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Through-Hole Solder Joint Evaluation

Training & Reference Guide

IPC DRM-PTH-D

Now updated to A-610 Rev. D

With Lead Free Solder Joints

References:
IPC-A-610D and
IPC J-STD-001D

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Introduction

This Through-Hole Solder Joint Evaluation Training and Reference Guide provides visual examples of acceptability requirements, defects and conditions found in through-hole solder joints on electronic assemblies. This manual is intended for use as an illustrated support document to assist in the training and practice of through-hole solder joint evaluation, and therefore, it references portions of the following two IPC standards:

First, the IPC-A-610 Rev. D, Acceptability of Electronic Assemblies, which illustrates the requirements for many types of solder connections.

Second, the IPC J-STD-001 Rev. D, Requirements for Soldered Electrical and Electronic Assemblies, establishes the minimum acceptability requirements for printed board assemblies soldering.

Classification

Through-hole solder joint requirements are divided into three classes depending on the ultimate use, life expectancy and operating environment of the electronic assembly. Those classes are as follows:

Class 1 General Electronic Products
Includes *consumer type* products suitable for applications where the major requirement is the function of the completed assembly, not necessarily for extended life, reliability of service, or cosmetic perfection.

Class 2 Dedicated Service Electronic Products
Includes *commercial type* 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 through extremes of temperature or contamination.

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. These *high-reliability* type products are used in such systems as life-support and aerospace.

Note: The inspector does not select the class for the part under inspection. Documentation which specifies the applicable class for the part under inspection should be provided to the inspector.

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Below are the definitions of terms you will run across while using this manual: (taken from IPC-T-50, Terms and Definitions for Interconnecting and Packaging Electronic Circuits)

Clinched Lead - A component lead that is inserted through a hole in a PWB and is then bent or clinched to hold the component in place and to make metal-to-metal contact with a land before soldering.

Cold Solder Connection - A solder connection that exhibits poor wetting, and that is characterized by a gray, porous appearance.

Component - An individual part or combination of parts that, when together, perform a design function.

Conductor - A single conductive (metal) path in a conductive pattern.

Contact angle - The angle formed by the edge of the solder fillet and the land's surface.

Dewetting - A condition that results when molten solder coats a surface and then recedes to leave irregularly-shaped mounds of solder that are separated by area that are covered with a thin film of solder and with the basis metal not exposed.

Disturbed solder connection - A solder connection that is characterized by the appearance that there was motion between the metals being joined when the solder was solidifying.

Excess solder connection - A solder connection that is characterized by the complete obscuring of the surfaces of the connected metals and/or by the presence of solder beyond the connection area.

Fillet - A normally-concave surface of solder that is at the intersection of the metal surfaces of a solder connection.

Flux residue - A flux-related contaminant that is present on or near the surface of a solder connection.

Icicle (solder projection) - An undesirable protrusion of solder from a solidified solder joint or coating.

Land - A portion of a conductive pattern that is usually used for making electrical connections, for component attachment, or both.

Lead - The wire or formed metal conductor that extends from a component to serve as a mechanical and/or electrical connector.

continued....

Nonwetting - The partial adherence of molten solder to a surface that it has contacted and basis metal remains exposed.

Pinhole - A small hole that penetrates from the surface of a solder connection to a void of indeterminate size within the solder connection.

Plated-through hole - A hole with plating on its walls (supported hole) that makes an electrical connection between conductive patterns on internal layers, external layers, or both, of a printed board.

Residue - Any visual or measurable form of process-related contamination.

Solder - A metal alloy with a melting temperature that is below 427°C (800°F).

Solderability - The ability of a metal to be wetted by molten solder.

Soldering - The joining of metallic surfaces with solder and without the melting of the base material.

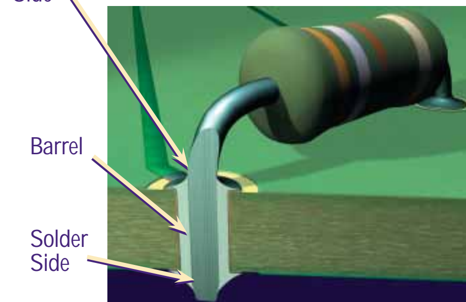
Solder bridging - The unwanted formation of a conductive path of solder between conductors.

Spatter - Extraneous fragments of solder with an irregular shape.

Webbing - A continuous film or curtain of solder that is parallel to, by not necessarily adhering to, a surface that should be free of solder.

Wetting - The formation of a relatively uniform, smooth, unbroken, and adherent film of solder to a basis metal.

Cross-section View of a Target Plated - Through Hole



Component Side: The side of a through-hole assembly containing the most component bodies. Also called the "primary side" or the "solder destination side."

Solder Side: The side that is coated with solder in the solder wave machine. Also called the "secondary side" or "solder source side."

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Acceptance Criteria

In this Desk Reference Manual, criteria are given for each class in one or more of the following levels of condition —

Target

Acceptable

Process Indicator

Defect

Photographs or illustrations of each condition are shown in the left column (examples on opposite page). The level of acceptance, class(es) and description of the illustration are all contained in the right column. In the following examples, definitions of each acceptance criterion are printed to the right of sample photographs. For easier viewing, colored bars connect each photograph or illustration to each description, with a different color used for each acceptance level.

Notes: Accept and/or reject decisions must be based on applicable documentation such as contract, drawings, specifications such as IPC-A-610 and IPC J-STD-001 or other referenced documents.

Denotes criteria that have changed from Revision C of these two standards.

Lead Free Soldering

The primary difference between the solder connections created with processes using tin-lead alloys and processes using lead free alloys is related to the visual appearance of the solder.

Acceptable lead free and tin-lead connections may exhibit similar appearances, but lead free alloys are more likely to have:

- Surface roughness (grainy or dull)
- Greater wetting contact angles*

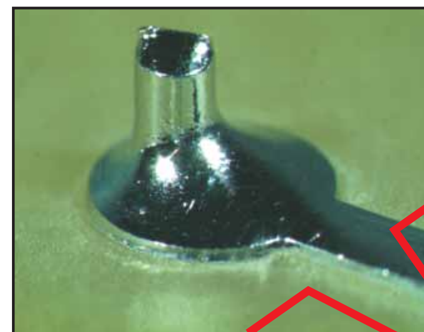
All other solder criteria are the same.

*Wetting cannot always be judged by surface appearance. The wide range of solder alloys in use may exhibit from low or near zero degree contact angles to nearly 90 degree contact angles as typical.

Denotes Lead Free

DEMO

Condition Levels

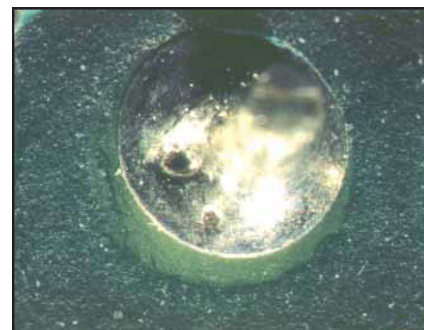


Target Class 1, 2, 3

A condition that is close to perfect; however, it is a desirable condition and not always achievable and may not be necessary to ensure reliability of the assembly in its service environment.

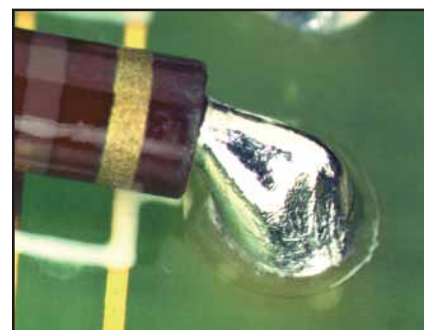
Acceptable Class 1, 2, 3

This characteristic indicates a condition that, while not necessarily perfect, will maintain the integrity and reliability of the assembly in its service environment.



Process Indicator Class 1, 2, 3

A process indicator is a condition that does not affect the form, fit and function of a product. However, process indicators signal a lack of good workmanship to the customer and should be used to improve the manufacturing process—even though the product is considered usable.



Defect Class 1, 2, 3

A defect is a condition that is insufficient to ensure the form, fit or function of the assembly in its end use environment. The manufacturer shall rework, repair, scrap, or "use as is" based on design, service and customer requirements.

ONLY

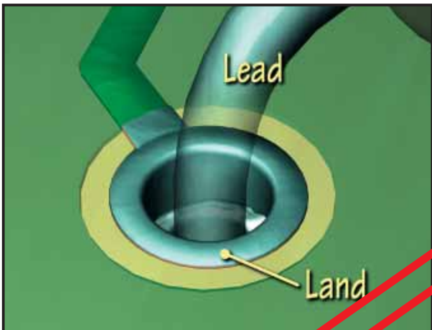
Component Side - Land Coverage

Target Class 1, 2, 3

Properly wetted solder fillet covers 100% of component side land area and feathers out to a thin edge on land area.

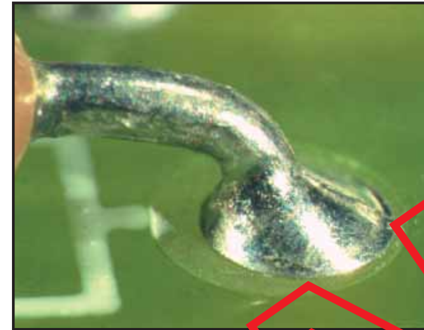
Acceptable Class 1, 2, 3

0% of the component side land area is covered with wetted solder.



References:
A-610D: 7.5.5.3, Table 7-6
J-STD-001D: 6.3.2, Table 6-5

Component Side - Excess Solder

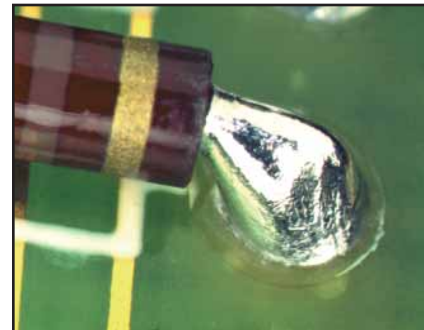


Target/Comparison Class 1, 2, 3

Solder fillet ends below lead bend area.

Acceptable Class 1, 2, 3

Solder in lead bend area does not contact the component body.



Defect Class 1, 2, 3

Solder in lead bend area comes in contact with the component body or end seal.

References:
A-610D: 7.5.5.6
J-STD-001D: 4.14.3

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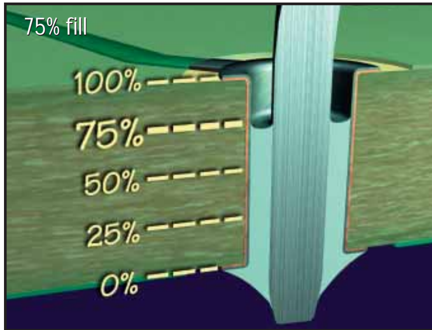
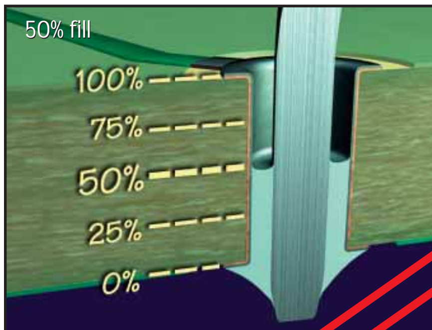
Barrel - Vertical Fill of Solder



Acceptable Class 2, 3

A minimum of 75% solder fill, or a total maximum of 25% depression including both component (primary) and solder (secondary) sides is permitted.

Notes:
Minimum acceptable condition for vertical fill of solder on Class 1 assemblies is not specified. Less than 100% solder fill may not be acceptable in some applications, e.g., thermal shock.



Acceptable Class 2

Defect Class 3

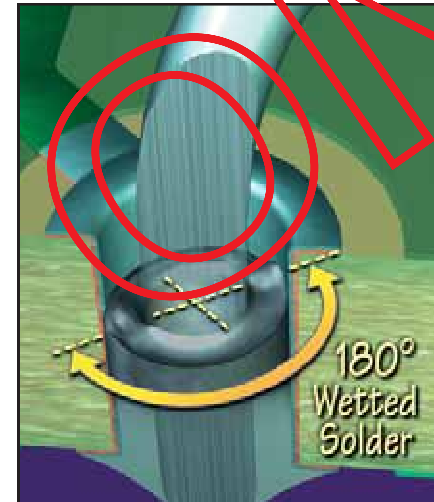
As an exception to fill requirements on internal layer thermal heat sink planes associated with plated through holes, a 50% vertical fill of solder is permitted, but with solder extending 360° around the lead with 100% wetting to barrel walls and to the lead on the solder (secondary) side. Component lead must also be visible on solder side of connection.

References:
A-610D: 7.5.5.1, Table 7-6
J-STD-001D: 6.3.2, Table 6-5, Fig. 6-2

Barrel - Wetting of Lead & Barrel

Target Class 1, 2, 3

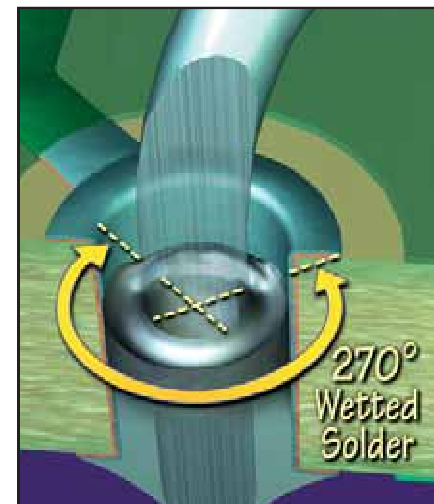
100% (360°) circumferential wetting present on component (primary) side of **lead** and **barrel**. Vertical fill at 100%.



Acceptable Class 2

A minimum of 180° circumferential wetting (50%) present on component (primary) side of **lead** and **barrel**. Vertical fill at 75%.

Note:
Minimum acceptable condition for circumferential wetting of lead and barrel on component side for Class 1 is not specified.



Acceptable Class 3

A minimum of 270° circumferential wetting (75%) present on component (primary) side of **lead** and **barrel**. Vertical fill at 75%.

References:
A-610D: 7.5.5.2, Table 7-6
J-STD-001D: 6.3.2, Table 6.5

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Solder Side - Wetting of Lead, Land & Barrel

Target Class 1, 2, 3

100% solder fillet and circumferential wetting present on solder (secondary) side of solder joint.

Acceptable Class 1, 2

A minimum of 270° circumferential (75%) wetting present on solder (secondary) side of **lead**, **land** and **barrel**.

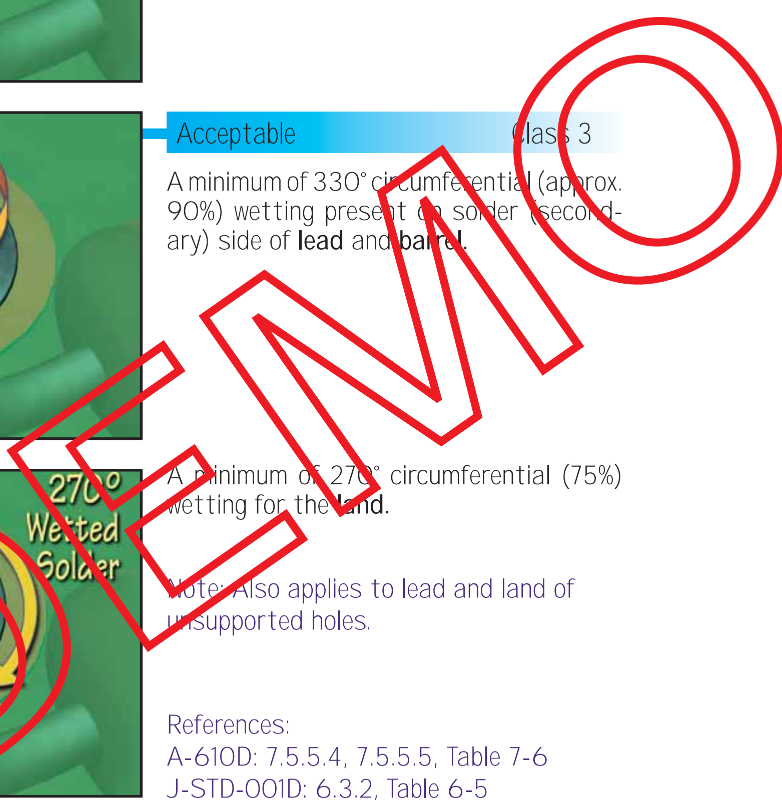
Acceptable Class 3

A minimum of 330° circumferential (approx. 90%) wetting present on solder (secondary) side of **lead** and **barrel**.

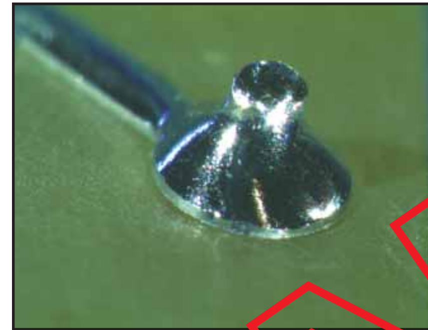
A minimum of 270° circumferential (75%) wetting for the **land**.

Note: Also applies to lead and land of unsupported holes.

References:
A-610D: 7.5.5.4, 7.5.5.5, Table 7-6
J-STD-001D: 6.3.2, Table 6-5



Solder Side - Contact Angle

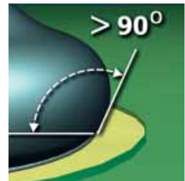


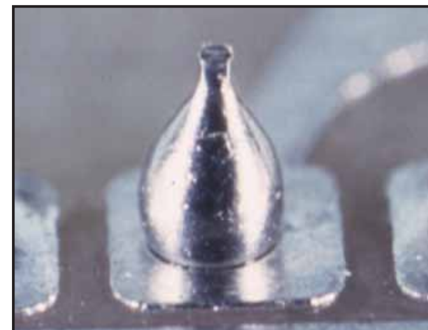
Target Class 1, 2, 3

The solder fillet forms a contact angle of 90° or less.

Acceptable Class 1, 2, 3

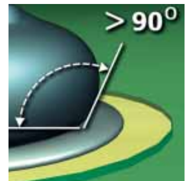
The solder fillet forms a contact angle of more than 90° due to quantity of solder extending over the edge of the land.





Defect Class 1, 2, 3

Nonwetting results in the solder forming a ball or beading on the surface. The fillet is convex and the contact angle is greater than 90°, but solder does not extend over the land. (See notes on page 5, lead free wetting contact angles.)



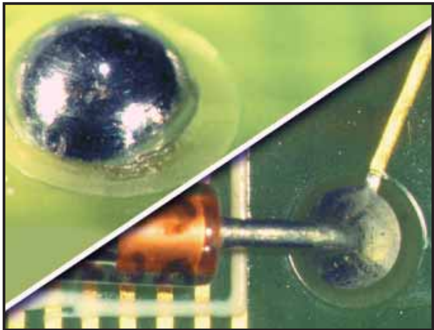
Very poor wetting results in the solder clumping on the surface. No feathered edge is apparent. Contact angle is irregular.

References:
A-610D: 5, 5.1
J-STD-001D: 4.14

Solder Side -Discerning the Lead

Target Class 1, 2, 3

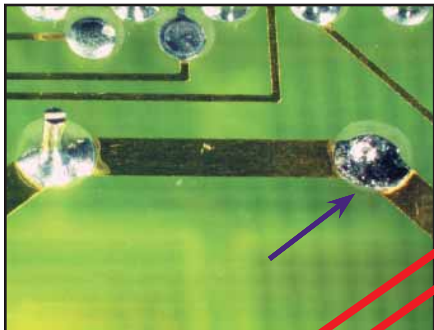
Lead and land are well wetted, secondary side lead is clearly visible. Solder fillet is concave.



Acceptable Class 1

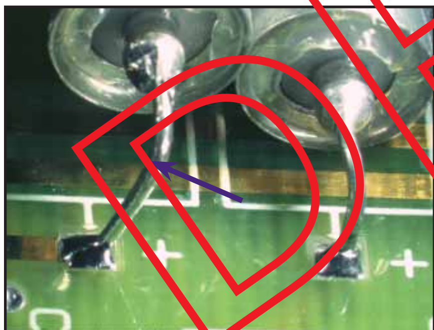
Process Indicator Class 2, 3

Fillet is slightly convex with good wetting, and the lead is not discernible on the solder (secondary) side due to excess solder. However, visual evidence of the lead in the hole can be determined on the component (primary) side.



Defect Class 1, 2, 3

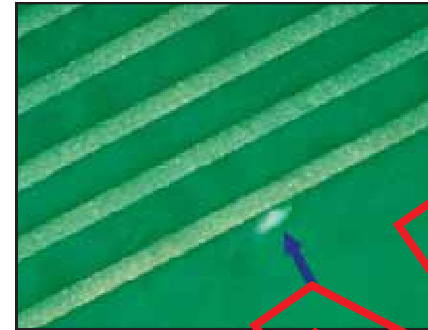
Lead not discernible on solder (secondary) side due to lifted component or bent lead on component (primary) side.



Lifted component or bent lead on component (primary) side.

References:
A-610D: 7.5.5
J-STD-001D: 6.1.3, Table 6-3

Solder Balls



Acceptable Class 1, 2, 3

Encapsulated solder ball

Defect Class 1, 2, 3

Solder balls not entrapped in no-clean residue or encapsulated with conformal coating, or not attached (soldered) to a metal surface, or that violate minimum electrical clearance.

Notes:
Entrapped/encapsulated/attached is intended to mean normal service environment of product will not cause a solder ball to become dislodged.

References:
A-610D: 5.2.6.1
J-STD-001D: 8.3.1

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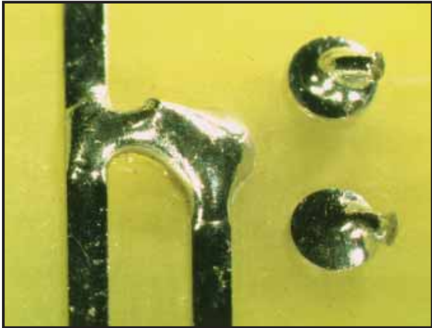
Solder Bridging



Defect Class 1, 2, 3

Solder bridging across conductors.

Solder has bridged to adjacent noncommon conductor.

References:
A-610D: 5.2.6.2
J-STD-001D: 4.14.3

Cavities, Voids, Pinholes, Blowholes, etc.

Target/Comparison Class 1, 2, 3

No void areas or surface imperfections. Lead and circuitry are well wetted.

Acceptable Class 1

Process Indicator Class 2, 3

Solder cavities which do not reduce circumferential wetting of lead and barrel, land coverage, or vertical fill below minimum acceptable requirements for class.

Defect Class 1, 2, 3

Solder cavities that reduce circumferential wetting of lead and barrel, land coverage or vertical fill below minimum acceptable requirements for class.

References:
A-610D: 5.2.2
J-STD-001D: 4.14

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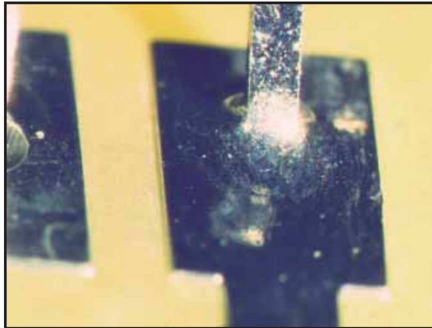
Cold Solder Joint



Target/Comparison — Class 1, 2, 3

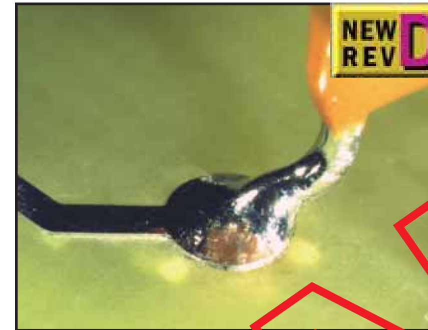
Solder joint is smooth, shiny to satin luster, well wetted on entire land and lead.

Defect — Class 1, 2, 3

Cold solder joint: lumpy and poorly wetted to land and lead.

References:
A-610D: 5.1
J-STD-001D: 4.14, 4.14.3

Coating Meniscus in Solder Joint



Target/Comparison — Class 1, 2, 3

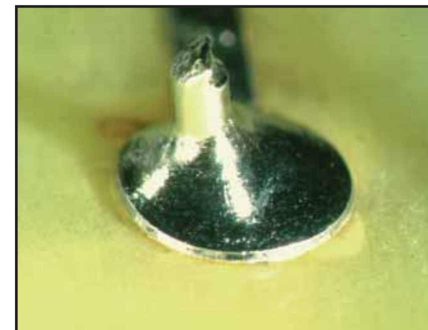
Coated or sealed components: There is a 1.2 mm or greater separation between the edge of the component coating (meniscus) and the solder fillet.

Acceptable — Class 1

Process Indicator — Class 2

Defect — Class 3

Component coating is into the plated-through hole. All other soldering requirements have been met (see photo below).



Solder (secondary) side exhibits 360° of good wetting, and coating is not visible within the connection on solder (secondary) side.

References:
A-610D: 7.5.5.7
J-STD-001D: 6.1.6

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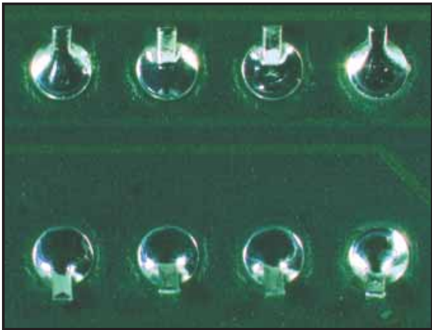
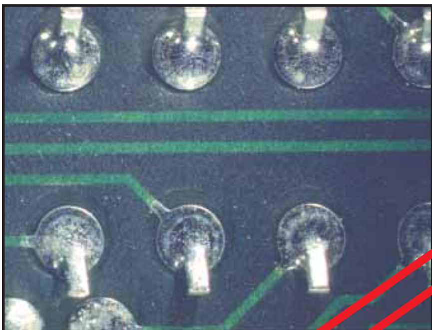
Corrosion/Surface Appearance



Target/Comparison Class 1, 2, 3

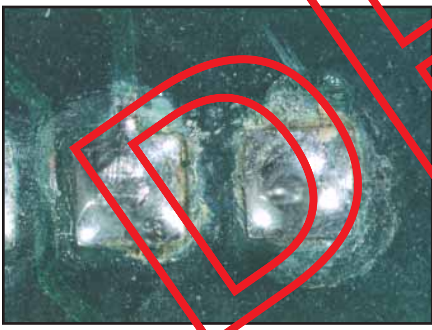
Shiny to satin luster and clean metallic surfaces.

Surface of lead free solder joints may be grainy or dull.



Acceptable Class 1, 2, 3

Slight dulling of clean metallic surfaces.

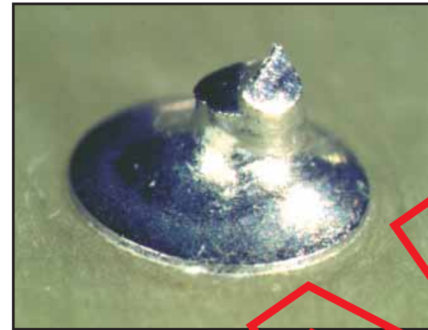


Defect Class 1, 2, 3

Colored residues or rusty appearance on metallic surfaces or hardware, or other evidence of corrosion.

References:
A-610D: 10.4.5
J-STD-001D: 8.3

Disturbed Solder Joint



Target/Comparison Class 1, 2, 3

Solder joint is smooth, shiny to satin luster, well wetted on entire land and lead.

Defect Class 1, 2, 3

Disturbed solder joint: has stress lines from movement in the connection while solidifying.

References:
A-610D: 5.2.7
J-STD-001D: 4.14, 4.14.3

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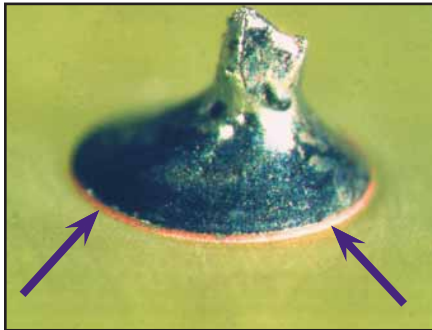
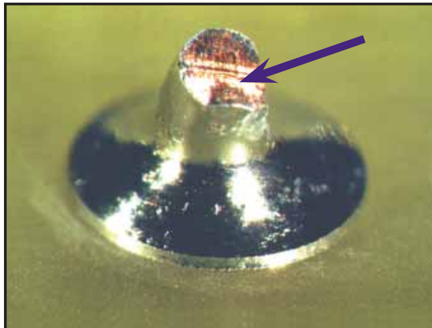
Exposed Basis Metal



Acceptable Class 1, 2, 3

Exposed copper on vertical conductor edges.



Exposed basis metal at cut ends of component leads or wires.

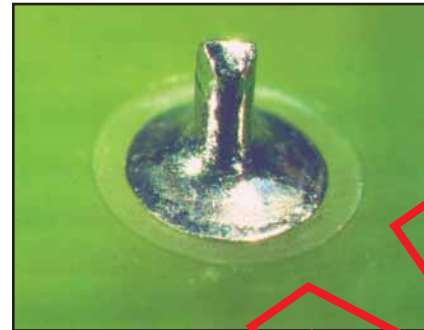
Notes:
Exposed basis metal on component leads, conductors or lands from nicks, scratches, dents, etc., are :

Acceptable - Class 1,
Process Indicator- Class 2, 3
Provided condition meets requirements for lead, conductor and land.

Certain board and conductor finishes may exhibit solder wetting only to specific areas. Exposed basis metal is acceptable in these circumstances if all other requirements are met.

References:
A-610D: 5.2.1, Figs. 5-26, 5-28
J-STD-001D: 4.14.1

Lead Cutting/Fractured Solder Joints

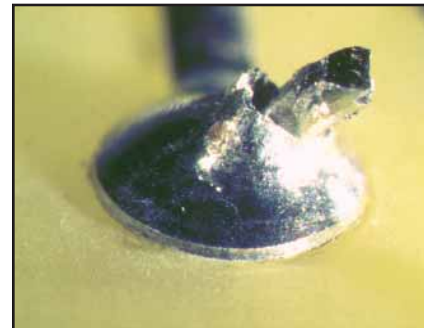


Acceptable Class 1, 2, 3

No fractures between lead and solder.

Defect Class 1, 2, 3

Fractured solder connection.

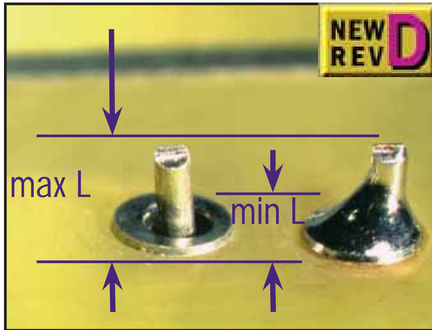


Notes:
Applies to printed board assemblies where the secondary side has had leads trimmed after soldering. When lead cutting is performed after soldering, the solder terminations need to either be reflowed or visually inspected at 10x to ensure that the solder connection has not been damaged or deformed.

References:
A-610D: 7.5.5.8
J-STD-001D: 4.14, 4.14.3, 6.1.4

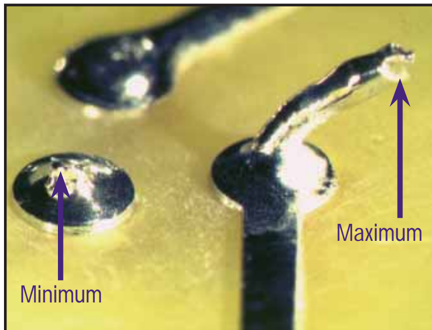
DEMO ONLY

Lead Protrusion



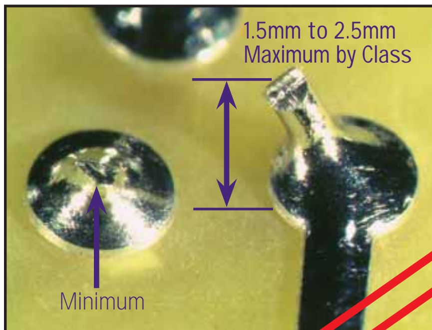
Target /Comparison Class 1, 2, 3

The protrusion of leads beyond the conductive surface is within the specified minimum and maximum of dimension "L." Lead protrusion should not allow the possibility of violating minimum electrical spacing, damage to solder connections due to land deflection, or penetration of static protective packaging during subsequent handling.



Acceptable Class 1

The lead end is visible in the solder joint (minimum) and there is no danger of violating electrical spacing or causing shorts (maximum).

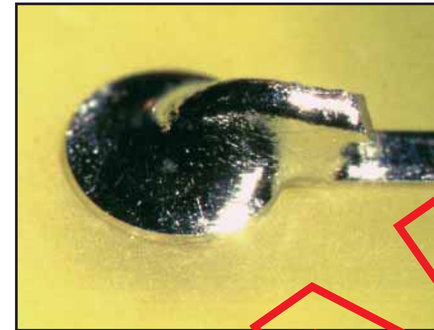


Acceptable Class 2, 3

The lead end is visible in the solder joint (minimum) and extends no more than 2.5 mm (Class 2), or extends no more than 1.5 mm (Class 3) from the top of the land (maximum) provided there is no danger of violating electrical clearance, or exceeding maximum design height requirements.

References:
A-610D: 7.5.3, Table 7-5, Figs. 7-96, 7-97
J-STD-001D: 6.1.3, Table 6-3

Lead Protrusion/Clinched

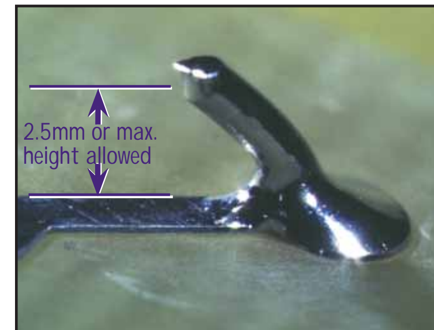


Target/Comparison Class 1, 2, 3

Lead end is parallel to the board and direction of the clinch is along the connecting conductor.

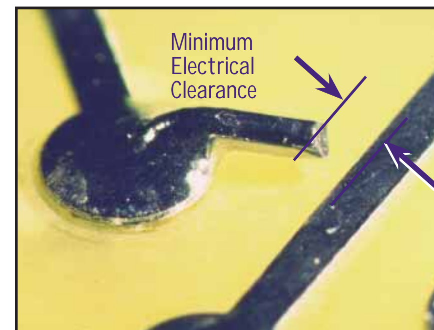
Acceptable Class 1, 2, 3

The clinched lead does not violate the minimum electrical clearance (C) between non-common conductors, and is not greater than the similar length allowed for straight-through leads.



Defect Class 1, 2, 3

The clinched lead extends more than the maximum height allowed for straight-through leads for its class. (Partially clinched leads for part retention shall be considered as unclinched leads, and need to meet protrusion requirements.)



The lead is clinched toward an electrically uncommon conductor, violating the minimum electrical clearance.

References:
IPC-610D: 7.5.4, Figs. 7-98, 7-99, 7-100, 7-101
J-STD-001D: 6.1.3, Table 6-3

DEMO ONLY

Nonwetting of Solder

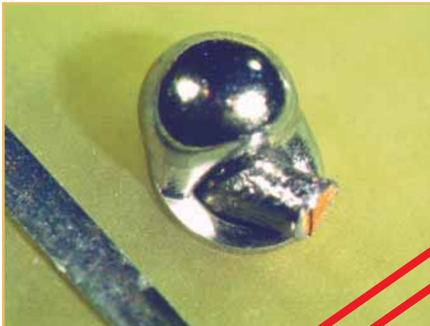
Target/Comparison Class 1, 2, 3

The solder fillet appears generally smooth and exhibits good wetting of the solder to the parts being joined. The outline of the parts is easily determined. A feathered edge is created by the solder at the part being joined.

Acceptable Class 1, 2, 3

The solder connection must indicate evidence of wetting and a smooth blend of solder to the surface forming a contact angle of 90° or less.

(Also see page 12, Solder Side- Contact Angle)



Defect Class 1, 2, 3

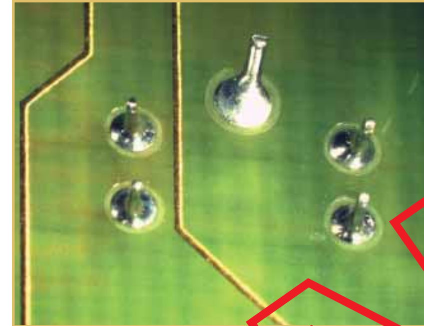
Non-wetting results in the solder forming a ball or beading on the surface. The fillet is convex; no feathered edge is apparent.

Molten solder has not adhered or formed an acceptable metallic bond between lead, barrel and land.

References:
A-610D: 5.2.4
J-STD-001D: 4.14

DEMO ONLY

Particulate Matter



Target/Comparison Class 1, 2, 3

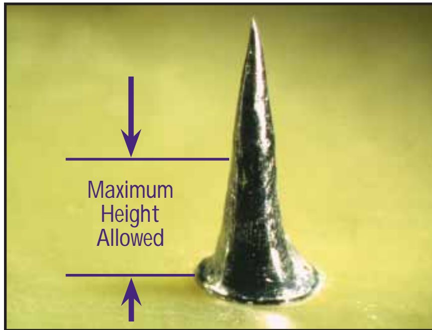
Clean.

Defect Class 1, 2, 3

Dirt and particulate matter on assembly. Assemblies should be free of dirt, lint, dross, and other particulate matter.

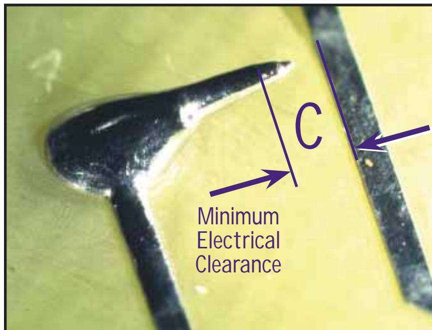
References:
A-610D: 10.4.2
J-STD-001D: 8.3.1

Projections

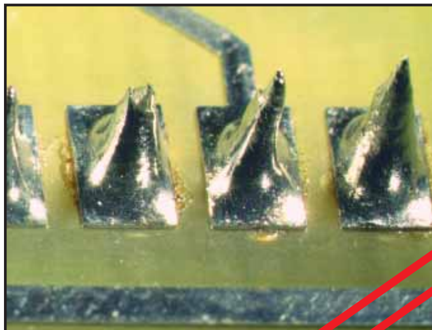


Defect Class 1, 2, 3

Solder projections that violate spacing or height requirements of the assembly design (assembly could short out to adjacent board or frame when placed in final system position).



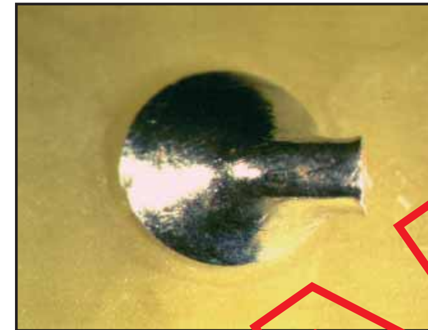
Solder projections that violate Minimum Electrical Clearance (C).



Solder projections that pose a safety hazard (someone could injure themselves on the projection).

References:
A-610D: 5.2.9
J-STD-001D: 6.1.3, Table 6-3, 4.14.3

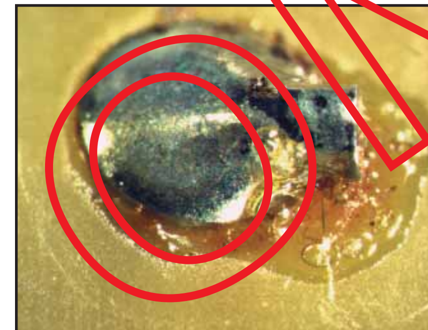
Residue



Target/Comparison Class 1, 2, 3

No visible residue. *

** Flux residues from "no-clean" processes may be allowed.**



Defect Class 1, 2, 3

Visible residue from "cleanable" fluxes, or any active flux residues on electrical contact surfaces.**

*** Class 1 may be acceptable after qualification testing. Check also for flux entrapment in and under components. Processes designated "no clean" need to comply with end product cleanliness requirements.*

References:
A-610D: 10.4.1
J-STD-001D: 8.3.2

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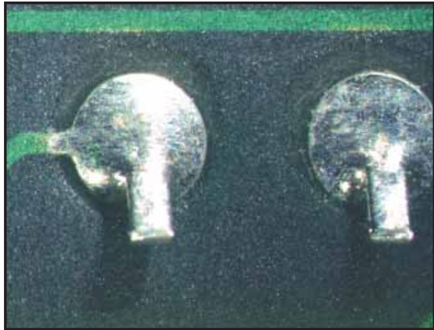
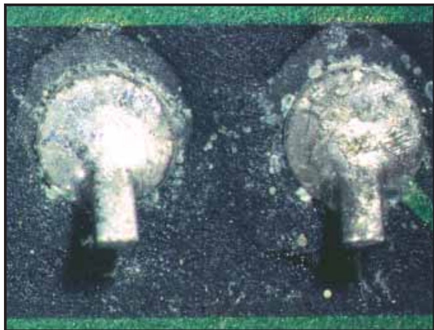
Residue—Continued



Target/Comparison Class 1, 2, 3

All assembly surfaces are clean, no visible residue.



Defect Class 1, 2, 3

Metallic areas exhibit crystalline white deposits. White residue on PWB surface, on or around soldered termination.*

** White residues resulting from no-clean or other processes are acceptable provided the residues from chemistries used have been qualified as harmless.*

References:
A-610D: 10.4.3
J-STD-001D: 8.3.2

Splashes of Solder /Webbing

Defect Class 1, 2, 3

Solder splashes.

Solder webbing.

References:
A-610D: 5.2.6.3
J-STD-001D: 8.3.1

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This reference guide does not take precedence over, or replace the requirements from any IPC Standard or Specification. While every effort has been made to represent applicable portions of the IPC J STD-001D and IPC-A-610D documents, this guide may not cover all related requirements and is not intended for use as an industry consensus standard. IPC disclaims any warranties or guarantees, expressed or implied, and shall not be held liable for damages of any kind in connection with the information set forth in IPC-DRM-PTH-D.

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