Evaluation of Braze Alloys for Vacuum Treating-Gas Quenching

Successful filler metals include No. 718 for 6061 aluminum, AMS 4777 for low alloy and stainless steels, and Ticuni for Ti-6Al-4V

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Introduction

Brazing and/or heat treating in a vacuum environment are important commercial processes for treating metals where contaminated-free surfaces are required. However, with most heat treat operations a rapid quenching rate is required to develop full mechanical properties in the base metal. To obtain these fast cooling rates, commercial vacuum furnaces are built either with quenching baths incorporated with the facility or the vacuum chamber is backfilled with an inert gas, which is then rapidly recirculated through a heat exchanger.

This type of equipment is not satisfactory for brazing and heat treating aluminum alloy containers where surface-free contamination is required. By backfilling the vacuum chamber with an inert gas and circulating the gas through a heat exchanger, the metal surfaces will remain clean, but the quenching rate is too slow to develop fully heat treated properties. If the metal surfaces processed in vacuum are quenched in water or oil, the surfaces are then contaminated with the quenching medium, and are not satisfactory for use as chemical containers.

To overcome the drawbacks of brazing and/or heat treating of metal containers in conventional commercial vacuum furnaces, a cooperative program was carried out with Edgewood Arsenal to investigate vacuum brazing of 6061 aluminum alloy containers, followed by a modified gas quench.

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Editor's Note: The initial portion of the Burrows-O'Keefe report is presented in the feature article section of this issue. Two other articles dealing with braze alloy evaluation can be found in the Welding Research Supplement of this issue.

Braze alloy selection for each of the base metals specified for study was aimed at being able to braze and either austenitize or solution treat at the same time, before gas quenching. In most cases this was not possible, since braze alloy development has not kept pace with heat treat requirements. Brazing temperatures are generally higher than the austenitizing or solution treating temperature range, which means the base metals must be brazed in one operation and then heat treated by a second process.

Braze alloy materials were evaluated with the various base metals by means of bar-to-bar "Tee" specimens, tube-to-sheet specimens, and lap shear tensile specimens as shown in Fig. 1. The bar-to-bar and tube-to-sheet specimens were used to evaluate braze alloy flow and the lap shear tensile specimens were used to determine braze alloy shear values.

Vacuum brazing studies were made using the Abar high temperature vacuum furnace. A calibrated chromel-alumel thermocouple was attached to one of the test specimens in each brazing run to accurately monitor temperatures. On completion of the brazing cycle, the brazed specimens were visually examined for braze alloy flow and then representative specimens were sectioned for metallographic examination.

Results of this study follow for each of the base alloys.

Aluminum Alloys

Commercial aluminum alloys that are considered as brazeable alloys by Alcoa are specified in Table 1. The alloys 2014 and 2219 are not included

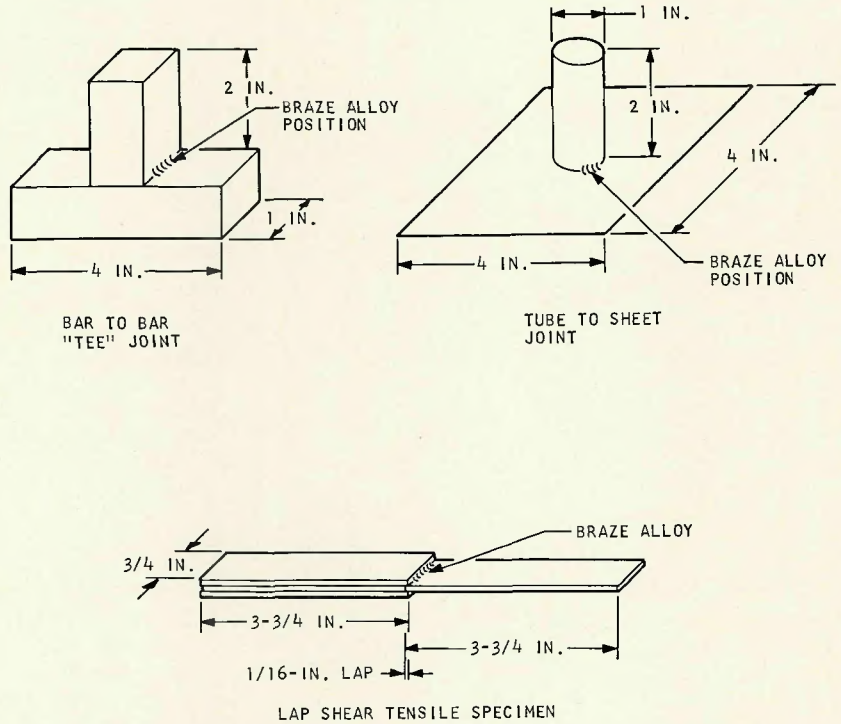

Fig. 1—Braze alloy test specimens

Table 1—Nominal Composition and Melting Range of Alcoa Brazeable Parent Metals

Alloy	Brazeability Rating[1]	Percent of Alloying Elements[2] Copper	Silicon	Manganese	Magnesium	Zinc	Chromium	Melting Range, °F
EC	A			(99.45% min Al)				1195–1215
1100	A			(99% min Al)				1190–1215
3003	A	—	—	1.2	—	—	—	1190–1210
3004	B	—	—	1.2	1.0	—	—	1165–1205
5050	B	—	—	—	1.2	—	—	1160–1205
6151	B	—	1.0	—	0.6	—	0.25	1025–1200
6951	A	0.25	0.35	—	0.65	—	—	1140–1210
5052	C	—	—	—	2.5	—	0.25	1100–1200
6053	A	—	0.7	—	1.3	—	—	1105–1205
6061	A	0.25	0.6	—	1.0	—	0.25	1100–1205
6063	A	—	0.4	—	0.7	—	—	1140–1205
Cast 43	A	—	5.0	—	—	—	—	1065–1170
Cast 356	C	—	7.0	—	0.3	—	—	1035–1135
Cast 406	A			(99% min Al)				1190–1215
Cast A612	B	0.5	—	—	0.7	6.5	—	1105–1195
Cast C612	A	0.5	—	—	0.35	6.5	—	1120–1190

NOTES: [1] A = generally brazeable; B = brazeable with special techniques; C = limited brazeability
[2] Aluminum and normal impurities constitute remainder

Table 2—Composition and Melting Range of Alcoa Brazing Filler Alloys[1]

Alcoa number	Aluminum association designation	AWS–ASTM class (tentative)	Percent of Alloying Elements[2] Silicon	Copper	Iron	Zinc	Magnesium	Manganese	Chromium	Melting range, °F
4043	4043	BAlSi-1	4.5– 6.0	0.30	0.8	0.10	0.05	0.05	—	1070–1165
No. 713 brazing sheet	4343	BAlSi-2	6.8– 8.2	0.25	0.8	0.20	0.10	—	—	1070–1135
No. 714 brazing alloy	4045	—	9.0–11.0	0.30	0.8	0.10	0.05	0.05	—	1070–1110
No. 716 brazing wire	4145	BAlSi-3	9.3–10.7	3.3 –4.7	0.8	0.20	0.15	0.15	0.15	970–1085
No. 718 brazing wire and sheet	4047	BAlSi-4	11.0–13.0	0.30	0.8	0.20	0.10	0.15	—	1070–1080
No. 719 brazing wire	4245	—	9.3–10.7	3.3 –4.7	0.8	9.3 –10.7	0.07	0.07	0.07	960–1040

[1] Alcoa Data, Table from Brazing Alcoa Aluminum
[2] Aluminum and nominal impurities constitute remainder

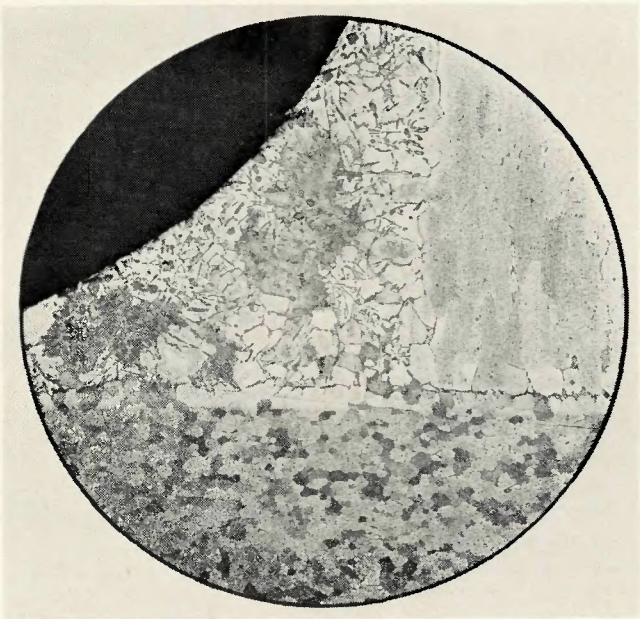

Fig. 2—Photomicrograph shows 2219 aluminum alloy tube vacuum brazed to 2219 alclad plate at 1060F with No. 719 filler metal. Mag: 75X

in this list while the alloy 6061 is noted as a brazeable material.

Aluminum Alloy 2014

The 2014 alloy is not considered a brazeable alloy because of a low melting temperature range of 950 to 1180F. The initial melting temperature of the alloy is below the melting temperature range of the commercially available brazing alloys noted in Table 2. If the 2014 alloy is heated above 950F, incipient melting occurs which renders the alloy unsuitable for further use.

Development of brazing alloy systems that will have a flow temperature in the range of 935 to 950F are under study by Edgewood Arsenal. Since there are no commercially available brazing alloys for use with 2014 material, no brazing studies were conducted with this alloy.

Alclad 2219 and 2014

The 2219 alloy is essentially a binary alloy of aluminum and copper. The primary difference between 2219 and 2014 alloys is the higher copper content and lack of magnesium in the 2219 alloy. The chemistry of the alloy is such that the solution

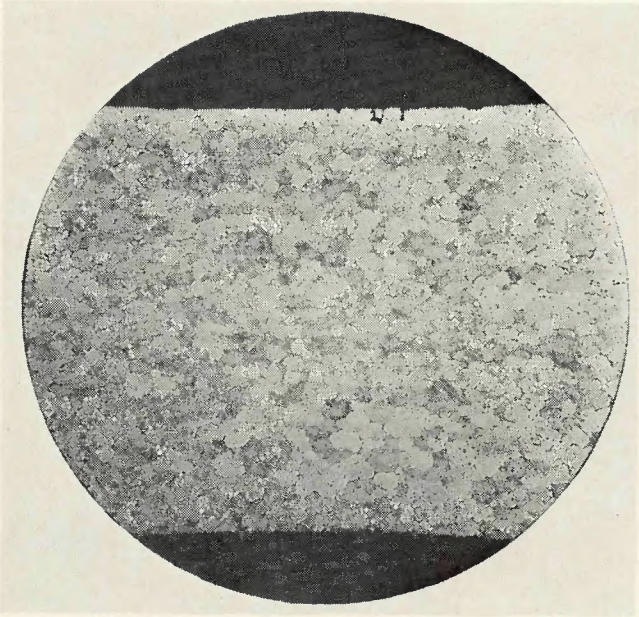

Fig. 3—Photomicrograph shows incipient melting in 2219 aluminum alloy after heating to 1060F. Mag: 75X

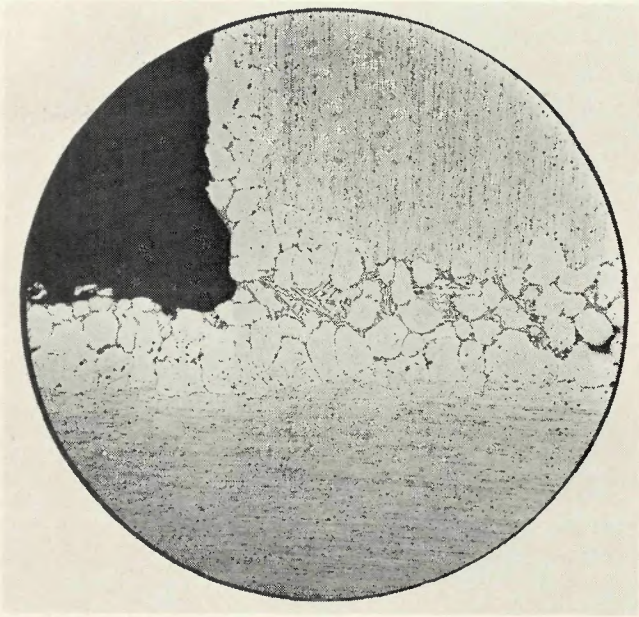

Fig. 4—Photomicrograph shows typical braze alloy fillet in 6061 aluminum alloy block-to-block "Tee" specimen vacuum brazed at 1100F with No. 718 filler metal. Mag: 75X

treating temperature is 995±10F, and the melting temperature range is 1010 to 1190F. The initial melting temperature is lower than the flow temperature of available aluminum brazing alloys No. 716 and No. 718 (see Table 2). Braze alloy No. 719, which is made only on special request, offers the lowest brazing temperature of the commercial alloys. No other brazing alloys could be obtained from commercial suppliers for use in the temperature range of 995 to 1010F. The effectiveness of the various braze alloys is noted in the following:

Braze Alloy No. 716

The melting temperature range for No. 716 brazing material is 970 to 1085F with a flow temperature of 1105F. Since the flow temperature is too high for the 2219 alloy, a vacuum braze test was made at 1050F using a 2219 tube to 2219 alclad plate specimen. The braze alloy showed partial melting and no flow. The 716 braze alloy is not satisfactory for use with 2219 base material due to a flow temperature that is higher than the melting temperature of the base metal.

Braze Alloy No. 719

The No. 719 brazing alloy has the lowest melting range temperature of all the commercially available alloys. Initial melting occurs at 960F; melting is complete at 1040F and alloy flow occurs at a temperature of 1060F in a vacuum environment of 5×10^{-5} torr. A brazing temperature of 1040F develops braze alloy melting but insufficient braze alloy flow. By increasing the braze temperature to 1060F, good alloy flow and filleting is obtained, as shown in Fig. 2 for a tube-to-plate braze. The brazing temperature of 1060F is above the initial melting temperature of the base alloy, which produces solid solution melting that is evident in the grain boundaries.

The extent of this solid solution melting is noted in the microstructure of Fig. 3. The No. 719 braze alloy, which develops excellent braze alloy flow and filleting, is not an approved alloy for use with 2219 bare and alclad base metals because of the presence of solid solution melting developed by a brazing temperature that exceeds the initial melting temperature of the base alloy.

Aluminum Alloy 6061

Aluminum alloy 6061 is listed by Alcoa as a brazeable parent metal with a brazeability rating of 'A' (Table 1). The alloy has a melting temperature range of 1100 to 1205F and is readily brazed with Alcoa No. 718 filler material which has a melting temperature range of 1070 to 1080F and a flow temperature of 1100F (Table 2).

A typical braze fillet is shown in Fig. 4 for a $1^5/_8 \times$ 1-in. block-to-block specimen. The braze alloy of $^1/_{16}$-in. diameter wire by $1^5/_8$-in. long was placed one side of the $1^5/_8$-in. width. During vacuum brazing at a vacuum level of 5×10^{-5} torr, the braze alloy flows completely across the joint producing excellent flow and penetration. A photomicrograph shows the alloying of the braze filler metal with the 6061 base metal surfaces as it flows through the metal joint. The 718 braze alloy offers excellent flow characteristics.

Tube-to-plate specimens with a 1-in. length of $^1/_{16}$-in. diameter No. 718 brazing wire placed on one area next to the tube-to-plate joint were vacuum brazed at 1100F. The braze alloy completely flows around the joint producing good braze metal fillets. The tube-to-plate braze is helium leak tight with a Veeco MS-9 sensitivity of 1×10^{-10} cc/atm/sec.

Shear lap tensile specimens (Fig. 1) were prepared from 0.125-in. gauge 6061. The shear specimens with a lap size of $^1/_{16}$-in. and a gap size of 0.6 mil were vacuum brazed with 718 filler wire at a temperature of 1100F using the Abar vacuum furnace. After brazing, the specimens were vacuum solution treated at 985F for 20 minutes, nitrogen gas quenched, and artificially aged at 320F for 18 hours in a circulating air furnace to the T62 condition. Three shear lap specimens show an average shear strength of 12,000 psi with failure taking place in the braze metal.

Steel Alloys

The preferred brazing process for the low alloy steels is to braze at the austenitizing or solution annealing temperature. By doing this, the brazement and heat treating of the material are accomplished at the same time, and maximum strength is obtained in the base metal. The austenitizing or solution annealing temperature for low alloy steels such as 4130, 4340, and maraging 18Ni250 steel is in the range of 1500 to 1575F.

The availability of commercial brazing alloys in this temperature range is extremely limited and the alloys that have suitable melting and flow tem-

peratures are mainly silver base alloys. Silver alloys are not desirable for vacuum brazing, because of the high vapor pressure of silver. At a temperature of 1558F and a vacuum of 0.1 μ (10^{-4} torr), silver is in equilibrium with its own vapor. Therefore, with temperatures in excess of 1558F or with a lower pressure, silver vapors will be removed from the braze metal and these vapors will, in turn, condense on cooler furnace surfaces.

A manganese-copper-nickel alloy 1600N (38.5Mn, 52.5Cu, 9.0Ni) with a minimum brazing temperature of 1700F is recommended for dry hydrogen brazing of alloy steels. This alloy is not satisfactory for vacuum brazing because of the high vapor pressure of manganese, which at 0.1μ (10^{-4} torr), the solid is in equilibrium with its own vapor pressure at a temperature of 1456F.

Nickel base alloys such as AMS 4777 produce excellent braze joints with the low alloy steels. The AMS 4777 alloy has a solidus of 1800F, a liquidus of 1875F, and a flow temperature in vacuum of 1825 to 1925F. The nominal composition of the alloy is 7% chromium, 3% iron, 4.5% silicon, 3% boron, 0.06% maximum carbon, balance nickel. The alloy is self-fluxing and offers excellent wettability and fluidity when heated in vacuum to a temperature of 1925F. Nickel base alloys are excellent braze alloys for vacuum applications, since the solid nickel is in equilibrium with its own vapor at a temperature of 2295F and a vacuum of 0.1μ (10^{-4} torr).

All of the low alloy steels were vacuum brazed with AMS 4777 alloy in the Abar vacuum furnace at a temperature of 1925F for 15 minutes and a vacuum level of 5×10^{-5} torr. In all applications, the braze alloy powder of 150 mesh was mixed with Raffi and Swanson No. 1830 clear lacquer binder to form a slurry for application around the joints to be brazed.

After brazing, the alloys were austenitized or solution annealed in the laboratory vacuum gas quenching facility using a nitrogen gas quench. Tempering or aging treatments were carried out in a circulating air furnace. Process temperatures, times and environment for the treatment of the low alloy steels are noted in Table 8 (feature article by same authors).

Tube-to-plate, bar-to-bar, and shear lap specimens were prepared for each of the low alloy steels. Each type of specimen was vacuum brazed with AMS 4777 filler metal. For the tube-to-plate specimens. four drops of the braze alloy slurry were applied on the base sheet next to the 1-in. diameter tube. On the bar-to-bar block specimens, the braze slurry was applied as a fillet across one width of the block. In both types, the braze alloy flow into the braze joints was determined, and the effectiveness of the braze seal in the tube-to-plate specimen was measured by a helium leak test using Veeco MS-9 helium leak detector.

Tensile lap shear specimens were prepared with a $^1/_{16}$-in. lap and a 0.006-in. gap. The detail pieces were resistance tack welded into place and the braze alloy slurry applied as a fillet on each side of the center detail.

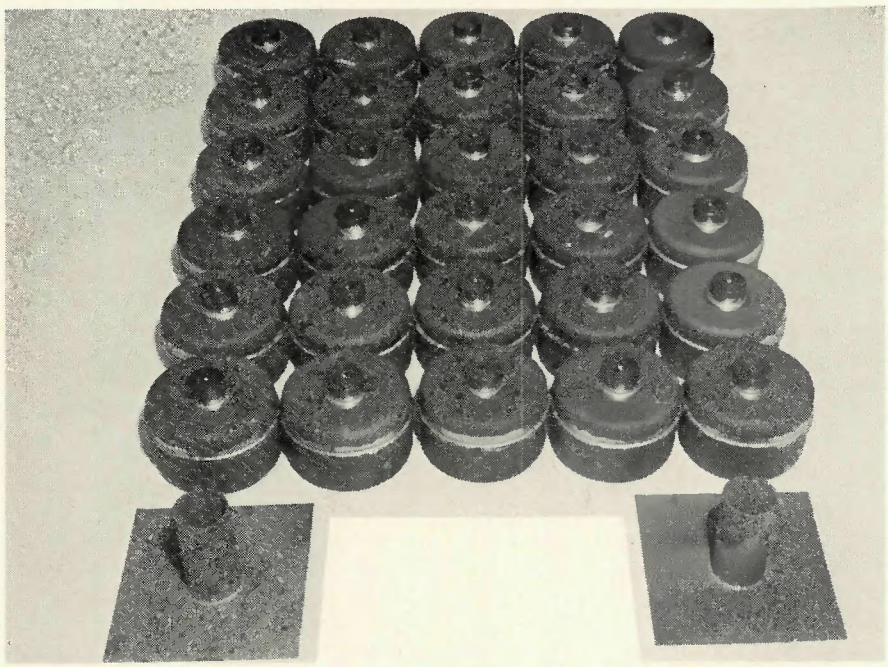

Fig. 5—Photograph shows 4130 steel containers and tube-to-plate specimens vacuum brazed at 1925F with Coast Metals No. 53 filler metal

The braze test specimens were vacuum brazed in the Abar furnace at a temperature of 1925F and a vacuum of 5×10^{-5} torr. The test specimens were located on a columbium hearth plate and no fixed tooling was used to hold the parts during the brazing cycle. The AMS 4777 brazing alloy starts to melt at 1800F and is completely melted at 1875F. At 1925F, the alloy shows excellent flow, wettability and filleting. To ensure adequate flow, the test specimens were held at 1925F for 15 minutes before furnace cooling.

Brazed tube-to-plate specimens in 4130 and 4340 steels show excellent braze alloy flow and filleting (Fig. 5). Three specimens of each alloy were brazed and all specimens are helium leak tight as measured by the Veeco MS-9 leak detector with a sensitivity of 1×10^{-4} cc/atm/sec. The tube-to-plate specimens in maraging 18Ni250 steel show complete braze alloy flow and filleting; however, on helium leak test, only one specimen out of three is helium leak tight.

Metallographic examination of the 4340 steel brazed joint indicates sound braze metal with a minimum amount of alloying with the base metal (Fig. 6). The braze alloy shows excellent flow through the joint with no evidence of porosity, voids or gaps. In the case of maraging 18Ni250 steel, the nickel base braze alloy alloys with the base metal, as shown in Fig. 7. The braze alloy shows good filleting and flow but contains considerable porosity, which accounts for the helium leak test failures.

Bar-to-bar specimens of 4130, 4340, and maraging 18Ni250 steels show complete braze alloy filleting and flow through the width of the metal-to-metal joint.

Shear lap specimens of 4130, 4340, and maraging 18Ni250 steels were prepared. The specimens with a $^1/_{16}$-in. lap and a 6-mil gap were vacuum brazed using AMS 4777 braze filler metal. Shear test specimens after brazing were vacuum heat treated, nitrogen gas quenched, and tempered or aged before test. Average shear strength values for the vacuum brazed steel alloys are as follows:

Alloy	Material thickness in.	Heat treat level psi	Average shear strength psi
4130	0.132	160,000	24,000
4340	0.125	190,000	29,000
Maraging 18Ni250	0.125	260,000	30,000

The shear strength values for the three alloy steels are dependent upon the braze alloy thickness and fillet size

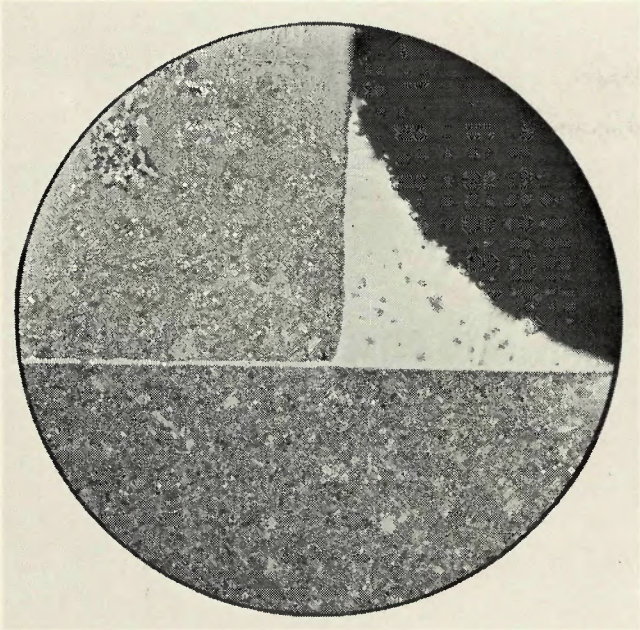

Fig. 6—Photomicrograph shows braze alloy filleting and flow in 4340 steel tube-to-plate specimen vacuum brazed at 1925F with Coast Metals No. 53 filler metal. Mag: 75X

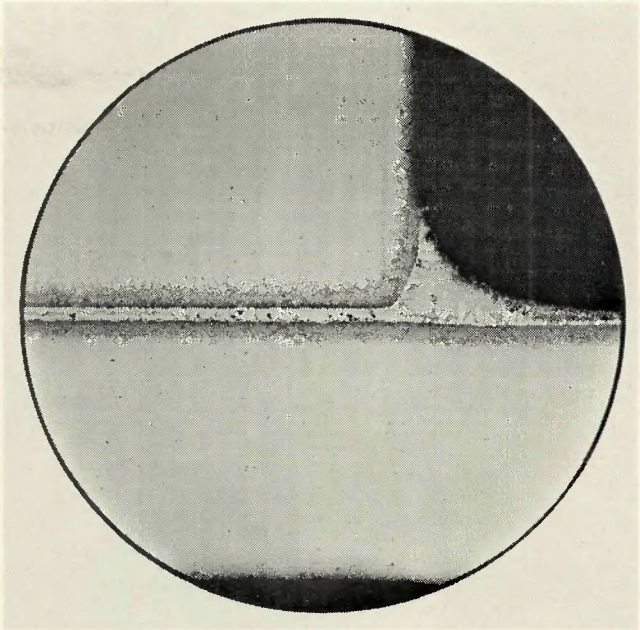

Fig. 7—Photomicrograph shows braze alloy filleting and flow in maraging 18Ni250 steel container vacuum brazed at 1925F with Coast Metals No. 53 filler metal. Mag: 75X

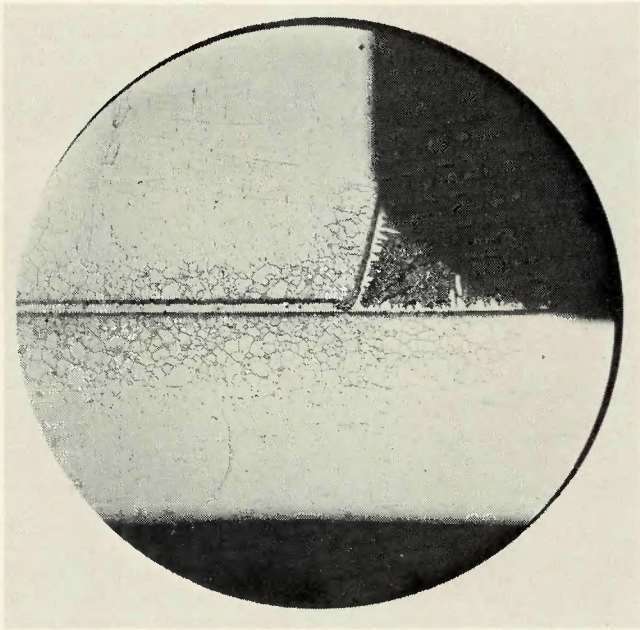

Fig. 8—Photomicrograph shows braze alloy filleting and flow in Type 316 tube-to-plate specimen vacuum brazed at 1925F with Coast Metals No. 53 filer metal. Mag: 75X

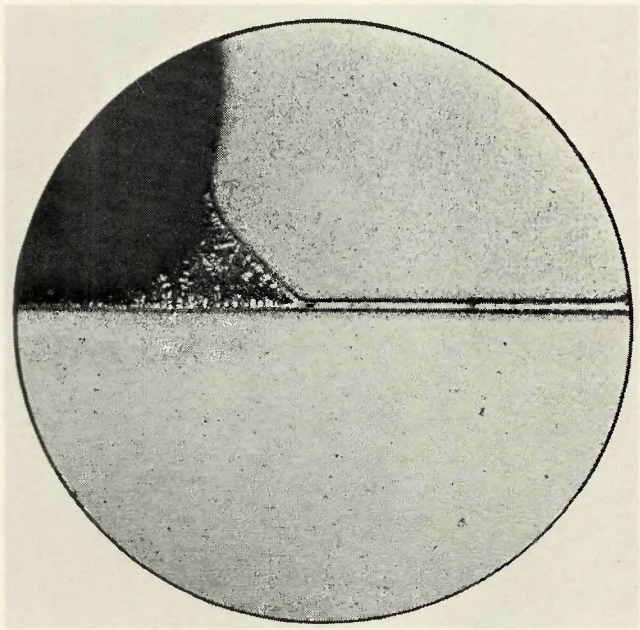

Fig. 9—Photomicrograph shows braze alloy filleting and flow in Type 321 tube-to-plate specimen vacuum brazed at 1925F with Coast Metals No. 53 filler metal. Mag: 75X

and are independent of the base metal strength as all test failures occur in the braze alloy.

Corrosion Resistant Steels

The corrosion resistant steels, types 316 and 320, are alloys that harden only by cold working. The annealing temperature for these alloys is in the range of 1900 to 2150F, which is the desired temperature range for brazing with nickel base brazing alloy AMS 4777. After the brazing process, the corrosion resistant steel alloys are in the annealed condition, and since the base alloys are not capable of being hardened by heat treatment, the brazed materials are evaluated in the annealed condition.

Tube-to-plate and shear lap specimens were vacuum brazed with AMS 4777 alloy in the Abar vacuum furnace at a temperature of 1925F for 15 minutes and a vacuum level of 5×10^{-5} torr. The braze alloy slurry was applied to the parts in the same manner as noted previously for the low alloy steels.

The tube-to-plate brazed assemblies of types 316 and 321 alloys show excellent braze metal flow and filleting. In all cases, the tube-to-plate specimens are helium leak tight as measured by a Veeco MS-9 helium leak detector with a sensitivity of 1×10^{-4} cc/atm/sec.

Metallographic examination of the brazed tube-to-plate specimens of type 316 shows sound metal brazed joints (Fig. 8). The nickel base alloy penetrates into the grain boundaries of the type 316 base metal and forms an alloy zone along the braze-base metal interface. To reduce the extent of the braze metal penetration into the grain boundaries, it is desirable to keep the brazing hold time at 1925F to a minimum. The type 321 alloy also shows a

sound metal braze with considerably less braze metal penetration into the grain boundaries of the base metal (Fig. 9). On the basis of the metallographic structures, the type 321 alloy will be preferred to type 316 for brazed structures. However, either alloy will develop satisfactory brazed joints.

Shear lap specimens of types 316 and 321 were prepared. The specimens with a $^1/_{16}$-in. lap plus a 0- or 6-mil gap were vacuum brazed using AMS 4777 braze filler metal. The shear lap specimens in the annealed condition develop vacuum brazed shear strength values as follows:

Alloy	Material thickness in.	Gap size in.	Average shear strength psi
316	0.125	0	72,800
316	0.125	0.006	41,300
321	0.125	0	77,200
321	0.125	0.006	40,300

The average shear strength value for the types 316 and 321 specimens with a gap size approaching zero effectively raises the average shear strength approximately 76% and 90%, respectively, over the material with a gap size of 0.006 in.

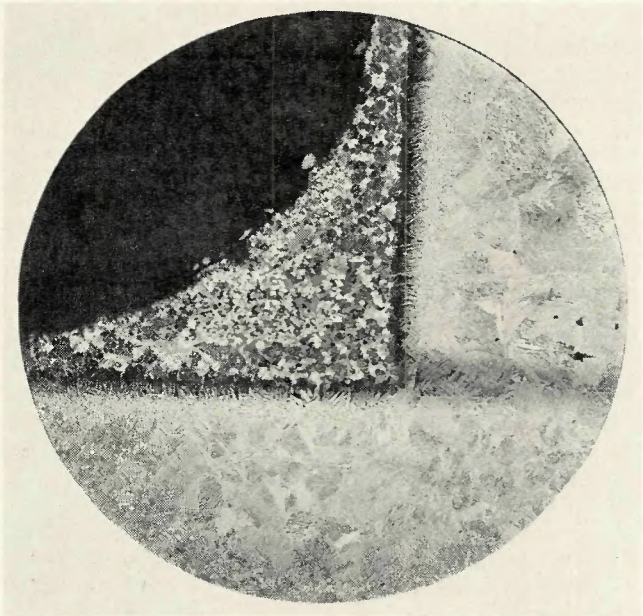

Fig. 10—Photomicrograph shows braze alloy filleting in 6Al-4V titanium tube-to-plate specimen vacuum brazed at 1825F with ticuni filler metal. Mag: 75X

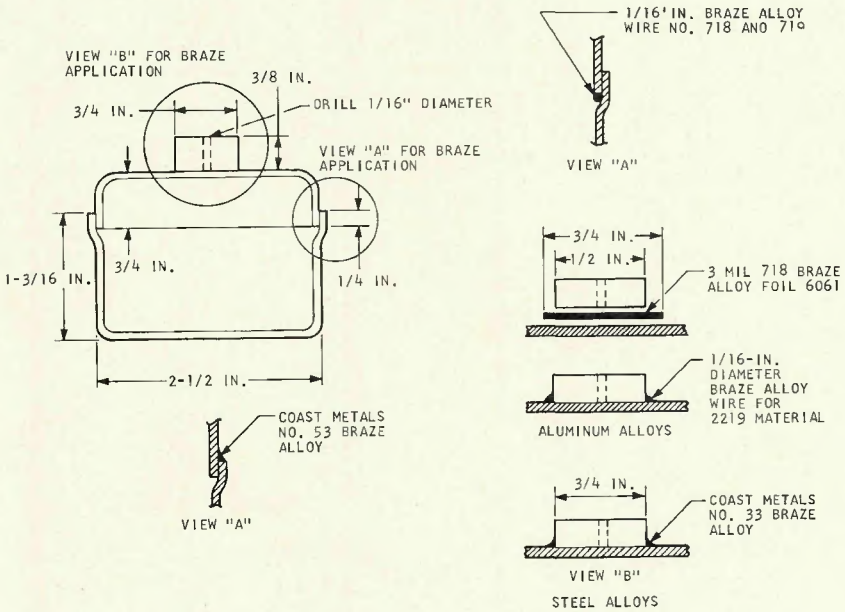

Fig. 11—Containers for vacuum braze-gas quenching evaluation

Titanium Alloy 6Al-4V

To obtain strength levels higher than for mill annealed material, the 6Al-4V material requires a duplex type heat treatment consisting of a solution treatment at 1725F, a rapid quench (equivalent to a water quench), and an aging treatment at 1000F for 24 hours. The solution treatment is carried out in the alpha-beta field below the beta transus temperature of 1825F at which the microstructure becomes entirely beta. This temperature limit is necessary because of a rapid drop in ductility and excessive grain growth. This temperature limitation restricts brazing operations to a temperature range of 1700 to 1825F.

The availability of commercial brazing alloys for use in this temperature range is essentially limited to Ticuni, a 70Ti-15Cu-15Ni alloy with a liquidus temperature of 1760F and a flow temperature of approximately 1825F and Tizurbi containing 48Ti-48Cr-4Be with a flow temperature of 1800F.

The Ticuni alloy in powder form of 150 mesh was mixed with Raffi and Swanson No. 1830 clear lacquer. Brazing was carried out in the Abar vacuum furnace at temperature of 1825F and a vacuum level of 5×10^{-5} torr.

Tube-to-plate, bar-to-bar, and shear lap specimens were prepared in the same manner as for the low alloy steels.

Brazed tube-to-plate specimens show poor braze alloy flow. As a result of the poor braze alloy flow, the tube-to-plate specimens do not pass the helium leak test.

Metallographic examination of the brazed areas show good filleting with some alloying between the base metal and the braze alloy (Fig. 10).

Bar-to-bar specimens ($1^1/_4$ by $1^3/_8$ in.) were brazed with Ticuni by applying the braze alloy slurry across one width of the bar. Braze alloy flow through the metal-to-metal joint is considerably better than the flow ob-

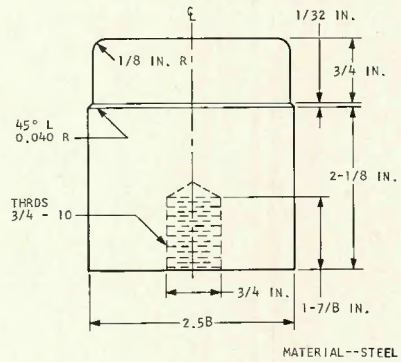

Fig. 12—Marform tool for forming containers

tained with the tube-to-plate specimens. A cross section of the brazed bar-to-bar specimen show braze alloy penetration approximately 60% of the $1^1/_4$-in. width.

Shear lap specimens with a $^1/_{16}$-in. lap and a 6-mil gap were vacuum brazed using the Ticuni filler metal. Shear test specimens after brazing at 1825F were tested in the as-brazed condition. The average shear strength for three specimens is 35,900 psi, with failure occurring in the braze metal.

The Ticuni braze alloy is a good filler metal alloy to use for vacuum brazing of 6Al-4V titanium alloy at a brazing temperature of 1825F. Since the braze alloy flow is limited, all joints must be fed by the brazing alloy.

Fabrication of Experimental Containers

To evaluate the vacuum brazing-gas quenching process for the manufacture of containers, a small experimental container (Fig. 11) was fabricated from 0.040-in. gauge sheet materials by a Marforming process. Shaped container cups formed over a mandrel (Fig. 12) were cut, machined, and sized to form a container with a press metal interlocking fit joint for vacuum brazing.

Materials selected for the fabrication of experimental containers included the following alloys:

Aluminum alloy 2219
Aluminum alloy 6061
Low alloy steel 4130
Low alloy steel, maraging 18Ni250
Corrosion resistant steel, type 321

The above materials in 0.040-in. gauge were formed on a Marform press of 800-ton capacity. The Marform press consists of a controlled pressure plate plus a forming rubber pad of 70-durometer hardness that is 6-in. thick. Operation of the press-to-form metal containers is as follows:

The pressure plate in brought up even with the mandrel and the material blank is centered over the mandrel.

The hydraulic press ram is brought down into contact with the Marform press. As full pressure is applied, the pressure plate gives way allowing the ram to push the blank into the rubber pad. The initial cup is formed to a depth of approximately 1 in.

To extend the draw and shape the radius of the cups, a shim plate, 8 in. square with a $4^{15}/_{16}$ circle cutout, is placed around the cup to take up the thickness of material. The shim plate is pinned in two places to the base plate. A radius plate is then put in place and the full pressure of the press is applied to complete the forming operation.

No problem was encountered in forming the 2219 and 6061 aluminum alloy cups. The 4130 steel, received in the normalized condition, could not be formed without cracking. All of the blanks were then annealed and cleaned by grit blasting to remove heat treat scale. After cleaning, the blanks were partially formed. To remove cold work effects, the partially formed cups were annealed and cleaned by acid pickling. The parts were then reformed on the Marform press to the final shape.

The maraging 18Ni250 steel in the solution annealed condition could not be formed to the initial 1-in. deep draw because of cracking at the bend radius. To overcome this problem, the process procedure and tooling was modified as follows:

The radius of the mandrel was changed from $^5/_{32}$ to $^5/_{16}$ in. to reduce the severity of the bend. The material blanks were dry grit blasted and tumbled to clean and polish the metal surfaces.

A draw ring with a diameter equal to the punch diameter plus 0.010-in. clearance was used to form the initial 1-in. deep cup. A load of 750 tons was applied to the first draw operation.

The first draw ring was removed and a second draw ring was used to close the metal cup around the offset area of the punch. For full pressure of the press, 800 tons were required.

On completion of the Marforming operation, the formed cups were cut to form one of two details. One detail was obtained by cutting a cup above the offset area, and a second detail was made by cutting a cup $^3/_{16}$-in. below the offset area, as noted in Fig. 11. The cup edges were machined using an aluminum collet to hold the cups on a metal lathe. The machined cups were fitted and sized to form a container.

A metal boss, $^1/_2$ to $^3/_4$ in. in diameter by $^3/_8$ in. high, was machined to fit on top of each container. A $^1/_{16}$-in. diameter hole was drilled through the button and the container top to allow for helium leak testing after vacuum brazing.

The fabrication of vacuum brazed containers and the process procedures employed follow for each alloy.

Aluminum Alloy 2219 Alclad

The 2219 alclad containers with a 2219 machined metal boss were brazed with No. 719 braze alloy wire of $^1/_{16}$ in. diam. The composition of the 719 filler alloy is noted in Table 2. The braze alloy wire was obtained from Alcoa as hard drawn $^1/_8$ in. diam wire in coil form. Since the $^1/_8$ in. diam wire was too large for the joints to be brazed, the wire was reduced to a $^1/_{16}$ in. diam by machining. The braze wire was annealed and formed into rings to fit inside of the container diameter and around the top boss. The container details and brazing wire were chemically cleaned.

The assembled containers were brazed in the Abar furnace at a temperature of 1060F and a vacuum level of 5×10^{-5} torr. A monitoring chromel-alumel thermocouple was enclosed in one of the containers. The furnace heat input was carefully controlled to prevent overheating of the material. Maximum power input to the furnace was 1.25 kilowatts.

After brazing, six canisters at a time were solution heat treated in the laboratory vacuum brazing-gas quenching facility. The canisters were solution heat treated at a temperature of 995 ±10F for 40 minutes in a vacuum of 5×10^{-5} torr. At the conclusion of the solution heat treatment, the canisters were nitrogen gas quenched with one full cylinder of gas. The quenching time from 995F to room temperature was recorded on a fast moving millivolt recording chart. The quenching rate for 6 containers per quench is 24 seconds.

On completion of the solution heat treatment, the canisters were precipitation heat treated by aging 36 hours at 375F in a circulating air furnace. Tensile specimens processed with the canisters show the following average mechanical property values of 0.040-in. gauge alclad material:

Metal treatment	Mechanical properties UTS ksi	YS ksi	Elong. %
Braze run with canisters	48.2	28.8	11.5
Tensile test evaluation	58.2	40.6	9.7
Alcoa minimum values for T62 condition	49.0	32.0	7.0

The standard vacuum heat treat and nitrogen gas quenching of 2219 alclad develops mechanical property values that are higher than those of the braze processed material by approximately 20% in ultimate strength and 40% in yield strength. While the braze material values are close to the minimum values specified for this gauge, the mechanical properties fail to meet T62 requirements. This reduc-

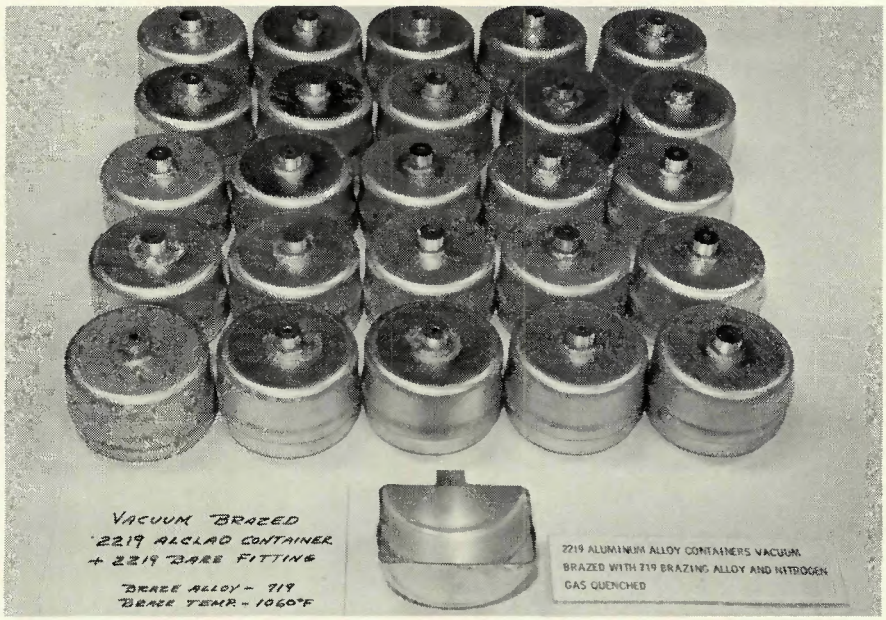

Fig. 13—Photograph shows vacuum brazed and vacuum heat treated-gas quenched 2219 alclad aluminum alloy experimental containers

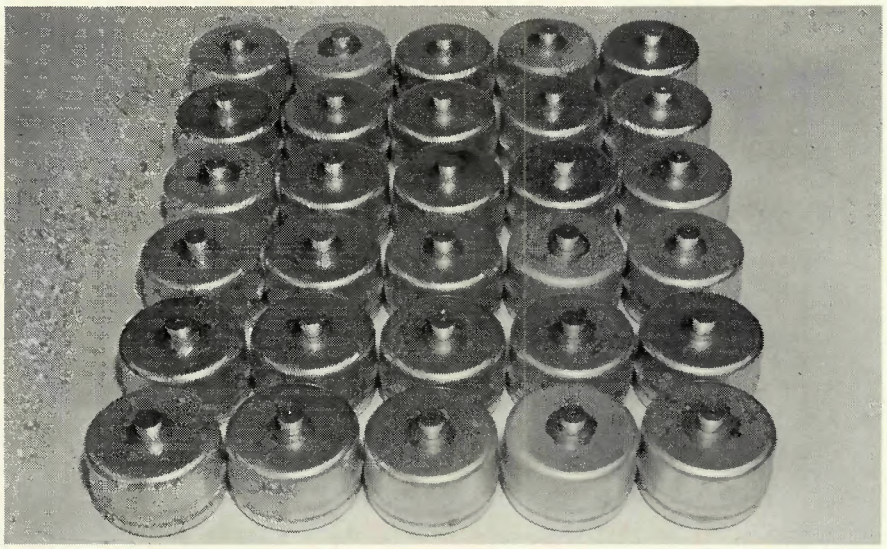

Fig. 14—Photograph shows vacuum brazed and vacuum heat treated-gas quenched 6061 aluminum alloy experimental containers

tion in properties is due to the presence of interstitial or solid solution melting developed by the brazing temperature, which exceeds the melting temperature of the base alloy (see Fig. 3).

Helium leak tests of 25 brazed and heat treated containers show 17 containers passed the helium leak test and 8 containers failed when measured on a Veeco MS-9 helium leak detector with a sensitivity of 1×10^{-4} cc/atm/sec.

The vacuum brazed, nitrogen gas quenched and artificially aged 2219 alclad containers are shown in Fig. 13.

Sectioning of a brazed container shows excellent braze alloy flow and filleting in the lap and fillet joints. Photomicrographs of the lap and fillet brazes indicate sound braze alloy joints with a minimum amount of alloying with the alclad coating of the bare material. Some solid solution melting is evident in the grain boundaries due to brazing temperature that exceeds the melting temperature of the alloy.

Vacuum brazing of 2219 alclad and 2219 with No. 719 filler metal at a temperature of 1060F produces excellent brazed joints making the process feasible for production operations, providing the presence of interstitial melting in the grain boundaries is not detrimental to the intended use of the material. Development of a braze alloy with a flow temperature that does not exceed a temperature of 1010F is required for the 2219 alloy.

Aluminum Alloy 6061

Experimental containers were formed of 6061-0 material in the same manner as the 2219 containers. The containers for brazing were assembled with a $^1/_{16}$ in. diam No. 718 filler wire placed inside of the container at the lap joint. For the attachment of the button to the container, 3 mil No. 718 brazing foil was used as a $^3/_4$ in. diam washer (Fig. 11).

The container details, brazing wire and brazing foil, were chemically cleaned before assembly. Vacuum brazing was carried out in the Abar vacuum furnace at a temperature of 1100F and a vacuum of 3.6×10^{-5} torr.

The brazed containers (Fig. 14) show excellent braze alloy flow and filleting. Metallographic examination of the brazed lap joint indicates that the braze alloy effectively wets the metal surfaces and forms a good brazed joint with a minimum of braze alloying with the base material.

On completion of the brazing cycle, the containers were solution heat treated at 970±10F for 20 minutes in the laboratory vacuum heat treat-gas quenching facility. Six containers were heated and nitrogen gas quenched per run. The average quenching time for 970F to room temperature was 20 seconds. The solution treated containers were then aged at room temperature for a minimum of three days before precipitation heat-treating at 320F for 18 hours in a circulating air furnace. This treatment completed the development of the T62 heat treat condition.

Thirty brazed containers were helium leak checked on a Veeco MS-9 helium leak detector. Twenty-five containers passed the leak test, and 5 containers developed a leak rate in excess of 1×10^{-10} cc/atm/sec. The defective containers did not pass the helium leak test because of defective braze area, where the braze alloy failed to wet the metal surface. This condition appeared to be caused by surface contamination from the precleaning operation.

Low Alloy Steel 4130

Experimental containers of 4130 steel were formed in the same manner as the 2219 and 6061 containers. The container cup details were assembled and the button was secured in place by means of four capacitance type welds made with a Weldmatic Model 1926C welding unit.

AMS 4777 braze alloy of 150 mesh was mixed with Raffi and Swanson No. 1830 clear lacquer binder to form a slurry, which was then applied to the brazed joints. After the lacquer binder dried, the excess braze alloy was removed from the container joints.

The containers were placed in the Abar vacuum furnace on a columbium hearth plate with a control alumel-chromel thermocouple placed in contact with one container. The containers were brazed at a temperature of 1925F for 15 minutes with a vacuum of 5×10^{-5} torr.

The containers show excellent braze alloy flow and filleting and on helium leak testing all 30 containers are helium leak-tight as measured by a Veeco MS-9 leak detector with a sensitivity of 1×10^{-10} cc/atm/sec.

Heat treatment of the containers was carried out by austenitizing at 1575±25F for 15 minutes in the laboratory vacuum heat treating and gas quenching facility. The containers, processed six at a time, were nitrogen gas quenched with a quenching rate of 52 seconds. After austenitizing, the containers were tempered in a circulating air furnace at 1050F for 1 hour to develop a strength level of 125,000 psi.

Maraging 18Ni250 Steel

Experimental containers were formed and assembled for brazing in the same manner as the 4130 steel containers. AMS 4777 brazing alloy was applied to the containers, and the vacuum brazing operation was carried out at 1925F for 15 minutes in the Abar vacuum furnace with a vacuum level of 5×10^{-5} torr.

Brazing of 30 containers show excellent braze alloy flow and filleting (Fig. 15). On helium leak testing, however, only 8 of 30 containers are helium leak tight as measured on a Veeco MS-9 helium leak detector. Two of the leaking containers were then rebrazed with AMS 4777 braze alloy in an attempt to seal the leaks. These containers show no change in the leak rate by the rebraze cycle.

Dye check inspection shows porosity in the braze areas. Metallographic examination of the brazed fillet joint confirms porosity and void areas in the braze metal. The braze alloy penetrates into the grain boundaries and forms an alloy zone with the base metal. This reaction appears to generate a gaseous condition, which produces the porosity areas in the braze metal.

The eight helium leak-tight containers were vacuum solution heat treated at 1500F for 30 minutes and nitrogen gas quenched with a quenching rate of 48 seconds for six containers. The quenched containers were aged at 900F for 3 hours in a circulating air furnace to complete the heat treat process.

Vacuum brazing of the maraging 18Ni250 steel with AMS 4777 brazing filler metal is not satisfactory due to resultant porosity in the brazed joint. Additional braze studies are required to obtain a suitable braze alloy that will melt and flow at a brazing temperature of 1500F to complete the brazing and solution treating processes at the same time.

Corrosion Resistant Type 321 Steel

Experimental containers were formed and assembled for brazing in the same manner as the 4130 and maraging 18Ni250 steel containers. AMS 4777 brazing alloy was applied to the containers, and the vacuum brazing operation was carried out at 1925F for 15 minutes in the Abar vacuum furnace with a vacuum level of 5×10^{-5} torr.

The brazed containers (Fig 16) show excellent braze alloy flow and filleting. All of the 31 brazed containers are helium leak-tight as measured with the Veeco MS-9 helium leak detector with a sensitivity of 1×10^{-10} cc/atm/sec.

Six of the brazed canisters were subjected to a vacuum heat treatment by heating to 1525F for 15 minutes followed by a nitrogen gas quench. The quenching rate for the six canisters is 50 seconds.

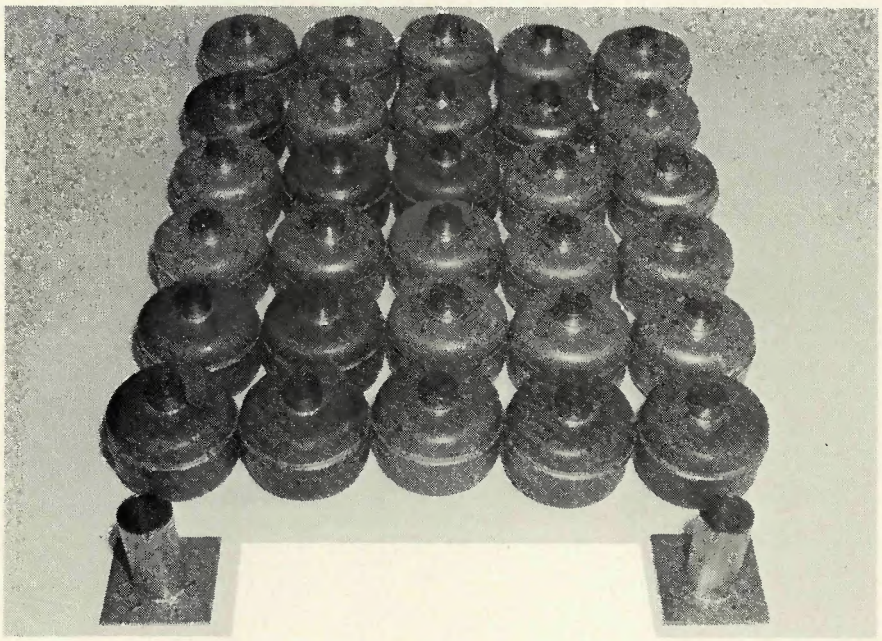

Fig. 15—Photograph shows vacuum brazed maraging 18Ni250 steel experimental containers

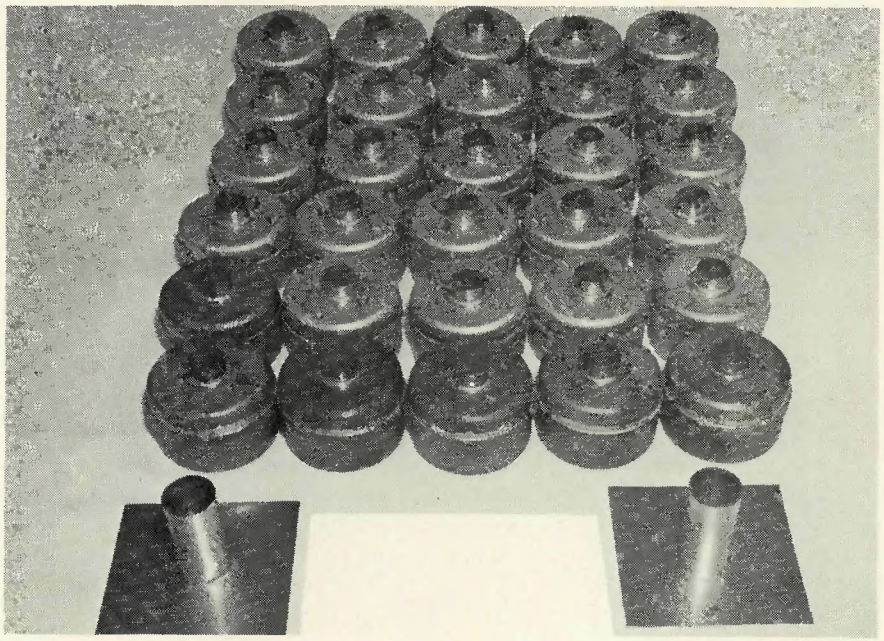

Fig. 16—Photograph shows vacuum brazed Type 321 experimental containers

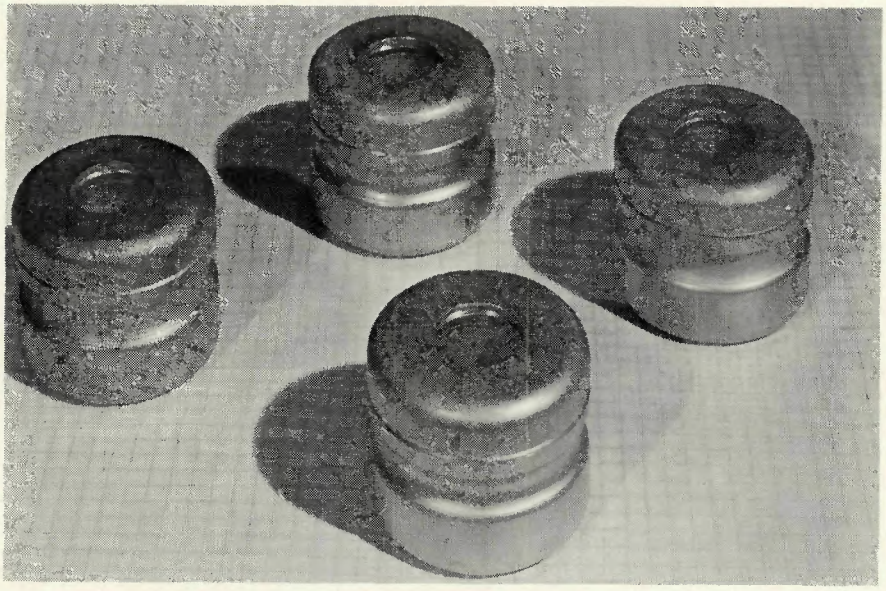

Fig. 17—Photograph shows vacuum brazed E139 bomblets

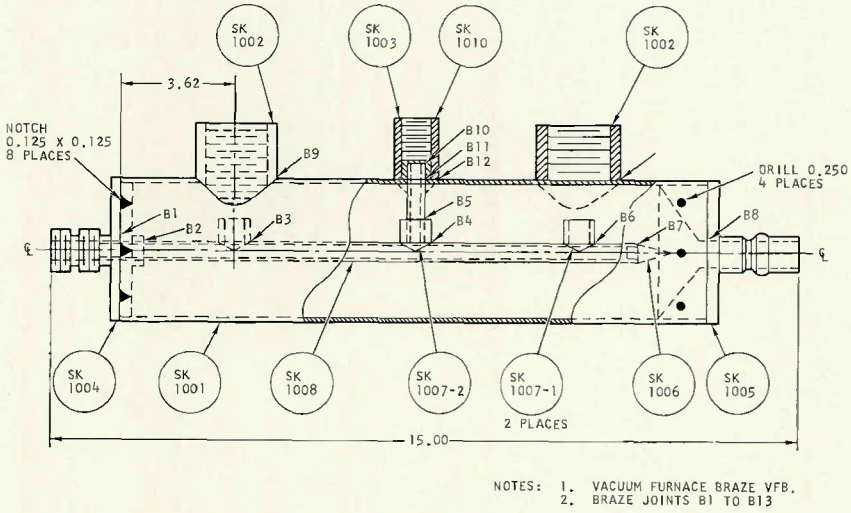

Fig. 18—Flame and/or disperser brazed assembly

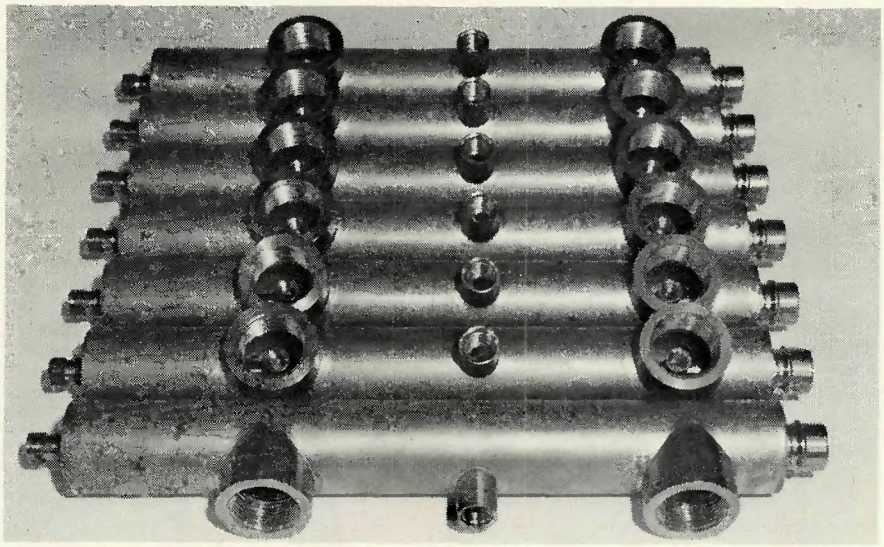

Fig. 19—Vacuum brazed manifold assemblies

Treating Hardware Items

Government furnished hardware items for treatment with the vacuum brazing and gas quenching process consisted of the following: E139 bomblets, 200; flame and/or disperser manifold assemblies, 9; and XM454 mines, 25.

All of these materials were vacuum brazed, but only the 200 bomblets were hardened by the gas quenching process because of a limitation of facilities. The procedures for treating each of the hardware items are noted in the following discussion.

Bomblets

Aluminum alloy 6061 bomblets (Fig. 17) were vacuum brazed in the Martin-Marietta Abar furnace and solution heat treated in the laboratory vacuum heat treat-gas quenching facility. The bomblet details were chemically cleaned and assembled with $^1/_{16}$-in. diam No. 718 brazing filler metal wire as noted previously for the 6061 experimental containers. The assembled bomblets were vacuum brazed at a temperature of 1100F and a vacuum level of 5×10^{-5} torr. The brazed bomblets were helium leak-tested, and out of the 200 bomblets, 34 possessed a leak rate greater than 1×10^{-10}cc/atm/sec as measured by a MS-9 Veeco leak detector.

The brazed bomblets were vacuum solution heat treated, six at a time, in the laboratory vacuum heat treat-gas quenching facility at a temperature of 980F for 20 minutes and nitrogen gas quenched. The quenching rate average is 24 seconds. After the quenching cycle, the bomblets were precipitation heat treated in a circulating air furnace at 320F for 18 hours.

The 6061 bomblets are readily vacuum brazed and heat treated by the gas quenching process. As noted previously for aluminum alloy brazing, if the detail parts are manufactured with a press fit tolerance, satisfactory helium leak-tight bomblets can be fabricated by vacuum brazing. Full 6061-T62 properties can be developed by the vacuum heat treat-nitrogen gas quenching process.

Manifold Assemblies

Nine manifold assemblies of type 321 corrosion resistant steel were vacuum brazed in the Martin-Marietta Abar furnace with AMS 4777 brazing filler metal at a temperature of 1925F and a vacuum level of 5×10^{-5} torr. The manifold assembly contained 13 brazed joints as noted in Fig. 18. Simple tooling held the parts in proper position for capacitance resistance tack welds. AMS 4777 brazing powder in slurry form was applied around

each joint as the detail parts were assembled. The assembly units were vacuum brazed without benefit of any tooling. Examination of the first brazed assembly indicated that the end fittings of the tube required additional braze alloy to complete the braze seal. The tubes were then notched at the SK1004 end fitting and four 0.125-in. diam holes were drilled in the tube at the SK1005 end fitting.

The brazed manifold assemblies (Fig. 19) were helium leak tested on the Veeco MS-9 leak detector. The first assembly brazed did not pass the helium leak test because of an insufficient amount of braze alloy at the end fittings. A rerun braze was made with additional filler metal and the assembly then passed the helium leak test. The additional assemblies with the notched and drilled holes at the end fittings are helium leak-tight as brazed and measured with a leak detector sensitivity of 1×10^{-10} cc/atm/sec.

Vacuum brazing of the manifold assemblies is an excellent method for fabricating a helium leak-tight part without evidence of warpage or distortion.

XM454 Mines

Twenty-five mines formed from low carbon steel were vacuum brazed in the Martin-Marietta Abar furnace with AMS 4777 brazing filler metal at a temperature of 1925F and a vacuum of 5×10^{-5} torr. The mine assembly contained seven brazed joints as noted in Fig. 20. A simple tooling plate was used to locate the center detail. The detail parts were assembled using capacitance-type resistance welds to hold the parts in place for brazing. AMS 4777 brazing alloy slurry was applied around the joint detail parts. The assembled unit was vacuum brazed without benefit of tooling (Fig 21).

The 25 brazed mine assemblies were helium leak-tested on the Veeco MS-9 leak detector and all assemblies passed a leak rate test of 1×10^{-10} cc/atm/sec.

The brazed mine assemblies were not hardened by the vacuum heat treat-gas quenching process because of their size, which was too large for the laboratory facility.

Conclusions

Vacuum brazing is a reliable joining process for producing helium leak-tight joints in aluminum alloy 6061, low-alloy steels 4130 and 4340, corrosion resistant steel alloys types 316 and 321 and titanium alloy 6A1-4V.

Filler metals for vacuum brazing include No. 718 for aluminum alloy 6061, AMS 4777 nickel base alloy for low-alloy steels 4130 and 4340 and corrosion resistant steels types 316 and 321 and Ticuni for titanium alloy 6A1-4V.

Vacuum brazing of aluminum alloy 2014 is not feasible at this time because of the nonavailability of a suitable commercial brazing filler metal.

Vacuum brazing of aluminum alloy 2219 alclad to produce helium leak-tight joints can be accomplished with No. 719 filler metal. However, the brazing flow temperature exceeds the initial melting temperature of the base metal producing interstitial melting, which lowers mechanical property values.

Vacuum brazing of maraging 18Ni250 steel with AMS 4777 nickel base filler metal does not produce helium leak-tight joints because of porosity in the braze alloy.

Prebraze joint tolerances for vacuum brazing to obtain helium leak-tight brazements are a press fit for aluminum alloys and a 0- to 5-mil for low-alloy steels, corrosion resistant steels and titanium alloy.

Flow temperatures of filler metals for vacuum brazing in a vacuum of 5×10^{-5} torr is 1060F for No. 719 aluminum alloy, 1100F for No. 718 aluminum alloy, 1925F for AMS 4777 nickel alloy, and 1825F for Ticuni titanium alloy.

The vacuum heat treat and inert gas quenching process develops full heat treat properties in aluminum, low-alloy steel and titanium alloys in gauges up through 0.125 in.

Inert gases of argon, carbon dioxide, helium and nitrogen will develop fulf heat treat properties in aluminum, low-alloy steel, corrosion resistant steel and titanium alloys by the rapid gas quenching process.

The optimum quenching gas for solution heat treatment of 2014 and 2219 alclad aluminum alloys is helium and for 6061 the optimum gas is carbon dioxide.

Nitrogen is a low cost quenching gas that will develop full heat treated properties in aluminum alloys 2014, 2219 and 6061; in low-alloy steels 4130, 4340 and maraging 18Ni250; and in titanium alloy 6Al-4V.

The vacuum brazing and vacuum heat treat-gas quenching process is a

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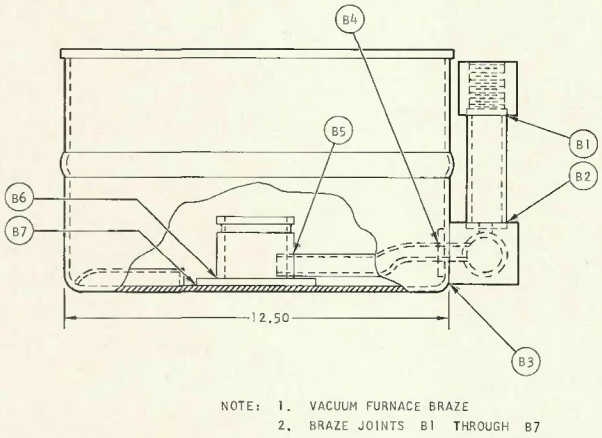

Fig. 20—Sketch of XM454 mine. Note: vacuum brazed joints B1 through B7

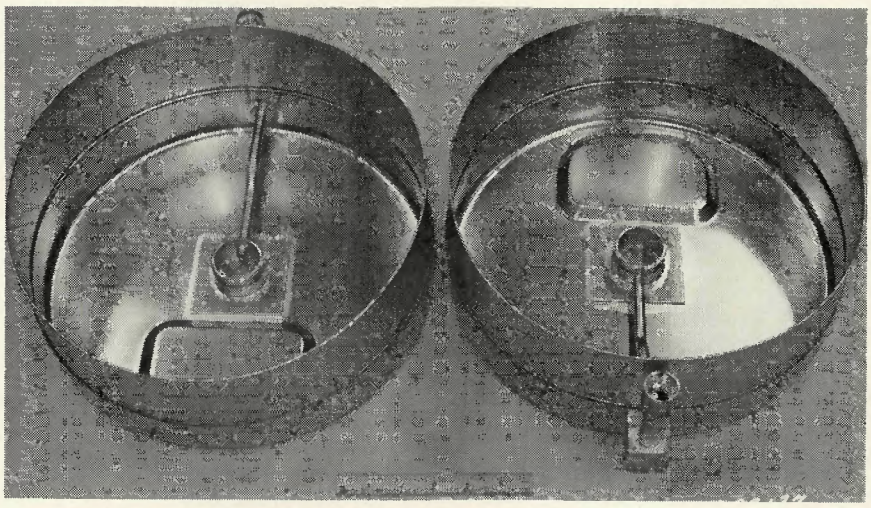

Fig. 21—Photograph shows tooling and detail parts of XM454 mine