systems that are or are not sensitive to these conditions. Therefore, it is recommended the User determine the primer cure times at conditions that approximate the average and the extremes of the temperature and relative humidity that might be in a given application.

Priming for Acrylics No primer is known to be needed for this coating type.

Priming for Urethane No primer is known to be needed for this coating type.

Priming/Adhesion Promotion for Poly-paraxylylene (Parylene™) The paraxylylene chemical vapor deposition process used to coat printed PCBs usually requires an adhesion promotion step prior to deposition of the polymer. This process can be done either by gas phase deposition or a liquid immersion process. The most common adhesion promotion agent is A-174, an organosilane ester.

The vapor phase process is performed by placing the cleaned parts into the deposition chamber and promoting them by depositing an organosilane coupling agent immediately prior to the start of the coating process. The coating equipment must be configured with this feature in order to perform in-chamber adhesion promotion.

The immersion process employs a dip process utilizing the organosilane-ester coupling agent in an IPA solution. The parts are immersed for 15-30 minutes an allowed to dry. The parts are then rinsed in fresh IPA and baked out, prior to any masking, fixturing or deposition.

10.1.3 Conformal Coating Inspection This paragraph provides guidance information on how to conduct the inspection of conformal coating, while the actual inspection criteria for conformal coating are listed in the Standard. It is desirable to have complete coverage, but because conformal coating is transparent, it is often difficult to confirm coverage. A UV tracer is sometimes added to the coating to help in confirming coverage. Under an appropriate UV lamp, the coating will fluoresce and uncoated areas will remain dark.

Magnification is not mandated for inspection of conformal coating; however, magnification up to 4X may be used for referee purposes. Normally, the presence or absence of conformal coating can be determined without magnification using visual inspection with or without black light. The use of higher power magnification may identify anomalies that are cosmetic in nature only.

10.1.4 Rework of Conformal Coating The requirement for documentation is twofold. First, to ensure that a consistent procedure that can be reviewed and approved by the customer is available (if necessary), and second to cause the reworking activity or group to think through the procedure. Many customers may feel that removal and replacement of conformal coating (as may be necessary to replace a defective component) constitute a repair and not a rework. The rationale is that replacement of conformal coating seldom (if ever) seals the surface as well as the original conformal coating, thus, degrading reliability.

Remove only that coating required to facilitate component removal. Remove the coating from all solder connections to allow for desoldering. Prior to desoldering, remove the coating along all sides of the component so that the coating does not bond the component to the PCB.

There are three methods available for the removal of conformal coating: chemical, thermal, and mechanical. Each is summarized in 10.1.4.1 through 10.1.4.3.

***10.1.4.1 Chemical** This method is effective on AR coatings (lacquers and varnishes), which solvents may dissolve. Typically, the chemical is swabbed onto the portion of the coating to be removed. The solvent action of the chemical softens the coating and allows removal by additional swabbing or light abrasion with a scraping tool. After removal, neutralize the area by rinsing with distilled or deionized water and blot dry with a disposable tissue.

Chemical Strippers (i.e., gels) are also sometimes used to remove Type UR or other types of conformal coating. Extreme caution must be used to ensure all traces of this material have been completely removed by the cleaning process after removal of the coating. Some of these chemicals are highly conductive and can result in corrosion or other forms of conductive paths that can cause leakage currents resulting in incorrect equipment operation if the chemical residue becomes trapped under components, sockets, wires, and other areas where it may be difficult to remove.

***10.1.4.2 Thermal** The application of thermal energy (controlled heat) is effective on all resin coatings that will soften or revert (overcure) when exposed to a controlled, localized low temperature heat source of 150°C to 205°C. Heat will not result in the removal of conformal coating but will facilitate removal of the coating that will, after overcuring, chip or flake easily with minor surface abrasion. The integrity of the bond between the coating and the PCB surface and components is usually weakened.

Elevated temperature is most effective when applied with one of the following:

- A “hot-knife” or “thermal parting tool,” wherein a heated sharp-edged tool (thermal parting tool, not a soldering iron tip) is applied to the coating to effect a cutting or peeling action.
- A hot air jet, as long as the tip of the hot air jet is not be held closer than 6.35 mm to 9.52 mm from the surface of the coating to be overcured. After overcuring, which is identifiable by a change in color or appearance, the coating can be removed by localized abrasion.

***10.1.4.3 Mechanical** Mechanical energy, or abrasion, is effective on all resin coatings, however, the effectiveness is dependent on thickness, hardness, surface shape, and transparency of the coating. Abrasion can be applied either through cutting with a sharp tool (scalpel, razor knife, etc.), manual abrasion with dental picks or orangewood sticks, or through power abrasion using dental drills, rotary tools, or similar small power tools.

Note: Air-abrasive equipment, which blows a jet of pressurized air into which various abrasive media (corn cob, walnut hulls, glass beads, silicon carbide, etc.) are mixed, can also be used for removal of conformal coating. Such equipment generates a localized electrostatic charge when used. The voltage generated is variable over a wide range and is dependent on the type of PCB laminate, abrasive media used, air velocity, and RH. Air abrasive equipment can be used if the User has data showing that any damaging electrostatic charge is neutralized. Some abrasive machines used for conformal coating removal have built-in ESD protection; however, if these fail to function properly and the failure is not detected by the operator, a damaging ESD voltage may exist. Therefore, it is recommended that the correct operation of the machine ESD protection be verified periodically, or otherwise, the voltage at the spray nozzle should be measured to ensure it will not damage ESDS components.

The preferred methods for removing various types of conformal coating are listed in Table 10-1.

Table 10-1 Preferred Conformal Coating Removal Methods
(1 = Preferred, to 5 = can be used but is inefficient)

Coating Type	**Acrylic Rosin AR**	**Epoxy Resin ER**	**Urethane Resin UR**	**Silicone Resin SR**	**Paraxylyene XY**
Methods Chemical	1				
Thermal Parting		2*	2*		2
Hot Air Over Cure	2	1	1		1
Abrasion Dental Burns		3			
Abrasion Disc/Bullets	5*				
Abrasion Rotary Brush	4*	5*	3	2	4
Manual Abrasion	3	4	4*	1	3*

*For thin coating only.

In general, conformal coating should be replaced with the same type of coating that was removed. Many conformal coatings do not adhere well to themselves, so a primer is sometimes needed to achieve a bond between the original coating and the replacement coating. Some coatings, such as paraxylyene, which is applied by vacuum deposition, do not lend themselves to localized (spot) replacement. See IPC-7711/7721 for additional information on the removal and replacement of conformal coating.

10.2 Encapsulation Conformal coating is applied as a very thin coating to the finished PCA. Encapsulation, or potting compound, is a thick material sometimes used to completely fill small subassemblies (power supplies or hi-gain amplifiers). Popular encapsulating materials include foam, rubber, and similar bulk materials, most of which are doped with dye to provide solid color through which the embedded components cannot be seen. Since the interior of the encapsulated assembly is usually not visible, it is essential that the encapsulation process (measuring, mixing, filling, and curing) be closely controlled to ensure that the finished product meets the customer’s needs. For instance, if the parts of an encapsulant are mixed by volume instead of by weight, the characteristics of the compound may be such that the only part of the compound that cures is the outside, or visible, portion, which is exposed to ambient air. The internal compound will remain in a near fluid, jelly-like consistency. Another example is bubbles in a high voltage power supply could produce failures. Tight process controls are the key to successful encapsulation.

In some areas of the industry, encapsulants and potting compounds will refer to two different applications. A potting compound completely encases the majority of the assembly in question. An encapsulant might cover only a few components. An example of an encapsulant would be a thermally conductive RTV silicone material, covering a hot component. The RTV encapsulates only a very localized area, rather than the entire assembly.

10.2.1 Application The assembly drawing/documentation will identify those areas of the assembly that require encapsulation and whether the complete assembly must be encapsulated. Failure to adhere to the requirements of the assembly drawing is a defect. In certain instances, the use of masking may be required to preclude the encapsulating material from adhering to areas where it should not be in accordance with the drawing/documentation. Encroachment of encapsulation material where it should not be present is considered a defect. The material used for masking must be capable of being removed without leaving any evidence of contamination. The presence of masking material that was required to be removed is a defect.

10.2.1.1 Encapsulant Free Surfaces This paragraph requires that certain areas be free of encapsulant materials. Such areas are normally specified on the assembly drawing/documentation. If not specified on the assembly drawing/documentation, check with the customer to define the areas that need to remain encapsulant-free. Since encapsulants are thicker and sometimes harder than conformal coating, any overfills, splashes, or leaks can be very difficult to remove. Prior to encapsulation, it is sometimes appropriate to use a swab (or similar applicator) with silicon grease to treat unmaskable areas, which must remain encapsulant free.

10.2.2 Performance Requirements Degassing or vacuum curing of encapsulants may be necessary to prevent bubble formations in the body of the potting compound.

The criteria specified in J-STD-001 paragraph 10.2.2 deal with the inspectable attributes of encapsulant materials and the adhesion of the encapsulant to the assembly. In addition to the preceding, each encapsulant has two other essential attributes, which may be prudent to test from time to time. First is the dielectric constant or volume resistance of the cured encapsulant material. If, for instance, the User is encapsulating a power supply assembly, the User may want to use some surplus encapsulant as a sample and evaluate the volume resistance or dielectric. Other testable attributes are the elasticity and coefficient of expansion of the encapsulant.

10.2.3 Rework of Encapsulant Material This requirement is invoked for the same reason as it is for rework of conformal coating. Some customers feel that removal and replacement of encapsulant material constitutes a repair instead of a rework and want certain applicable procedures followed. The removal of an encapsulant is a more delicate operation than the removal of conformal coating, because when removing an encapsulant that contains a dye, the User is unable to see what component or part of the assembly the User is digging into. Consequently, damage to wires, conductors, PCBs, and components is much more likely to happen when removing encapsulants than when removing conformal coatings. The best option is to control processes closely enough that the removal of encapsulant is not required. See IPC-7711/7721 for additional information specific to the removal and replacement of encapsulant material.

10.2.4 Encapsulant Inspection Encapsulated assemblies **shall** be visually inspected to confirm that the criteria of J-STD-001 Section 10 are met.

10.3 Staking (Adhesive) Similar to the use of conformal coating and encapsulation to secure and/or cover certain components, staking is sometimes required by the assembly drawing/documentation to secure components in place to minimize the risk of components coming off the assembly, or otherwise being damaged during adverse environmental conditions such as shock and vibration. If the drawing/documentation does not identify the staking criteria, the J-STD-001 provides criteria for the following staking applications; failure to adhere to these criteria is considered a defect unless otherwise noted in the Standard.

a. Placement – Staking material must not contact component lead seals since the material could adversely impact the sealing function unless the staking material has been selected to preclude this.
b. Unsleeved axial leaded components mounted horizontally – The Standard defines criteria for how much and where staking material must be placed in relation to the component. This criteria is designed to ensure the staking will be adequate to maintain the component on the assembly.
c. Unsleeved axial leaded components mounted vertically – Same as (b) above.
d. Sleeved axial leaded components – Same as (b) above.
e. Glass bodied components – Same as (b) above. Some glass bodied components may crack if not properly staked.
f. Radial leaded components whose longest dimension is their height (e.g., CKR capacitors, Single In-Line (SIP) resistor networks) – Same as (b) above.
g. Radial leaded components whose largest dimension is their diameter or length (e.g., T05 semiconductors, etc.) – Same as (b) above.
h. Fasteners – Most fasteners are normally provided with some means of locking (e.g., split-ring lock washer, nylon locking inserts, locking helical coil inserts, liquid locking compound, etc.) which eliminates the need for staking the fasteners in place. The Standard provides criteria for how to accomplish the staking.

10.3.1 Staking is adequately defined in the Standard.

10.3.2 Staking (Inspection) The Standard also provides accept/reject criteria to judge the acceptable of assemblies that have been staked and also indicates that inspection may be performed without magnification; however, magnification from 1.75X to 4X may be used for referee purposes. This criteria is basically the same as the criteria for conformal coating and/or encapsulation. However, one important criteria must be considered and that is the staking must not negate component stress relief otherwise the component may be damaged if subjected to a shock or vibration environment.

12 PRODUCT ASSURANCE

Quality cannot be inspected into a product. It must be manufactured-in and this can only be realized by establishing, maintaining, and continuously improving the manufacturing processes by implementing an effective process control methodology. Continuous process improvement is also one of the key principles of a high level Quality Management System (QMS), such as ISO 9001.

12.1 Hardware Defects Requiring Disposition ar defined throughout the Standard. Section 1.5.1 defines “defects” and “process indicators”.

12.2 Inspection Methodology The intent of inspection is to verify the product meets customer requirements. How products are inspected can be as important as the product itself.

There is no one right answer for “how” to inspect finished product. Typically, the inspection procedure will use a combination of process verification, visual inspection, magnification aids, lighting, and sampling inspection to verify product meets requirements. This collective effort is the inspection methodology.

12.2.1 Process Verification Inspection. Process verification evaluates the operations used to produce the product. These operations include the practices, methods, procedures and written inspection plans used by the people doing the work. Without process control and verification, product variability could occur, resulting in noncompliant product. A process control plan (see 12.3) is recommended to identify the methods and materials used in the soldering process.

Process verification should consist of the following:

1. Surveillance or auditing of each operation in the control plan verifies all of the activities required to produce the end product. By auditing the process, we can see the interactions between the various operations needed to make the process work.
2. Verification of the output of each process operation ensures compliance of the product to the established acceptance criteria. Verification can be achieved by various means such as but not limited to; “Go-No Go Gauges”, GD&T measurements, and visual inspection.

12.2.2 Visual Inspection A finished assembly is required to be 100% visually examined to ensure acceptance criteria has been met.
Conformal coating, staking and encapsulation tend to hide or distort the appearance of solder connections. Solder and cleaning inspections must be completed before the application of coating materials to ensure inspection is unimpeded. When visual inspection cannot be applied, X-ray or other non-destructive means or inspections may be utilized to determine acceptability such as hole fill or BGA voiding.

12.2.2.1 Magnification Aids The magnification power for visual inspection is identified in Tables 12-1 for solder connections and 12-2 for other criteria.. If the condition is not clearly a reject at normal magnification then the condition is acceptable.
This magnification is to be used when inspecting hardware, and if a condition is identified, but not clearly rejectable at the defined magnification, then the condition is acceptable. This literally means that if one cannot determine compliance to criteria such as: plated through hole minimum vertical barrel fill, minimum adhesive staking/bonding height, maximum side overhang for a gullwing device… at the defined inspection magnification prescribed herein, then the condition in question is acceptable, and no further action need be taken. Note reference section 1.4.1 Verification of Dimensions in this document for a further

There are times when an inspector will detect something is different or raises a concern at normal magnification power, and then must utilize the referee magnification power to determine acceptability. If the inspector does not detect anything unusual at the inspection magnification, the higher referee magnification power is not to be utilized.12.2.2.2 Proper use of a microscope requires adjustment of the eyepieces to the vision of each user. The sequence to adjust a microscope is as follows:
a. Adjust the scope height to fit the operator height in a comfortable position
b. Adjust auxiliary lighting to illuminate the viewing area
c. Set the zoom control to the lowest setting
d. Adjust the spacing of the eyepieces to fit snuggly into each eye socket to provide one circle of visible light
e. Set the zoom control to the highest magnification and view a component using the right eyepiece only (close left eye) Adjust for the sharpest image using the focus control.
f. Reset the zoom control to the lowest setting. View the component using the left eyepiece only (close right eye). Rotate the adjustment ring on the left eyepiece for the sharpest image.
g. Each operator must adjust the focus performance of the microscope to aid their specific visual needs. Check proper focus operation frequently during the day to avoid eye fatigue.

Note: The adjustment ring may be on the right eye piece only or on both eyepieces. Adjust for sharpest image at the lowest zoom setting by rotating the adjustment ring(s) as needed.

12.2.2.3Mixed Land Widths When hardware contains multiple land widths and requires different magnification powers, the higher inspection magnification power may be used for inspecting the entire assembly..

12.2.2.4 Eye Tests An eye test may be required to ensure operator visual acuity. Eye testing may be required by contract or may be standard operating practices for manufacturers. When testing is required and the parameters are not defined, the requirements outlined in IPC-OI-645 may be utilized.

12.2.2.5 Lighting is defined in section 4.2.3 of the Standard. Adequate lighting requirements are necessary to reduce shadows, and to aid in the inspection process. The light range identified is approximately equivalent to day light reducing yellow tinting.

12.2.3 Sampling Inspection is adequately defined in the Standard. Sampling plans such as AQLs (Acceptable Quality Limit) may be utilized once the process has been proven with supporting documentation.

12.3 Process Control Requirements The philosophy of process control is to establish and control each process involved in the manufacture of a product with the ultimate goal of obtaining a 100% acceptable product yield. The process parameters and production output are monitored and adjustments made to ensure the process remains within the established control limits. Monitoring yield results provides performance feedback data used to reduce or eliminate the production of defective product and identify the necessary corrective action to reduce variation in the process.

Process control must be a documented system, available for review, that meets the intent of IPC-PC-9191, EIA-557-1, or some other user-approved system.

The process control plan should include or reference documentation that contains the following:

- Proper training of personnel with responsibilities in development, implementation, and utilization of process control and statistical methods that are commensurate with their responsibilities.
- Quantitative methodologies with objective evidence to demonstrate that the process is capable and in control.
- Improvement strategies to define initial process control limits and methodologies, which should lead to continuous process improvement and subsequent defect reduction.
- Defined criteria within the process control plan for switching to or from sample-based inspections.
- The occurrence of a defect(s) in a sample inspection can prompt 100% inspection of the lot for that defect condition in accordance with the process control plan.
- Monitoring systems to identify and correct the occurrence of process indicators. This also applies to out of control processes and discrepant assemblies.
- Documented audit plans to monitor process characteristics.

12.3.1 **Effective Corrective Action Systems** Usually begins with documenting the discrepancy and identifying the discrepant hardware. The discrepancy is then evaluated against the process and end product requirements to determine if the product is useable, requires rework, or cannot be used. If the fault is attributable to the manufacturer's internal processes, corrective action to eliminate the cause is usually prescribed. Where faults are attributable to external causes, such as purchased parts or assemblies, the supplier is usually asked to provide root cause analysis and corrective action. All actions in the corrective action system should be recorded for reference. Trends and overall activity levels are typically monitored to allow management of the procurement and assembly processes.

Continuous improvement means constantly looking for ways to improve the yield of a process and reduce production costs and cycle time. Practically speaking, there is a point where the cost of improving the process exceeds the gains of the improvement. Care must be taken to recognize that gains may occur outside of the traditional manufacturing cost environment, such as product life, costs, and customer satisfaction.

12.3.2 Opportunities Determination is adequately defined in the Standard.

12.4 Statistical Process Control is adequately defined in the Standard.

13 Rework and Repair

The requirements of Section 13 are applicable to any assembly defect condition as defined by this Standard, as well as any additional characteristics contrary to the assembly drawing. Defects other than solder connections include, but are not limited to, conformal coating defects, component positioning/placement, component lead damage, insufficient stress relief, printed board damage, and violation of electrical clearance requirements.

The defect definition data should be used to asses and adjust, as necessary, any process parameters that are responsible for, or contributing to, a defect or nonconformance. The correction of a defect, either through rework or repair, is incomplete unless the information describing the defect is fed back upstream to prevent recurrence.

Defects in Class 3 hardware are required to be documented before either rework or repair are performed. As an exception, normal hand soldering touch-up (i.e. a second application of the soldering iron on a single connection) is not considered a rework for the purposes of the Standard. Therefore, defects touched-up immediately after the initial hand soldering operations are not required to be documented.

13.1 Rework

Rework is defined as:

- Any manual solder touch-up operation on connections that were formed by a mass soldering operation (e.g. wave solder, reflow),
- Connections that require a third application of the solder iron or that leave the hand solder operation area and are later found to be noncompliant,
- Removal and replacement of a component or conformal coating.

In these cases, the defects are required to be documented.
Any reworked condition should fully meet the requirements of the Standard and the assembly drawing.
It is critical to note that rework performed to correct a cosmetic condition may be detrimental to the assembly and should be avoided. One is encouraged to reference IPC-A610 for guidance.

13.2 Repair

A repair is the act of restoring the *functional* capability of a defective article in a manner that precludes compliance of the article with applicable drawings or specifications. Some customers may require approval before the repair is performed. The procedures listed in IPC-7711/7721 are widely accepted as industry best practice and should be used after agreement has been reached with the User.

13.3 Post Rework/Repair Cleaning

The same cleanliness requirements that apply to the assembly before rework/repair also apply afterward. In general, a thorough cleaning of the rework/repaired area with isopropyl alcohol followed by a thorough rinse with deionized water is used, although other compatible cleaning and rinsing agents could be used. Original assembly cleaning process may not be available due to material compatibility issues with the cleaning media and the final assembly.

A cleanliness verification process should be established which includes as a minimum a visual inspection.

> **Note:** Some customers may ask the cleanliness of the assembly be verified by test or inspection before any conformal coating, which may have been removed to facilitate rework/repair, is re-applied. Depending on the assembly level the product has reached, cleanliness testing may not be practical or possible, especially on conformally coated assemblies or assemblies with components that may not be submerged into liquid.

Appendix A of J-STD-001 Handbook

Appendix A

Guidelines for Soldering Tools and Equipment

The following guidelines for tools and equipment selection and use have been found through industry practice to be effective in meeting the requirements of this standard (see J-STD-001- Clause 1.7.3)

A-1 ABRASIVES

Knives, emery cloth, sandpaper, sandblasting, braid, steel wool, and other abrasives are not to be used on surfaces to be soldered.

A-2 BENCHTOP AND HAND SOLDERING SYSTEMS

Selection criteria of benchtop and hand soldering systems include:

a. Soldering systems are selected for their capacity to heat the connection area rapidly and maintain sufficient soldering temperature range at the connection throughout the soldering operation.

b. Equipment should be able to maintain control within ±10°C [+18°F] of the selected or required temperature during multiple point-to-points or thermal mass on demand soldering operations to verify temperature stability.

c. Temperature stability-degradation to peak [set] recovery temperature – should be periodically checked to demonstrate soldering device can provide temperature control limits defined in Section (b) for multiple load, point-to-points soldering [for example; soldering of a multi-leaded component (s)] or depending on thermal mass demand soldering**.**

   Note: Frequency of verification of temperature stability should be dictated by objective evidence of compliance to Section (b).

d. Temperature stability-degradation to recovery overshoot - should be checked using point to point or on thermal mass demand soldering and **shall not** exceed the limits defined in section (b).

e. Resistance between the tip of soldering systems and the workstation common point ground should not exceed 5 ohms. Heated element and tips are measured when at their normal operating temperature.

f. AC and DC current leakage from heated tip to ground should not create deleterious effects on equipment/components.

g. Tip transient voltages generated by the soldering equipment should not exceed 2V peak ($Z_{in} \geq \Omega$).

   Note for Definition Purposes: Impedance, represented by the symbol **Z**, is a measure of the opposition to electrical flow. It is measured in ohms.

   For DC systems, impedance and resistance are the same, defined as the voltage across an element divided by the current (R = V/I).

   In AC systems, the "reactance" enters the equation due to the frequency-dependent contributions of capacitance and inductance. Impedance in an AC system is still measured in ohms and represented by the equation Z = V/I, but V and I are frequency-dependent.

The appropriate guidelines of this section also apply to nonconventional benchtop soldering equipment; including equipment which utilizes conductive, convective, parallel gap resistance, shorted bar resistance, hot gas, infrared, laser powered devices, or thermal transfer soldering techniques. Tools used are to be maintained such that no detrimental damage results from their use. Tools and equipment are to be clean prior to use and should be kept clean and free of dirt, grease, flux, oil and other foreign matter during use. The heat source is not to cause damage to the printed board or components.

A-3 HEATED SOLDERING TOOL HOLDERS

Soldering tool holders are to be of a type appropriate for the soldering tool used. The holder should leave the soldering tool heating element and tip unsupported without applying excessive physical stress or heat sinking and is to protect personnel from burns.

A-4 WIPING PADS

Sponges and pads for wipe cleaning of soldering iron tips and reflow soldering tool surfaces are to be manufactured from materials which are not detrimental to solderability or which could contaminate soldering tool surfaces. The operator is to keep sponges and pads free of contaminants that are detrimental to solderability or that would contaminate the soldering tool surfaces.

A-5 SOLDERING GUNS

Soldering guns with the transformer incorporated into the hand piece are not to be used.

A-6 SOLDER POTS

Solder pots should maintain the solder temperature within ± 5°C [± 9°F] of the selected temperature. Solder pots are to be grounded.

A-7 USE AND CONTROL

All equipment is to be operated in accordance with manufacturers' recommendations and calibrated where necessary to maintain manufacturers' specifications. Equipment grounding, protection and temperature control testing should be performed when qualifying equipment for purchase and/or inspection of new or repaired equipment.

A-8 MACHINE SOLDERING SYSTEMS

The design of automated machine soldering systems should provide:

a. The capability to preheat printed wiring assemblies.
b. The capacity to maintain the soldering temperature at the assembly surface within ± 5°C [± 9°F] of the selected temperature throughout the span of any continuous soldering run.
c. The capability to rapidly heat the surfaces to be joined and the capacity to re-attain the present temperature within ± 5°C [± 9°F] during repetitive soldering operations.

The heat source is not to cause damage to the printed board or components, or contaminate the solder when direct contact is made between the heat source and metals to be joined.

Soldering equipment should be utilized in accordance with a documented process that is available for user review.

A-8.1 Carriers Devices used for the transport of printed boards through preheat, soldering, and cooling stages should be of such material, design, and configuration that they will not cause board, part or component degradation or ESD damage to components.

A-9 MACHINE MAINTENANCE

Machines related to the soldering process are to be maintained to assure capability and efficiency commensurate with design parameters established by the original equipment manufacturer. Maintenance procedures and schedules should be documented in order to provide reproducible processing.

APPENDIX B
Minimum Electrical Clearance – Electrical Conductor Spacing

APPENDIX C
J-STD-001 Guidance on Objective Evidence of Material Compatibility

OVERVIEW

Most electronics assembly operations are a series of mechanical, thermal, and chemical processes, each having a potentially adverse effect on the long term functionality and reliability of the assembled product. The average electronic assembly will have been subjected to at least 20 different chemical processes, many employing especially aggressive chemicals. To accurately determine that mixtures of these various chemicals do not produce adverse effects, the Manufacturer needs to have examined chemical interactions within their chosen material sets. J-STD-001 has always required that ‘‘objective evidence’’ of ‘‘chemical compatibility’’ be on hand for review. The difficulty is that very few people understand what chemical and electro-chemical compatibility means, how one might investigate such compatibility, to what level data has to be produced, or what kinds of data constituted ‘‘objective evidence.’’ This appendix was generated by a focus group of the J-STD-001 committee to generate guidance on this issue.

It should be understood that this issue is a complex one, with many factors for consideration. The level of desired data may be different between a consumer electronics product, a medical life support system, or an engine control module for an aircraft. The historical relationship between material Supplier, Manufacturer and User may also factor into a decision on the appropriate amount of objective evidence that is necessary.

J-STD-001 REFERENCES

J-STD-001 contains the following requirements (essentially the same requirements in all recent versions of J-STD-001):
Flux: Flux ***shall [D1D2D3]*** *be in accordance with J-STD-004 or equivalent.*
Flux ***shall [N1D2D3]*** *conform to flux activity levels L0 and L1 of flux materials rosin (RO), resin (RE), or organic (OR), except ORL1* ***shall not [N1D2D3]*** *be used for no-clean soldering.*
When other activity levels or flux materials are used, data demonstrating compatibility ***shall [N1D2D3]*** *be available for review.*
Note: *Flux or solder paste soldering process combinations previously tested or qualified in accordance with other specifications do not require additional testing.*
Flux Application: *When an external flux is used in conjunction with flux cored solders, the fluxes* ***shall [all classes]*** *be compatible from a cleaning process standpoint and a chemical standpoint.*

WHY IS THIS A CONCERN?

Fluxes are complex mixtures of resins, activator chemicals, binding agents, rheology modifiers, etc. When a flux from Supplier A (e.g., liquid flux) mixes with the flux from Supplier B (e.g., cored wire solder), the resulting combination of chemicals may not be predictable in their effects on performance or reliability. Flux A and Flux B may have been shown to have acceptable individual performance, but the mixture may not perform as desired. The resulting mixture may be more difficult to clean, may promote the growth of tin whiskers, may not be pin-probable for in-circuit testing, may result in corrosive elements in a no-clean process, etc.

Consequently, most original equipment manufacturers (OEMs) require that their suppliers investigate such mixtures as part of their acceptance process. Because different OEMs approach this issue differently, the kind of data and the amount of data should be an item as agreed between Manufacturer and User.

EXAMPLES OF ACCEPTABLE 0BJECTIVE EVIDENCE

HISTORICAL DATA

If a manufacturer has been using a defined material set for many years, with no identified reliability issues related to flux residues, this should be considered as objective evidence. A proven track record on manufactured product with demonstrated field reliability should be considered as acceptable. To require such a manufacturer to do some other form of testing is not the intention of J-STD-001.

Example: An aerospace manufacturer has been manufacturing with the same RMA paste/flux/wire solders for 15 years with no compatibility issues. No other testing should be required.

PRODUCT QUALIFICATION TEST DATA

If a manufacturer produces product that meets the customer requirements and passes the customer-required product qualification testing, this may constitute objective evidence. The key consideration is whether the qualification testing contained test regimens which would show electrochemical failures. If the testing performed does NOT contain energized circuits in a high humidity environment for an extended period of time, then electrochemical failures from undesirable flux residues cannot manifest.

Example 1: A Class 2 consumer electronics manufacturer has a qualification test set containing: drop (mechanical) shock, thermal cycling, vibration, and visual criteria. These tests do not contain a humidity factor. This would not be considered as acceptable objective evidence of flux compatibility.

Example 2: A Class 3 aerospace OEM has an FAA mandated qualification test set containing: thermal cycling, vibration, visual criteria, salt spray, and humidity testing. Because this testing involves opportunities for flux residues to react negatively to humidity and electricity, successful passing of the test set should be considered as acceptable objective evidence of flux compatibility.

MATERIALS STUDIES

There are two different approaches to materials studies. One involves material characterization tests, in which material interactions may be studied eliminating other outside factors, and the second involves process characterization testing, in which material interactions can contain the sum effects of process chemicals and manufacturing effects. Of these two approaches, the more desirable approach may be process characterization, which is intended to investigate acceptable synergistic electrochemical compatibility with all other process materials that might include solder resist, soldering fluxes (wire, liquid, paste) underfill, adhesive, cleaning media and conformal coating. J-STD-001 does not differentiate between the two approaches and considers both to be equally valid.

Most flux vendors will have already tested the compatibility of their own products with each other. Such tests may include ion chromatography (IC) testing and surface insulation resistance (SIR) testing per IPC standards. If an assembler is using a sole flux supplier, then vendor-produced compatibility information would be considered as acceptable objective evidence provided the assembler is using the fluxes to the flux vendor's recommended guidelines. If the assembler is not using the fluxes to the vendor's recommendation, then some level of additional verification should be pursued. This additional verification would be as agreed between Manufacturer and User.

Example: Flux Supplier A follows the test protocols outlined in J-STD-004. An IPC-B-24 test board is printed with Solder Paste A, reflowed to the vendor's recommendation, then the comb fingers of the B-24 board are manually soldered with Cored Wire Solder A with the addition of Liquid Flux A. The intent is to examine the interaction of the solder paste residues with cored wire flux residues and liquid flux residues. Processed samples are tested in both the cleaned and uncleaned states using SIR protocols. The SIR and visual evaluation criteria of J-STD-004 are followed. A resulting test report can be considered as objective evidence of flux compatibility if the J-STD-004 criteria are met.

If an assembler is using a combination of fluxes from different flux suppliers, then the assembler might contract suitable flux testing by the flux Supplier(s) involved, or an independent test laboratory, using the methodology in the example above. If the J-STD-004 criteria are met, then the test report would be considered as acceptable objective evidence.

A critical consideration in this area is whether the Manufacturer is using the fluxes and pastes as recommended by the flux Supplier. If the material testing by the vendor involved restrained amounts of fluxes and pastes, yet the manufacturing practices use excessive amounts of fluxes and pastes on the product board, then the data package is suspect. The material compatibility testing should mirror the amounts used on the product board in production to be scientifically valid.

IPC-9202 TESTING

Because the issue of investigating materials and process compatibility has been with the industry for some time, and because previous test approaches were not considered optimum, a new approach was generated. IPC-9202 *Material and Process Characterization/Qualification Test Protocol for Assessing Electrochemical Performance* was published in October 2011.

It is not necessary for a manufacturer to have IPC-9202 data to be compliant to J-STD-001. This was a frequent misunderstanding in previous versions of IPC-J-STD-001.

As is illustrated in this document, there are many different methods to show material and process compatibility and any one may be acceptable for J-STD-001. The best way to view IPC-9202 is that if the Manufacturer does not know how to assess flux compatibility, and the customer does not know how to assess flux compatibility, IPC-9202 is an excellent place to start.

OTHER SPECIFICATIONS

Bell Communications Research (Bellcore) had flux compatibility testing now found in Telecordia document GR-78-CORE. The telecommunications industry has manufactured product for many years using the flux qualification methodologies in that document. GR-78-CORE testing, provided the testing shows a combination of the fluxes used, would be considered as acceptable objective evidence.

Previous versions of IPC-J-STD-001 had appendices which outlined testing to be done to generate objective evidence of flux compatibility. The data from those tests should be considered as acceptable objective evidence.

Companies may have developed data packages using custom designed test vehicles for ionic cleanliness testing and/or surface insulation resistance testing. In this case, the test report should indicate what the pass fail criteria is for the test board and how that criteria was determined. The data from such tests should be considered as acceptable objective evidence.

IPC-CH-65 (Guidelines for Cleaning of Printed Boards and Assemblies) Section 6 (Process Development and Verification) contains additional guidance for material compatibility testing and includes sample test plan guidelines and test method considerations.