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INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard

SAE ARP1332 REV. B

Issued 1974-03
Revised 1997-03
Reaffirmed 1994-07
Superseding ARP1332A

WAVE SOLDERING PROCEDURE

FOREWORD

Changes in the revision are format/editorial only.

1. SCOPE:

1.1 The purpose of this recommended practice is to provide recommendations concerning the procedure for wave soldering.

1.2 The detailed recommendations are based on manufacturing experience and laboratory experiments. The recommendations reflect those design practices and fabricating procedures which have been found to be most effective in producing functional electronic modules for critical communications or control systems. Electronic modules include assemblies, components, and printed circuit (PC) or printed wire (PW) boards.

1.3 In the following text, references to printed circuit (PC) boards shall be construed to include printed wire (PW) boards.

1.4 Safety-Hazardous Materials:

While the materials, methods, applications and processes described or referenced in this procedure may involve the use of hazardous materials, this document does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

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2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 ASTM Publications: Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM D 257

2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-202, Method 208

2.1.3 Other Publications:

American Society for Metals Handbook

3. GENERAL:

3.1 A soldered joint is formed when the molten solder "wets" the surfaces of the substrates. Wetting creates a metallurgical bond by formation of intermetallic compounds of tin with the substrate. Penetration into re-entrant cavities and filling of space between surfaces occur by capillary action. Best soldering results are achieved when substrates and leads are wetted quickly and completely by the molten solder. The entire substrate surface should approach perfect wetting conditions.

3.2 Surface contamination will impede this metallurgical reaction. Substrate surfaces must be free from oxides and other contaminants to ensure reliable, repeatable soldering conditions required for rapid reaction in the solder wave, where dwell time may be less than 2 seconds. All components and printed circuit board conductor runs should be determined, by lot acceptance test, to possess the optimum surface condition for best solderability. Manipulation of fluxing and soldering often will overcome marginal solderability but can only provide minimum help to components possessing poor solderability.

3.3 The solder wave machine uses a vertical wave of molten solder usually produced by an impeller immersed in a sump of molten solder. The impeller pumps the solder between parallel plates so that a crest of solder will exist above the quiescent solder level. Other means of producing a solder wave are acceptable. The electronic module assembly passes over the wave by means of chain-driven conveyer set at a critical angle with respect to the wave crest axis. The depth of board penetration into the solder crest is critical. Depth must be great enough to cause hydrostatic displacement of flux in holes and allow molten solder to flow through the holes by capillarity. Depth must not be so great as to cause solder to break across the component side of the PC board. Advanced soldering lines now incorporate in-line fluxing and pre-solder/ post-solder cleaning systems.

4. RECOMMENDATIONS:

4.1 Solder Bath:

4.1.1 The optimum composition of tin is 59.5% to 63.5% with the balance of the solder bath consisting of lead and the items in 4.1.2.2.

4.1.2 Contamination and composition change of the solder bath will occur during operation. The solder should be sampled and analyzed on a periodic basis or when the quality of the soldering decreases. Certain metallic elements are soluble in molten solder and gradually contaminate the solder bath.

4.1.2.1 Extremely heavy deposits of gold plating on electronic components may alloy with molten solder to cause degradation of solidified solder fillets by formation of brittle gold-tin intermetallic compound phases. Surface dewetting will be more prevalent as gold content in the bath increases. Thin (under 120 microinch (3 µm) thickness) coatings of pure gold are extremely solderable and do not cause degradation of solder joints because all the gold is dissolved away during the soldering operation.

4.1.2.2 Some elements such as zinc, aluminum, and cadmium render the solder sluggish and porous. Other elements such as copper and nickel render the solder hard and brittle. Metals such as silver and antimony have little detrimental effect on the solder. Nonetheless, impurities should be maintained at levels as low as possible, preferably below the following limits:

TABLE 1

Element	Content, % by Weight min	Content, % by Weight max
Antimony	0.2	0.5
Copper (4.1.2.2.1)	--	0.3
Bismuth	--	0.25
Gold (4.1.2.2.1)	--	0.20
Silver	--	0.10
Arsenic	--	0.03
Iron	--	0.02
Nickel	--	0.01
Phosphorous	--	0.01
Aluminum (4.1.2.2.1)	--	0.006
Cadmium (4.1.2.2.1)	--	0.005
Zinc (4.1.2.2.1)	--	0.005
Sulfur	--	0.001

4.1.2.2.1 Total of copper, gold, aluminum, cadmium, and zinc shall not exceed 0.4% by weight.

4.1.2.3 When chemical analysis indicates impurity levels greater than the individual contaminant levels, the entire bath should be discarded or should be restored by addition of virgin solder to maintain low impurity level. A low contamination level is needed to control solder bath fluidity at a given temperature.

4.1.3 The molten solder should be temperature controlled at 230 to 290 °C (450 to 550 °F) for best results. Higher temperatures can cause component degradation and dewetting. Lower temperatures can cause solder bridging, icicling, and poor wetting.

4.1.4 The balance between carriage speed and solder temperature is also critical. Because metal component leads and laminate conductor runs or pads possess greater inherent heat capacity than the dielectric board material, the electronic module assembly may be wave soldered at faster speed when the solder temperature is higher with less component or dielectric damage than when wave soldered at slower speed and lower solder temperature.

4.2 Oil Intermix:

4.2.1 A tinning oil serves to inhibit dross formation and to promote the solder wetting process. Tinning oil is superior to vegetable oil for use in oil intermix systems. Several proprietary formulations are satisfactory.

4.2.2 A daily machine cleaning discipline is necessary to maintain peak soldering performance. Some intermix oils should be changed after 4 hours of operation. Any oil should be changed daily. Weekly, monthly, and quarterly machine cleaning and maintenance schedules should be established. Remove all oil-derived solids from the solder machine sump and other cavities or surfaces on a monthly basis, or sooner if solder quality decreases.

4.3 Presolder Cleaning:

4.3.1 To ensure a soldered product with adequate solder wetting and filleting and improved post-solder cleanliness levels, it is imperative that presolder cleaning be performed. Boards will be contaminated with polar, nonpolar, ionic, and insoluble residues. Each type of residue must be treated individually. Plating or other masking tape should be removed prior to any cleaning operation.

4.3.2 Nonpolar contaminants such as grease, oil, fatty acids, and organic resin residues from plating or masking must be removed from the board prior to other cleaning steps. This kind of contamination is usually hydrophobic and will repel other subsequently applied solvents. A nonpolar solvent may be selected from the following list:

a. Halogenated hydrocarbons, such as 1,1,1 trichloroethane, and either generic compounds or proprietary formulations.
b. Ethers or esters (excellent nonpolar solvency).
c. Ketones or ketone derivatives (excellent nonpolar solvency).
d. Aromatic hydrocarbons, including benzol and xylene (excellent nonpolar solvency).

4.3.3 Metal oxides and polymerized varnish shall be removed prior to the soldering operation. Sand or particle blasting is not recommended because microscopic particles will become embedded in the softer surfaces and promote dewetting during soldering. Certain oxides, however, will be removed by chemical action of the solder flux. Other foreign particles should be removed prior to the soldering operation.

4.3.4 The polar and ionic contaminants such as body salts, perspiration, plating residue, etching residue, and other ambient contamination should be removed prior to the wave soldering operation. A polar solvent may be selected from the following list:

a. Alcohol, alcohol blends, and alcohol azeotropes (although alcohol is bipolar, this solvent provides excellent polar solvency).

b. Deionized demineralized water (a water rinse, preferably at elevated temperature, provides excellent polar solvency).

4.3.5 A presolder cleaning rule should be to remove as much contamination prior to soldering by an elaborate cleaning schedule as is compatible with the economics and specified reliability standards of the electronic module being fabricated.

4.4 Flux and Flux Application:

4.4.1 Rosin-base fluxes suitable for use in the wave soldering process contain activators that react with the surfaces to be joined by the solder. Both RMA (mildly activated) and RA (activated) fluxes contain activator compounds and the activated flux residues must be completely removed by proper cleaning procedures. While RA flux provides superior solderability, special precautions must be taken to ensure complete removal of the flux residue, otherwise residual corrosive ions may produce malfunction through the slow accumulation of corrosion products long after the soldered component has been placed in service. Strict adherence to the cleaning procedures recommended herein should provide adequate protection.

4.4.2 Flux viscosity may be controlled by adding a solvent or thinner to the flux. The thinner is usually a higher alcohol, such as isobutyl or isopropyl. The specific gravity of the flux should be maintained within ±3% of the manufacturer's value.

4.4.3 Flux should be applied to the surface of the board to be soldered by a method that will produce an evenly coated surface. When desired, flux may be applied to both sides of the PC board. Wave soldering machines usually incorporate a foam fluxer. Improved soldering results are obtained if the printed circuit board component side is flux coated. Component-side fluxing may be obtained by breaking through the wave or by component-side spray of thinned or foamed flux.

4.4.4 The flux-coated board should be preheated to 75 to 105 °C (160 to 220 °F). The radiant heat level will depend on the solder carriage travel speed.

4.4.5 Several flux application methods in addition to foam fluxing are also recommended, such as:

4.4.5.1 Wave Fluxing: Flux is applied the same way as the solder wave applies solder.

4.4.5.2 Dipping: This method can use certain pastes as well as liquid flux.

4.4.5.3 Spraying: Spraying is readily adaptable to automation and is used on automatic solder lines.

4.4.5.4 Brushing: Either manual or powered brushes are usable.

4.4.5.5 Rolling: Various types of rollers may be used for precision selective soldering.

4.5 Wave Soldering:

4.5.1 The soldering machine conveyer angle with respect to the wave axis may vary with machine conveyer design. It has been found that 6 degrees ± 3 degrees is optimum for some designs while an angle as high as 10 degrees will produce satisfactory soldering with other designs. The conveyer chassis is usually inclined by means of a lead screw and measured by means of an inclinometer. The intercept angle with the solder wave is critical because that angle determines the extent of breakaway fillet as the solder plane of the electronic module exits the solder wave. The breakaway fillet shape is also dependent on the surface tension of the molten solder, which is directly related to pot temperature.

4.5.2 A double-sided, laminar-flow wave of sufficient width is required to provide adequate contact time between the surfaces to be soldered and the molten solder. The wave should be 3.0 to 4.0 inches (75 to 100 mm) wide to ensure sufficient dwell time. The height of the solder wave is less important than the shape of the wave. The solder side of the electronic module will intercept molten solder for a longer time if the solder wave crest is flat (⊓) rather than sharp (Λ).

4.5.3 The travel speed of the PC board through the molten solder wave should be not less than 10 inches per minute (4.2 mm/s). The time constant of a given segment of the board as it passes through the wave should not exceed 6 seconds per inch (0.25 s/mm). Enough heating time must be allowed to achieve the metallurgical reactions that result in wetting but less than the thermodynamical conditions leading to dewetting. Usually the proper conveyer carriage speed will range from 30 to 90 inch per minute (12.5 to 38 mm/s). The controls should possess 0 to 180 inch per minute (0 to 75 mm/s) capability.

4.5.4 PC boards which have been rejected for defects, such as icicling or bridging, may be resoldered by passing through the wave a second time.

4.6 Post-Solder Cleaning:

Flux residues and other contaminants must be removed immediately, but in no case longer than 30 minutes, after wave soldering. A series of cleaning solvents should be used to remove flux residues, polar contaminants, and nonpolar contaminants. A procedure should be used that incorporates solvents and techniques capable of removing flux residues and contaminants to specified levels of cleanliness.

4.6.1 The recommended cleaning practice for post-solder cleaning is as follows:

a. Remove flux residues such as rosin and organometallic compounds.
b. Remove nonpolar contaminants such as oil, wax, grease, resins, polymerized rosin, and fatty acids.
c. Remove polar and ionic contaminants such as body salts, perspiration, process residues, flux activators, and other ambient contamination.
d. Dry and store in a noncontaminating environment.

4.6.1.1 A proper cleaning, regime is advisable and a recommended sequence follows:

a. Remove oil, oil residues, and flux residues in a rough cleaning step.
b. Remove nonpolar contaminants in a fine cleaning step.
c. Remove polar contaminants in a fine cleaning step.
d. Remove final traces of contamination in a finish cleaning step that includes a drying operation.

4.6.2 Rough Cleaning:

4.6.2.1 Immerse the electronic module in a nonpolar solvent to remove the oil from wave soldering. Mechanical methods such as agitation, directed pressurized stream of solvent, or brushing may be used to apply the solvents. Ultrasonic cleaning may damage certain electronic components and should generally be avoided. Nonpolar solvents recommended for removal of oil are as follows:

a. Halogenated hydrocarbons.
b. Ethers or esters.
c. Ketones or ketone derivatives.
d. Aromatic hydrocarbons.
e. Aliphatic petroleum distillates.
f. Proprietary solvents or solvent blends.

4.6.2.2 Immerse the electronic module in a flux solvent to remove the rosin flux and flux residues from wave soldering. Insoluble flux residues are extremely tenacious and may require additional energy such as brushing, directed pressurized stream of solvent, or agitation to remove from surfaces. Solvents recommended for removal of flux residues are as follows:

a. Hologenated hydrocarbons: 1,1,1 trichloroethane (methyl chloroform); proprietary solvents, and azeotropes.
b. Alcohols, alcohol blends, and alcohol azeotropes (the alcohol-based solvents are preferred for dissolving rosin); isopropanol, ethanol (special denatured 190 to 200 proof).
c. Fluorocarbon-alcohol azeotropes.
d. Fluorocarbon-alcohol azeotrope/alcohol blend.

4.6.3 Fine Cleaning:

4.6.3.1 In the fine cleaning step, removal of both nonpolar and polar residues should be accomplished by hot solvent submersion followed by a directed pressurized stream of fresh or refluxed solvent and then vapor phase condensate bombardment until the vapor ceases to condense on the surface of the PC board.

4.6.3.2 Clean the electronic module in a nonpolar solvent to remove residual nonpolar contaminants using the technique of 4.6.3.1.

4.6.3.2.1 Nonpolar Solvents:

a. Halogenated hydrocarbons: 1,1,1 trichloroethane (methyl chloroform); trichlorobenzene.
b. Ethers and esters: ethyl ether, butyl ether, certain acetates; proprietary formulations such as Cellosolve/Carbitol.
c. Ketones or ketone derivatives: acetone, methyl ethyl ketone, methyl isobutyl ketone, amyl ketone.
d. Aromatics: benzol, xylene.
e. Aliphatic petroleum distillates: mineral spirits, naphtha, n-pentane.

4.6.3.3 Clean the electronic modules in a polar solvent to remove contaminants using the technique of 4.6.3.1.

4.6.3.3.1 Polar Solvents: Alcohol, alcohol blends, alcohol azeotropes: isopropanol, ethanol, fluorocarbon-alcohol azeotrope, fluorocarbon-alcohol azeotrope/alcohol blend.

4.6.3.4 Remove final traces of polar contamination by immersing in hot, deionized, distilled water and dry by subjecting the wet board to vapor phase condensate bombardment from a fluorocarbon liquid source until the vapor ceases to condense on the surface.

4.6.3.4.1 Final Cleaning Water: Deionized, distilled water of 1 μ mho per cm conductivity or less, (1 x 10^6 ohm-cm resistivity or greater).

4.6.3.4.2 Final Drying Agent:

a. Fluorocarbon liquid.
b. Proprietary fluorocarbon liquid.

4.7 Post-Cleaning Tests:

The PC board cleaning process should be monitored on a sampling basis to determine the effectiveness of the post-solder cleaning sequence. Several tests suitable for detection of residual flux residues or residual ionic contamination should be applied to determine the cleaning system and cleaning technique capability. Various levels of residual contamination may be acceptable in accordance with the functional requirements of the circuit being fabricated. These monitoring tests may be used for:

a. Cleaning schedule development.
b. Preproduction process confirmation.
c. Process control.

4.7.1 Ionic Contamination Test: The cleaning procedure should remove all traces of ionic contamination, determined by the following laboratory testing technique:

4.7.1.1 Immerse the sample PC board in sufficient deionized water to submerge the entire board, but which relates the surface area to volume of water (5 mL of water for each cm^2 of board surface).

4.7.1.2 The "as produced, deionized water conductance level must be noted prior to board immersion (less than 1 μ mho/cm conductivity).

4.7.1.3 The conductance of the washing aliquot must be measured by means of a conductivity bridge or other instrument of equivalent range and accuracy.

4.7.1.3.1 NOTE: All laboratory ware must be scrupulously clean.

4.7.1.4 The conductance of the water extract shall be measured as noted by change in conductance. The extractant shall exhibit a change of less than 0.5 µ mho/cm conductivity after stirring for 5 minutes with the sample board submerged. If the ionic contamination exceeds the allowable level, the cleaning procedure must be modified (or the procedure must be repeated) to bring contamination to a value below the above specified allowable limits.

4.7.2 Rosin Based Flux Test: The cleaning procedure should remove all traces of rosin, determined by the following laboratory testing technique:

4.7.2.1 Immerse the sample PC board in warm absolute (190 proof or higher) alcohol for 5 minutes.

4.7.2.2 Evaporate the flux extractant (alcohol) to dryness while keeping the surface area of the liquid as small as practical.

4.7.2.3 Dissolve the residue in a few milliliters of acetic anhydride while warming.

4.7.2.4 Test for the presence of rosin by adding a few drops of 50% sulfuric acid.

4.7.2.5 Formation of a color change indicates the presence of unremoved rosin.

4.7.2.6 The colors may range from yellow to pink to dark red according to increasing concentrations of rosin.

4.7.2.7 When the reagents remain colorless, no rosin is present.

4.7.3 Chloride Ion Test: This test is used to detect the presence of residual chloride ions remaining on the cleaned PC board. Several techniques may be used to detect chlorides. The entire board may be immersed in distilled and demineralized water solvent to extract residual chloride ions. Test the extractant for presence of chloride ions by additions of silver nitrate solution. If chloride ions are present, the extractant aliquot will become cloudy. Store in a light free container for 24 hours prior to this observation. Observe the treated liquid by one of two methods:

a. A light beam - Precipitate will disperse the light or become illuminated.
b. A black spot plate - Place a quantity of the liquid on a black spot plate to observe the white precipitate.

4.7.3.1 The chloride ion test may be used to detect the presence of chloride ions on localized surface areas. A drop of distilled water may be applied to the test spot, allowed to stand for 2 minutes, and removed by means of a capillary pipette. Treat the drop as described above to detect the presence of chlorides.

4.7.4 Humidity Test for Corrosion Potential: See environmental test in 4.10.7.

4.8 Wave Soldering Process Certification:

In addition to continued monitoring of the wave soldering process parameters, it is imperative that the soldering line operators and inspectors be trained adequately and be certified as competent to adjust parameters as required and to produce solder joints in electronic modules to specification requirements.

4.8.1 Soldering line operators should be trained to observe the wave soldering operation, be familiar with the results of wave solder parameter change, and be able to make correctly any necessary changes. Each line operator must be certified to produce soldered hardware to the requirements of the cognizant specification. Certified status may be maintained upon successful completion of annual examinations or by continued satisfactory work in this field.

4.8.2 Soldering line inspectors should be trained to inspect visually the results of the wave soldering process and to determine subtle differences between acceptable and rejectable soldered hardware. Each line inspector must be certified capable to inspect to the requirements of the cognizant specification. Certified status may be maintained upon successful completion of annual examinations or by satisfactory work in this field.

4.8.3 The wave soldering line should be certified as capable of producing soldered hardware to the requirements of the cognizant specification.

4.9 Solderability Acceptance Criteria:

Inspection should be performed on all printed circuit boards to ensure that soldering and cleaning processes continue to perform desired functions within the decreed limitations of the cognizant specification. In addition, materials used both for hardware fabrication and in the wave soldering process require inspection or quality tests.

4.9.1 Each first article component lead material or each batch of components received should be tested for solderability to determine wettability and joint formation capability. Solderability of component leads or other hardware items, such as copper pads and conductor runs, may be tested by one of several available methods. Lead and conductor wire solderability tests may be conducted by means of commercially available solderability testers or by laboratory solder pot immersion.

4.9.2 Commercial solderability testing machines may be designed to measure some soldering parameter such as time to form a wetted fillet or the surface tension forces required to remove wire samples from a molten solder surface.

4.9.2.1 The wetting time test measures the wetting characteristics by recording the least time required to produce perfect, complete solder coverage. Each test sample, after fluxing, is immersed in a solder bath for a period of time. Subsequent samples are immersed for longer time spans until dewetting ceases and a pin-hole-free bright surface is obtained. Nonwetting is characterized by uncoated areas surrounded by ridges or mounds of solder exhibiting high contact angle. Dewetting is characterized by solder coating on the substrate with globules or ridges of solder, exhibiting high contact angle, protruding from the surface. Pinholes are indicative of a marginal solderability condition where a definite tendency for dewetting exists. Inadequate surface preparation or unsolderable substrate condition can be readily detected.

4.9.2.2 The globule method depends upon the use of a volume of molten solder, variable with respect to wire diameter, at 235 °C ± 2 °C (455 °F ± 4 °F) into which a fluxed sample wire is immersed. The time, in hundredths of a second required to wet the sample wire circumferentially, becomes the basis for measurement of solderability. This is the Ball Solderability Number (BSN). If the wetting time exceeds 2 seconds (BSN = 200), the solderability for wave soldering may be unsatisfactory. If BSN = 300 or more, the sample may be considered unsuitable for wave soldering.

4.9.2.3 Solderability testers that use the force between solder and test sample as a measure of solderability are available. The test specimens may be wire component, board sample, or metal strip. The degree of wetting and soldering time may be deduced by analysis of transducer traces.

4.9.3 The solder-dip test satisfies the test requirements by visual examination of the solidified solder on the wire. The integrated surface area wetted and contact angle determination provide indication of the degree of metallurgical bond formed by reaction of the molten solder with substrate surfaces.

4.9.3.1 The dip method for solderability test has been defined by MIL-STD-202, Method 208, where the measure of solderability is surface coverage. A dipped lead showing less than 95% coverage indicates failure to comply with solderability requirements. The line of tangency where solder fillets are formed is examined. A very sharp, acute angle indicates excellent solderability. Rounded, mounded, fillet edges, where the contact angle approaches 90 degrees indicates very poor solderability.

4.10 Wave Solder Process Control:

Continued 100% visual inspection with subjective comments will show incipient solder problems as they arise. Changes in contact angle and dewetting are precursors to full scale failures.

4.10.1 Periodically, at a rate based on PC board production schedules, a sample of the solder should be analyzed for contamination to ensure that the impurity level does not exceed the values shown in 4.1 and that the tin content remains within the specified range.

4.10.2 The specific gravity of the flux solution should be measured periodically and adjusted according to the required density.