Fundamentals of Ultrasonic Soldering

Investigations were made to determine the mechanism of wetting of lap and capillary joints without flux, the effects of soldering variables and the effects of solder properties

BY J. N. ANTONEVICH

ABSTRACT. In the development of fluxless ultrasonic soldering of aluminum, improvement of process reliability was achieved only after considerable study of the basic variables. This paper describes investigations made to determine the parameters that influence the quality of ultrasonically soldered joints and the reliability of ultrasonic soldering processes.

Experimental procedures were developed to study immersion and nonimmersion methods using ultrasound. The results are discussed in terms of the relationships among base materials, solder properties and ultrasound with respect to wettability, capillarity, fluidity and joint integrity.

Introduction

Ultrasonic fluxless soldering appears to have been first conceived in Germany in 1936. The first such soldering iron was patented there in 1939 (Ref. 1). Since then numerous devices have been reinvented with the main purpose of eliminating flux in conventional soldering operations.

The initial successful application of ultrasonic soldering methods to an aluminum bell and tube joint in 1966 was realized when 95Zn-5Al solder was used to presolder parts and the solder reflowed after assembly. Only marginal success was obtained in prior years using Cd/Zn alloys deemed best suited for aluminum at the time. By 1969 sufficient interest was generated to develop a soldering system in which a tube and fin aluminum air conditioning coil assembly could be made using the presolder-reflow method. By 1971 the reflow process proved to be acceptable and the single dip method of producing coil assemblies was promising.

However, the inconsistency of joint quality required investigations into the basic parameters affecting the ultrasonic soldering process. For reasonable success the necessity of degreasing and adequate preheating was quickly determined. Further improvement of joint reliability, from 85% to 99%, required investigation into the more fundamental aspects of making solder joints ultrasonically. Surface tension, fluidity and the effect of ultrasound on these properties of solders were investigated for immersion soldering of surfaces and capillaries. The effect of holding force, ultrasonic motion and exposure time on the quality of nonimmersion soldering methods was also investigated.

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Experimental Procedures

Surface Tension Measurements

To measure surface tension and study the effects of ultrasound on surface tension force, a calibrated cantilever spring was used (Ref. 2). A sample was either suspended from the cantilever by means of a hook or rigidly clamped to the spring. A

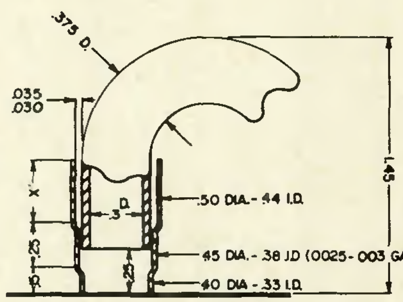

Fig. 1 — Test Joint. Aluminum bell and return bend

capacitance pickup transducer was used to measure the spring deflection. Samples were weighed prior to each test and used as a reference weight for calibrating the spring deflection. The output of the pickup transducer was connected to the y axis of an x-y recorder and the x axis of the recorder to its sweep rate generator. Dynamic surface tension and buoyancy forces were measured by lowering the sample into solder, in an ultrasonic solder pot, at a constant rate of 0.2 in./s to a predetermined depth of 1/2 in. The effect of ultrasound was noted by exciting the solder pot after a brief dwell time of the sample in the pot.

For lead-tin solder studies a 4 × 9 × 2 in. deep ultrasonic soldering pot was used to insonate the solder and maintain solder temperature. For zinc-aluminum solder studies an 8 × 33 × 4 in. deep pot was used. Surface tension and buoyancy forces of zinc solders were obtained by using a 316 stainless steel sample 0.375 × 0.06 × 5 in. long, thinly coated with a chalk powder. The coating eliminated the tendency of solder to wet the sample. The denser sheet sample reduced tilting due to buoyancy experienced with aluminum samples. Reproducibility of results was good. The sample was lowered into solder slowly to get peak force, then allowed to dwell to reach a lower equilibrium force. The sample was then raised until surface stresses and meniscus were zero by visual observations and force differences due to surface tension were noted.

Immersion Soldering Procedure

Capillary and wetting data were obtained using the above mechanical system to lower rigidly attached samples into the solder. Flat samples of 3003 aluminum 0.375 × 0.063 × 5 in. long (9.5 × 1.6 × 127 mm) were used for studying ultrasonic effects on surface tension force of zinc solder. Aluminum tubing 3/8 in. OD × 0.325 in. ID (9.5 OD × 8.3 mm ID) were used for capillary and wetting studies of zinc solder. To obtain a variety of capillary sizes, the 1200 series aluminum tubing was flattened with shims inserted into the tubes. Samples used in lead-tin solder studies were copper sheets 2 × 2 × 0.006 in. (50 × 50 × .5 mm) or 1/2 in. (12.7 mm) tubes. All samples were precleaned in an ultrasonic vapor degreaser using a fluorinated hydrocarbon.

Sample 3/8 in. (9.5 mm) tube and fin coils used in this investigation were made of 1200 aluminum. The bell and return bend joints of the coils were as shown in Fig. 1. Except as noted, coils were precleaned in an ultrasonic vapor degreaser. All joints were preheated manually with a torch to about 900 F then immersed into the solder pot to a given depth for 3 s before ultrasound was applied. All coils had 18 joints. Each joint was cut after soldering and the depth of solder penetration and alloying was measured and averaged for the coil.

Vibration Soldering Procedure

To determine effects of ultrasonic power, time, and holding force on the quality of a tube and bell joint made without a solder pot, sample coils as above were also used. The return bends, however, were precoated with solder and made without dimples. The experimental arrangement consisted of a clamp to hold the coil rigid, an acetylene torch directed at the joint, a thermocouple on the far side of the joint with respect to the area heated by the torch, and an ultrasonic transducer mounted on bearings which was forced with its contoured probe into the area heated with a force calibrated air cylinder.

The procedure used was to drive the return bend into the bell for positive seating in the bell with a rubber mallet and to preheat the joint to 900 F. At this temperature, the flame was then modulated to maintain the temperature constant. A 1/8 in. (3.18 mm) diam 95/5, Zn/Al, solder wire was force fed manually into the joint until a puddle of solder built up about the joint periphery. Then a control circuit was excited and went through the sequence of reducing gas supply to the torch and driving the transducer's contoured solder probe into the bell wall. On contact the ultrasonic generator turned on at a preset power level and for a predetermined time. When the time had elapsed, the ultrasound turned off and the transducer withdrew. The joints were cut and measurements made of the area and depth of the joint that had been wetted and alloyed with solder.

Experimental Results

Surface Tension

Figure 2 shows a typical curve trace obtained with the force measuring arrangement when a sample of 3003 aluminum 0.375 × 0.063 × 5 in. (9.5 × 1.6 × 127 mm) long is lowered into a solder pot at a constant rate, held for a given time and then insonated. The initial rapid increase in negative force is due primarily to surface tension. The second lower rate is due solely to solder displacement. If the displacement force line is drawn to intersect the y axis, the point of intersection should give the surface tension force acting on the sample. The section of the curve with no slope is the dwell time. A sudden change in force is observed when the ultrasound is turned on.

The enlarged trace of a curve in Fig. 3 shows the variation of force with time while ultrasound is applied. Correcting the curve trace for weight loss and buoyancy loss due to cavitation, it is noted that the surface tension force had been reduced to 14% of its normal value within 2.5 seconds and remained constant. Variations in power level, from cavitation threshold to full power rating of the systems, showed little or no change in minimum ultimate surface tension. Full soldering of samples was noted in less than 1/3 second, the low limit of the timing circuit used.

Figure 4 shows similar curve traces using a 2 × 2 × 0.006 in. (50 × 50 × .15 mm) copper sample immersed into 60Sn-40Pb solder at 400 F. Although the density of the sample and solder are near equal, there is a negative (buoyancy) force of appreciable magnitude ascribed to minute bubble formations uniformly distributed over the surface of the immersed sample. Reduction of forces due to ultrasonic intensity appears to be maximum between 75 and 150 watts input to the

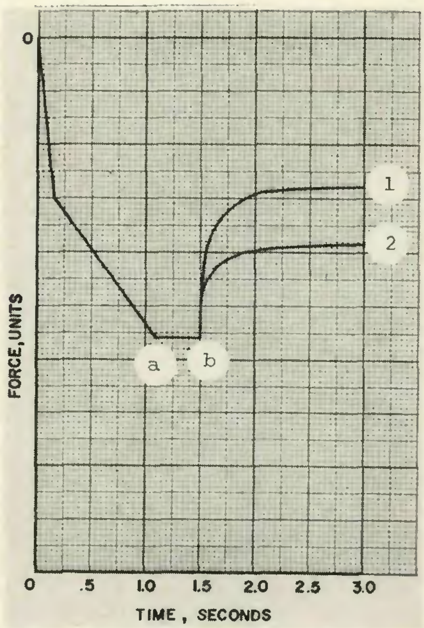

Fig. 2 — Relationship between force acting on aluminum sheet immersed into 95Zn-5Al solder and time. (a) Time to immerse sheet, (b) time ultrasound applied. (1) Time ultrasound off for degreased sheet, (2) time ultrasound off for uncleaned sheet

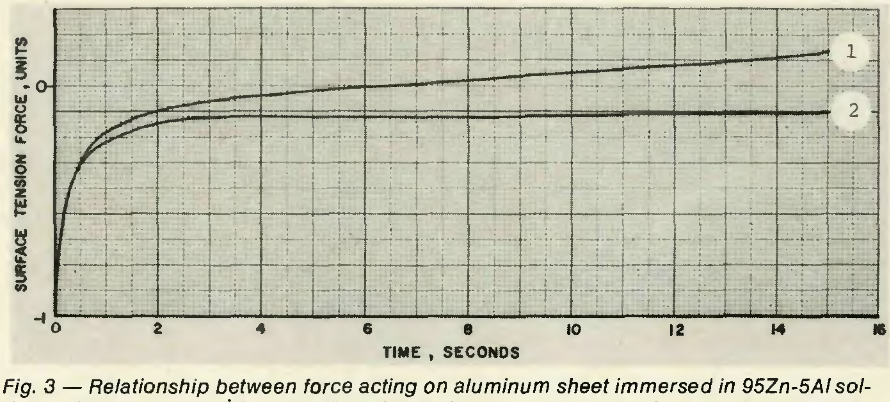

Fig. 3 — Relationship between force acting on aluminum sheet immersed in 95Zn-5Al solder and ultrasound on time. (1) Experimental curve trace, (2) surface tension force

solder system. Higher or lower power levels appear to be less effective.

The bubble formations on the sample do not appear to be dislodged by the ultrasound. On removing the samples from the pot, they are found to be wetted with solder except at bubble sites. Similar observations are noted on samples immersed with ultrasound applied continuously during and after immersion. However, samples dipped the second, third or fourth time, with ultrasonics continuously applied do not have the unwetted circular islands. (Samples coated with an active flux, but no ultrasound, required about the same time as those with ultrasound to reach equilibrium.) If it is assumed buoyancy forces were not removed by ultrasound then the surface tension forces had dropped to zero. This appears to be the case since the meniscus of the solder after ultrasound is barely discernable at the sample solder interface.

As shown in Fig. 5 the measured surface tension of zinc solders varying from 1.5 to 7% aluminum content were near constant at 0.96 gf/cm. A 95/5 solder with 0.002% beryllium had a surface tension of 1.05 gf/cm. Curve traces of forces acting during immersion of samples, were relatively smooth. However, all curves obtained using pure zinc were quite erratic once the sample broke through the solder, indicating a wet-flow process. Superposed on the normal curve were appreciable sinusoidal force variations. Observing the samples while being immersed into zinc, revealed a periodic build-up and release of surface stress on the solder surface as the sample jerked through the solder, coincident with recorded force variations. Peak to peak values of these forces were between 10 to 50% the surface tension force. Aluminum-containing solders had less than 7% peak to peak deviation about the portion of the force curve ascribed to buoyancy.

Viscosity measurements of the various alloy compositions were made by timing the flow of the alloys through a 0.150 in. (3.8 mm) hole in the bottom of a 3 by 1.875 in. (76.2 by 47.6 mm) diameter stainless steel cup coated with a chalk powder. Flow time for zinc was 23 s, for aluminum compositions 21 ± 0.5 s. A 95/5 solder with 0.002% beryllium had a flow time of 23 s.

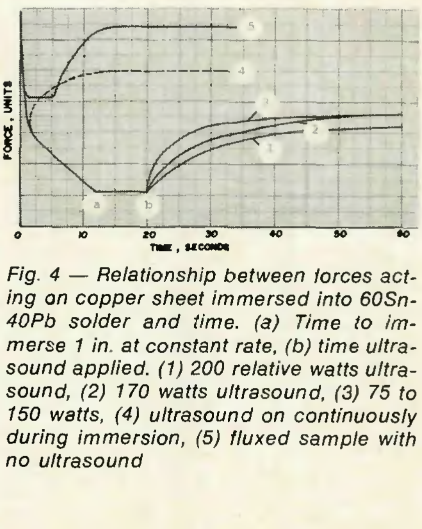

Fig. 4 — Relationship between forces acting on copper sheet immersed into 60Sn-40Pb solder and time. (a) Time to immerse 1 in. at constant rate, (b) time ultrasound applied. (1) 200 relative watts ultrasound, (2) 170 watts ultrasound, (3) 75 to 150 watts, (4) ultrasound on continuously during immersion, (5) fluxed sample with no ultrasound

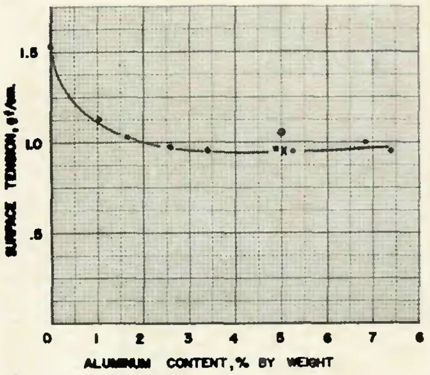

Fig. 5 — Relationship between surface tension and aluminum content of zinc solder. 'X' point determined from head in 0.325 in. diam tube. 'O' point measured for solder containing 0.002% Be

Immersion Soldering

Figure 6 shows the effect of ultrasound on wetting tubes dipped vertically to various depths in the solder pot. Without ultrasound a negative head of between 0.25 and 0.3 in. (6.35 and 7.62 mm) was developed in the 3/8 in. (9.53 mm) aluminum tubes having a 0.325 in. (8.23 mm) inside diameter. Tubes immersed the full solder depth of 3.25 in. (82.55 mm) and ultrasonically activated for 5 s, after a 25 s dwell, gave a maximum positive head of 0.08 in. (2 mm). Near maximum positive head is achieved at a 2 in. (50.8 mm) immersion which is one half wave length of sound in the solder. However, it is noted that no alloying or metallurgical bonding occurred between the solder and inside diameter of tube above the normal liquid level. This would indicate that forces other than surface tension caused the positive head. Tubes flattened to have a 0.017 in. (0.43 mm) gap had similar characteristics with the alloyed line below the solder level.

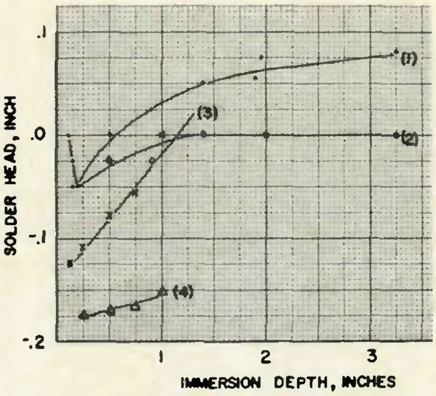

Fig. 6 — Relationship between head of solder and immersion depth after 5 s ultrasonic exposure. (1) Head in 0.325 in diam tube, (2) head above alloyed length of tube. (3) head in flat tube with 0.017 in. gap, (4) head above alloyed length of tube

Figure 7 shows the results of immersing flat tubes of various gap dimensions into a solder pot with and without ultrasound applied. They were immersed to a depth of 2.5 in. (63.5 mm). There is an indication that a 0.030 in. (0.762 mm) gap is optimal for solder flow under excitation. All gaps filled to zero or positive heads, indicating forces other than surface tension were acting when ultrasound power was applied.

Due to the difficulty of observing capillary effects at solder temperatures, a simple experiment using water and a glass capillary tube was conducted. The tube was slowly lowered vertically into a standing wave pattern within the water and the water head developed in the capillary was measured. A head 5 times that due to normal surface tension was approached sharply as the tube went through pressure antinodes where cavitation is visibly observed. The positive solder head in nonwetted capillaries is ascribed to cavitation at the end of the capillary also.

Figure 8 shows the relationship between percent of joint alloyed and gap between a single return bend and two bell joints where length of joints were 0.4 in. (10.16 mm). Minimal gap for maximum penetration is indicated to be 0.030 in. (0.762 mm). Figure 9 shows the results obtained for a group of coils. Each pair of points represents the average values for a coil. Figure 10 shows the relationship between joint made and exposure time at 1 kW relative power. With exposures in excess of 4 s two or more return bends of the coils made were eroded through.

The effect of power on penetration and alloying is shown in Figure 11. Increasing power beyond a given level appears to reduce joint penetration and increase erosion of return bends. With inadequate preheat or degreasing, erratic joint qualities were observed. Both conditions allow full penetration but seldom wetting or alloying within the joint. Random bells on a coil were purposely coated with an oil/solvent film or coated lightly with chalk powder before preheating. The degree of bell wetting with solder was dependent upon the amount of residue on the outside diameter of the bell. Seldom was a joint made. When joints were not adequately preheated to between 840 and 940 F before transport into the solder pot they would not make. On occasion they would externally wet and be filled with solder. These occasional joints usually passed a 550 psi air leak test but gradually open under repeated thermal or mechanical stress.

Immersion tinning of copper tubes in Pb-Sn solder indicated that increased solder temperatures reduced the efficiency of ultrasonic soldering due to rapid oxidation of the copper surface.

Coating materials with solders that do not metallurgically bond to the material surface was done by immersion soldering. Carbon rods, glass, ceramic, oxidized nickel, and generally any smooth inert surface were coated with zinc solders. For over 20 years indium solder coats have been applied ultrasonically to ceramic substrates to provide terminals for film deposits on the substrates. The success of ultrasonic coating as in soldering is ascribed to the intense shock waves generated by cavitation driving molten metal into intimate contact with base material. Intimate contact and filling all surface irregularities brings into play strong adhesive forces to make bonded coatings durable for product applications.

Vibration Soldering

Figure 12 shows the relationships between extent of test joint alloying and ultrasonic power at various holding forces using a probe to make joints. The joints used were those of Fig. 1 except the return bends were pretinned and force assembled without projections to make the total joint length (X+0.25 in.) equal to 0.6 in. (15.24 mm). The effective joint length is considered to be 0.35 in. (8.89 mm) long.

Attempts to make joints using a 10 lb (4.536 kg) holding force were difficult. A resonance or optimum condition was noted when using this force at 60 relative watts of power input. Almost no joints with complete peripheral soldering were noted at 20 watts input. Between 30 and 50 watts input the chance of full peripheral soldering was about 50% when holding forces of 2.5 lb (1.134 kg) and 10 lb were used. At these power levels, 5 lb (2.268 kg) holding forces always produced full peripheral soldering of joints.

Experimentation using various times of ultrasound application indicated that at times greater than 3 s and 80 watts relative input, damage is done to the bell either by full alloying of the bell wall adjacent to the soldering probe or by mechanical fatigue of solder or bell. In addition, low holding forces resulted in atomization or expulsion of oxidized solder from the joint. Three seconds appeared to be the limit for the solder to remain in the molten state. Equivalent joints were made with the ultrasound on for 1, 2, or 3 s, indicating that flow and alloying in joints occurs in less than 1 s, as in the case of immersion soldering of joints.

Heating the entire periphery of the bell (as opposed to the procedure used in obtaining these data) up to a temperature causing an orange plasma type halo to form at the bell joint, allows full penetration and alloying of the joint at lower holding forces or power level. Excessive power or exposure time will generally result in solder flow through at the seat of the bell and bend. If the bell was coated with zinc, the halo effect was difficult to detect.

Immersion coating of copper tubes with zinc base solders was effective as in coating aluminum. Pot preheat as opposed to torch preheat was necessary to reduce copper oxide formation. For transition joints between pretinned copper and aluminum tubes, simply forcing one into the other and reflowing the solder under a twisting or force fit action or ultrasonic vibrations produced reliable joints. Reflow without friction fit or ultrasonic vibrations generally produces a joint with a heavy intermetalic layer that fractured and caused a leaky joint. Friction fit or ultrasound appeared to reduce the thickness of the intermetalic layer and increased its mechanical strength.

Lap joints between flat surfaces of aluminum were readily made by pretinning with zinc base solders and using simple sliding motions or ultrasonic motions while heat was applied to the joint. Attempts at lap joining sheets of aluminum by preheating and feeding solder with ultrasound applied to the plates were futile unless a gap of 0.032 in. (.813 mm) was maintained to allow force feeding of solder into the gap. Flat preforms of solder sandwiched between plates

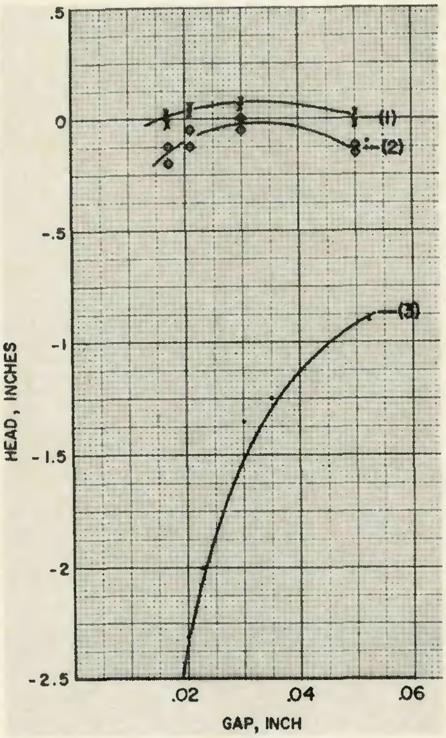

Fig. 7 — Relationship between head and gap in flat tubes with and without 5 s ultrasound. (1) Head after ultrasound, (2) head above alloyed length of tube, (3) head without ultrasound calculated

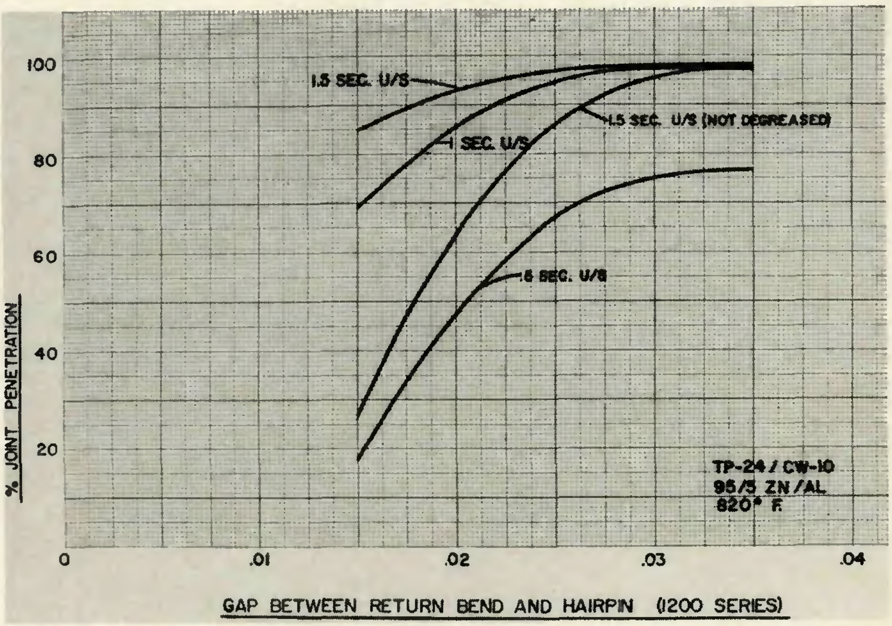

Fig. 8 — Relationship between solder penetration and gap of test joint

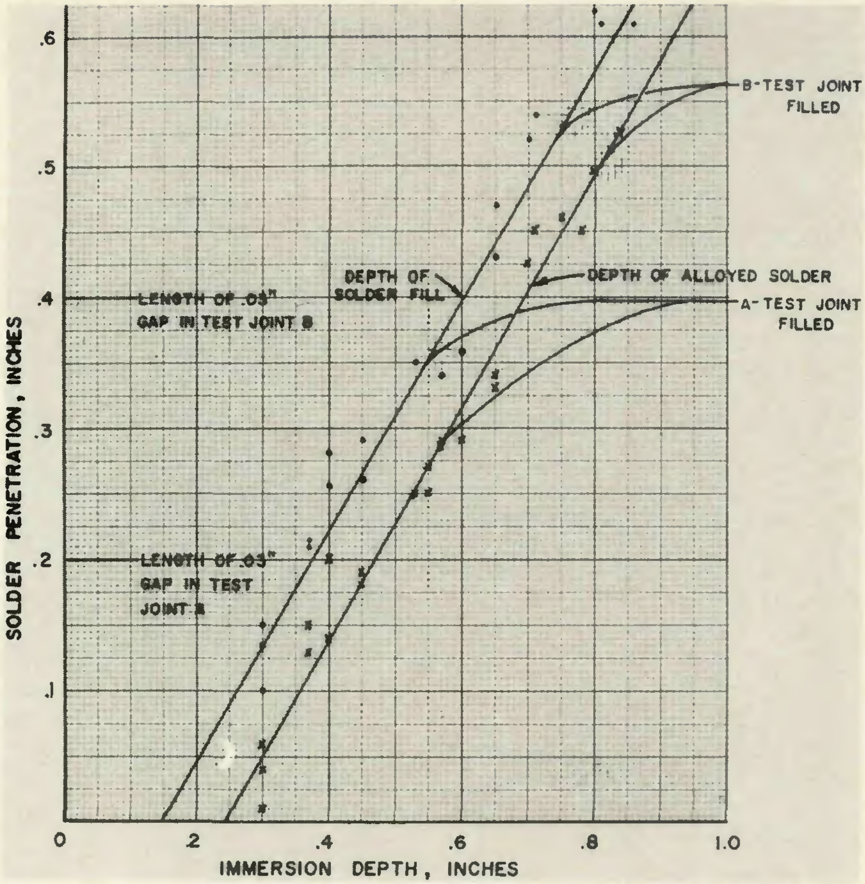

Fig. 9 — Relationship between solder penetration and immersion depth of test joints in ultrasonic solder pot at constant power and time

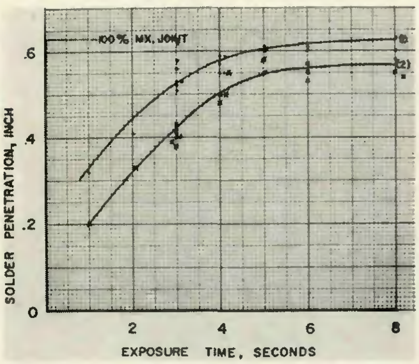

Fig. 10 — Relationship between solder penetration into test coil joints and ultrasonic exposure time. (1) Solder penetration, (2) alloyed length of joints

were joined with reasonable success but the entire surface of the lap joint had to be scanned with a flat soldering tip of an ultrasonic device.

In general, alloying occured only at areas directly under the solder tip. It was also found necessary to clamp the lapping members, since the reduced friction between surfaces and solder form caused members to slip out of position with little or no force. With solder tips covering the entire area to be lap joined a roughened tip was necessary. If manually applied during soldering the tip inevitably skidded off the joint area. Excessive clamping force applied with the tip tended to reduce soldering reliability, indicating relative motion between laping surfaces was essential to the process.

Experiments were conducted with hand held ultrasonic soldering irons. In all instances where the soldering iron tip was well wetted with solder and in contact with a solder puddle and surface at the melting temperature of the solder, coating of the surface occurred. With the tip in contact with the solder but not the surface, the result was local wetting or atomization of the solder from the surface.

Figure 13 shows the relationship between minimum displacement of a solder tip vibrating at 40 kHz and temperature to wet a copper surface with 60Pb-40Sn solder. A hot plate was used to heat sample sheets. At high temperature, soldering was improved but oxidation of the surface was high. Using 20 kHz vibrations no minimum displacement was determined due to instant atomization before onset of wetting. Working with zinc base solders and aluminum, surface wetting occurred instantly at much lower ultrasonic amplitudes.

Excessive time or power level led to thorough alloying of the solder and aluminum with atomization at extreme amplitudes. Patching of holes or cracks in aluminum was readily accomplished by either immersion soldering or with a soldering tip. In both cases, time, temperature, and/or intensity control was necessary to avoid solder flow through the flaw.

Discussion and Application

The Zn/Al solder alloys having from 2 to 7% by weight of aluminum were found to have near similar negative surface tension characteristics and surface tension values between 0.95 and 1 gram force per centimeter. Alloys with lower aluminum content, increase to a value of 1.5 gram force for pure zinc. A 0.001% addition of beryllium to 95Zn-5Al increased the surface tension 5%. A 0.003% additive increased the surface tension 10%.

Although a crude arrangement was used to compare fluidity of various alloys, indications were definite. Between 1 and 6% aluminum content, fluidity was constant with a possible 2% lower fluidity between 3 and 4% aluminum content and at 7 and 7.5% aluminum content. Pure zinc and 95Zn-5Al with 0.003% Be added were 10% lower in fluidity than 95Zn-5Al. The near equivalence between alloys in surface tension and fluidity in the 2 to 6% aluminum alloys should and generally do produce equivalent fill and wet characteristics in capillary joints made by dip soldering.

Low aluminum content solders readily make joints but are aggressive in their dissolution of aluminum joint material. High aluminum content solders tend to produce high shrink stresses or voids in joints. The higher surface tensions and lower fluidity of solders containing beryllium may account for higher solder dragout, reduced webbing and rounded rather than sharp icicles when immersed joints are withdrawn from solders containing beryllium.

Soldering of sheets or plates partially submerged indicates that ultrasonic agitation of the solder can reduce surface tension forces by 90%, approaching 100% when wetting occurs. Similar results can be obtained by submerging aluminum samples and slowly withdrawing them. The meniscus observed on withdrawal becomes zero. Without ultrasound the apparent meniscus between 3003 aluminum and zinc solders is between 0.15 and 0.25 in. (3.8 and 6.5 mm). After ultrasonics it is less than half the value. With 1200 aluminum the meniscus is near zero after ultrasound.

The difference between alloys is

ascribed to the surface layer difference between them or their solderability. The action of ultrasound may be to effectively raise and lower the solder at the aluminum-solder contact line through surface waves or pressure waves, thus changing the contact angle and surface tension force until acting forces reach equilibrium.

In addition, surfaces in contact with solder are acted upon by cavitation shock waves which erode the surfaces leading to wetting and alloying. Wetting below the solder level also changes the effective contact angle between the solder and aluminum. Combining ultrasonic surface perturbation and contact effects, the process could be considered as a cyclic incremental wetting and flowing of solder until equilibrium of all forces is reached.

With heavily oxidized surfaces, ultrasound had minor effects on meniscus or surface tension forces. After prolonged ultrasound, minute sites of oxide erosion and pin-point wetting were noted on surfaces submerged. On lightly oxidized surfaces of plates this appearance was noted just below the solder aluminum contact line roughly to the solder contact line or meniscus before ultrasound was applied.

Etching aluminum before soldering with zinc alloys results in full alloying up to about 0.25 in. below the liquid surface. In the 0.25 in. length the number of minute sites of alloyed points progressively diminish to zero at the solder level.

When making capillary joints by immersion, the solder filling the capillary has a length of solder which does not wet the capillary wall, a lower length of pinpoints of alloyed material, and then the fully alloyed length. This would indicate that cavitation is the prime cause of oxide removal and wetting. As the number of cavitation sites become fewer near the free solder surface, so does the extent of oxide removal and alloying. Ultrasonic surface waves or perturbations cause rapid fill of capillaries, and cavitation implosions generate shock waves that tear oxide layers from surfaces.

When capillary joints are coated or heavily oxidized on the outside diameter to inhibit wetting by solder, ultrasound will cause solder to fill the partially submerged capillary, but no alloying will usually occur. If capillaries are positioned to have their bottom end in the intense cavitation field, positive heads of solder can be developed in the capillary. This is ascribed to volume changes associated with cavity formation, radiation pressure of the sound field and the high velocity flow of solder at the capillary when cavities implode or pulsate in resonance. Normally the positive solder head does not wet or alloy the capillary. If the capillary participates in the ultrasonic vibrations or is large enough in diameter to allow solder to follow pressure variations in the solder pot, cavitation could occur in the capillary leading to oxide removal and alloying.

Only on rare occasions are aluminum solder joints or coated surfaces found to have unwetted islands as noted in soldering copper with lead-tin solders. These unwetted surfaces are ascribed to gas bubbles which can often be seen on withdrawal of samples from an ultrasonic pot. Since all bubbles appeared to be of similar dimension and rather uniformly distributed it is believed the gases were occluded in the surface of the sheets and on exposure to ultrasonic pressure variations grew to a stable resonant size, through the process of rectified diffusion. The amplitude of the sound pressure was inadequate to dislodge the bubbles and they remained pinned by surface tension at their periphery where the sample was wetted. The cushioning effect of the bubble was sufficient to attenuate cavitation shock waves keeping the gas pockets intact.

If the samples were immersed into the solder while the ultrasound was on, the extent of bubble formation diminished since much of the gas is expelled as solder tries to fill surface depressions prior to submergance. The problem of immersion soldering with lead-tin solders is ascribed primarily to the high power levels required to cavitate them. Using water as a reference whose cavitation threshold ranges from 0.1 to 1 watt per square centimeter, the calculated threshold for zinc is 1.5 times that of water, for lead 10 times and tin 20 times.

As power input to solder, or any liquid, increases much above the threshold, the cavitation cloud attenuates energy flow leading to a saturation effect. When attempts to increase power are made, as the data

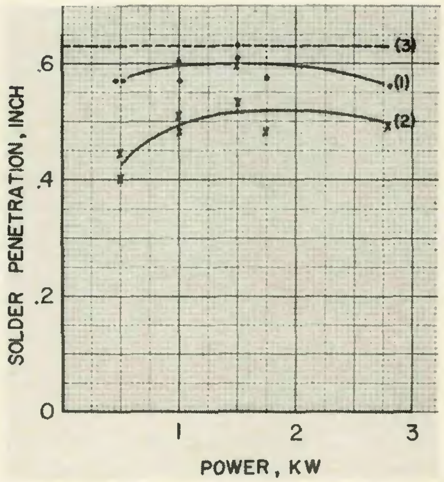

Fig. 11 — Relationship between solder penetration into test coil joints and relative ultrasonic power. (1) Depth of penetration, (2) alloyed length of joint, (3) 100% joint

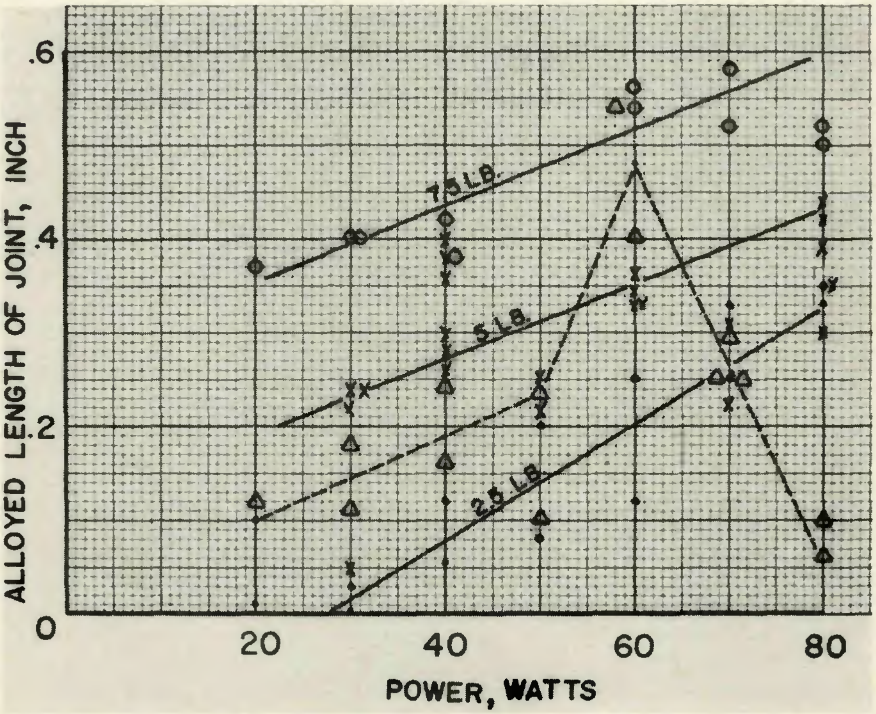

Fig. 12 — Relationship between alloyed length of joint and relative ultrasonic power at various holding forces

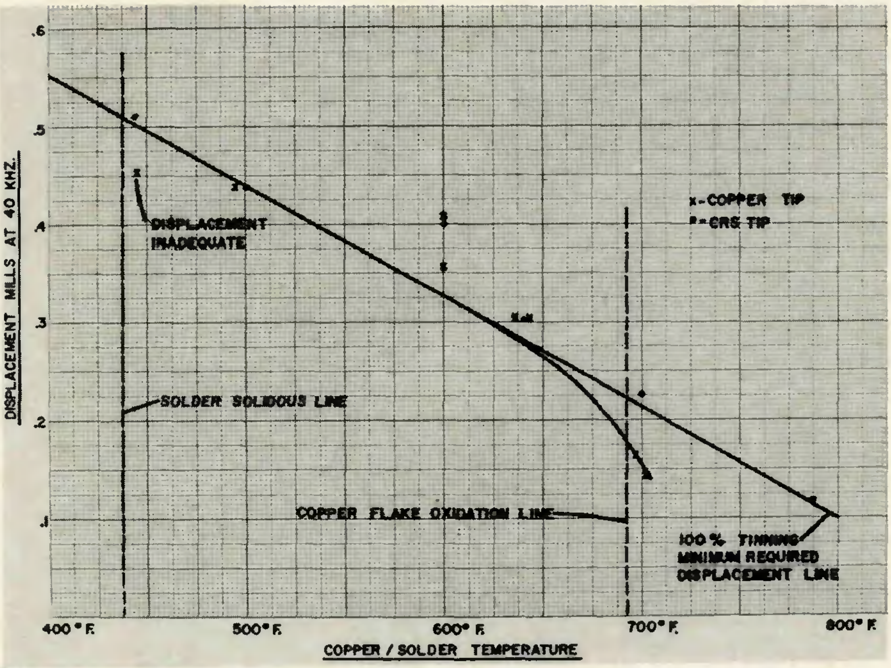

Fig. 13 — Relationship between minimum ultrasonic displacement and temperature to solder copper

shows, a reduction of through power occurs due to reflection by the vapor cloud. This usually occurs when sound fields collapse and the cavitation cloud covers the source of ultrasound. For lead-tin soldering, shallow solder pots or close proximity transducers are most effective, particularly for relatively heavy oxidized or soiled surfaces.

Immersion soldering of capillary joints requires that due consideration be given to joint configuration. Joint gaps greater than 0.030 in. (.76 mm) for aluminum are satisfactory for good rapid filling with zinc solders in ultrasonic solder baths. The largest gap size is limited by the solder used and by the head of solder its surface tension can sustain without the solder flowing out of the joint, when the joint is taken out of the pot. If the joint is of the bell and tube type used in air condition coils, it may require a very narrow gap in addition to the joint gap to allow gas pressure relief during soldering and insure against solder overflowing the joint.

There is a limit to the head that even a crack in a bell, for example, will withstand before solder will flow through under the influence of ultrasound. As the straight line relationships between solder penetration, alloying and head on the test joint show, joint designs should allow for adequate head development when the joint is immersed to give sufficient length of alloyed surface for strength, and sufficient length of pressure relief gap to insure against overfill of the capillary joint. For an 0.03 and 0.003 in. (0.762 and 0.076 mm) gap combination, an immersion head of about 0.25 in. (6.35 mm) will produce alloying over the entire length of the joint.

In general, the normally unalloyed length of head in capillaries is often reduced or eliminated when ultrasound is applied, due to relative motion between members making the capillary. Under ultrasonic excitation, as in the case of the return bend and bell joint, members are periodically freed of each other and held together by the surface tension and buoyancy forces during ultrasonic excitation. This freedom allows abrasion of contacting surfaces for instant solder alloying and progressive undercutting of adjacent oxide films.

To increase joint reliability by minimizing chances of occluded gas bubbles due to decomposing soils at elevated temperatures a preclean step such as degreasing or chemical etch should be considered.

Preheat of aluminum alloys is mandatory to bring about alloying. Many times preheating accomplishes the cleaning or surface preparation of the joint. The halo effect observed when heating most aluminum alloys at 900 to 940 F may be due to oxides or soils being dislodged by the flame of the heating torch. Copper, brass and other alloys which rapidly oxidize in air should be preheated in the solder bath or an inert atmosphere.

If the parts to be joined are excessively oxidized, it is better to remove the oxide chemically or mechanically than to rely on increased exposure time or intensity of the sound field. If the sound field does not attack the heavy oxide layer uniformly, severe erosion or pitting can occur at surfaces in the more intense sound zones. Normally, parts need only be flushed or rinsed In a solvent. Capillary or intricate joints may require an ultrasonic wash and vapor rinse in a solvent.

Excessive time or intensity of sound applications usually results in a pitting phenomenon. This is due to the generations of sites on surfaces where nucleation is profuse and a local stable cavitational sphere of influence takes place. These spherical zones of influence produce high velocity microstreaming, dissolving the surface rapidly at the sites (Ref. 3).

Using hand held ultrasonic devices, the prerequlsites of preheat and surface preparation, as for immersion soldering, are usually required or preferred. When soldering accessible surfaces the soldering device can be designed to preheat or prepare surfaces prior to or during ultrasonic excitation. An ultrasonic soldering iron for example could have a heated tip and the tip constructed to scratch or upset oxide on areas to be wetted.

In hand soldering, as in immersion soldering, cavitation must occur in the solder puddle to either remove a tenacious oxide film or drive solder into intimate contact with the surface for good adherence. Intensity levels are generally limited to the onset of solder atomization. If the atomization threshold is lower than the cavitation threshold of the solder in a given soldering arrangement, ultrasonics cannot be used. This condition is seldom encountered if the soldering iron tip is well wetted and in the solder puddle.

For lap joints where the soldering iron is not in contact with the solder but with a laping member, excessive ultrasonic motion between members will pump out and atomize molten solder from between the lapping members. A 30 mil (0.76 mm) gap in the lap joint can avold this problem. In all hand soldering the parts to be joined should be fixtured or held in place before applying ultrasound or they will move out of position. Friction forces, which normally hold parts together, diminish to near zero on the application of ultrasound.

In the case of making or repairing bell and tube joints with an ultrasonic soldering device, ways and means of containing the solder in the joint before and during soldering is necessary. The usual positive surface tension forces in sweat soldering with flux are not present. Solder will flow due to ultrasound or gravity forces without wetting.

Where joints can be positioned vertically the bell and cup must seat positively or solder will flow through when ultrasound is applied. For horizontally positioned joints, a dam must be built about the joint opening or a clamp designed to restrain solder as if the joint were a mold and the clamp a part of the mold. Such joints are best made when one or both members are pretinned before force driving one into the other.

When mechanically assembled, either vertically or with a gate arrangement, the joint is preheated until a wire of solder will melt on contact. Then the solder is force fed aggressively into the joint directly or through a gate until it fills. Once filled the heat can be removed, the ultrasonic soldering device applied under a force to the periphery of the bell and excited for a second or two. With one part pretinned, concern over the oxide film on the solder wire is minimal but where the parts as well as the wire have a film of oxide, extra effort must be made to aggressively force the wire into the joint, so as to abrade the joint surface and break up the oxide layer on the wire.

Good practice is to abrade the solder wire and surfaces to be wetted before soldering. The reason for concern is that a barrier of oxide between bell and solder could be heavy enough to act in decoupling the molten solder from the vibrating bell. Without coupling caviation will not occur. The limited friction forces generated would not be adequate to initiate intimacy and alloying between solder and part. It is obvious that if both parts are adequately pretinned and properly designed so that the solder will fill the lapping space on reflow of the solder, the joint can be made by simply preheating and force fitting without ultrasound. Ultrasonic energy superposed on this method of joint making would assure break up of the oxide of the mating surface and improve joint strength (Ref. 4).

An alternate procedure for bell and tube joints is to use tapered preformed shims as in making lap joint described earlier. Forced wedging of the preform between bell and tube will fracture oxide layers. The fractured zones will allow coupling of ultrasound to the solder after it is heated to soldering temperature.

Fluxless ultrasonic soldering of joints is essentially ascribed to cavitation erosion of nonwettable surfaces of a solderable material while enveloped in solder. The flow of solder in ultrasonic soldering processes is ascribed to crispations or surface waves which alter the contact angle between solder and a surface tending to reduce effective surface tension forces. Ultrasonic radiation pressure and alternate pressure variations also contribute to force driving solder into capillaries or joints where cavitation can come into play and cause wetting. Where soldering is accomplished without cavitation the process is a result of friction abrasion between surfaces separated by a solder film. The later might be considered a friction soldering process and not an ultrasonic soldering process per se.

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