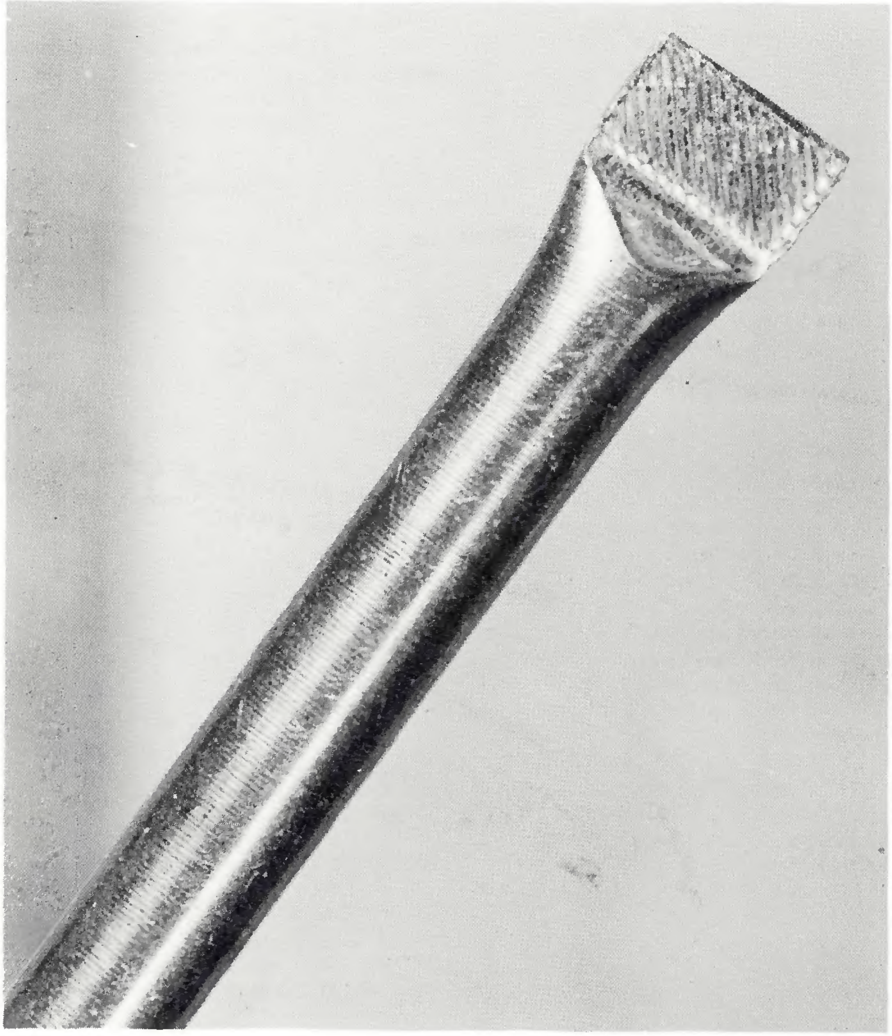
Ultrasonic Closure Welding of Small Aluminum Tubes

A two-step procedure is developed which produces welds with leak rates less than $1x10^{-6}$ std cc/sec

BY C. L. ESTES AND P. W. TURNER

ABSTRACT. Ultrasonic welding was utilized for making hermetic closures in Type 1100 aluminum alloy tubes. A two-step procedure comprised of a cold crimp and a welding cycle was developed. Welding tooling consisted of both a serrated tip to impart vibratory energy efficiently to the interface of the collapsed tube, and a slotted anvil to limit the geometry of the weld and to constrain lateral flow. Welding tip life without a second dressing was 250 welds per tip for tips heat treated to an optimum hardness of 60 to 62 Rc. It was typical to find cracking of tips of high hardness, and excessive wear of tips of low hardness.

Welded tubes were evaluated by measuring the helium leak rates with a mass spectrometer, by thermal cycling, and by metallography. Leak rates were less than 1×10^{-6} std cc/sec. Metallography indicated that welds contained local regions of dispersed surface films. Results indicated that leak-tight welds can be made without precleaning either the tube exterior or the tube bore, provided wide variations in the hardness and geometry of tubes are avoided.



Ultrasonic crimp weld in a type 1100-H14 aluminum tube (leak rate less than 1.0×10^{-9} std cc/sec of helium)

Introduction

Many joining processes are being used to hermetically seal small containers and to close the ends of small tubes attached to vessels. This article describes work performed to determine the optimum joining process, tooling, and parameters for producing closure welds on Type 1199-0, 1100-0, and 1100-H14 aluminum alloy tubes with a 130 mil mean bore diameter and a 182 mil mean outside diameter. Design requirements were as follows:

1. The mass spectrometer integrated leak rate of the tube and container must not exceed 1.0×10^{-6} std cc/sec for helium.
2. The closure procedure must be applicable to systems containing different internal pressures ranging from partial vacua to positive pressures at room temperature.
3. The ambient air must be occluded from the system during and after welding.
4. The welding process must be relatively insensitive to normal oxidation of the tube bore.

C. L. ESTES and P. W. TURNER are with the Y-12 Plant, Nuclear Division, Union Carbide Corp., Oak Ridge, Tenn.

Based on a paper presented at the AWS National Fall Meeting held in Baltimore, Md., during October 5-8, 1970.

5. Length of the tube after closure and trimming must not exceed 525 mils to provide for packing clearance and to prevent damage. The trimmed tube must not be sharp or otherwise pose safety hazards to personnel during handling.

6. Welding parameters should be amenable to control under manufacturing conditions and should assure an acceptance quality level of 97%.

7. Leak rate and integrity of the closure should not be degraded by cyclic temperatures ranging from −65 to +165 F.

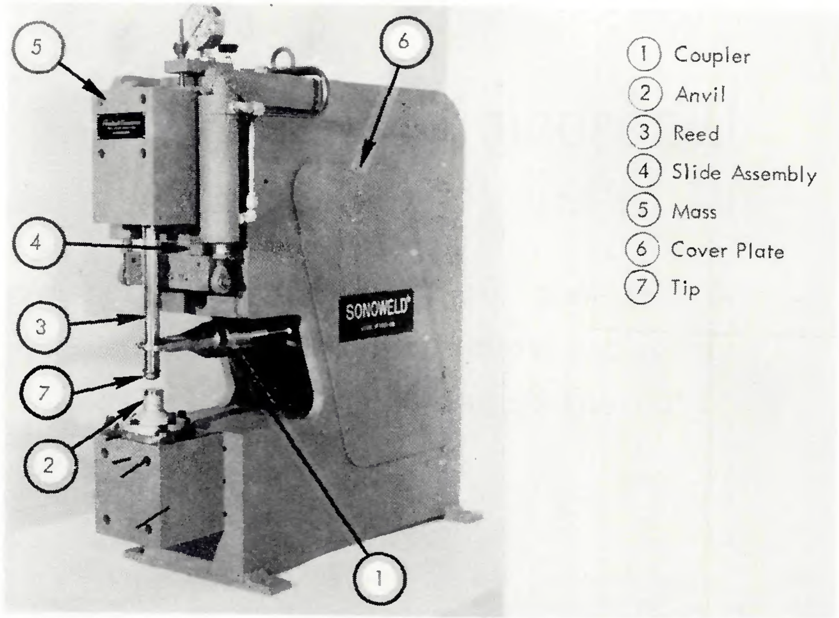


Fig. 1 — Commercial ultrasonic spot welding machine equipped with a conventional tip and anvil

Process Selection

Electron beam welding is often used to close containers when a relatively hard vacuum seal is desired. Atmospheric and partial vacuum seals on small tubes have been made by resistance welding, gas tungsten-arc welding, cold welding, and soldering. Initially, four processes were considered for hermetically sealing aluminum tubes: gas tungsten-arc, cold, ultrasonic, and resistance welding.

After screening tests at the Oak Ridge Y-12 Plant, ultrasonic welding was judged to be the best of the four for this particular application. The arc process was rejected because the fusion zone was often porous. Also, molten metal tended to be pulled into the tube unless it was mechanically crimped, severed, and then sealed. This procedure resulted in overheating and a burn down of the outer edges of the tube unless the procedure was carried out by a highly skilled welder. Furthermore, the period between severing the crimped end and seal welding was long enough for the ambient atmosphere to diffuse into the system.

No reproducible procedures could be worked out for cold welding tube ends unless the tube bores were abrasively cleaned just prior to welding. The cleaning schedule, the likelihood of abraded particles being aspirated into evacuated containers, and extremely thin and fragile closures were causes for rejecting the cold-welding process. Recent work,[1] however, indicates that with improved die design cold-welded tube closures are relatively insensitive to reasonable amounts of contamination and acceptable leak rates have been consistently obtained in these materials.

Bush[2] describes an application of resistance welding for hermetically sealing small tubing. A two-step procedure involving crimping and welding was recommended. Recently, Bush and Moment[3] described composite resistance welding electrodes which were used to improve the nugget geometry of resistance-welded tube closures. Most of their work was, however, performed on austenitic stainless steel tubes.

In the present study, resistance welding was considered impractical for hermetically closing tubes made of such high conductivity metals as aluminum and copper. However, it was found that a tooling design similar to that used in resistance welding could be adopted for hermetically closing the ends of aluminum tubes with ultrasonic spot welding.

Ultrasonic spot welding was selected because it is less sensitive to the amount of contamination of the tube bore, which could not be cleaned prior to welding, than the other processes under consideration. Vibratory motion assists the pressure-bonding mechanisms characterizing cold welding. This feature permits closures to be made without excessive thinning of the tube wall. Likewise, this process is analogous to the resistance welding process in that it crimps and metallurgically seals the tube before the downstream portion of the tube-and-valve assembly is cut off. This feature eliminates the possibility of atmospheric contamination of the system. The lead photograph shows an ultrasonic crimp weld* in a Type 1100-H14 aluminum tube which represents the product resulting from a procedure developed during the course of the program. The leak rate of this closure is less than 1.0×10^{-9} std cc/sec of helium.

This term was coined at the Oak Ridge Y-12 Plant to describe the two-stage (crimp and weld) operation used to produce hermetic closures in small tubing with ultrasonic spot welding equipment.

Crimp-Weld Tooling

Ultrasonic welding[4] is a process for joining metals by the introduction of high-frequency vibratory energy into the overlapping metals in the area to be joined. Neither flux nor filler metal is used, no electrical current passes through the weld metal, and preheat is usually not applied. The workpieces are clamped together under moderately low static pressure, and ultrasonic energy is transmitted into the weld area. A sound metallurgical bond is produced without an arc or melting of the base metal. Consequently, the cast structure associated with melting is not formed. Instead, a solid-state bond that is free of pores and voids characterizes the ultrasonic weld.

In ultrasonic welding, components to be joined are clamped between a welding tip and a supporting anvil with only sufficient static pressure to hold and contain them in intimate contact. Tooling for ultrasonic spot welding normally consists of a welding tip having a one to 5 in. radiused end, which contacts the workpiece, and an anvil with a flat surface, which supports the workpiece. The functional parts of an ultrasonic spot welding unit are identified in Fig. 1.

Initial tube-closure investigations were carried out using a rectangular tip having a working surface area 0.150 by 0.250 in. and a flat, smooth anvil. Encouraging results were obtained with tooling. However, lateral flow of the tube was unrestrained by the flat anvil. This condition resulted in extremely thin and fragile closures when parameters of power

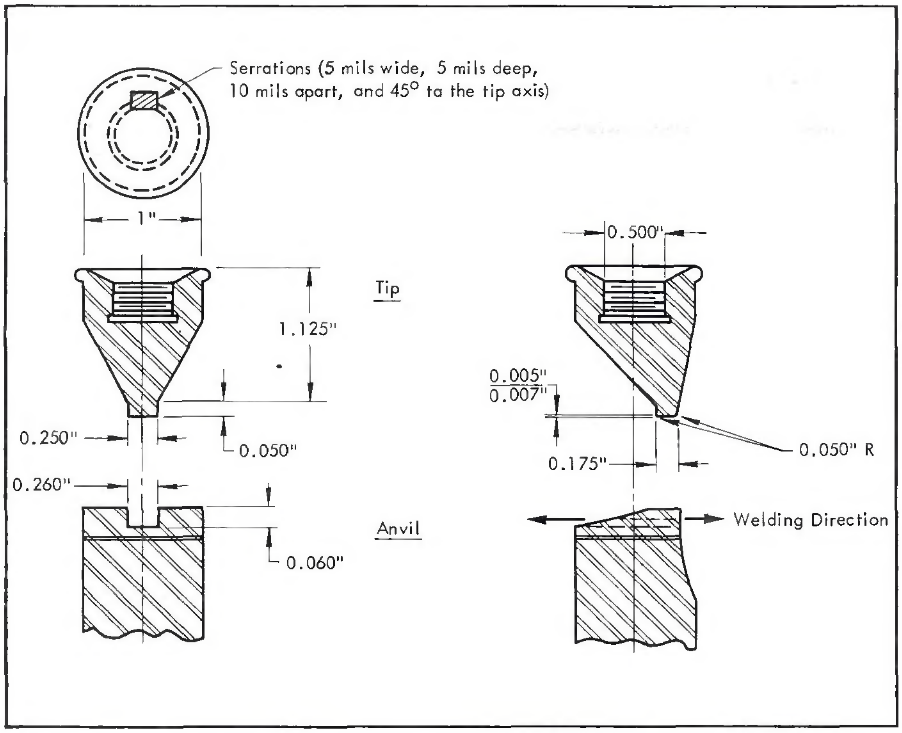


Fig. 2 — Ultrasonic tube crimp-weld tip and anvil configuration

Fig. 3 — Worn (A) and fractured (B) ultrasonic tube welding tips

and force necessary to produce leak-tight closures were used.

After various anvil geometries were investigated, it was determined that the tip and anvil shown in Fig. 2 produced the best results. The slot in the anvil prevented excess lateral flow of the tube material and produced closures approximately 0.260 in. wide. Serrations were put on the tip to aid in imparting vibratory motion to the interface of the collapsed tube.

The radius on the front of the tip and on the slope from front to back of the working surface was necessary to prevent thinout of the tube wall at the junction of the crimp radius and weld zone.

Welding Tip Evaluation

Welding tips and anvils must be treated as important variables when sophisticated welding procedures are employed. Because the tip is the vehicle through which vibratory motion is imparted to the weldment, it must be reshaped or replaced at the first indication of wear or damage.

Tips ranging in hardness from 44 to 70 Rc were subjected to a protracted series of welding cycles to determine an index of useful tip life. Tips that are too soft have short lives because of excessive wear; tips that are too hard are subject to fatigue failure. Figure 3(A) illustrates the wear on a tip with a hardness of 58 Rc after 530 crimp welds were made with it. The serrations were no longer visible, and the tip is no longer serviceable. Tips ranging from 44 to 50 Rc were worn excessively after 100 welds were made. Figure 3(B) shows a broken tip with a hardness value of 68 Rc. The ultrasonic welding unit can be considered a fatigue machine, and calculations indicate that this tip failed at about 500,000 cycles.

Tips ranging in hardness from 65 to 75 Rc were crack sensitive, with cracks occurring at the threaded region of the tip, as indicated in Fig. 3(B). The results indicated that optimum tip hardness for the tube closure should be between 58 and 64 Rc. Therefore, 60 to 62 Rc was specified for all tips of this or similar configuration, and the number of welds per tip was limited to 250.

Figure 4 shows a new tip (A) and a worn tip (B). Special attention is called to the working surfaces of the tips. In Fig. 4(B) the serrations are completely worn off, and the working surface is damaged.

Crimp and Weld Procedure

Normally, an ultrasonic welding unit such as used for this work is operated from one switch. For our

Table 1 — Summary of the Effect of Parameter Variation on Weld Thickness and Helium Leak Rate on Type 1100-0 Aluminum Tubes

Range[a] of parameter	Helium leak rate, std cc/sec	Weld thickness, mils
Parameter: weld time, seconds		
0.04	1.0×10^{-5}	37
0.13	$<1.0 \times 10^{-9}$	19
Parameter: power, electrical watts		
1,300	$<1.0 \times 10^{-7}$	30
2,000	$<1.0 \times 10^{-9}$	19
Parameter: force, pounds		
400	7.0×10^{-7}	35
525	$<1.0 \times 10^{-9}$	19
Parameter: frequency, hertz		
14,763	2.0×10^{-9}	20
14,812	$<1.0 \times 10^{-9}$	21

(a) The low and high value of each of 4 parameters is listed.

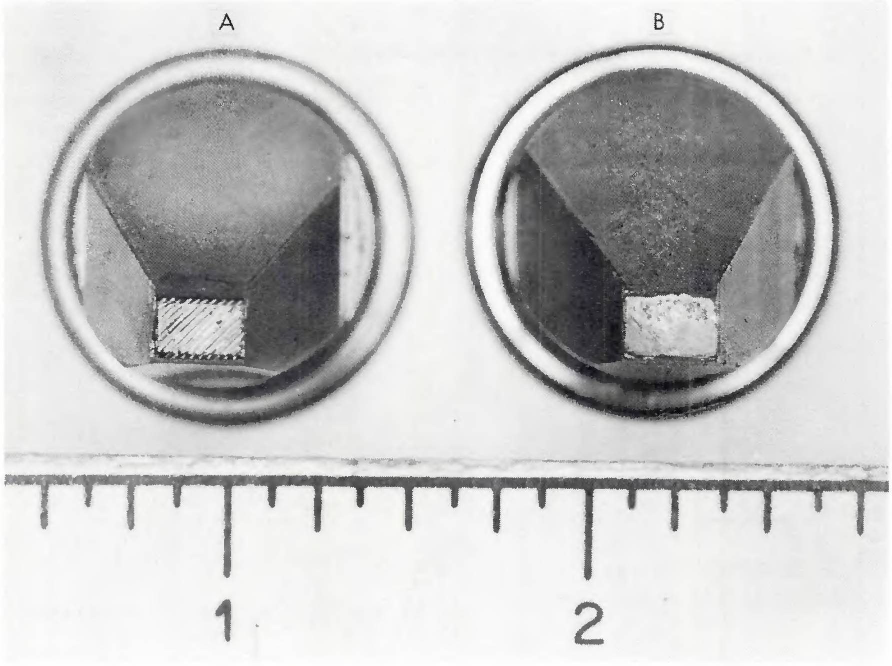


Fig. 4 — New and worn ultrasonic tube welding tips

purposes, however, a two-switch, two-step procedure was developed that provided operator control of weld cycle starting time with respect to the force or crimping cycle. This procedure allowed the operator to visually determine that all controls were properly set and that a correct force was applied before starting the weld cycle. The force (crimp cycle) was designed to reduce the thickness of nominally 0.182 in. diam tubes to a 48-52 mil by 0.260 in. wide rectangular configuration by forcing the interfaces into contact before the welding cycle was started.

A further reduction in the tube crimp thickness occurs during the welding phase of the two-step crimp-weld sequence. During this time there is a local temperature rise caused by the combined effects of elastic hysteresis, localized interfacial slip, and plastic deformation. It is during this phase of the crimp-weld cycle that a delicate balance between power, weld time, and force must be maintained so that excessive thinning of the crimp does not occur. Optimum dimensions at each stage of the operation are defined in Fig. 5.

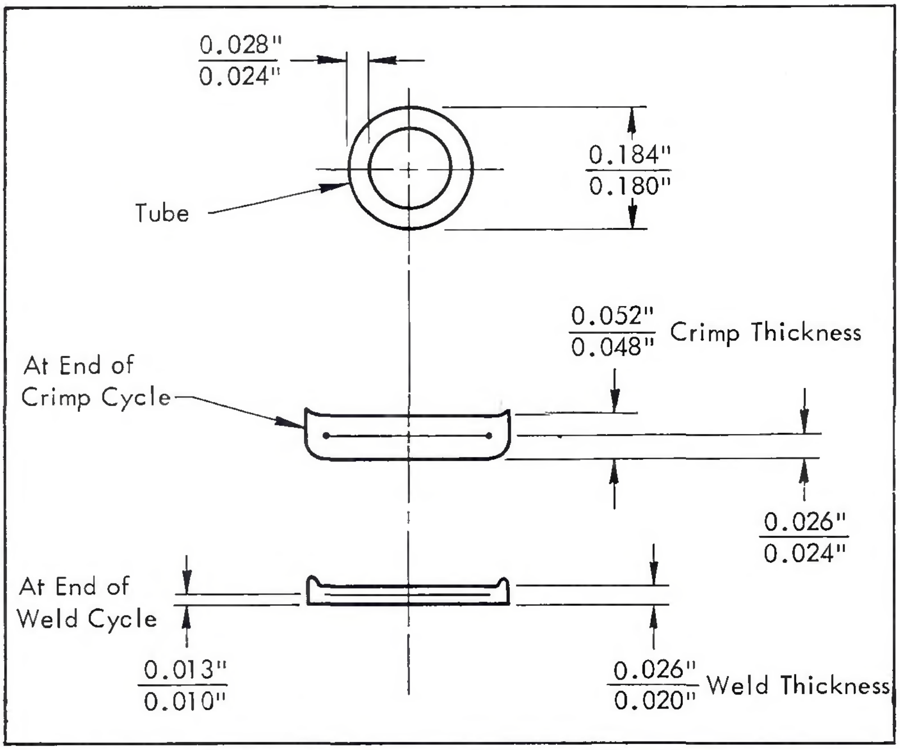


Fig. 5 — Optimum dimensions for ultrasonically crimp welding aluminum tubes

Effects of Four Controlled Parameters on Weld Thickness and Leak Rate

Experimental Procedure

Early in the development program for crimping and welding circular geometries, it was recognized that, of the four operator-controlled parameters (power, frequency, force, and weld time), the applied force was the most sensitive variable with weld time, power, and frequency following in order. Therefore, experiments were designed to study the effects of variations of these parameters on weld thickness and leak rate.

Leak-rate easily was correlated with weld thickness, and — in this regard — discrete changes in weld thickness could be determined with much better precision than could incremental changes in small leak rates. The tendency to leak increased as welds became either thinner or thicker than a lower and an upper thickness limit (~ 15 and 30 mils, respectively).

After preliminary tests and adjustments were made, four groups of six tubes each were crimp welded. One of the four parameters was varied for each group. Effects of parameter variations on weld thickness and the

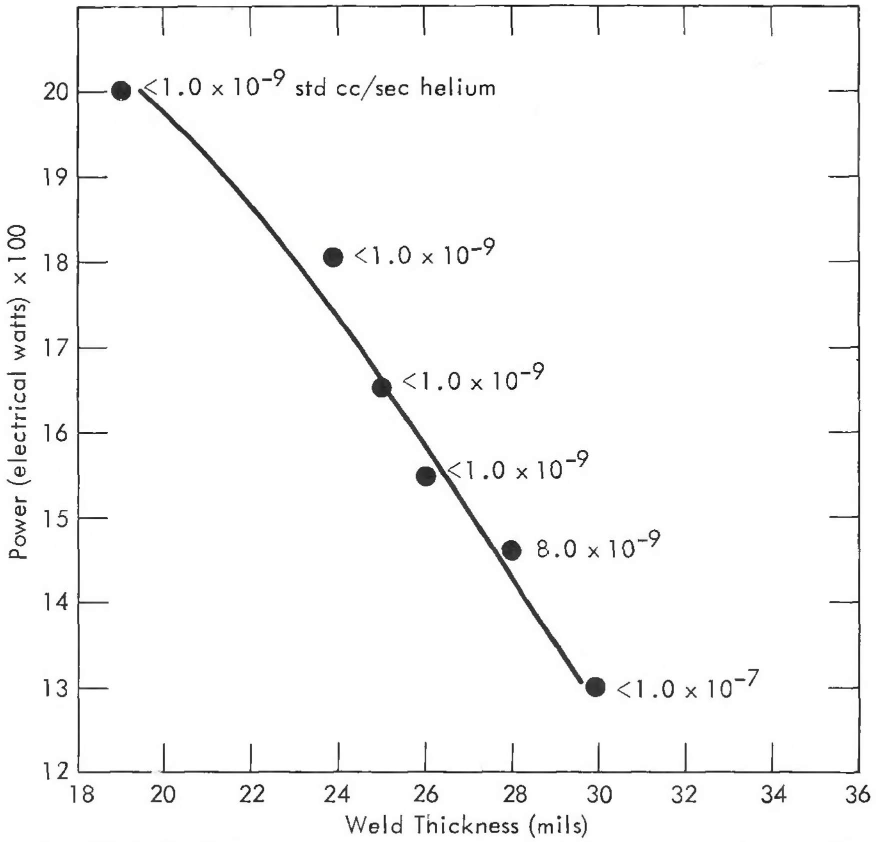


Fig. 6 — Effect of welding power (electrical watts) on weld thickness and leak rate on Type 1100-0 aluminum tubes. (Power values were calculated from graphs supplied by the ultrasonic equipment manufacturer)

helium leak rate are summarized in Table 1. Only the high and low values for each parameter are listed. Figures 6 through 10 graphically show the effects of variation of these factors on weld thickness and leak rate over the entire experimental range.

Effect of Power

Figure 6 indicates that optimum values of weld thickness and leak rate were obtained with power ranging from 1,550 to 1,800 electrical watts and with thicknesses ranging from 24 to 28 mils. The power values were calculated from graphs supplied by the manufacturer of the ultrasonic welding equipment.

Effect of Frequency

Figure 7 notes that optimum values of weld thickness and leak rate were obtained with frequency variations ranging from 14,760 to 14,790 Hz, and indicates that the influence of frequency variation on weld thickness and leak rate is less than that of any of the other three controlled variables.

Effect of Force

Figure 8 points out that optimum values of weld thickness and leak rate were obtained (22 to 25 mils) with 425

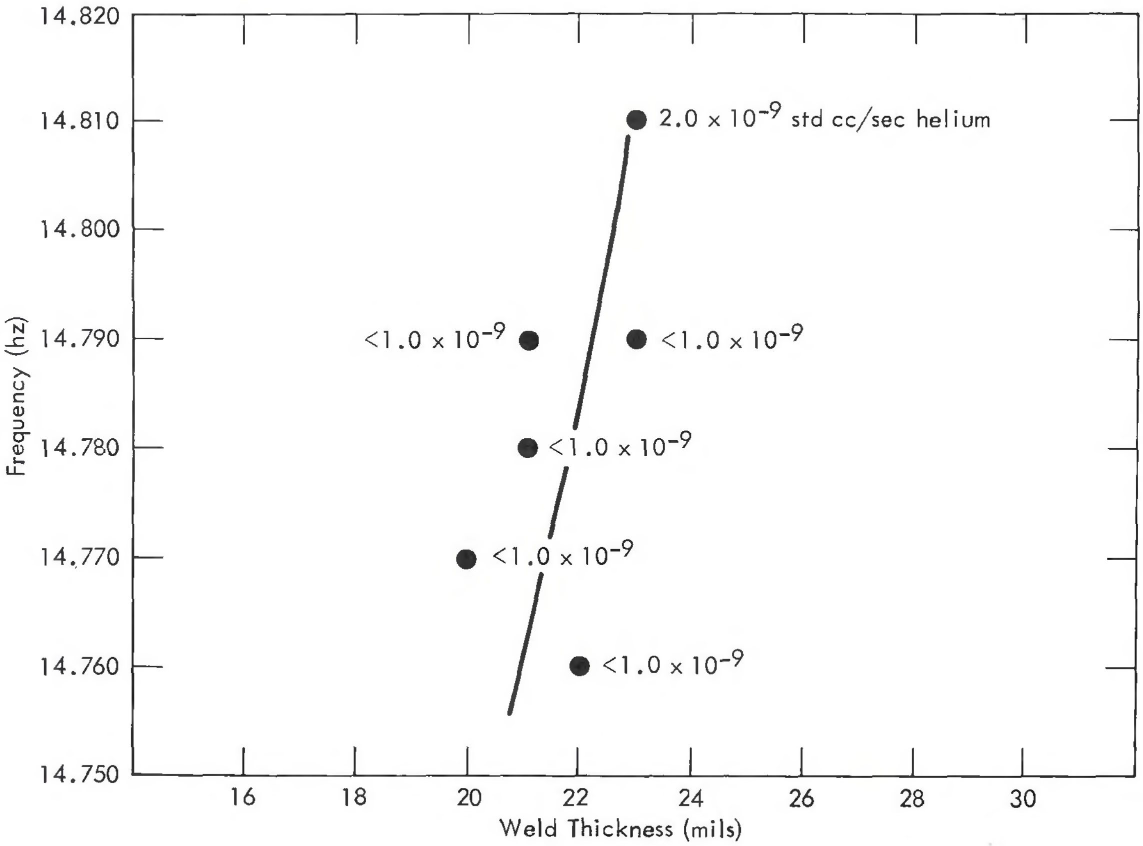


Fig. 7 — Effects of welding frequency on weld thickness and leak rate on Type 1100-0 aluminum tubes

Table 2 — Relationship of Tube Hardness to Crimp Thickness Prior to Starting the Weld Cycle

Coupon	Al Type	Temper	Hardness, DPH	Crimp[(a)] Thickness, mils
1	1199	0	23	44
2	1100	0	30	50
3	1100	H-14	36	55
4	1100	H-16	50	60
5	1100	H-18	68	68

(a) All crimps made at 450 lb force.

to 500 lb of force. At 400 lb, the thickness and leak rate are borderline; at 525 lb, the tube with a thickness of 17.5 mils is fragile, subject to damage in handling, and sharp enough to be hazardous to operating personnel.

The effects of 450 and 500 lb forces on crimp thickness before welding Type 1199 and 1100 aluminum alloy tubes with various hardnesses are seen in Fig. 9.

Effect of Weld Time

Weld time, as used in this article, is defined as the duration of electrical energy delivered to the transducer and is determined by the weld timer setting. Maximum recommended limits are 0.01 to 1.25 sec. Figure 10 shows the influence of weld time on weld thickness and leak rate, and indicates that an optimum weld thickness was obtained at 0.08 to 0.10 sec. The 1.0×10^{-6} std cc/sec helium leak rate for the weld made at 0.04 sec also indicates that coupling occurs very early in the weld cycle.

Effect of Other Significant Variables

Effect of Tube Hardness

An experiment was conducted to relate thickness of the crimped tubes prior to welding to material hardness. The results of the first experiment are listed in Table 2. Additional data given in Table 3 show the effects of material hardness on crimp thickness and weld thickness, and the relationship of weld thickness to the helium leak rate for the same coupons listed in Table 2. Parameters were identical for the five closures, and are presented in Table 4 (Procedure 1).

Table 4 also shows the parameters for welding tubes that fall into two hardness ranges. The difference in the two procedures is in the values for the tip force and welding time. The in-

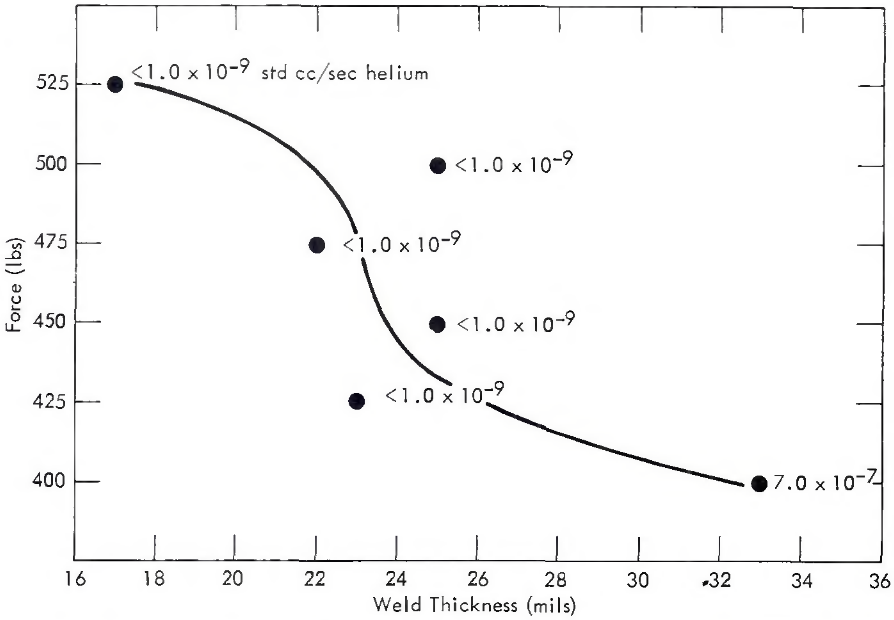


Fig. 8 — Effects of welding force on weld thickness and leak rate on Type 1100-0 aluminum tubes

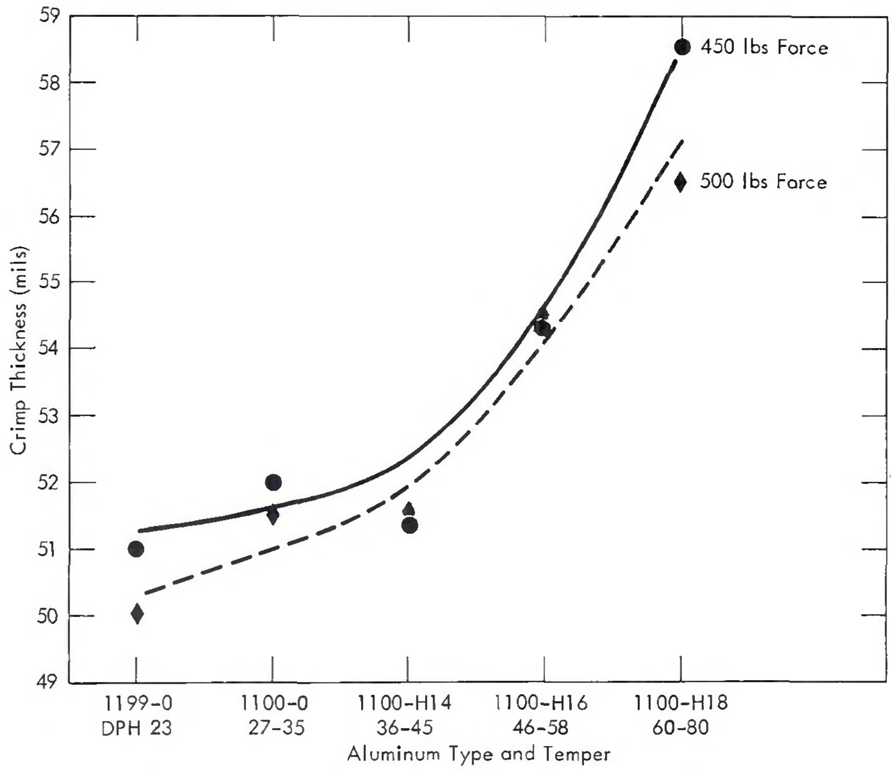


Fig. 9 — Aluminum tube crimp thickness before welding — average of 5 tubes

Table 3 — Relationship of Tube Hardness and Crimp Thickness to Weld Thickness and the Helium Leak Rate of the Tubes Listed in Table 2

Coupon	Hardness, DPH	Crimp thickness mils	Weld[(a)] thickness, mils	Helium leak rate std cc/sec
1	23	44	20	$<1.0 \times 10^{-9}$
2	30	50	32	$<1.0 \times 10^{-9}$
3	36	55	36	$<1.0 \times 10^{-7}$
4	50	60	43	$>3.0 \times 10^{-6}$
5	68	68	52	$>3.0 \times 10^{-6}$

(a) All welds made with identical parameters.

crease in force for the harder material was necessary to assure interface contact before the welding phase was initiated; a reduction in welding time was required to offset excessive thinning of the crimp when the higher force was used.

Table 5 emphasizes the effect of tube hardness on weld thickness and helium leak rates for tube closures made with the two sets of parameters. Coupons 4 through 7 were welded with Procedure 1. Acceptable leak rates were obtained on Coupons 4 and 5, which had hardnesses of 22 and 35 DPH, respectively. The hardnesses for Coupons 6 and 7 were 46 and 44 DPH, respectively, and the leak rates were unacceptable; however, when Procedure 2 was used for Coupons 8 and 9, which were in the same hardness range, very low leak rates were obtained.

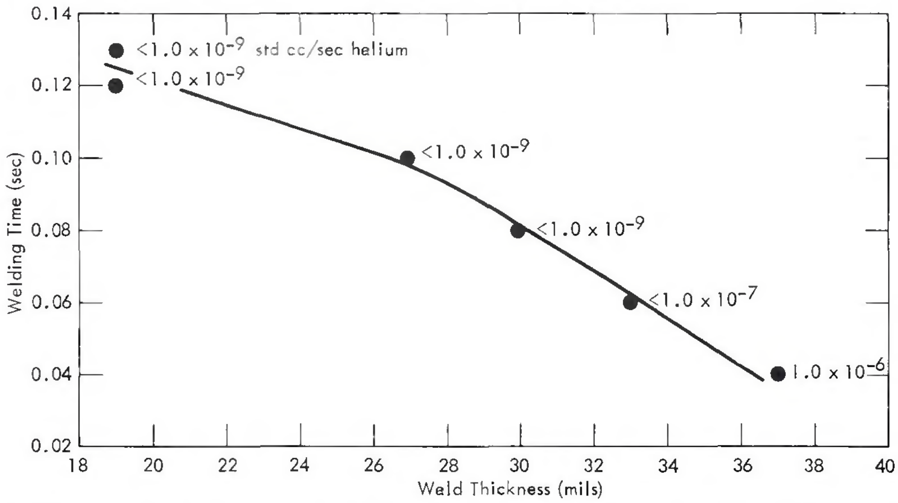


Fig. 10 — Effects of welding time on weld thickness and leak rate on Type 1100-0 aluminum tubes

Table 4 — Ultrasonic Crimp-Weld Parameters Recommended for Type 1199-0, 1100-0, and 1100 H14 Aluminum Tubes

Procedure	Weld time, sec	Weld force, lb	Weld power,[a] watts	Weld frequency, Hz	Hardness, DPH	Application
1	0.12±0.01	450 ±5	1,800 ±50	14,794 ±30	22 - 35	Type 1199-0 and 1100-0 aluminum
2	0.10±0.01	500±5	1,800 ± 50	14,794 ± 30	36 - 48	Type 1100-0 and 1100-H14 aluminum

(a) Calculated from graphs supplied by the manufacturer of the ultrasonic welding equipment.

Table 5 — Summary of Aluminum Tube Hardness Investigation

Coupon	Al type	Hardness, DPH	Weld thickness, mils	Helium leak rate, std cc/sec	Weld Procedure[a]
4	1199-0	22	15	$<1.0 \times 10^{-8}$	1
5	1100-0	35	23	7.0×10^{-8}	1
6	1100-H14	46	29	$>3.0 \times 10^{-8}$	1
7	1100-H14	44	28	$>3.0 \times 10^{-6}$	1
8	1100-H14	47	22	$<1.0 \times 10^{-9}$	2[b]
9	1100-H14	48	19	$<1.0 \times 10^{-9}$	2

(a) Welding Procedure 1 for Type 1199 and 1100-0 aluminum tubes (see Table 4).
(b) Welding Procedure 2 for Type 1100-0 and 1100-H14 aluminum tubes (see Table 4).

Effect of Tube Dimensions

In addition to the four controlled variables (tip force, power, frequency, and weld time) and tube hardness, another significant variable is tube dimensions. Tube dimensions as well as hardness affect metal flow at the outer folded edges of the collapsed tube where leaks occurred most often. For example, welding parameters for crimp-welding tubes having outside diameters ranging from 180 to 184 mils, wall thicknesses ranging from 24 to 28 mils, and hardnesses ranging from 22 to 35 DPH were not applicable to crimp-welding tubes with dimensions or hardnesses outside this range.

The welding schedule was modified, however, by increasing the welding force and time. Then, comparable results were obtained on 250 mil tubes ranging from 36 to 48 DPH in hardness.

The slot in the anvil was designed to constrain the lateral flow of tubes during crimp welding and to assure that all closures would have the same geometry. This anvil design, however, increased the need to maintain close tube dimensional tolerances (outside diameter and wall thickness). This is because weld thickness and leak rate then became, to a great extent, a function of tube dimensions and hardness. Increasing or decreasing the resistance of the tube to the applied force by changes in either mass or hardness resulted in variation in crimp thickness, weld thickness, and leak rate.

Effect of Thermal Cycling

Numerous ultrasonic crimp welds were subjected to thermal cycling from −65 to +165 F without any significant increase in the leak rate.

Monitoring In-Process Performance

The electrical power delivered from the power source to the transducer may be measured with a high degree of accuracy with conventional meters. However, only a portion of this power reaches the weld zone as acoustical power because of losses in conversion to vibratory energy, transmission, and reflection at impedance discontinuties.

A method for determining the acoustic power delivered to a weldment is by measuring the standing wave ratio (SWR) in the coupler system during welding.[8,9] This technique involves the use of two barium titanate microphonic sensors adhesively bonded to the anvil or coupler in an array approximately ¼ wave length apart. These sensors respond to vibrations in the system to produce signals which are delivered to an oscilloscope equipped with two dual trace amplifiers. The area of the elliptical trace (Lissajous figure) displayed on the oscilloscope is proportional to the acoustical power transmitted through the weld. The SWR is represented by the ratio of the major and minor axes of the elliptical figure.

An attempt was made to monitor the in-process performance of the ultrasonic tube welder by relating the vibratory responses of the anvil to changes in the welding parameters and to the closure weld quality as indicated by weld thicknesses and leak rates. The results showed that neither the standing-wave ratio nor cycles per weld resulting from anvil vibrations is satisfactory for monitoring equipment performance when ultrasonically welding small aluminum tubes. However, subsequent measurements of welding performed with standard ultrasonic spot welding tooling (anvil and tip), as previously described, and sensors attached to the anvil agreed with the findings of Jones, et al. [8,9] The cycle-counting and standing-wave-ratio techniques provided reliable data when welding conventional, flat, overlapping coupons. Results showed that material thickness should be within the capabilities of the welding unit so that resonance coupling occurs in the weldment.

A second-generation ultrasonic monitoring package consisting of a counter, storing oscilloscope, camera, and a comparator was developed. The comparator was used to trigger the oscilloscope after a preselected number of cycles were recorded on the counter. Thus, by making a series of identical welds and photographing a succession of oscillographic traces throughout a specific welding period, one may determine from the changes in the Lissajous figures whether coupling occurred, the time that it occurred, and optimum time required to accomplish a weld without overwelding and causing excessive indentation, distortion, and damage to the weldment.

Force Limiting Device

A breakdown in the control of the hardness of the material used for production tubes made it necessary to crimp weld Type 1100-0 tubes (23-25 DPH) and Type 1100-H14 tubes (36-45 DPH) without positive identification of the material hardness or temper prior to welding. Procedure 2, listed in Table 4, was used.

Application of the higher pressure specified in Procedure 2 and an occasional malfunction of the equipment resulted in overcrimping the softer material and leaking closures. This problem was solved by the use of a force-limiting device which limited the downward movement of the welding tip and assured that minimum weld thickness would not be thinner than a predetermined value. The device is seen in Fig. 11.

After installing the device, Procedure 2 was used for welding either

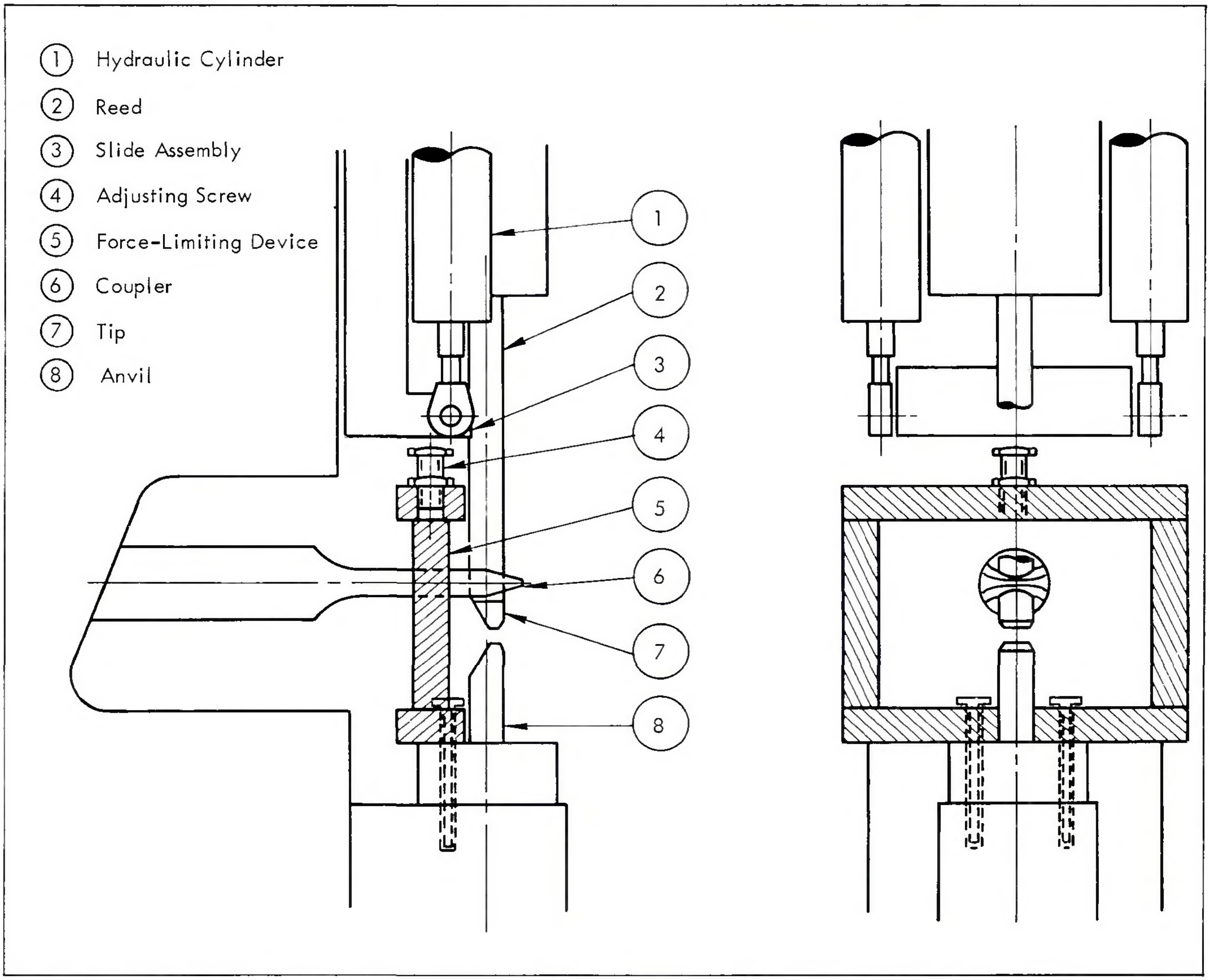


Fig. 11 — Force-limiting device and its relationship to the moving parts of the welding machine

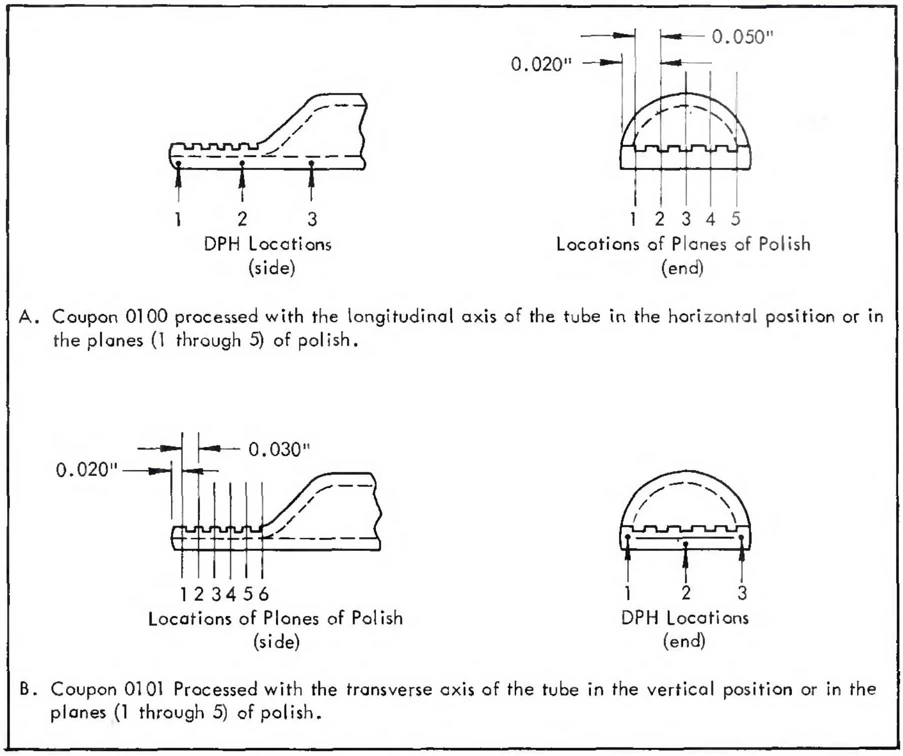


Fig. 12 — Locations of planes of polish and diamond pyramid hardness reading locations for crimp welds in aluminum tubes

Table 6 — Microhardness Values for Crimp-Weld Tube Processed with the Axis in a Horizontal Position (Coupon 0100)

Horizontal polishing plane (a)	Diamond pyramid hardness and location (a) 1	2	3	Average	Weld thickness mils
1	40.4	40.1	40.4	40.3	24
2	39.2	36.6	36.6	37.5	—
3	40.4	39.2	38.0	39.2	—
4	38.9	39.5	41.4	39.9	—
5	39.8	39.8	39.5	39.7	—
Average	39.7	39.0	39.2	39.3	—
Spread	1.5	3.5	4.8	2.8	—

(a) Refer to Figure 12-A for clarification of locations 1, 2, and 3. Load to 300 grams.

Table 7 — Microhardness Values for Crimp-Weld Tube Processed with the Axis in a Vertical Position (Coupon 0101)

Vertical polishing plane (a)	Diamond pyramid hardness and location (a) 1	2	3	Average	Weld thickness mils
1	43.8	49.6	45.6	46.3	29
2	45.6	41.4	45.2	44.1	—
3	44.0	37.2	40.4	40.5	—
4	44.5	41.0	44.0	43.1	—
5	40.4	44.0	43.8	42.4	—
Average	43.7	42.6	43.8	43.4	—
Spread	5.6	12.4	5.2	5.8	—

(a) Refer to Figure 12-B for clarification of locations 1, 2, and 3. Load to 300 grams.

Type 1100-0 or 1100-H14 material without difficulty.

Ultrasonic Aluminum Tube Weld Characteristics

Although considerable metallurgical work and tube-hardness investigations were performed during the development program, additional metallurgical work was undertaken for a more complete evaluation. Therefore, two tubes, designated 0100 and 0101, which were crimp welded according to Procedure 2 (see Table 3), were selected for extensive study.

The integrated leak rates for the tubes, and containers to which they were attached, were 0.14×10^{-6} and 0.12×10^{-6} std cc/sec helium for the tubes designated 0100 and 0101, respectively. The tubes were then detached from the containers and again leak tested. The leak rate of each tube was less than 1.0×10^{-9} std cc/sec helium.

Tube 0100 was horizontally mounted with the longitudinal axis of the tube in the polishing plane. Tube 0101 was vertically mounted with the tube axis normal to the polishing plane. Views A and B of Fig. 12 show the locations of the metallographic polishing planes and hardness determinations for each specimen. The same procedure was carried out at each of the five locations, and nearly identical metallographic and hardness results were obtained. Therefore, only the results from Polishing Plane 4 are included in this report. Tables 6 and 7, however, are included to show the relative hardnesses of the tube material throughout each specimen. Figures 13 and 14 show the results of work performed on Specimen 0100, and Figs. 15 and 16 show the results of work performed on Specimen 0101.

Referring to the weld interface evident by the intermittent surface oxide film or dark lines in Figs. 14 and 16, a theory based on published data[10] and personal observations during the development program is presented.

During ultrasonic welding of materials with high thermal conductivity, the heat generated at the faying surfaces is rapidly conducted away from this interface, and oxides and other contaminants are not melted or dispersed as when fusion welding processes are used. This type of material, of which copper and aluminum have been investigated most thoroughly, is characterized by a bond interface which displays local regions of incomplete surface film dispersion. Surface films consisting of oxide and other contaminants which cannot be removed from internal surfaces of tubes immediately prior to

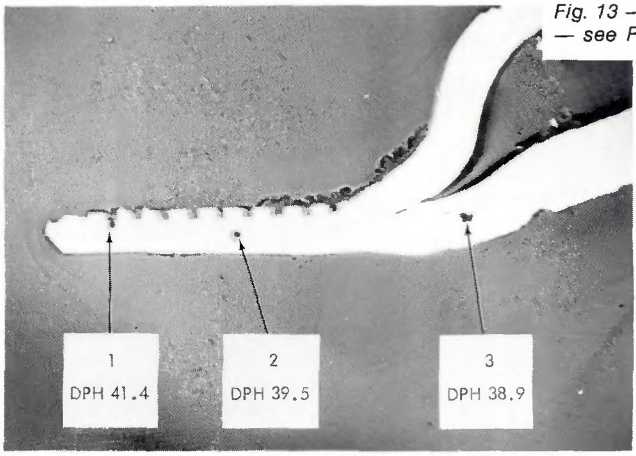


Fig. 13 — Hardness determinations on tube 0100 at polish plane 4 — see Fig. 12, View A; X15, reduced 45%

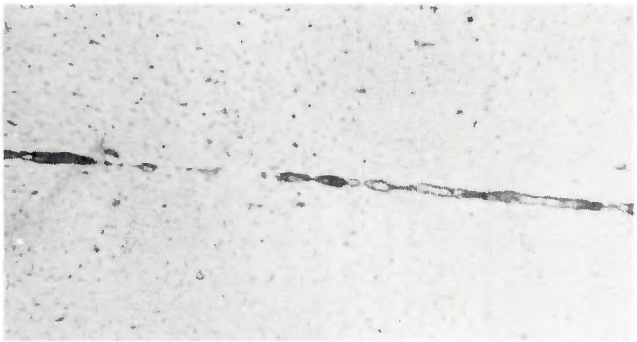


Fig. 14 — Photomicrograph of the center of the welded area shown in Fig. 13. X1000, reduced 45%

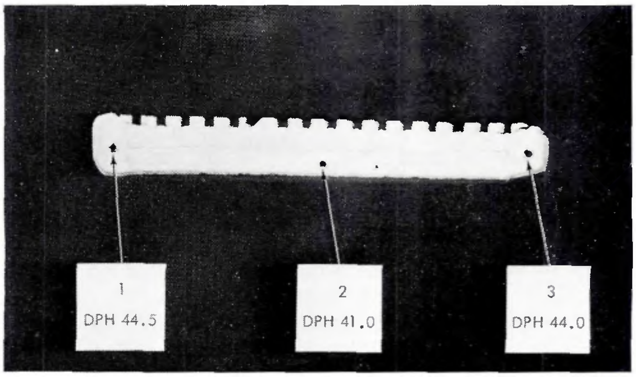


Fig. 15 — Hardness determinations at polish plane 4 — see Fig. 12, View B; X15, reduced 45%

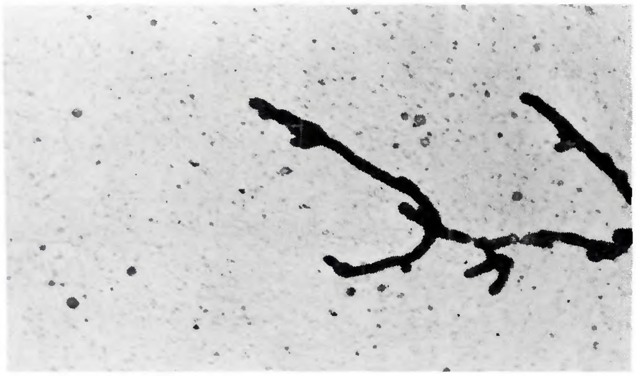


Fig. 16 — Photomicrograph of the left side of the area shown in Fig. 15 X1000 reduced 45%

closure welding and impurities present in Type 1100 aluminum contribute to this condition. Surface films may become dispersed within the metal or remain a part of the interface bond.

The degree of deformation at the weld interface is also an important factor in determining the film dispersion and cross migration of the base metals in ultrasonic welds in aluminum; i.e., dispersion will occur in direct proportion to the deformation at the weld interface when a proper relationship of force to power and weld time is used.

Deformation at the interface of closure welds in aluminum tubes is limited by the weld thickness required to assure a stable, reasonably thick-walled closure that will not be damaged by handling or be injurious to personnel because of a sharp edge; therefore, maximum dispersion of surface contaminants does not occur in ultrasonic welds in aluminum tubes. This condition does not appear to adversely affect the leak rate of closure welds in aluminum tubes. One group of five tubes were allowed to oxidize in ambient air for a period of five weeks between vapor degreasing and crimp welding. The leak rates for all closures in this group were less than 1.0×10^{-9} std cc/sec helium. Also, the low leak rate of Tubes 0100 and 0101 indicate that both are excellent quality ultrasonic welds for aluminum tubes which cannot be internally cleaned and deoxidized immediately prior to welding.

The influence of impurities in the Type 1100 aluminum alloy on the weldability of this material by the ultrasonic welding process was not established. However, the ratio of closures with acceptable leak rates in Type 1199 aluminum alloy tubes to those with unacceptable leak rates was approximately 1½ times higher than the corresponding ratio for closures in Type 1100 aluminum alloy tubes welded with Procedure 1, listed in Table 2.

Procedure Control

Normally a control tube was welded and leak tested immediately prior to the start of a series of runs and also after an extended down time. Product quality assurance also included periodic testing and certification of the pressure gage, weld timer, and power in electrical watts delivered to the transducer at 90 day intervals. Maximum repeatability of force from the hydraulic system was attained after the system had been in operation for a minimum of two hours before welding was started.

A general inspection of the welding station was performed at 30 day intervals with special attention given to the tip and anvil. These components were examined for fatigue cracks, wear, damage, and alignment.

Conclusions

1. The acceptance quality level (acceptable leak rate) of ultrasonically welded Type 1100-0 and 1100-H14 aluminum tubes exceeded 97%.
2. Rejects (unacceptable leak rates) usually were related to worn or damaged tips or to material which exceeded the range of hardness or dimensions for a specific set of parameters.
3. Rejects (unacceptable leak rates) were not related to normal internal contamination of the tube bore or thermal cycling from −65 to +165 F.
4. Ultrasonic welding parameters were based primarily on material

hardness and thickness (mass of the weldment) which means that control of tube hardness and dimensions was of prime importance.

5. Three sets of parameters were required to ultrasonically crimp weld aluminum tubes with hardnesses ranging from the H18 to 0 condition.

6. Although the standing-wave ratio and cycles per weld indicated by signals from microphonic sensors bonded to the anvil did not provide acceptable data for monitoring quality when crimp welding aluminum tubes, it was determined that these indicators are useful for sensing the time that coupling occurs. The optimum time to accomplish a weld without overwelding and causing excessive indentation and distortion when welding with a standard spot welding tip and anvil was not established.

7. A force-limiting device, designed to limit the downward movement of the welding tip and assure that minimum weld thickness would not be thinner than a predetermined value, proved to be a valuable addition to the welder. The device did not interfere in any way with the efficiency of the welder.

8. The length of tubes extending from the container ranged from 0.475 to 0.500 in. after crimp welding and severing.

Acknowledgements

The authors wish to acknowledge with thanks the assistance of Nicholas Maropis and the technical staff of Aeroprojects, Incorporated in preliminary tool design and technical assistance during the development program. Appreciation is also expressed to the management of the Oak Ridge Y-12 Plant for permission to prepare and publish this article.

References

1. Irons, J. L., et al; *Cold Welding Aluminum Tubes,* Union Carbide Corporation-Nuclear Division, Oak Ridge Y-12 Plant, Oak Ridge, Tennessee; to be published.

2. Bush, S. A.; "Small Tube Unconfined Area Resistance Closure Welding," *Welding Journal,* **46** (8), 665 to 675; (1967).

3. Moment, R. L. and Bush, S. A.; "A New Concept in Resistance Welding Electrode Design," *Welding Journal,* **48** (7), 557 to 566; (1969).

4. "Ultrasonic Welding," *Welding Handbook Section 3-B,* Sixth Edition, Chapter 59; American Welding Society, Miami, Florida (1971).

5. Hazlett, T. H., and Ambekar, S. M.; "Additional Studies on Interface Temperatures and Bonding Mechanisms of Ultrasonic Welds," *Welding Journal,* **49** (5), 196 to 200 (1970).

6. Rhines, F. N.; *Study of Changes Occurring in Metal Structure During Ultrasonic Welding,* Summary Report TP82-162; Metallurgical Research Laboratory, University of Florida; April 1962.

7. Estes, C. L.; *Practical Applications for the Ultrasonic Welding Process,* SME Paper AD-70-571; September 1970.

8. Jones, J. Byron, Marolis, Nicholas, Thomas, John G., and Bancroft, Dennison; *Fundamentals of Ultrasonic Welding,* Phase I, Research Report 59-105; Aeroprojects, Incorporated; May 1959.

9. Jones, J. Byron, Maropis, Nicholas, Thomas, John G., and Bancroft, Dennison; *Fundamentals of Ultrasonic Welding,* Phase II, Research Report 60-91; Aeroprojects, Incorporated; December 1960.

10. "Ultrasonic Welding," *Welding Handbook Section 3-B,* Sixth Edition, Chapter 59, p 59.6; American Welding Society, Miami, Florida (1971).