AERONCA, INC.

GERMANTOWN ROAD - MIDDLETOWN, OHIO

VOLUME I - BRAZING ALLOY DEVELOPMENT AND SELECTION

FINAL REPORT

DEVELOPMENT OF HIGH STRENGTH,
BRAZED ALUMINUM, HONEYCOMB SANDWICH
COMPOSITES ADAPTABLE FOR BOTH ELEVATED
& CRYOGENIC TEMPERATURE APPLICATIONS,

FOR

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

CONTRACT NO. NAS8-5445

PERIOD OF PERFORMANCE JULY, 1963 THROUGH SEPTEMBER, 1966

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NOTICES

This report was prepared by the Middletown Division of Aeronca, Inc. under National Aeronautics and Space Administration contract NAS8-5445, "Development of High Strength, Brazed Aluminum, Honeycomb Sandwich Composites Adaptable for both Elevated and Cryogenic Temperature Applications". The work was administered under the technical direction of the Propulsicn and Vehicle Engineericg Division, Engineering Materials Branch of the George C. Marshall Space Flight Center with F. P. LaIacona acting as Project Manager.

ABSTRACT

This report is Volume I of two volumes which describe the work accomplished on fluxless brazing high strength aluminum alloys under contract NAS 8-5445 for NASA, Marshall Space Flight Center, Huntsville, Alabama. In addition to the present two volumes, an annotated bibliography on aluminum brazing was published separately. The program covered a three year period from July '1963 to September 1966. The primary tasks were divided as follows:

1st Year: Investigate commercially available brazing alloys.

2nd Year: Optimize processes and tools to improve wetting and flow of commercially available brazing alloys.

3rd Year: Develop new brazing alloys with improvements over those commercially available.

Volume I of this report presents the brazing alloy development and selection while Volume II contains the results of fabrication, testing (-423°F to 600°F) and evaluation of feasibility hardware.

Commercially available brazing alloys, No. 716 and No. 719, were used to successfully braze X7005, X7106 and 7039 honeycomb core sandwich panels. New brazing alloys in the systems Al-Ge-Si-Zn and Al-Ge-Si-Ag, were developed and successfully joined X7106. Feasibility hardware have shown that node flow can be achieved and that node filleting plus the properties of the brazing alloy demonstrated improvements over comparable bonded structures. Brazed sandwich panels show improved resistance to delamination and predictable performance over a wide temperature spectrum.

It was concluded that optimum brazing alloy wetting and flow required the brazing alloy to be clad onto the substrate metal. However, acceptable" brazements were produced by using separately placed brazing alloy foil,.

The experimental results from quenching and heat treating studies showed that aluminum honeycomb sandwich panels can be quenched into liquid nitrogen with minimum distortion. Large flat and cylindrical section sandwich brazements were fabricated by that method. Consequently, high strength alloys with rapid quench rate requirements may be utilized for both core and facing materials,

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1. INTRODUCTION

Realizing the advantages of brazed honeycomb sandwich structures for applications such as liquid oxygen tankage and space vehicles, NASA, by contract to Aeronca, Inc., undertook the development of processes for brazing high strength aluminum alloys. The requirements of the program, as set forth in NAS8-5445, were the following (in abbreviated form):

(1) The sandwich face sheet materials shall be readily available high strength alloys which shall include the 2000, 5000, 6000, and 7000 aluminum alloys series.

(2) The core materials shall be from the 5000 and 6000 aluminum series. The honeycomb core structure shall be restricted to the hexagonal core configuration with the thickness confined to the one-half inch to one inch range.

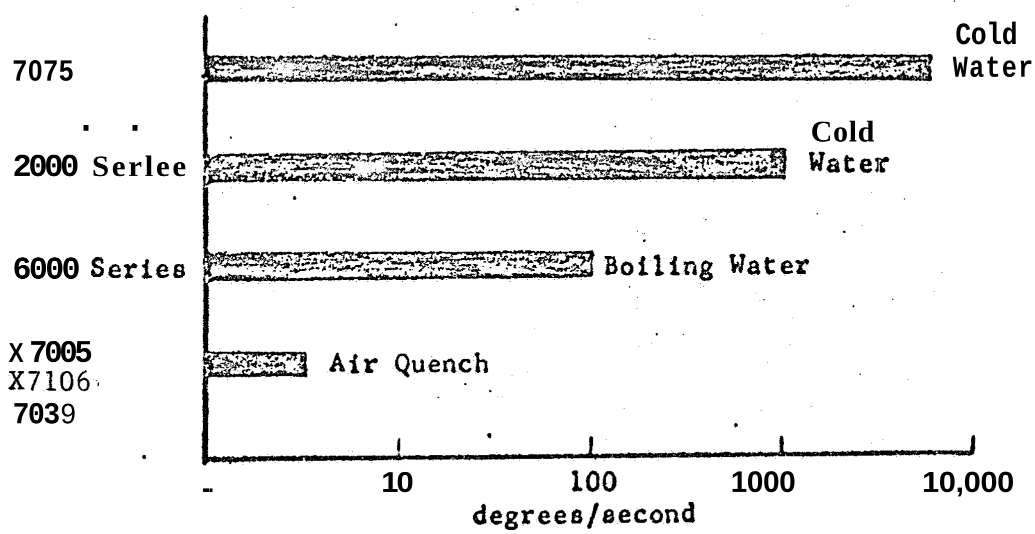
(3) Braze materials shall be selected initially from the brazing aluminum-silicon group with subsequent selections from experimental aluminum braze alloys.

A brief background on properties of heat treatable aluminum alloys will serve to explain the direction of work. Listed below are the recommended solution heat treatments and the melting ranges of some alloys.

Alloy	Solution Heat Treatment	Melting Range
7075	870°F	890 - 1175°F
6053	970	1100 - 1205
6061	970	1100 - 1205
6951	970	1140 - 1210
2014	940	950 - 1180
2024	920	935 - 1180
2219	1000	1010 - 1190
X7005	750	1125 - 1195
X7106	860	1090 - 1185

To develop' full mechanical properties of these structural alloys, it would be necessary to braze at or above the solution heat treat temperature, followed by quenching and age hardening.

The recommended quenching rates of some alloys are given below:



Clearly, the 6,000 series and X7005 alloys would be preferred for manufacturing sheet metal brazements based on melting point, quenching rate, and fewer distortion problems. The 2,000 series alloys might be acceptable, if very good control was exercised and suitable brazing alloys were found.

Acceptable melting ranges (or liquidus temperatures) of brazing alloys for the structural alloys and melting ranges of available brazing alloys are compared in Table 1. It is apparent that the available brazing alloys, at best, are useful for X7005, X7106, X7039 and the 6,000 series structural alloys.

The second category of brazing alloys would be those which would have liquidus temperatures within the approximate range of 750° to 1050°F. This range includes the zinc-base soldering alloys, other hard solders, and

Table 1

Melting Ranges of Aluminum Structural Alloys & Aluminum Brazing Alloys

Structural A	Acceptable Melting Range for Brazing Alloys	Melting Range of Available Brazing Alloys
2014	900 - 940 °F	1070 - 1165 °F - 4043
2024	approx. 900 - 920	1070 - 1135 - 713
2219	930 - 1000	970 - 1085 - 716
6000 series	970 - 1095	1070 - 1080 - 718
X7106	860 - 1080	960 - 1040 - 719 (available only in wire)
X7005	750 - 1100	

perhaps less well known but applicable alloys. A literature search was conducted to uncover such alloys and/or suitable systems *for* alloy development. The results of that survey were published separately.*

*References are given in: "Bibliography on Development of High Strength, Brazed Aluminum Honeycomb Sandwich Composites Adaptable for Both Elevated, and Cryogenic Temperature Application", NAS8-5445, Aeronca Mfg. Corp., B. E. Kramer, September 27, 1963.

1.1 SYNOPSIS OF PROGRAM **WORK** STATEMENT

1963 - 1964: Phase I - Literature search for readily available braze alloy for fluxless brazing and air quenching honeycomb structures of'alloys in the 2000, 5000, 6000 and 7000 series.

Phase II - Select six most promising braze alloys from literature search above.

Phase III - Fabricate, test and evaluate hardware from alloys selected above.

1964 - 1965: Phase I - Expansion of literature search.

Phase II - Select four new readily available braze alloys, determine way to obtain metallurgically bonded honeycomb core, investigate tooling and processes necessary to achieve suitable wetting of the braze alloy on the desired structural materials.

Phase III - Fabricate, test and evaluate hardware from alloys selected above.

1945 - 1966: Phase I - Develop brazing alloy combinations not commercially available and conduct screening tests.

Phase II - Select two alloys from above and fabricate, teat and evaluate hardware from high strength alloys selected.

2. EVALUATION AND SELECTION OF COMMERCIALLY AVAILABLE MATERIALS

2.1 EQUIPMENT, MATERIALS AND METHODS

Laboratory Tube Furnace

Laboratory brazing tests and flow tests of experimental brazing alloys were conducted within a quartz muffle containing a pure argon atmosphere. The equipment is schematically shown in Figure 1 .

The quartz retort was square bore, large enough to braze sandwich specimens approximately ½" x 1" x 3". Face-to-core clamping pressure was provided by dead-weight loading using strips of copper and the copper weights were separated from the aluminum specimens by fiber glass cloth to prevent alloying,

A high purity grade of argon was used. It was analyzed and certified at <4 ppm oxygen and used at Aeronca to calibrate Beckman hygrometers, which are installed in the argon service line to the Manufacturing Department. The argon gas used for production brazing is equivalent in purity to the laboratory supply; consequently, production brazing would be done under equivalent gas conditions.

Prior to heating the specimens, the quartz tube was purged until its atmosphere of argon measured -80°F dew point. Cup type dew pointers were placed at both the inlet and outlet gas lines. The relationship between dew point and parts per million water vapor is shown below:

Dewpoint (All Gases)*

Dewpoint is the temperature at which a given mixture of gas and water vapor is saturated. Below that temperature, water will condense out of the gas. The table below shows approximate dewpoints based on the moisture content in grains per 1,000 cu. ft.

Moisture Content (Grains per 1,000 cu. ft.)*	Dewpoint Deg. F.	Deg. C
.01	–141	–96
.02	–135	–93
.04	–128	–89
.06	–124	–87
.08	–121	–85
.1	–119	–84
.2	–111	–80
.4	–104	–75
.6	–99	–73
.8	–96	–71
1.0	–93	–69

Moisture Content (Grains per 1,009 cu. ft.)*	Dew int Deg. F.	Deg. C
2	–84	–64
4	–76	–60
6	–70	–57
a	–66	–54
10	–62	–52
20	–52	-47
40	–42	–41
60	–35	–37
80	–30	–34
100	–27	–33

*1 grain equals approximately 3 parts per million. 7,000 grains equal 1 lb.

*Linde technical bulletin.

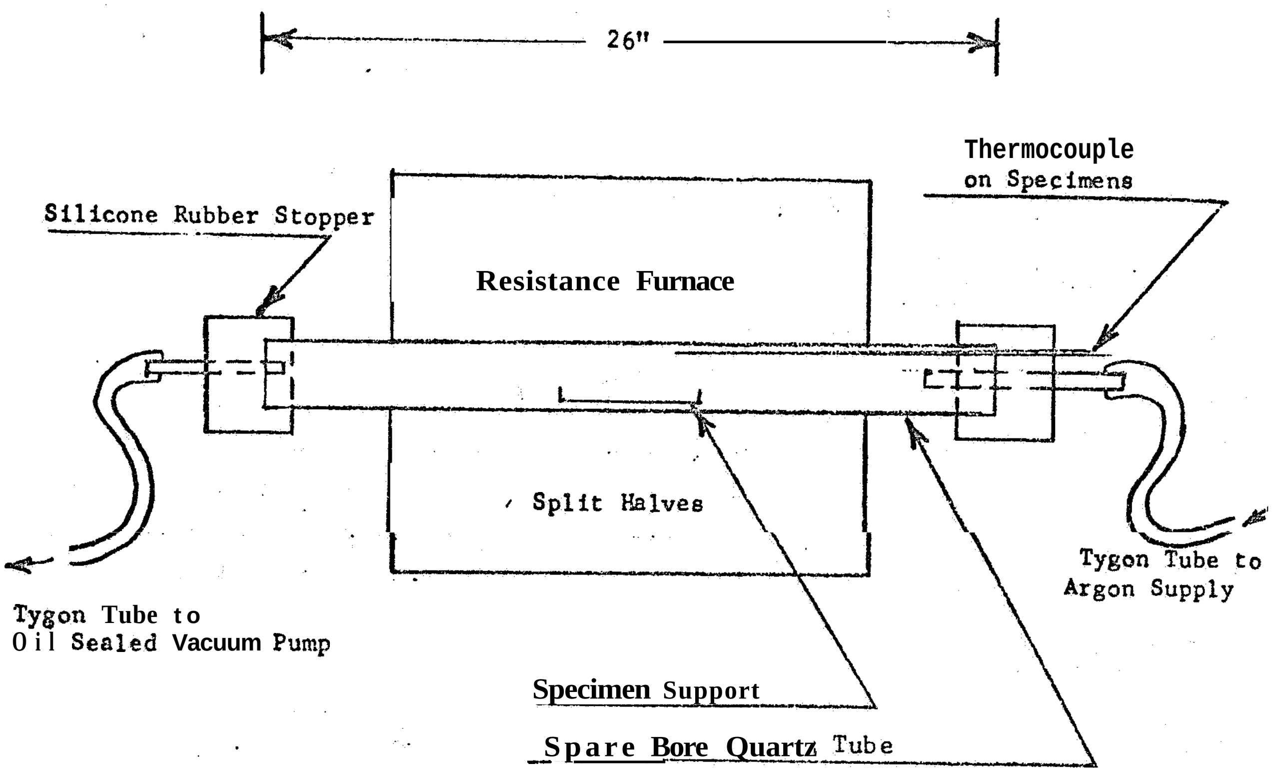


Figure 1 Schematic Drawing of Apparatus Used €or Melting Point and Flow Tests of Experimental Brazing Alloys

Scale-Up Brazements

Sandwich specimens larger than 1" x 3" were brazed within welded retorts. Sandwich face-to-core clamping pressure was provided by partially evacuating the retorts. The clamping pressures used were, typically, within the range 0.1 to 0.5 psi. Retort materials were carbon steel, stainless steel, and aluminum alloys. Reasons for the choice of specific retort materials are described within in the appropriate sections. Although the design of retorts is flexible, Figure 2 shows the type of retort which was used.

Honeycomb Core Procurement and Fabrication

During the majority of this program, honeycomb core procurement has been a substantial problem and contributed to some schedule delays.

An arbitrary decision, early in the program, was that core to be used would be heat treatable alloys, metallurgically bonded. First, it proved to be impossible to obtain any of the desired heat treatable alloys as foils from commercial sources.*

Inasmuch as the alloys would have to be rolled experimentally, it was decided to work with rather thick gages - 0.005" to 0.010". Alcoa gratuitously supplied small quantities of 6951 and X7005 in these gages for experimental work. Alloys 0.008" thick were arbitrarily selected for further work and 25 lbs. each of 0.008" thick 6951 and X7005 were procured from the Alcoa Research Lahoratory.

For the second and third year of the program 0.005" thick X7005 and 2024 foils were procured. Alloy 2024 was obtained commerically, but X7005 was obtained by rolling 0.032" thick sheet to 0.005". The rolling was done by Rodney Metals, New Bedford, Mass.

Samples of various thin gage core materials were sent to the various core makers and requests for quotations solicited.

Only Kentucky Metals, Incorporated, Louisville, Kentucky, was able to supply welded core. Their welding was done by hand, one node at a time, on ultrasonic welding equipment. Kentucky Metals supplied approximately 30 square feet of core, 3/8" cell size, by ½" thick blanket, in square cell configuration.

In addition, resistance welded core was produced at Aeronca.

*Foils of 1100 and 3003 are readily obtainable. 2024 is now available from American Lamolite Corporation, Cleveland, Ohio.

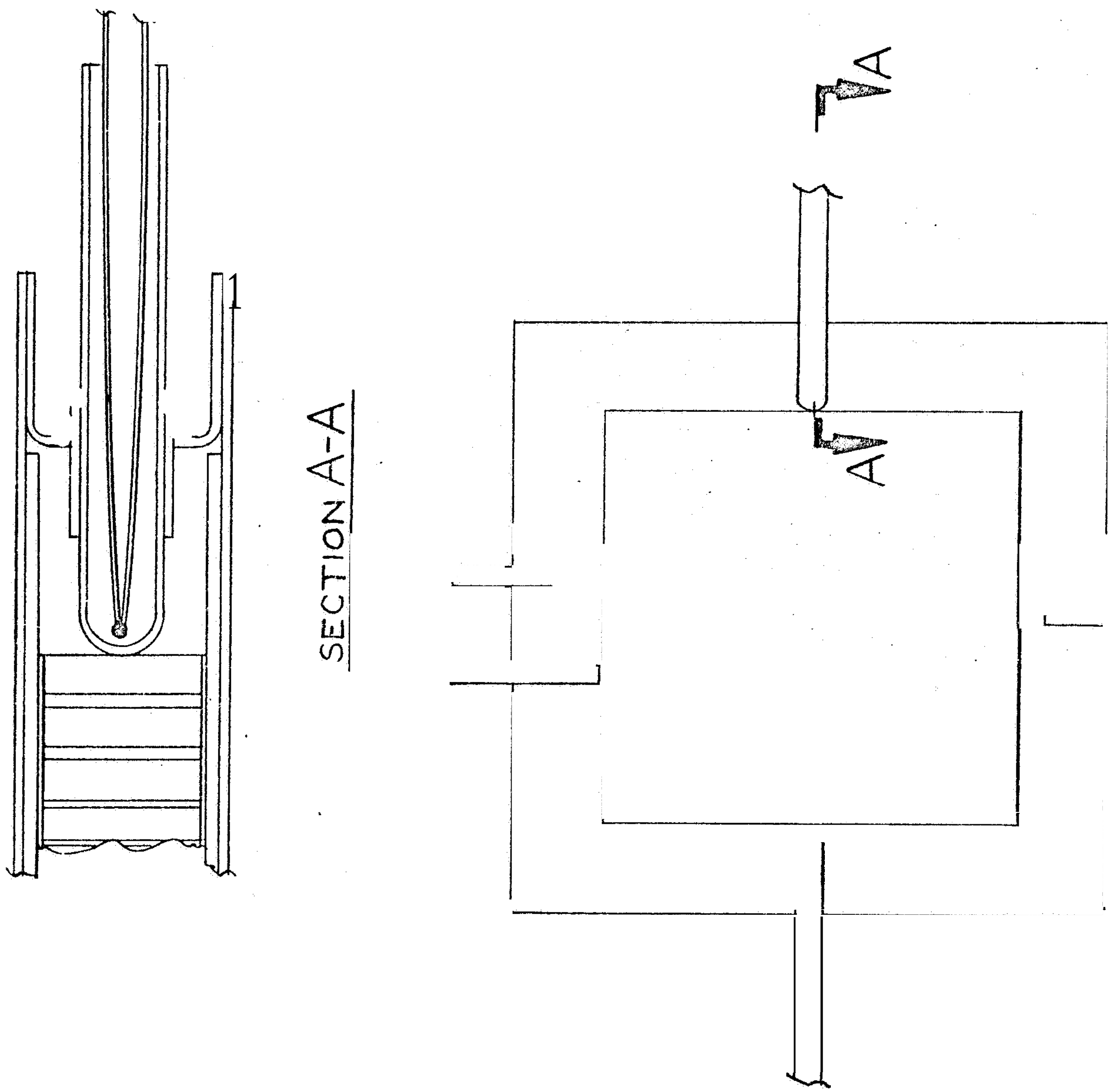


Figure 2 - Schematic Drawing of a Typical Brazing Retort

The Aeronca core blankets were of the hexagonal cell configuration. Accordingly, all discussions of honeycomb core throughout this report can be related to the appropriate vendor: square cell - Kentucky Metals; hexagonal cell - Aeronca.

A typical Aeronca produced core blanket is shown in Figure 3. The blanket thickness was 0.6". The core type was 6-80 n.p., hexagonal cell (3/8" cell size, 0.008" thick non-perforated ribbon).

Heat Treatment Study - Tensile Data

Inasmuch as all of the brazing cycles constituted more or less non-standard heat treatments, some of the bare and braze clad materials were heat treated through typical brazing cycles, aged, and tensile tested. The procedure follows:

Specimens: 0.040" thick sheet metal, 5" x 8" in size

Material Condition: F temper - as rolled

Instrumentation: Chromel-Alumel thermocouple bead peened into a slit in each sheet specimen

Furnace: Hevi-Duty recirculating air furnace

Procedure: An instrumented specimen was placed on a brick within the pre-heated furnace, withdrawn after the correct time and quenched as shown in Table 2.

Table 2 presents the results of the tests conducted.

Below each group of data, 'minimums' or 'typicals' are listed in parentheses. 'Minimums' (where available) were from 'Aerospace Structural Metals Handbook, Volume II, Non-Ferrous Alloys, 'ASD-TDR-63-741, March, 1963. 'Typicals' and other 'Minimums' were from Alcoa handbooks or data sheets.

Reductions in tensile strength, yield strength, and elongation were noted for the brazing alloy clad aluminum alloys. Because any aluminum - aluminum brazing alloy system must be a reactive system, some degradation in mechanical properties was to be expected for a brazed configuration. However, it will be shown in Volume II that in some instances the aluminum brazing alloys increased the yield strength of X7005, although the tensile strength and elongation were reduced.

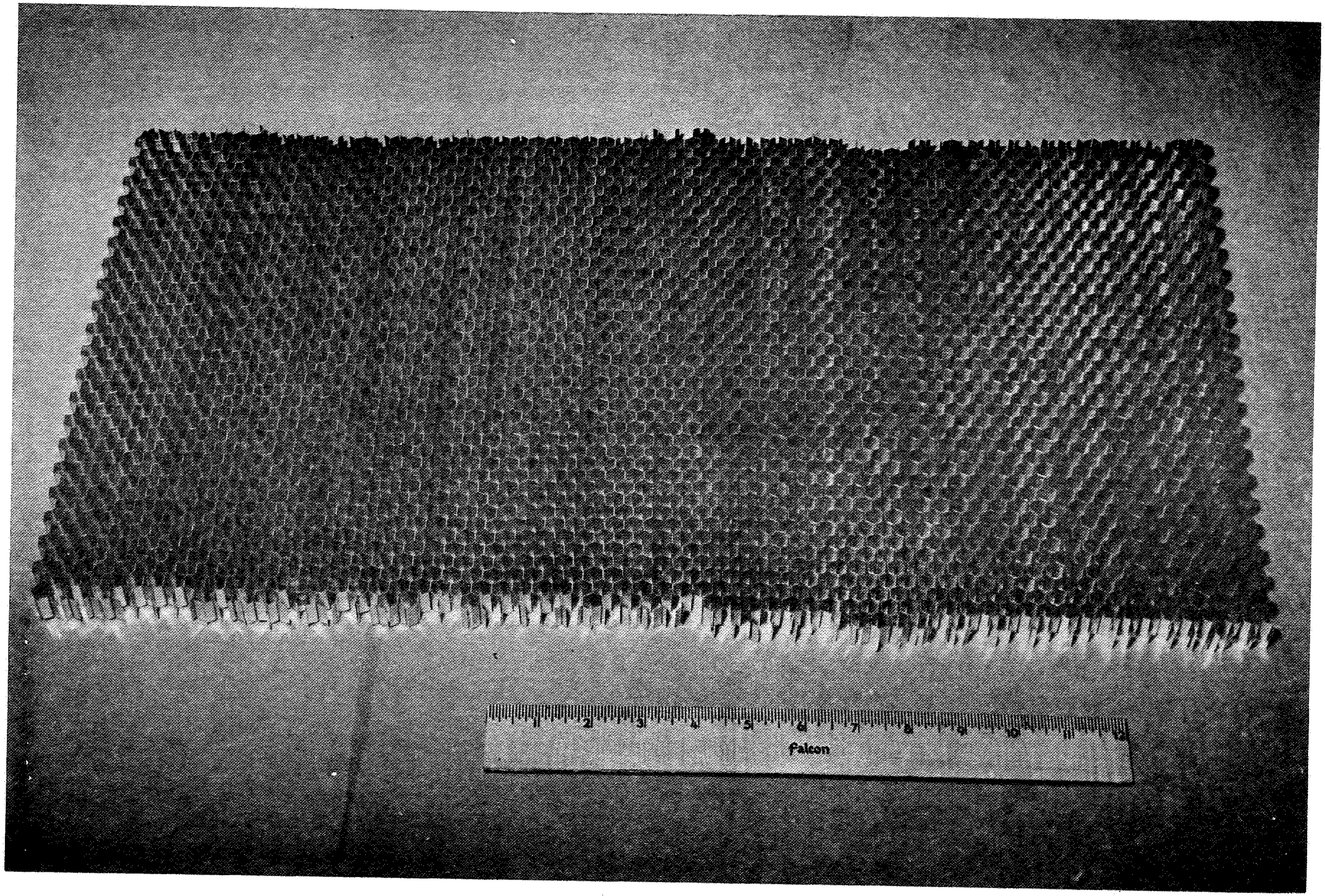


Figure 3 Resistance Welded Honeycomb Core Blanket shown prior to Trimming.
Material is X7005-0, 0.008" Foil Thickness.
Core Type is 6-80x6/10" n.p.

TABLE 2

TENSILE DATA - HEAT TREAT STUDY

Material: Aluminum Alloy Sheet, 0.040 Thickness

Specimen Number	Ultimate Tensile Strength - KSI	Yield Strength 0.2% Offset KSI	Elongation Pei- Cent
1. 2014, 930°F 5 min., water quenched, aged 9 hours at 340°F			
1	74.7	62.5	16.5
2	75.2	62.0	10.5
3	75.7	62.5	10.0
T-6 Min.	(67)	(59)	(7)
2. 2024, 930°F 5 min., water quenched, aged 9 houre at 375°F			
1	66.5	50.0	10.0
2	69.0	50.0	13.5
3	69.7	49.5	13.5
4	68.0	50.7	10.5
T-6 Min.	(64)	(50)	(5)
3. 2219, 990°F 5 min., water quenched aged 9 hours at 375°F			
1	64.0	46.1	10.5
2	64.0	45.7	10.0
3	63.0	45.2	9.0
4	62.5	44.2	9.5
5	63.0	45.5	11.0
T-62 Typ.	(60)	(42)	(11)
4. 6061, 1050°F 5 min., boiling water quenched, aged 20 hours at 320°F			
1	31.2	44.7	13.0
2	51.5	44.7	14.0
3	51.5	45.1	13.0
T-6 Typ.	(45)	(40)	(12)
T-6 Min.	(42)	(35)	(4-10)
5. 6951, 1110°F 10 min., boiling water quenched, aged 20 hour8 at 320°F			
1	46.0	39.7	11.5
2	45.9	39.8	12.0
3	45.4	39.7	12.5
4	46.2	39.9	11.5
T-6 Typ.	(39)	(33)	(13)

TABLE 2

Specimen Number	Ultimate Teneile Strength - KSI	Yield Strength 0.2% Offset KSI	Elongation Per Cent
6. 6951, 1110°F 5 min., boiling water quenched, aged 20 hours at 320°F			
1	46.6	40.0	13.0
2	46.1	40.1	11.5
3	46.3	39.9	11.0
4	46.4	39.9	12.0
5	46.3	39.6	13.5
T-6 Typ.	(39)	(33)	(13)
7. Brazing Sheet #23 (6951 clad one side 10%, 714 alloy) 1110°F 10 min., boiling water quench, aged 20 houre at 320°F			
1	37.2	32.3	5.5*
2	36.1	31.7	5.0
3	36.1	32.4	4.5
4	36.6	33.1	5.0
8. Brazing Sheet #23 (6951 clad one side 10%, 714 alloy) 1110°F 5 min., boiling water quench, aged 20 hours at 320°F			
1	35.7	31.9	5.0
2	34.6	34.2	0.6*
3	35.4	33.1	3.0
4	34.6	32.4	1.0
9. X7005, 1100°F 10 min., boiling water quench, aged 5 days room temperature and 48 hours at 250°F**			
1	49.4	39.6	16.0
2	47.5	38.9	14.0
3	48.6	39.2	15.5
4	47.9	39.1	25.0
T-6 Typ.	(51)	(42)	(13)
T-6 Min.	(45)	(36)	(7)
10. X7005, 1100°F 5 min., water quench (room temp. water), aged 5 days room temperature and 48 hours at 250°F**			
1	47.3	38.3	12.5
2	46.9	37.9	14.0
3	45.4	37.8	14.0
4	47.1	38.1	14.0
5	46.4	37.9	11.0
T-6 Typ.	(51)	(42)	(13)
T-6 Min.	(45)	(36)	(7)

*Failed outside of gage length. Uneven brazing alloy flow noted.
**Non-standard. Recommended Procedure: Air quench, age 1 day at room temperature followed by 48 hrs. at 250°F.

TABLE 2

	Specimen Number	Ultimate Tensile Strength - KSI	Yield Strength 0.2% Offset KSI	Elongation Per Cent
11. X7005 Braze Clad (X7005 clad one side 4%, 718 alloy) 1100°F 10 min., boiling water quench, aged 5 days room temperature and 48 hours at 250°F.				
	1	42.3	33.0	6.5
	2	41.2	32.6	0.5
	3	41.1	31.7	7.0
	4	42.3	33.2	6.5
12. X7005 Braze Clad (X7005 clad one side 4%, 718 alloy) 1100°F 5 min., boiling water quench, aged 5 days room temperature and 48 hours at 250°F.				
	1	35.7	29.5	4.0
	2	44.3	33.4	11.5
	3	44.0	33.9	10.5
	4	43.6	33.7	9.5

Brazing Alloys

The commercially available aluminum brazing alloys were listed in the introduction and are described more fully in Appendix A of this report, All of the commercial brazing alloys were evaluated except 4043 which was not compatible in melting range with the basis metals used.

Cleaning

From the literature survey, it was apparent that oxide-free aluminum components could not be assembled for brazing unless such assembly was done either very quickly or within an inert environment. Significantly, Corey and Russel* vacuum brazed aluminum alloys without any precleaning other than degreasing. The oxide film was said to craze during heating which exposed clean metal to the brazing alloy. The brazing alloy used by them was Al-8%Si**.

The present industrial method of removing oxide coatings from aluminum alloys, involves the use of etchants. Reference i-3 describes several of these methods,*** In addition, the Miller patent, reference H-2, described the interesting aluminum oxide solvent consisting of anhydrous hydrogen fluoride dissolved in alcohol. It was said to remove the oxide without attacking the substrate. Miller uses it for etching aluminum metallographic specimens.

The sodium hydroxide-nitric acid method was invariably used throughout the present work, unless specifically noted otherwise.

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* Alcoa, personal communication.

** All alloy compositions listed within are given in weight per cent.

*** References are listed in the separately published Bibliography, see Page 4, within.

2.2 SANDWICH PANEL BRAZING INVESTIGATIONS

This section and Section 2.3 describe the brazing methods and results for 17 honeycomb core sandwich brazements, the order of one square foot in size. Prior to brazing each panel, laboratory sandwich brazements were made in the tube furnace to establish brazing temperatures; but, the brazeability of a metal system was not considered established until its merits were determined in production-type hardware fabrication. The chronology of these brazernents was related to procurement of materials and honeycomb core.

Panel No. 1

Faces: 0.040" 823 Brazing Sheet

Core: 6-80 x 1/2" n.p. 6951, square cell

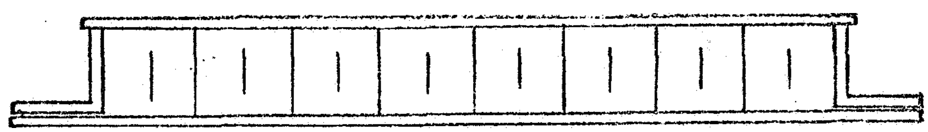
Edge Members (2): L section, 0.040" #23 Brazing Sheet

Nominal Size: 8" x 12" overall

Vacuum Within Retort: to produce 0.2 psi pressure on panel

Brazing Schedule: 1110 $\pm$ 5°F, 6-10 min., heat and quench at fastest practical rate.

The panel cross section is illustrated below:



(Not to Scale)

The core was machined flat on Onsrud core machining equipment. A thickness of 0.030" was removed from each side leaving a core thickness of 0.42". Ivory soap was used as the lubricant during machining and the core was chucked to the machine bed in a water soluble product trade named Zincalate. The lubricant and/or chucking medium left a residue, or reaction product, on the core, which could not be removed by standard degreasing and NaOH-HNO_3 cleaning. An HNO_3-HF mixture was found to be satisfactory for removing it; consequently, all of the aluminum details were duplex cleaned: first in HNO_3-HF, then by the standard process of hot NaOH followed by a rinse and HNO_3.

The cleaned parts were stored in an argon filled cabinet until panel assembly could be done. No flux nor flow promoter was used.

The assembled detail parts are shown within the retort in Figure 4. Additional metal within the retort was steel tooling core and X7005 and 6951 coupons for tensile specimens.

A photograph of the panel is shown in Figure 5. The radiographic inspection record is shown in Figure 6.

Analysis of the panel was as follows:

Core-to-Face Braze: Braze was good, but fillets were small; void area was noted on lower face.

Node Flow: None

Core Buckling: None

Edge Member to Upper Face 'T' Joint: 80% brazed

Shear Tie (Core edge-to-vertical edge member): None was planned, but where contact was made the braze was satisfactory.

Metal-to-Metal (flat, horizontal portion of the edge member-to-bottom face): about 50% void.

Recommendation: Extend heating cycle about 2 minutes or increase temperature 5 to 10°F. Provide for additicnal pressure on flat, horizontal portion of edge member (metal-to-metal).

Pane? No. 2 was brazed similarly, but with the addition of 2 gm/sq. ft. magnesium powder applied eo the braze clad faces, and the partial pressure within the retort was adjusted to provide 0.3 psi on the retort.

Analysis of panel No. 2 follows:

Core-to-Face Braze: Good filleting throughout

Node Flow: None

Core Buckling: None--very slight face dimpling occurred

Edge Member to Upper Face 'T' Joint: Good braze overall

Shear Tie (core edge-to-vertical edge member): None was planned, but where contact was made the braze was satisfactory.

Metal-to-Metal (flat, horizontal portion of edge member-to-bottom face): 100% braze one side of the panel, about 50% void on the other side.

Analysis of Brazed Panels No. 1 and No. 2

Panels No. 1 and No. 2 had 6951 core (type 6-80 x 1/2") and #23 brazing sheet faces (6951 clad with 714 alloy). They were brazed nearly identically except that Panel No. 2 had magnesium powder added to promote brazing alloy flow and filleting. Photomicrographs in Figures 7 through

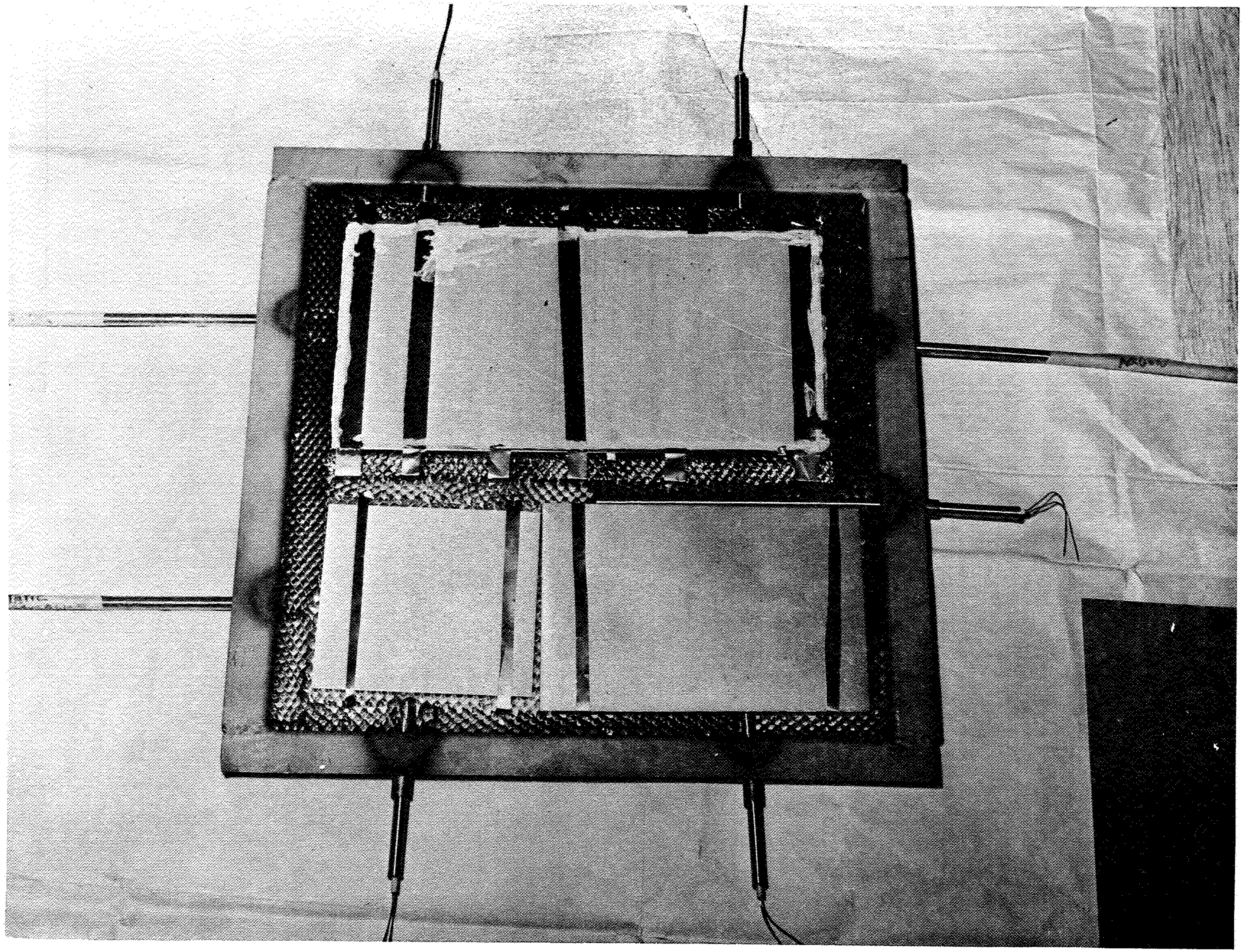


Figure 4 Lay-up of Detail Parts for Panel No. 1. The parts are surrounded by Stainless Steel Tooling Core and are within a Mild Steel Retort. Closed end Thermocouple Tubes and Gas Tubes are shown welded into the Retort Wall.

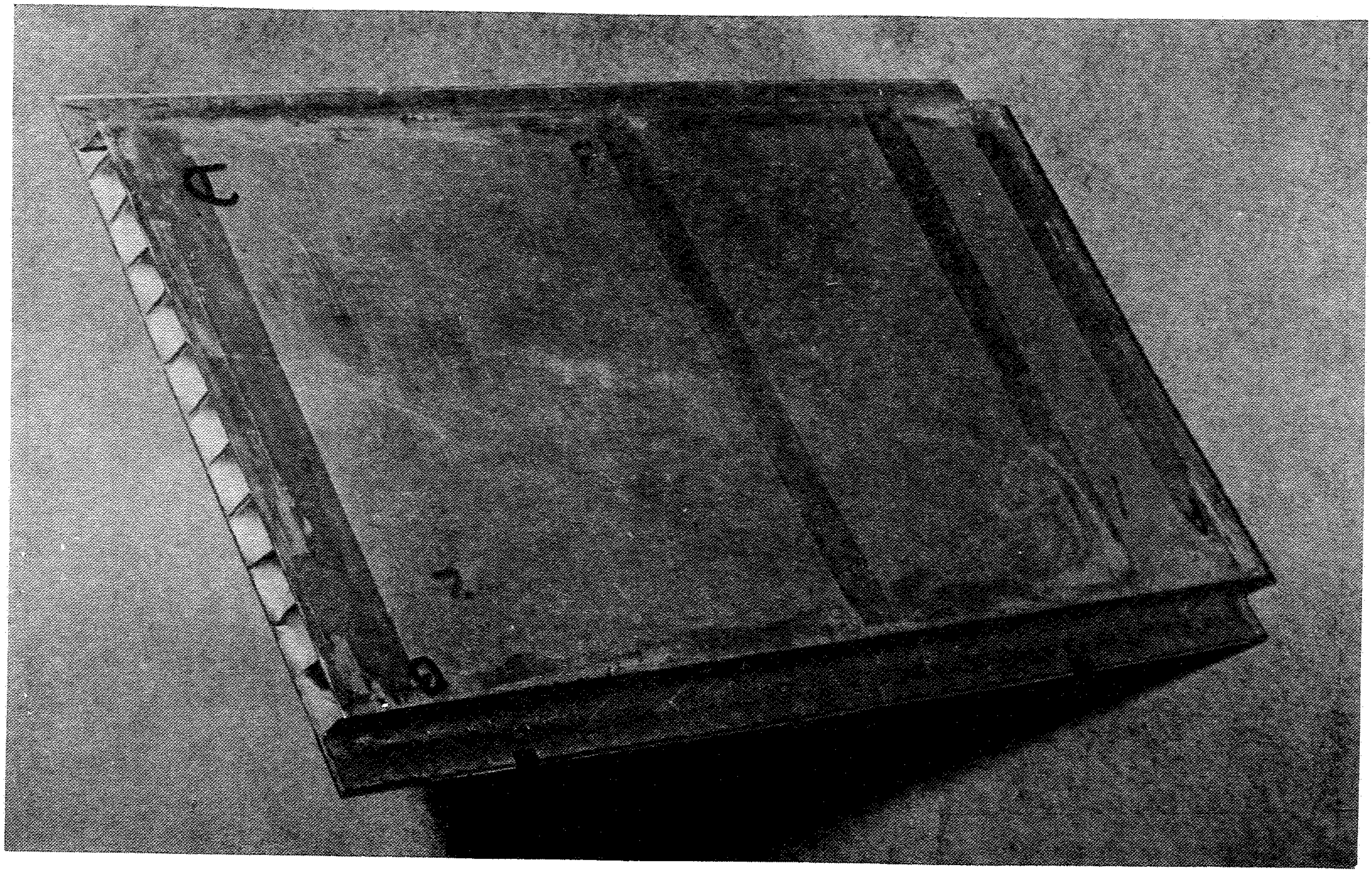


Figure 5 Panel No. 1 shown after Brazing. Faces are 0.040", #23 Brazing Sheet (6951), and the Core is 6-80 x ½ np 6951. Braze Cycle was 7 minutes within the Range of 1100°F, Argon Atmosphere, 0.2 psi on Retort as a result of Partial Vacuum within the Retort. Overall Panel Size was 7" x 12".

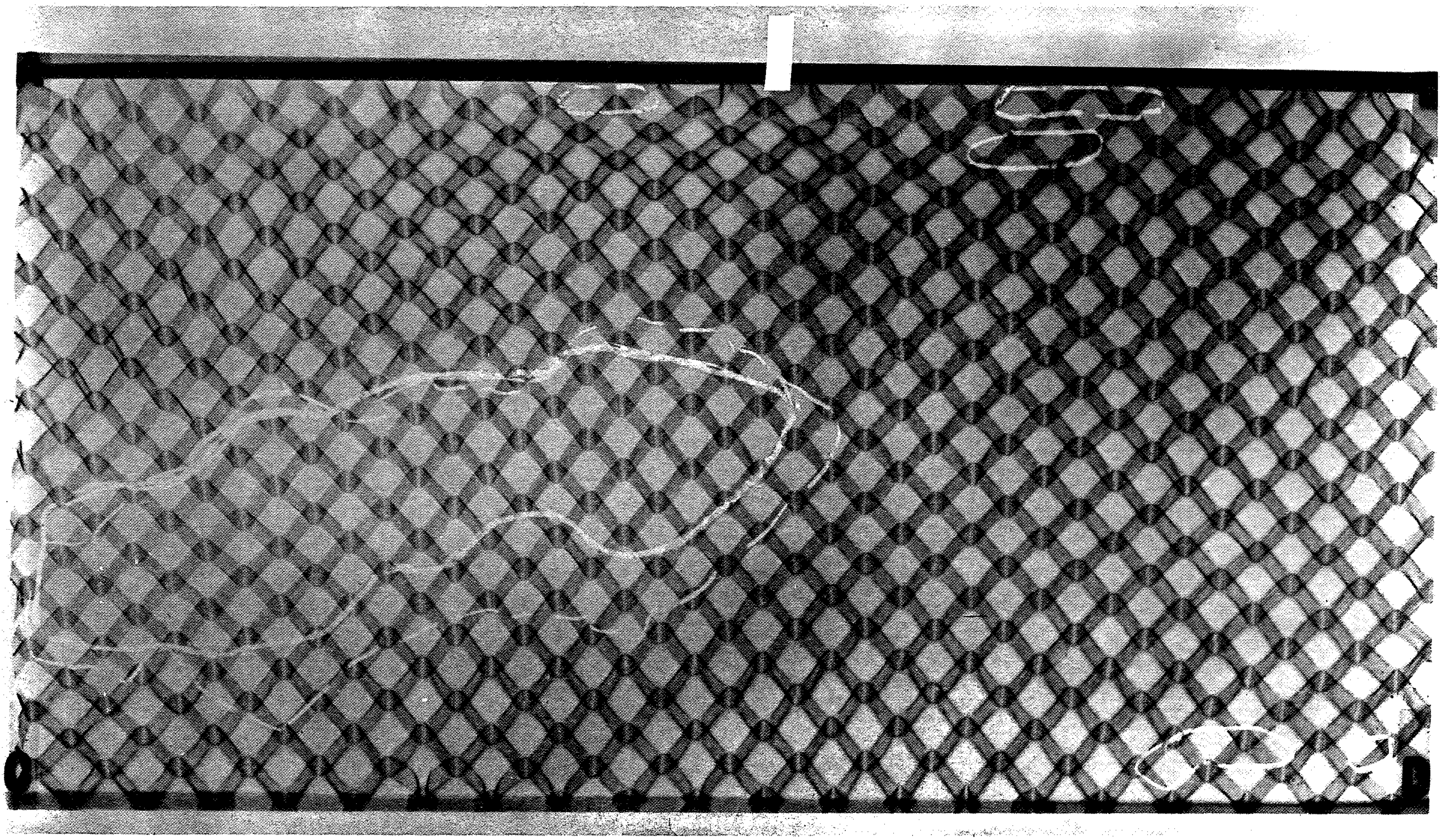
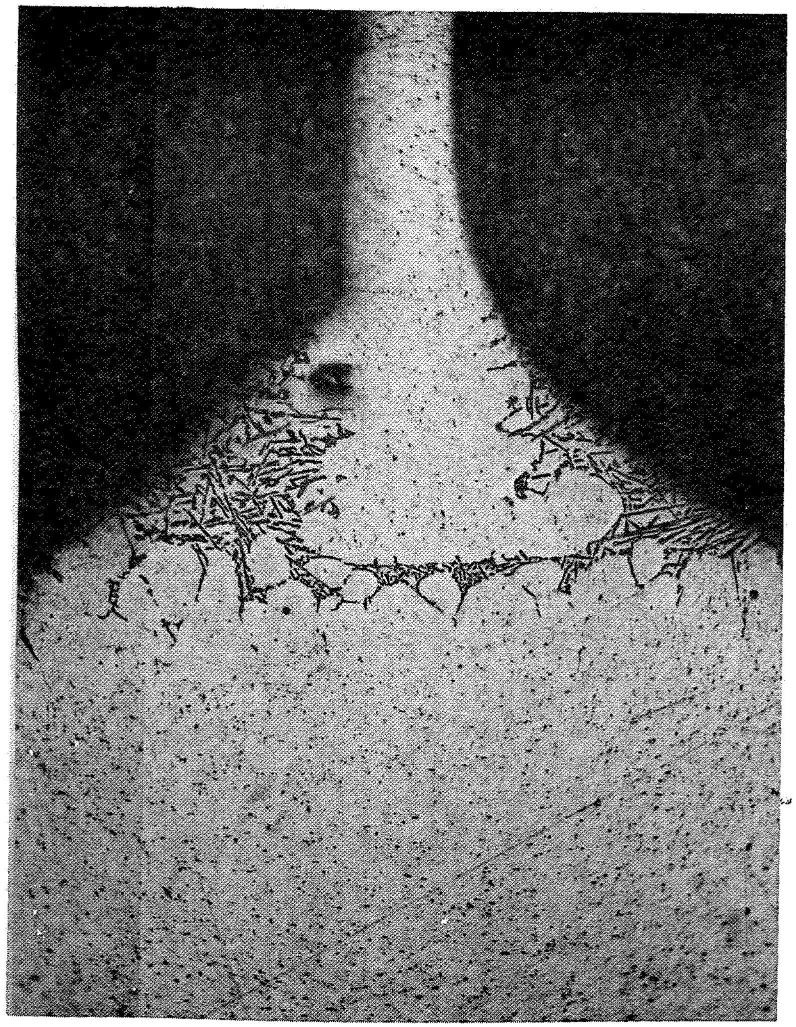


Figure 6 Radiograph of Panel No. 1. Faces: 0.040" #23 Brazing Sheet (6951).
Core: 6951, Type 6-30X½np.



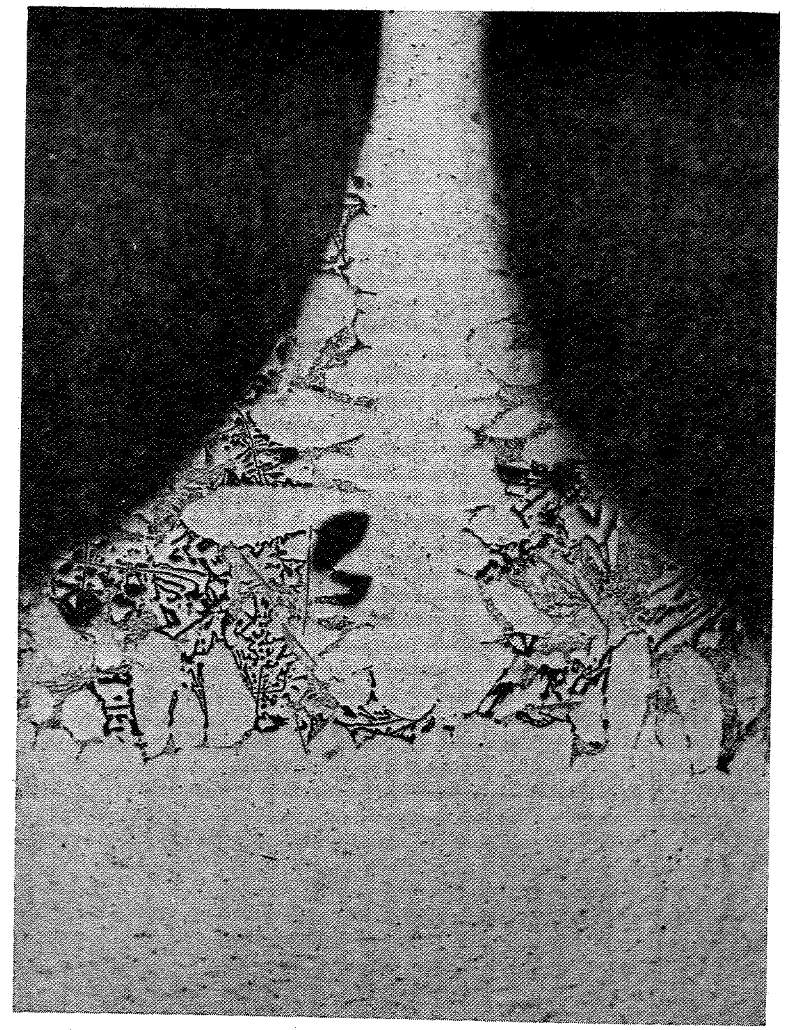


Figure 7 Cross Section Photomicrographs of Core-to-Face Joints. Faces: 0.040" #23 Brazing Sheet (6951) Core: 6951, Type 6-80x½.

Left: Panel No. 1 Brazed without Flux or any Other Flow Promoters.

Right: Panel No. 2 Brazed Nearly Identically except that 200 Mesh Size Magnesium Powder was spread on the Faces of the Panel. Note Increased Fillet Size, Alloy Flow Distance, and Structural Differences.

Mag: 100X
Etchant: Flick's

11 show that both panels brazed satisfactorily, but that magnesium caused an increase in fillet size and brazing alloy flow distance. Based on the time-temperature brazing cycles and the proceeding laboratory brazements, the addition of magnesium also lowered the brazing temperature by about 10°F.

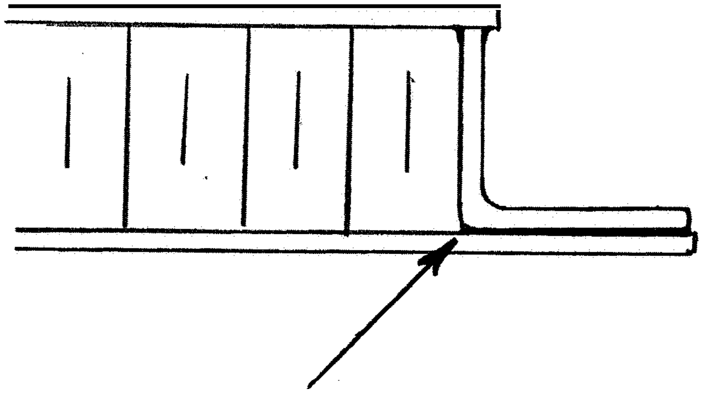
Tensile data on specimens from the panels and from X7005 (clad with 718 alloy), which was included in the brazing retort, are reported in Table 3 . Cross sections of tensile specimens are shown in Figure 12 . The reason for decreased strength of X7005 is clearly shown in the photomicrograph, Figure 12 bottom. Silicon diffusion into the X7005 occurred to a depth of one-third the cross section of the 0.040" thick sheet.

Panels No. 3 and No. 4

Panels No. 3 and No. 4 were nearly identical and were brazed together in the same retort. The brazing schedule was eight minutes at 1100°F. The panel descriptions are given below:

Panel	Faces	Core	Time	Temp. °F	Remarks
3	0.040 X7005 clad with No. 718	6-50x½ X7005	About 10 min.	1090-1100	4"x10" - No Flux - No Flow Promoter
4	0.040 X7005 clad with No. 718	6-100x½ X7005 clad with No. 718	About 10 min.	1090-1100	4"x10" - No Flux - No Flow Promoter

Photomicrographs of specimens from the two panels are shown in Figure 13. Figure 14 shows one of the panels split apart for comparison with the radiographic report.



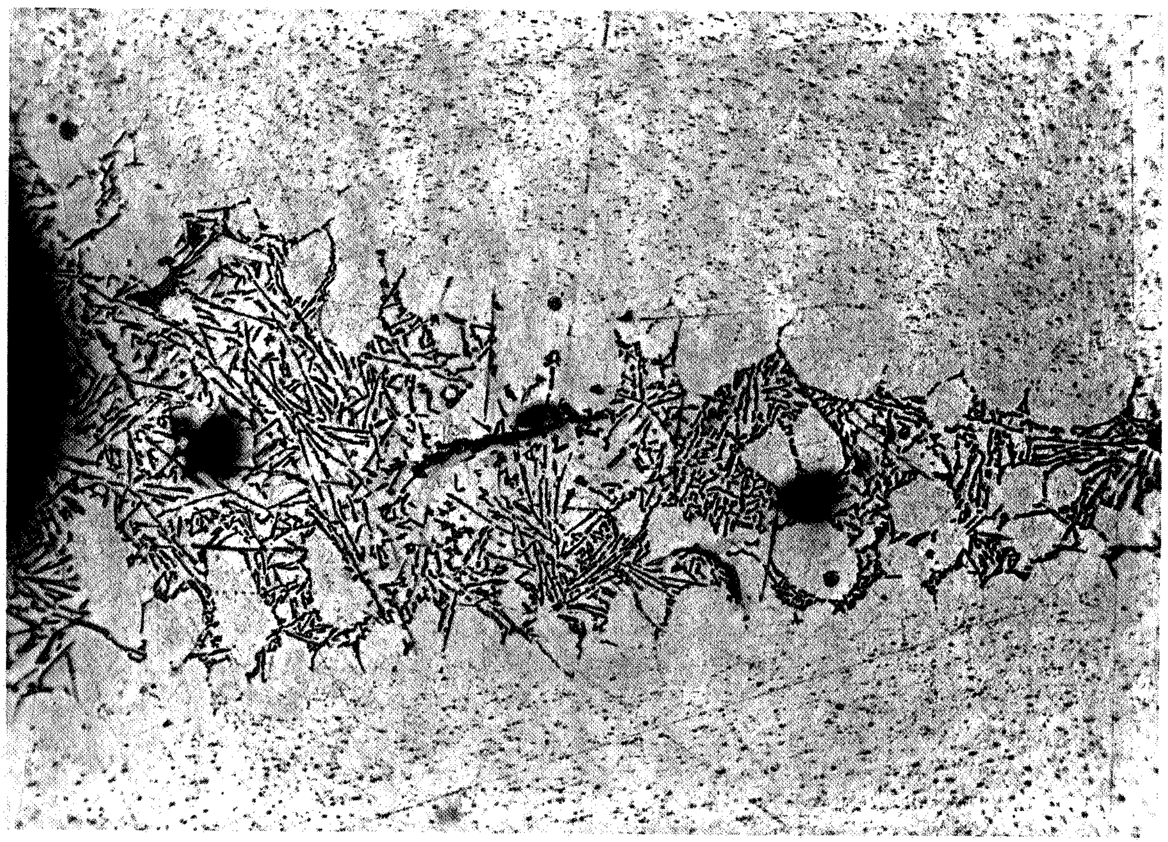
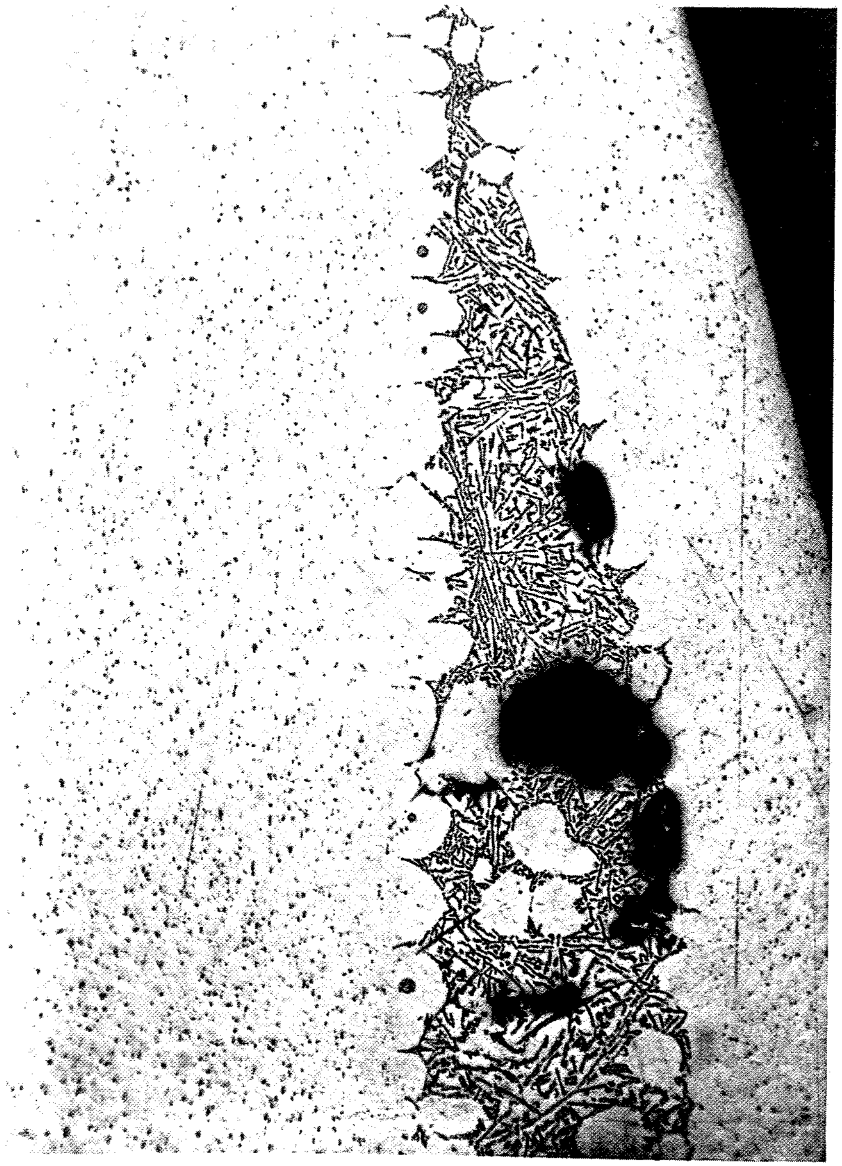


Figure 8 Brazing Alloy Fillet, as shown, for Edge Member of Panel No. 1, Brazing Sheet #23 (6951).

Mag: 100X
Etchant: 2% HF



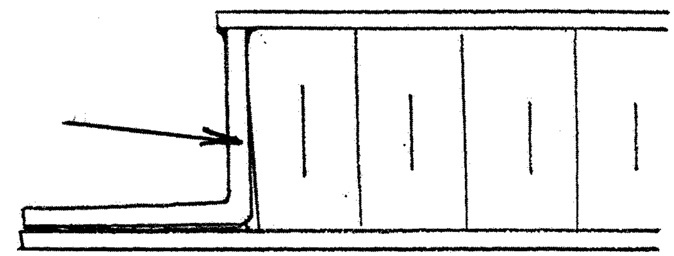
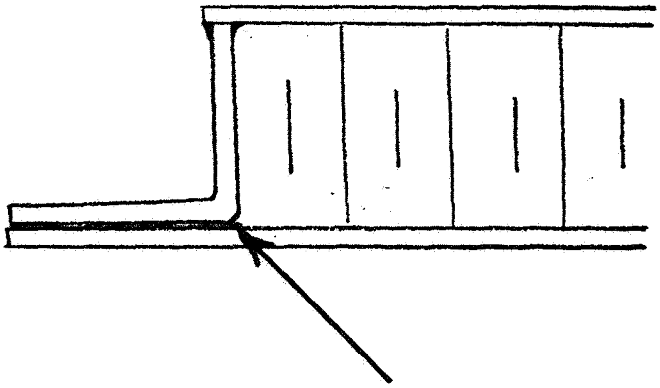


Figure 9 Brazing Alloy Fillet at Core Shear Tie, as shown, Banel No. 1
Panel No. 1 Brazing Sheet #23 (6951).

Mag. 100X
Etchant: 2% HF



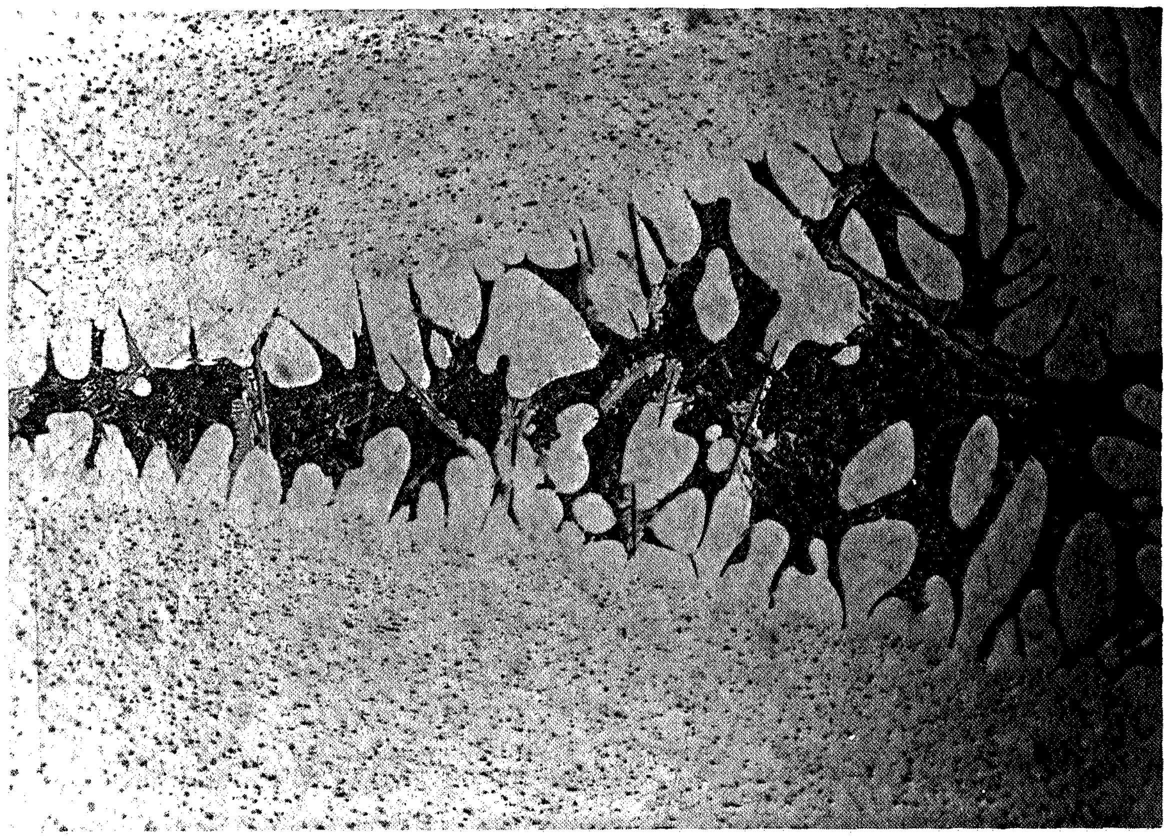
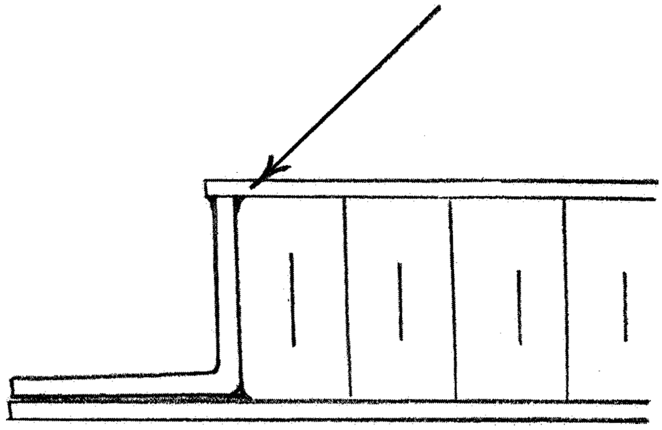


Figure 10 Brazing Alloy Fillet, as shown, for Edge Member of Panel No. 2, Brazing Sheet #23 (6951) with 200 Mesh Magnesium Powder added to promote Flow and Vetting. Compare with Figure 8.

Mag: 100X



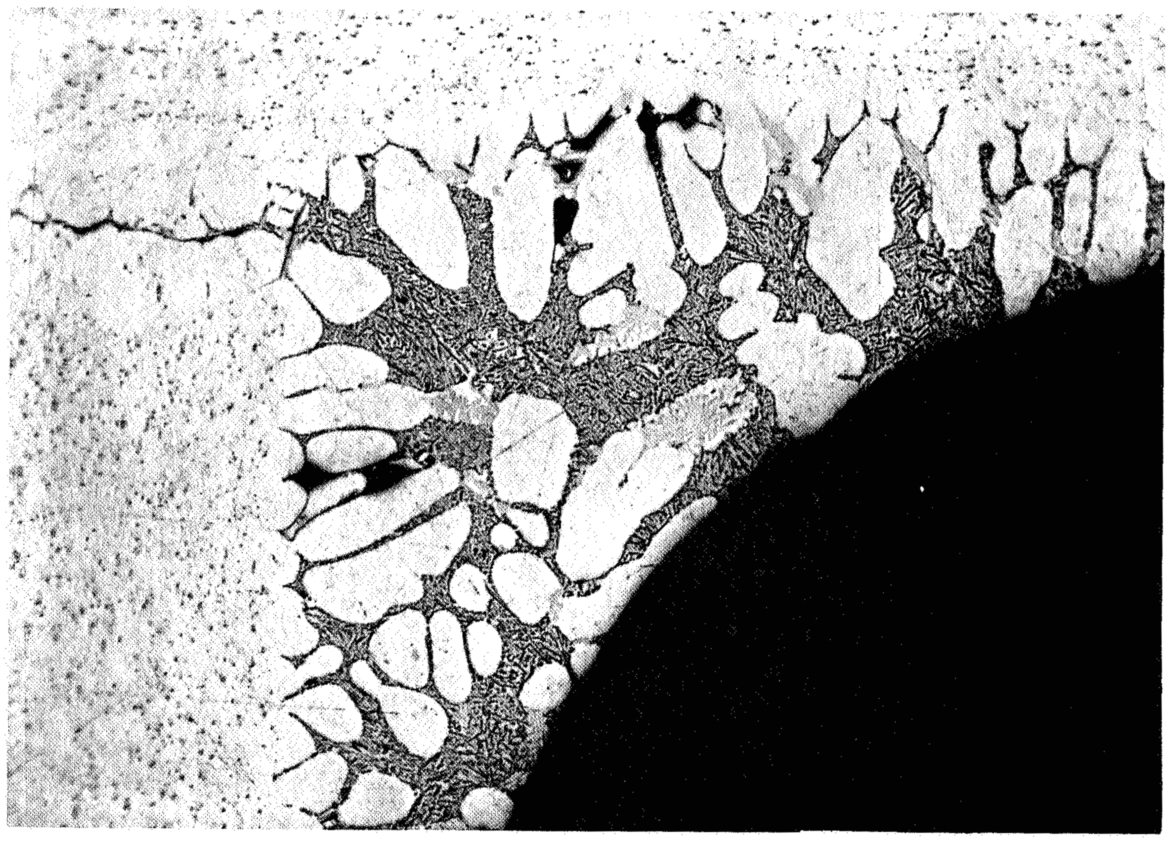


Figure 11 Brazing Alloy Fillet, as shown, for Edge Member 'T' Section of Panel No. 2, Brazing Sheet #23 (6951) with 200 Mesh Magnesium Added to promote Flow and Wetting.

Mag: 100X
Etchant: 2% HF

TABLE 3

TENSILE DATA-BRAZED AND HEAT TREATED 6951 AND X7005 ALLOYS

BARE MATERIAL - HEAT CYCLED WITH PANEL NO. 1, THEN AGED*

Material	U.T.S. psi	Y.S. 0.2% Offset psi	Per Cent Elongation
6951	36,000	25,750	13
6951	36,000	26,750	12
6951	35,950	26,100	13
6951	36,000	26,750	14
9651	36,000	26,250	14
X 7005	50,750	40,500	15
X 7005	50,750	41,450	15
X 7005	50,000	41,450	15
X 7005	50,250	41,500	15
X 7005	50,750	41,750	15

BRAZE CLAD ONE SIDE - HEAT CYCLED WITH PANEL NO. 2, THEN AGED*

Material	U.T.S. psi	Y.S. 0.2% Offset psi	Per Cent Elongation
6951	32,790	25,800	8.5
6951	32,700	25,500	8.0
6951	30,700	25,300	3.5
6951	32,630	25,700	7.0
6951	32,300	26,050	6.5
X 7005	43,900	33,900	11.5
X7005	43,200	33,900	9.5
X7005	41,450	32,900	8.0
X7005	44,000	34,000	11.5
X 7005	41,750	32,800	8.5

*One week at room temperature followed by 20 hrs. at 320°F for 6951 and 48 hrs, at 250°F for X7005.

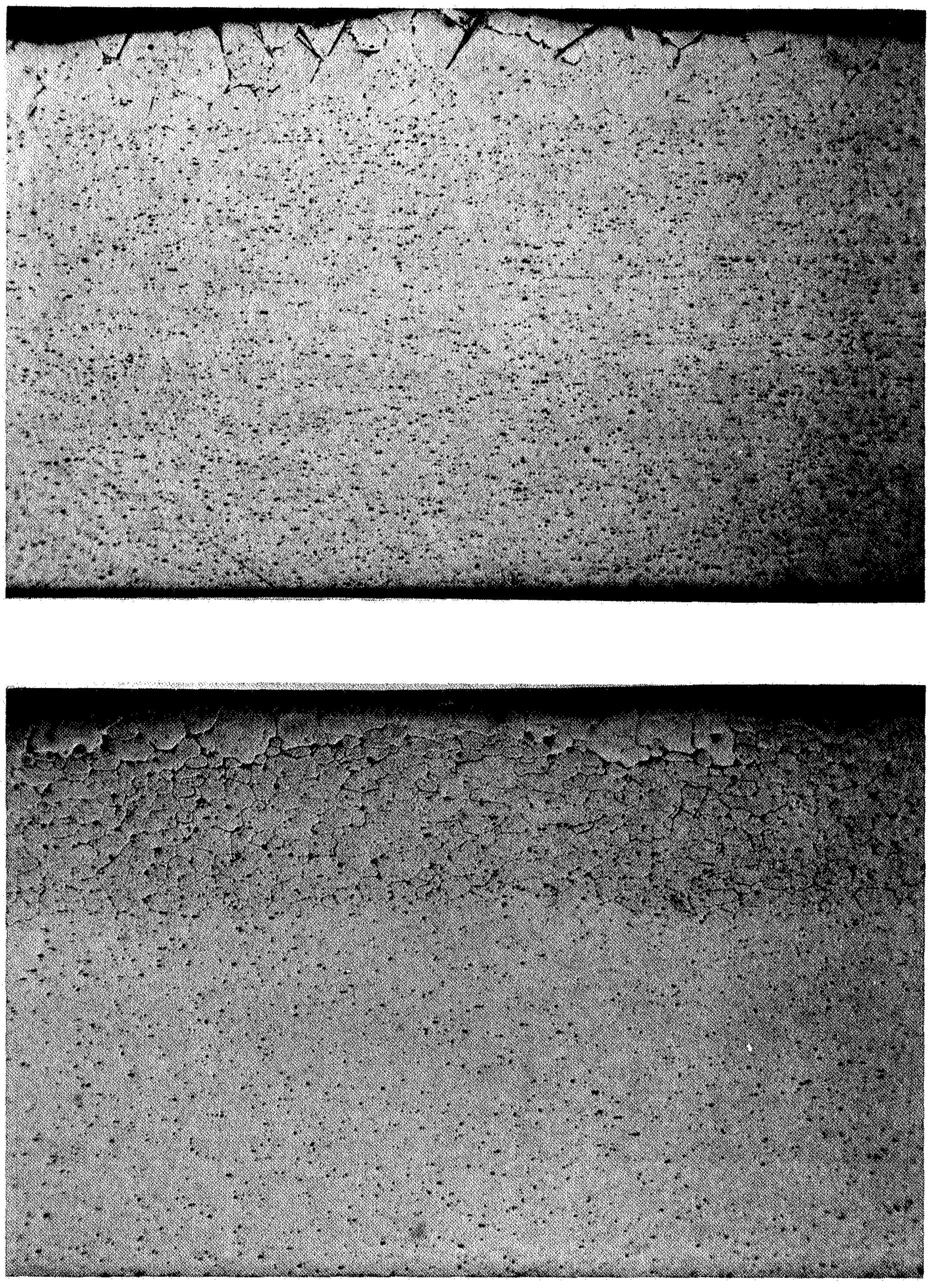


Figure 12 Top: Cross-Section of #23 Brazing Sheet (6951) Tensile Specimens Processed with and Identical to Panel No. 1.

Bottom: Cross-Section of X7005 Brazing Sheet Tensile Specimen Processed with Panel No. 2. Mote Silicon Diffusion through 1/3 the Thickness of the Specimen,

Mag: 100X
Etchant: 2% HF

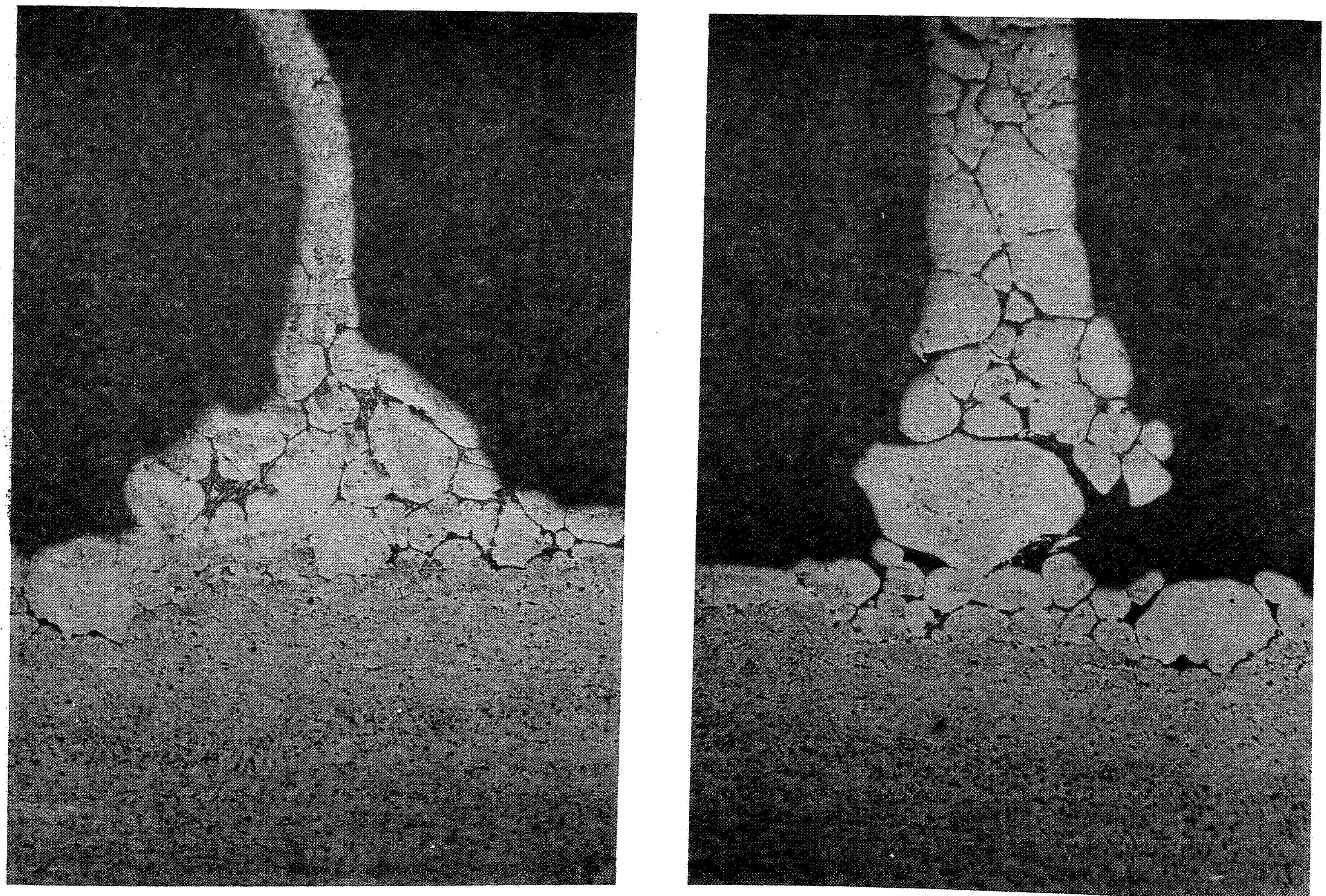


Figure 13 Left: Cross Section of Core-to-Face Braze, Panel No. 3. Faces: 0.040" X7005 Brazing Sheet (Clad with 718 Alloy). Core: X7005, Type 6-50x½.

Right: Cross Section of Core-to-Face Braze, Panel No. 4. Faces: 0.040" X7005 Brazing Sheet (Clad with 718 Alloy). Core: X7005, Type 6-100x½, Core Ribbon also Clad with 718 Brazing Alloy.

Mag: 100X
Etchant: [illegible]

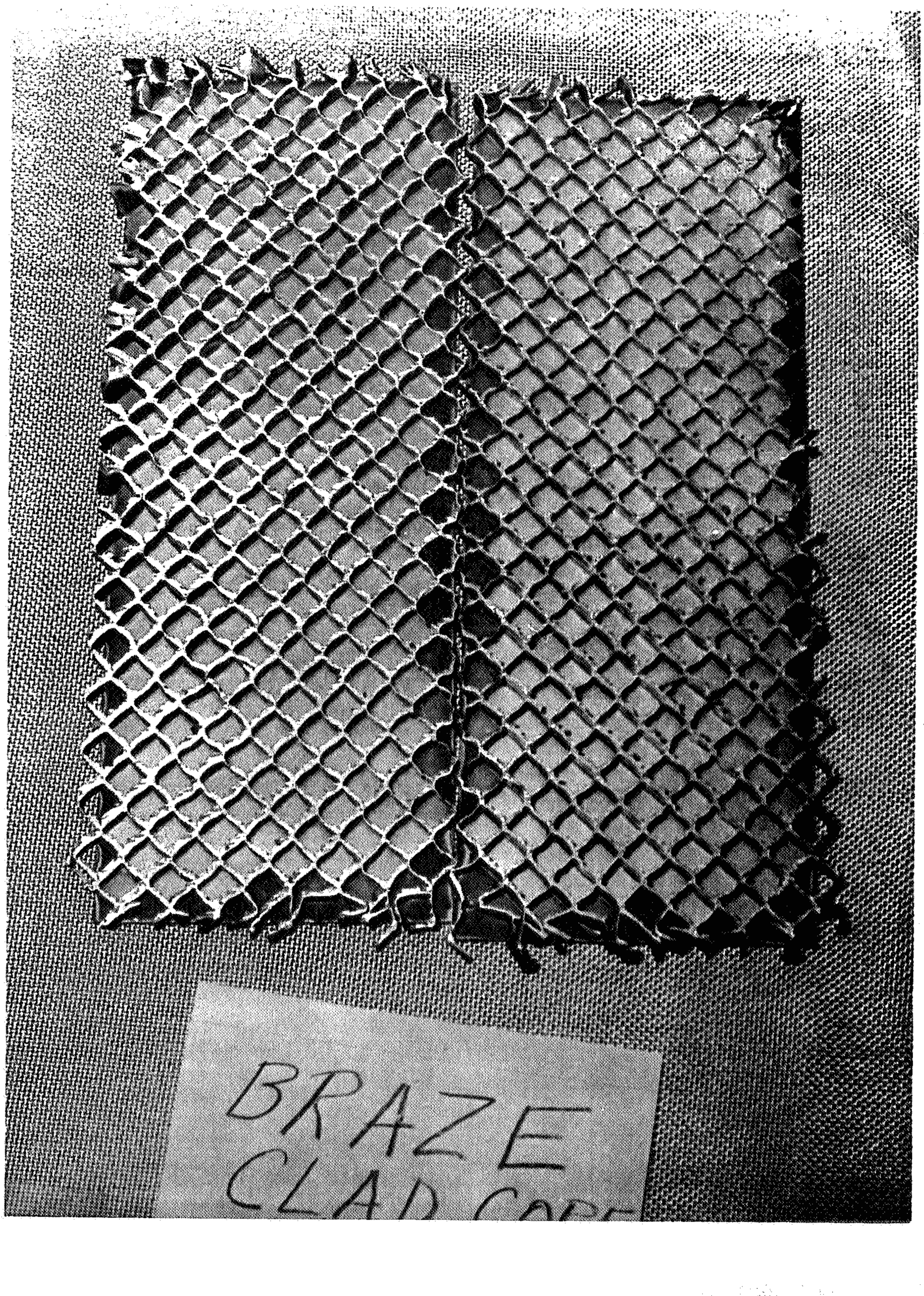


Figure 14 Panel No. 4. X7005 Faces and Core Clad with 718 Brazing Alloy. Core Type: 6-100x½ np. The panel was split open to correlate Braze Quality with X-Ray Inspection.

Tensile data from Panel No. 4 after processing and aging 5 days at room temperature and 48 hours at **250°F** are shown below:

Specimen	Tensile Strength psi	Yield Strength 0.2% Offset psi	Percent Elongation
1	43,400	34,100	10
2	45,100	35,800	11
3	44,700	35,900	10
4	40,900	31,200	6

After obtaining these data, Panel No. 3 (brazed and heat treated identically) was solution heat treated by the following:

20 minutes at 800°F

Withdraw from furnace and air cool, age 5 days at room temperature plus 48 hours at 250°F.

Tensile data follow:

Specimen	[redacted] Strength	Yield Strength 0.2% Offset psi	Percent Elongation
1	40,200	31,700	8.5
2	38,300	30,500	6.5
3	41,400	32,400	9.0

It was apparent from panels No. 3 and No. 4 that X7005 was detrimentally affected by the No. 718 alloy. In particular the thin foil of the honeycomb core was partly dissolved.

Panel No. 5

The panel was comprised of the following:

Faces: 0.040" thick X7005 sheet clad with 4% 718 braze alloy, one side.

Core: X7005, type 6-50 x ½" n.p., ultrasonically welded.

Nominal Size: 7" x 10"

The panel was brazed at 1105" ± 5°F, for 6 minutes and a quenching rate ranging from 150°/min. at the start to about 75°/min. in the range of 500°F was obtained. Thereafter, it was about 50°/min. to room temperature.

A print of the radiograph is shown in Figure 15.

The panel was fully brazed and found to be flat and, therefore, thought to be acceptable. However, there appeared to be crushed core in the central region, even though the cell walls and nodes were observed to be straight and uniform by the X-ray print.

Upon sectioning the panel it was found that the core roots were partially dissolved by the brazing alloy during the brazing process. However, the core cell walls were not eroded, and good fillets were obtained throughout. Typical core-to-face attachment is shown in Figure 16.

Compared with earlier photomicrographs of X7005 brazing sheet, which was brazed for a 10-minute cycle, this panel brazed with a 6-minute cycle, evidenced less silicon diffusion into the facing sheets. The tensile data below substantiated the microscopic evidence.

Panel No. 5 as processed, then was aged 5 days at room temperature plus 48 hours at 250°F. The following data were obtained:

Specimen	Tensile Strength psi	Yield Strength 0.2% Offset psi	Percent Elongation
1	43,600	37,200	6.0
2	42,400	37,000	5.0

Brazing and Water Quenching

Panels No. 6 and No. 7 had faces of 2024 and 2014, respectively, and pure zinc foil was the brazing alloy. No provisions were made for fixturing and tooling to retain shapes or flatness.

The retort and furnace equipment are shown in Figures 17 and 18.

The retort was brought to the temperature of the pre-heated furnace within 15 minutes and stabilized at 895" + 5°F within 3 minutes, followed by water quenching.

Ths panels are shown after brazing in Figure 19. The zinc (two layers of 0.002" foil were used) penetrated the 2024, but not the 2014. Following brazing, the panels were aged at the appropriate temperature, then tensile coupons were machined from the faces and tested. Bare 2014 and 2024 were heat treated similarly and tested for comparison. The data are shown in Table 4.

The adverse effects of pure zinc are clearly shown; however, the non-standard heat treatment may have contributed to low strength values.

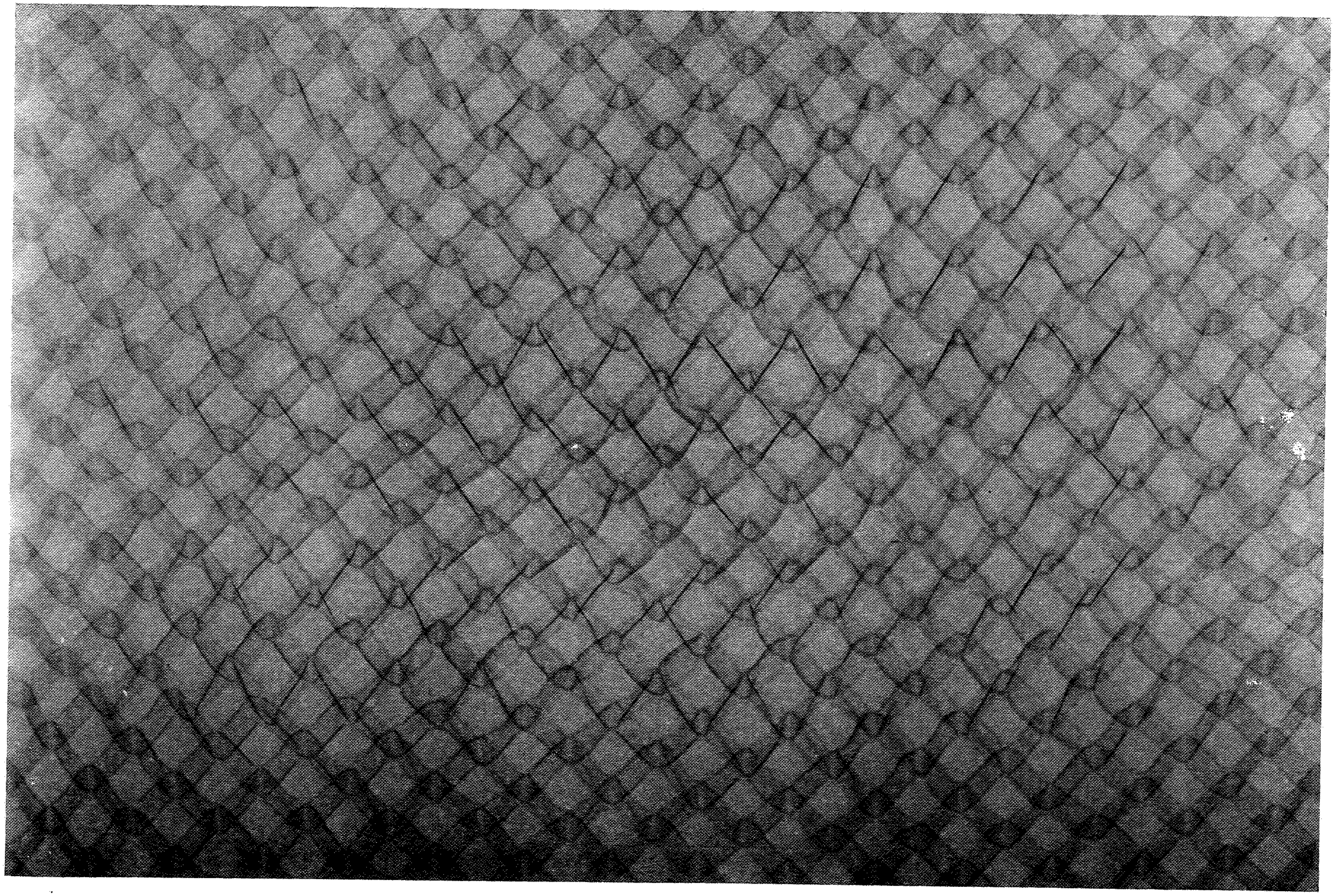


Figure 15 Radiograph of Panel No. 5. Faces: 0.040" X7005 Clad with 718 Brazing Alloy. Core: X7005, Type 6-50x½ np. Shaded Core Roots in Central Area of Panel Indicate Core Crushing at the Brazing Alloy-Core Root Joint at Both Faces.

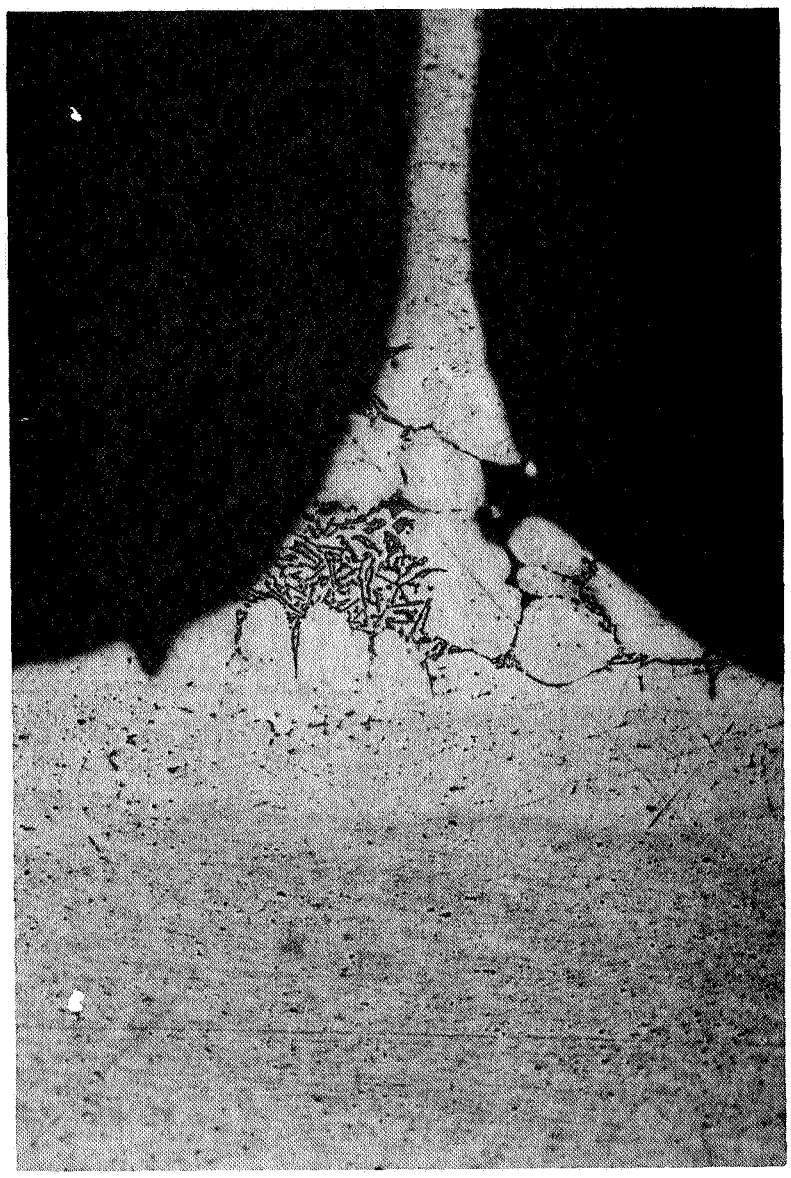


Figure 16 Cross-Section **of** Core-to-Face Joint Panel **No.** ***5.*** **Note that** there **was Less** Silicon **Diffusion** than **for** Panels **No.** 3 **& Nxx** No. ***4,*** Figure 9, because **of** the Shorter Brazing **Time Cycle.**

Mag: 100X
Etchantt 2% HF

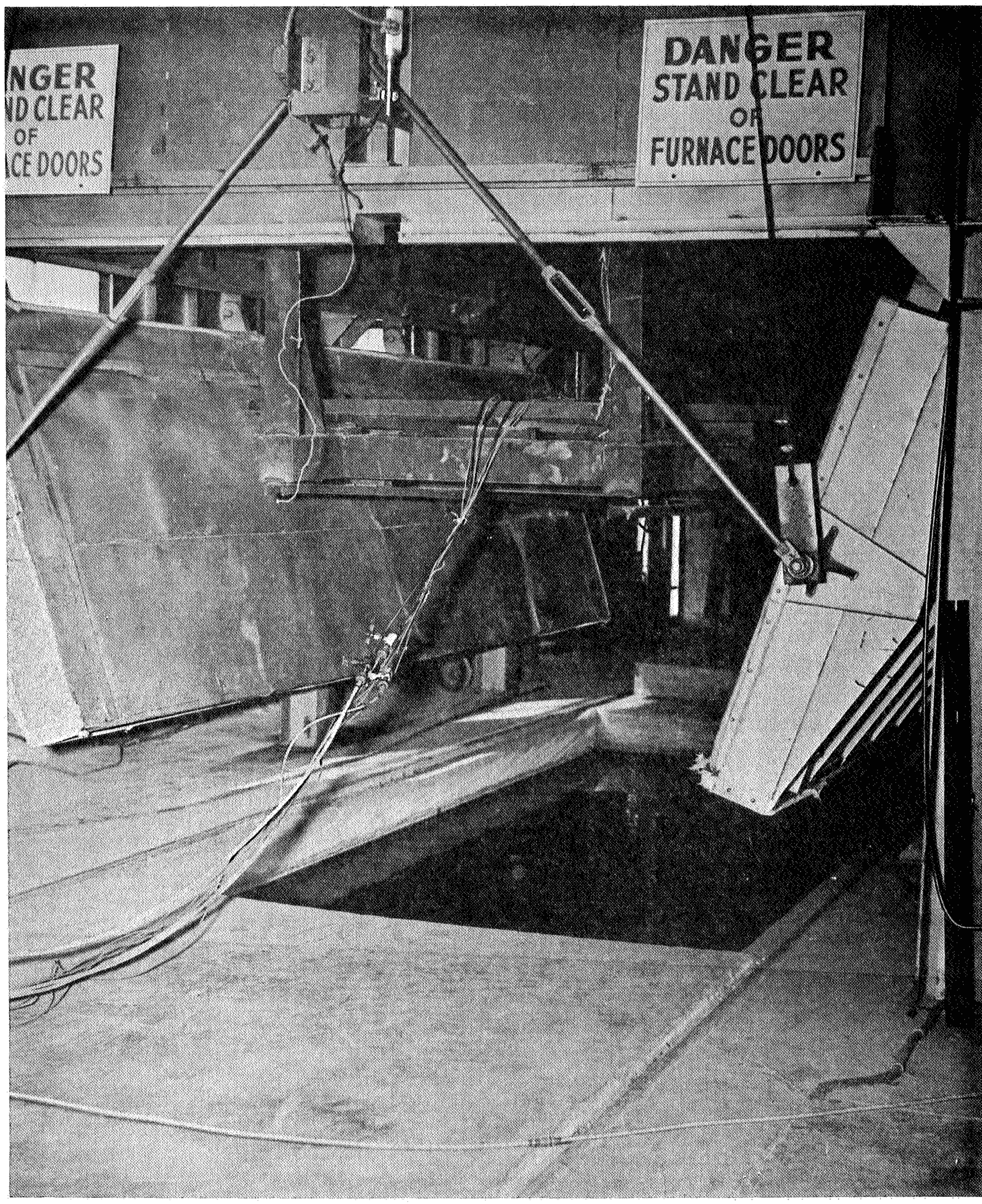


Figure 17 Beginning of Quench Cycle for Retort Containing Panels No. 6 & No. 7, 2024 and 2014 respectively.

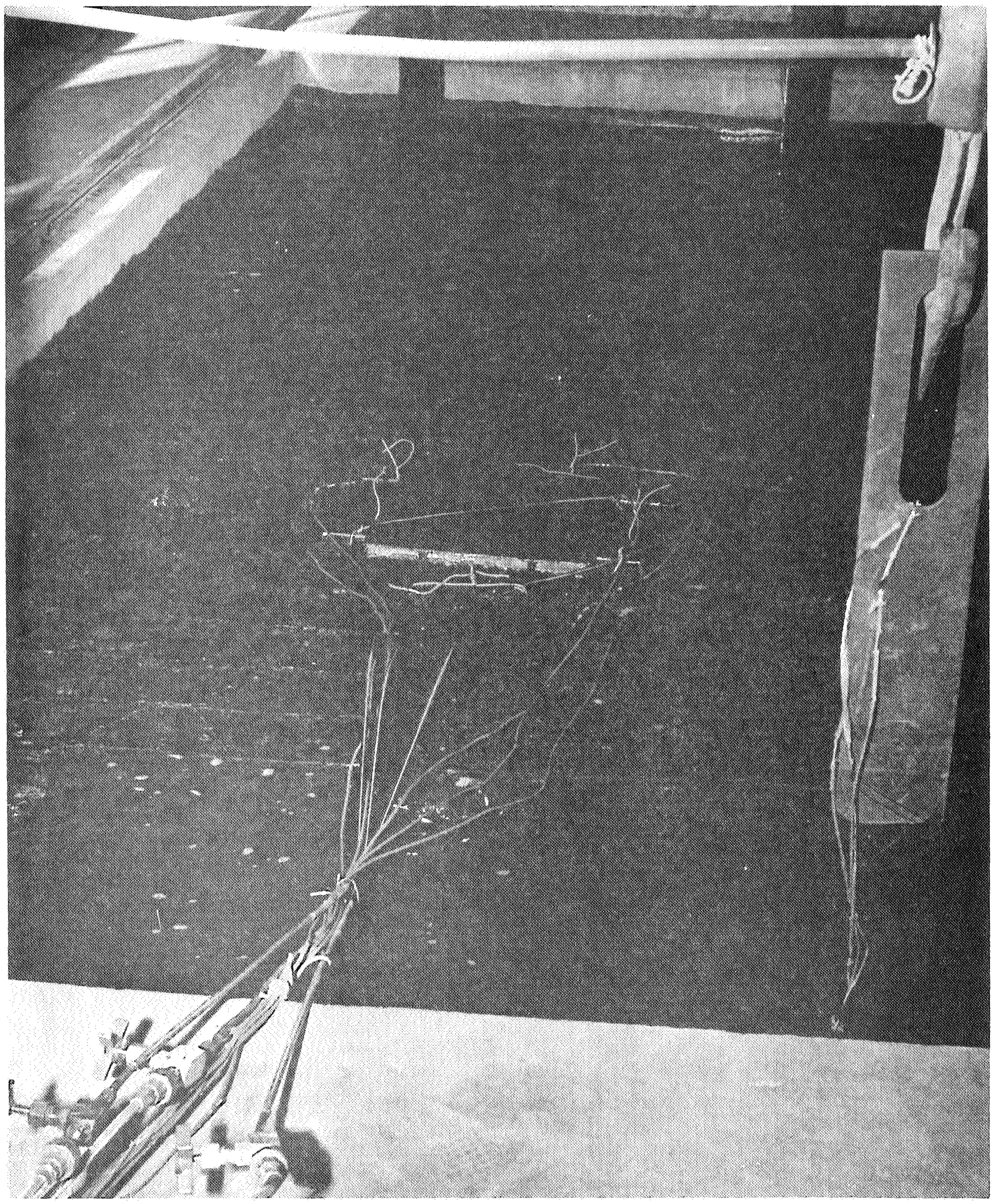


Figure 18 Retort containing Panels No. 6 & No. 7 and Furnace Bed after dropping into Water Quench Tank.

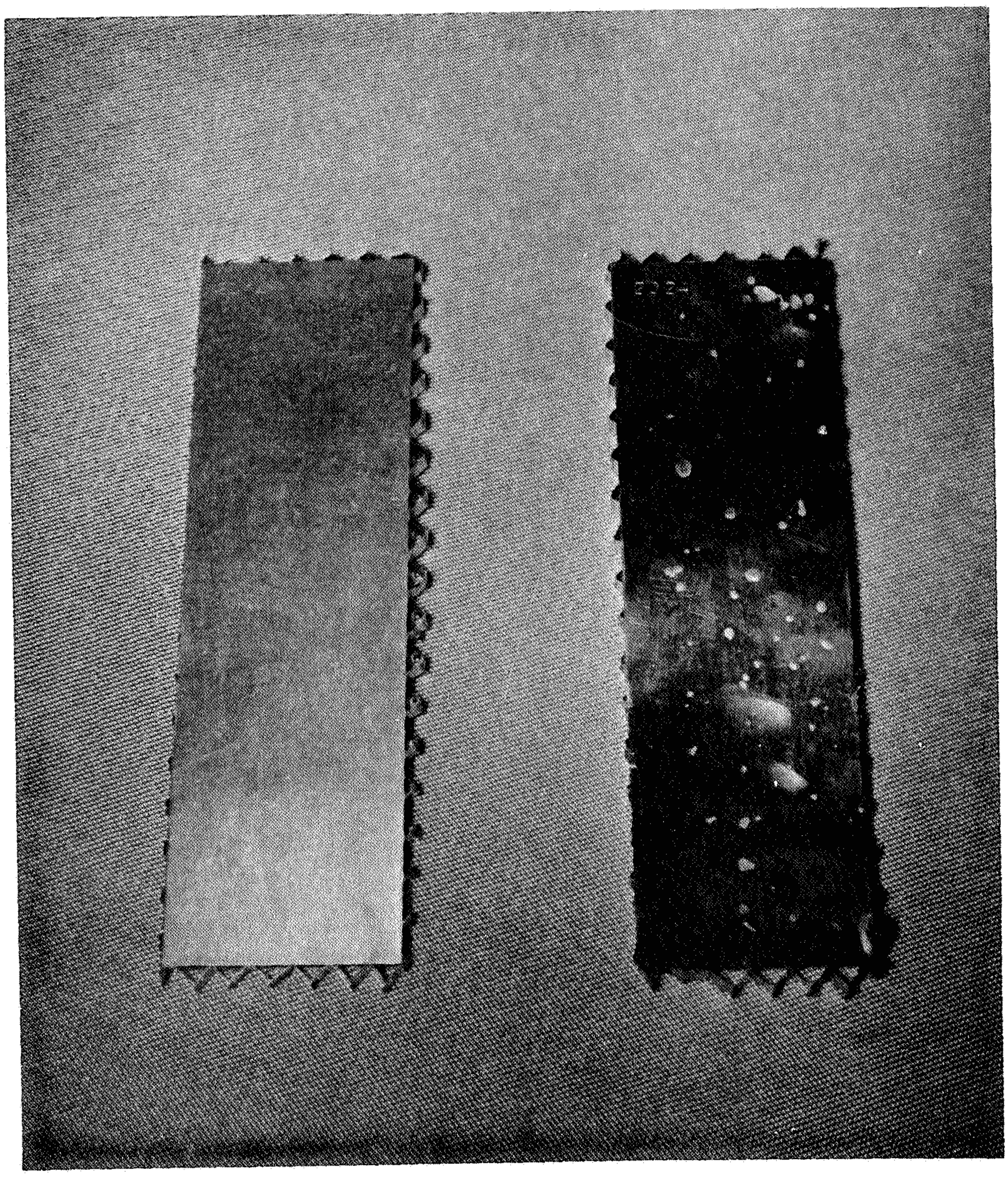


Figure 19 Panels No. 6 (2014) and No. 7 (2024) Brazed with pure Zinc. Note Zinc penetration through the 2024 Face of the Panel, (No. 7).

Table 4

Tensile Data - Brazed Panels

Panels No. 6 and No. 7 solution heat treated by the brazing cycle, approximately 5 minutes at 900°F, aged as follows: 2014 - 9 hrs. at 340°F, 2024 - 9 hrs. at 375°F.

Specimen	U.T.S. psi	Yield Strength 0.2% Offset psi	Percent Elongation
2014-1	38,000	18,600	13.0
2014-2	35,100	18,300	6.0
2014-3	32,200	18,200	4.5
2014-4	36,300	18,250	6.0
2024-1	38,500	31,200	3.0
2024-2	40,700	31,800	3.5
2024-3	41,200	32,300	3.5
2024-4	34,500	32,600	1.0

Panel No. 8

Retort lay-up and panel assembly were the same as that described for Panel No. 5.

Panel No. 8 was 1 square foot in size, with 0.040" thick 6061 faces, 6061 core, and 0.010" thick #718 brazing alloy. The brazing schedule was 10 minutes at 1075" to 1080°F.

The panel was clean in appearance and flat, but the core-to-face braze was unsatisfactory. The brazing alloy sheet was not fully melted and fillets were small over approximately one-half the panel; the other half was void. No further tests were planned on Panel No. 8 and it was not anticipated that any more brazing of 6061 would be done with the 718 alloy because the proper brazing temperature would be too close to solidus of 6061.

Panels No. 9, No. 10 and No. 11

From the data given previously for X7005 and 6951, the following minimum tensile properties could be expected for brazed sandwich panels. (Note that they apply specifically to 0.040" thick sheet brazed with the specific aluminum base brazing alloy).

Material	Brazing Alloy	F_{tu} KSI	F_{ty} KSI	Percent Elongation
X7005 Air Quench	718	38	32	5
6951 Boiling Water Quench	714	36	31	4
6951 Air Quench	714	30	25	3

Small sandwich specimens of 6061 and X7005 were brazed in the laboratory using flattened 719 alloy wire. Based on metallographic examination, a schedule of 10 minutes at 1050°F would be satisfactory for both systems. There was no evidence of silicon diffusion into X7005 or 6061. Consequently, it was thought that the 719 alloy would be a better choice than 718 for brazing either 6041 or X7005. There were problems of availability, however. To that date, the 719 alloy tad been supplied as wire only.

To provide additional clad systems, 1/8" dia. wires of 719 and 716, respectively, were flame spray deposited onto sheets of X7005, X7006, X7106, and 6061.

Small specimens of these materials were brazed in the laboratory furnace. Microscopic examination indicated less effect (diffusion) on the substrates by brazing alloys 719 and 716, than was shown for the 718 alloy.

Panel No. 9

Various sandwich facing materials were flame spray coated with 719 brazing alloy from 0.003" to 0.005" thick, and assembled within a retort with two types of core as shown in Figure 20. The brazing cycle for this panel was 1050" to 1060°F for 8 minutes.

The panel was unsatisfactory, having small fillets over approximately one-half of the panel with the other half unbrazed. Representative photomicrographs of specimens from Panel No. 9 are shown in Figure 21. Comparing this panel No. 9 with laboratory specimens, it was concluded that there had been an insufficient amount of brazing alloy.

Panel No. 10

This panel was similar to Panel No. 9 except that the brazing alloy was 716. The brazing schedule was 1075 to 1080 for 8 minutes. The brazed panel was similar to No. 9, mostly small fillets and approximately one-half of the panel was not brazed.

Figure 22 shows typical photomicrographs of specimens from Panel No. 10.

Panel No. 11

Panel No, 11 was one square foot in size and was comprised of X7005 and X7106 faces, X7005 core (6-80 x ½"), and 719 brazing alloy, flame sprayed onto the facings to a thickness of 0.010".

The brazing schedule was 1050°F for 10 minutes. Figure 23 shows a portion of the radiograph and Figure 24 shows the two edges of the panel. Photomicrographs of core-to-face joints are shown in Figures 25 and 26.

Single brazing alloy coated tensile specimens of X7005 and X7106 were cut from the faces, aged 48 hours at 250°F, and tested. The data are given below:

					Based on Original Thickness	
Specimen	Gage	UTS KSI	YS KSI	Elongation Percent	UTS KSI	YS KSI
X7005	0.068"	39.3	33.0	4.5	42.5	36.6
X7106	0.067"	33.4	25.1	2.0	36.8	27.6

Identical Specimens then were post-braze solution heat treated 1 hour at 900°F, air quenched to room temperature, and aged 1 week at room temperature, followed by 48 hours at 250°F.

The following data were obtained:

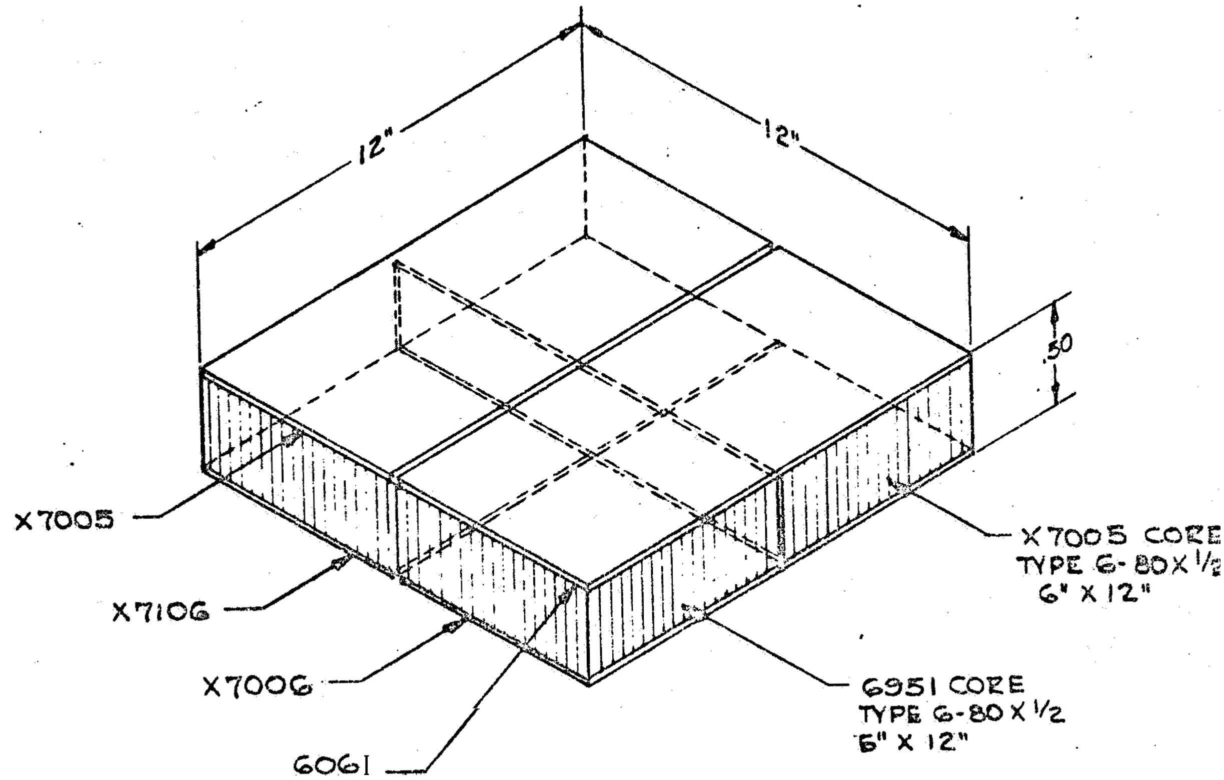


Figure 20 Test Panel Brazement. Brazing Alloy 719, 0.003" to 0.005" Thick Applied by Flame Spraying 1/8" dia. Wire.

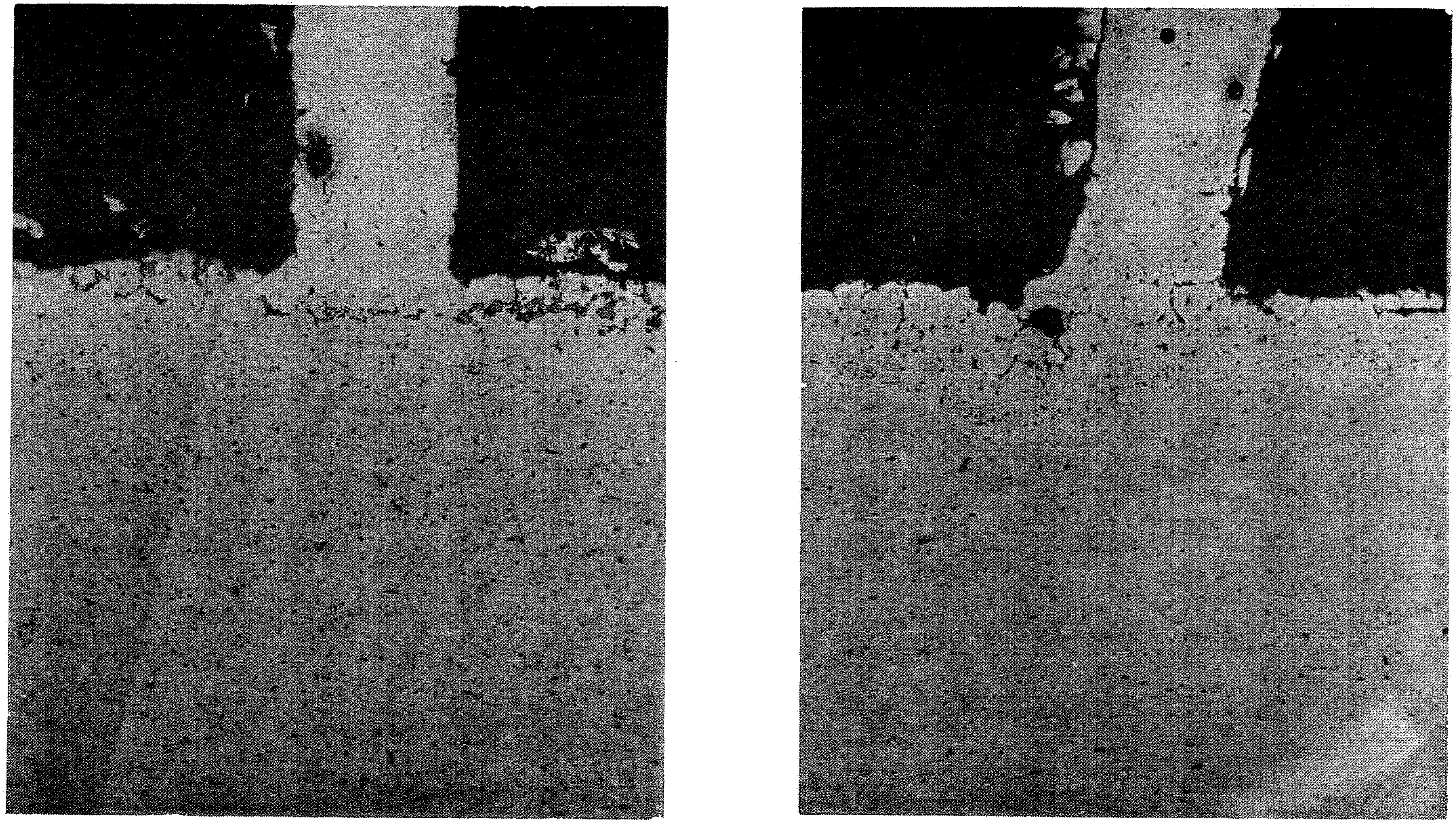
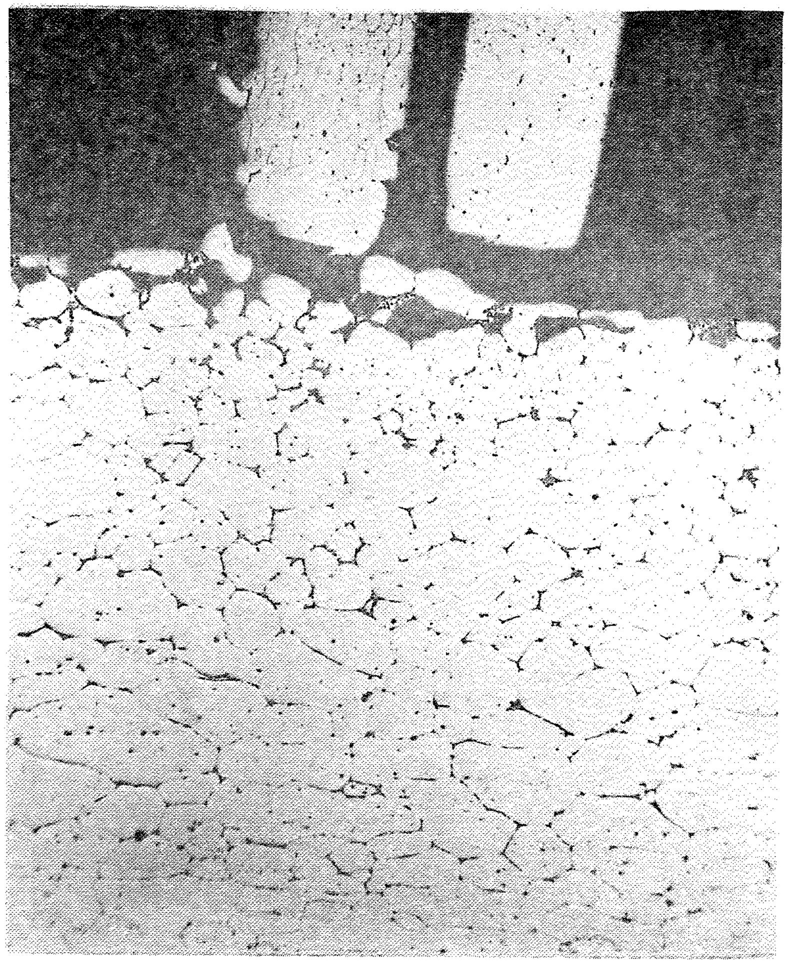


Figure 21 Cross-Section Photomicrographs of Core-to-Face Braze of Two Specimens Sectioned from Panel No. 9. The Brazing Alloy was 719 applied as 0.003" to 0.005" Coating by Flame Spraying. The Brazing Cycle was approximately 10 Minutes at 1045°F in an Atmosphere of Argon.

Left: 6951 Core and 6061 Face
Right: 6951 Core and X7106 Face

Mag: 100X
Etchant: Flick's



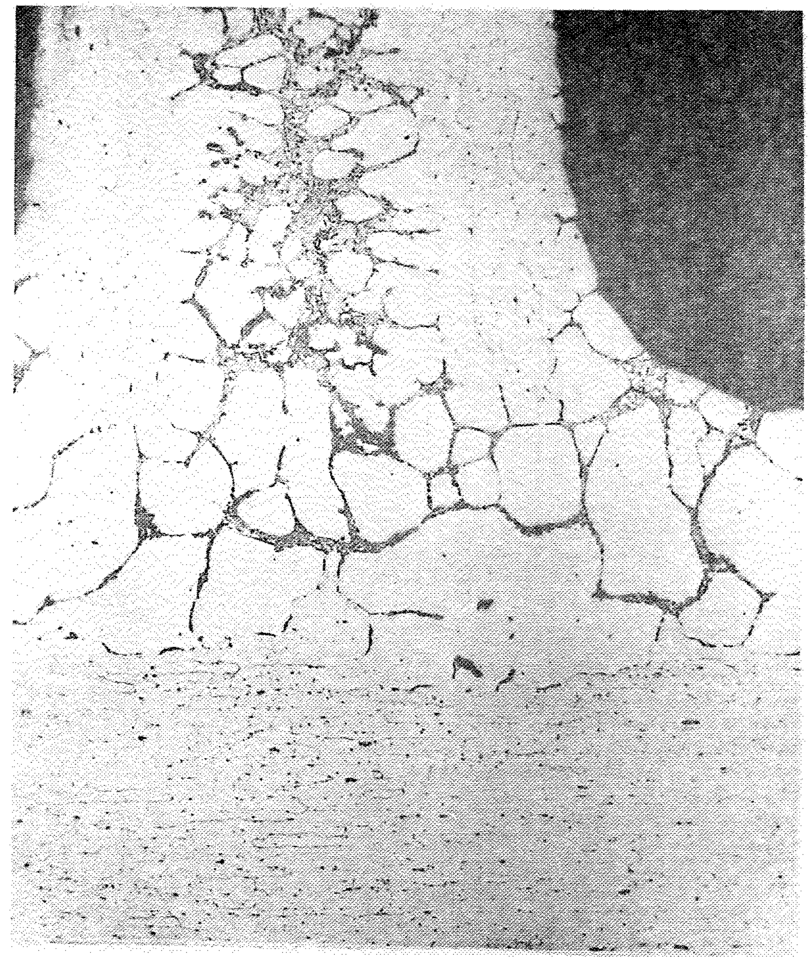


Figure 22 - Cross-Section Photomicrographs of Core-to-Face Braze of Two Specimens Sectioned from Panel No. 10. The Brazing Alloy was 716 applied as 0.005" Coating by Flame Spraying. The Brazing Cycle was approximately 10 Minutes at 1085°F in an atmosphere of Argon.

Left: X7005 Core and X7106 Face. Grain growth was evident across approximately two-thirds of the Face Sheet thickness; consequently grain growth was not caused by temperatures above solidus of the X7106.

Right: X7005 Core (at Node Joint) and X7005 Face.

Mag: 100X
Etchant: Flick's

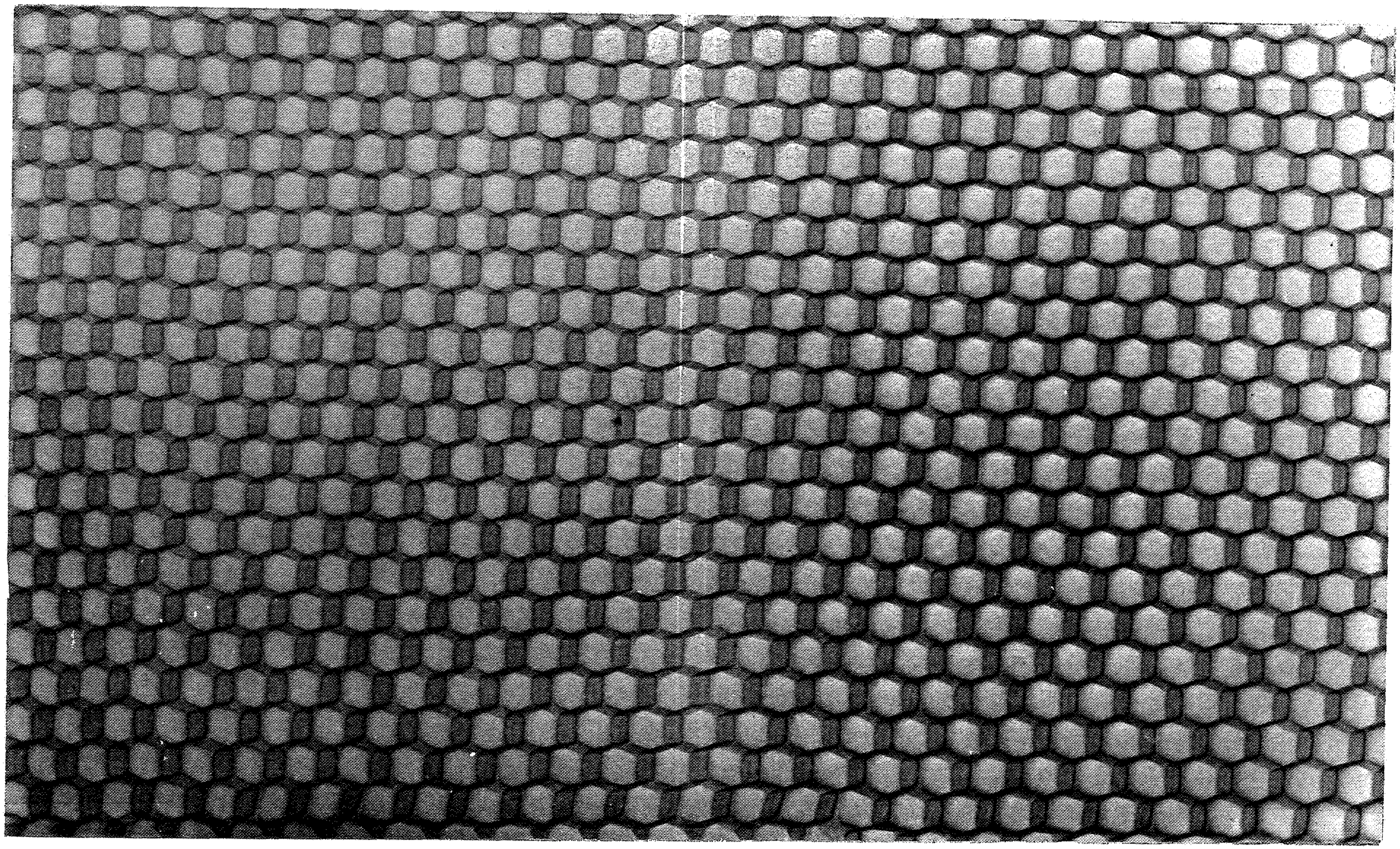


Figure 23 A portion of the Radiograph for Composite Panel No. 11. Faces: X7005 and X7106. Brazing Alloy: 719, 0.010" thickness applied by Flame Spraying. Core: Resistance Welded X7005.

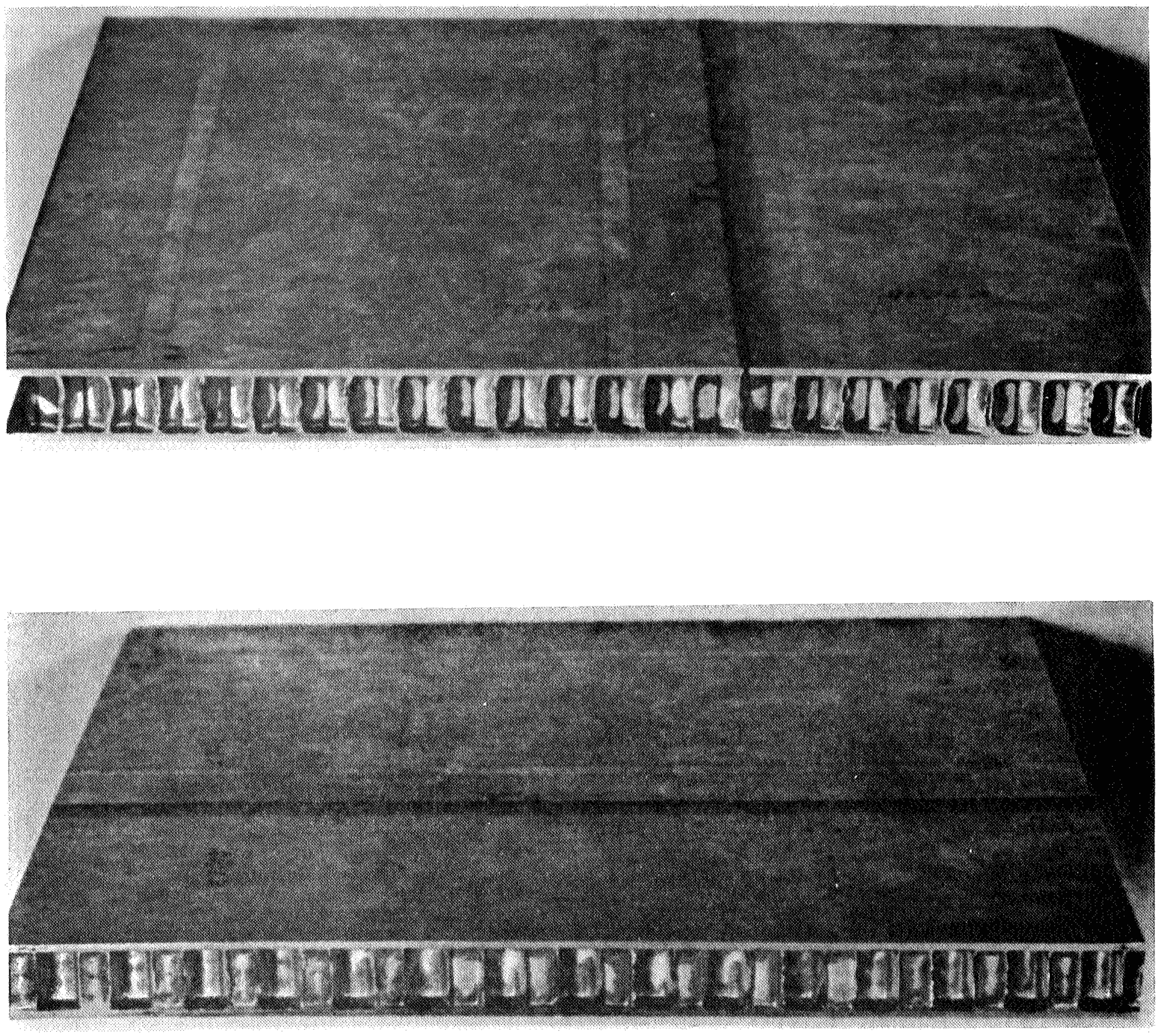


Figure 24 Two Views of Panel No. 11 showing Brazing Alloy Flow and Filleting. See Figure 61 for Radiograph of full description.

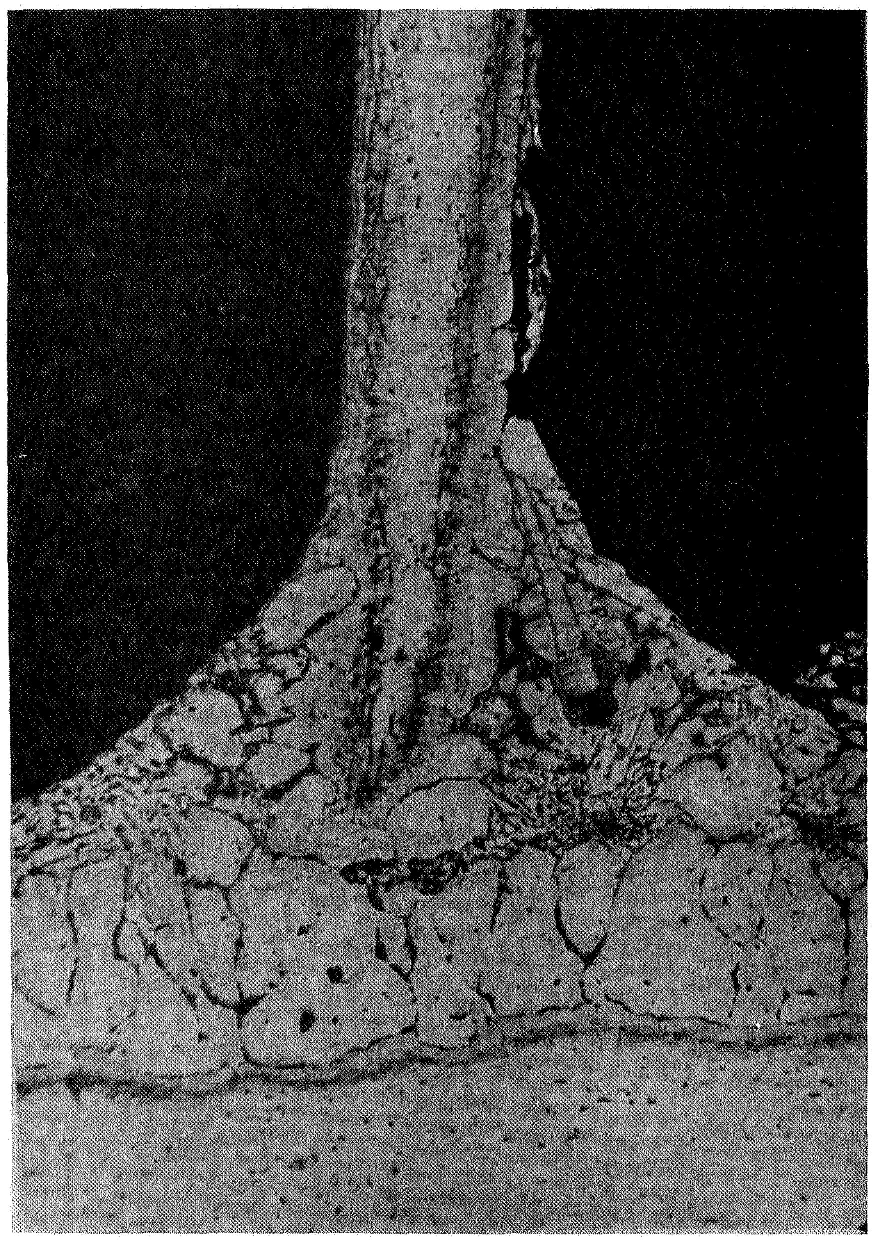


Figure 25 Cross-Section Photomicrograph of Core-to-Face Braze of a Specimen Sectioned from Panel No. 11. The Core and Face were X7005. The Brazing Alloy was 719 applied as 0.010" Coating by Flame Spraying. The Brazing Cycle was approximately 10 Minutes at 1050°F in an Atmosphere of Argon.

Mag: 100X

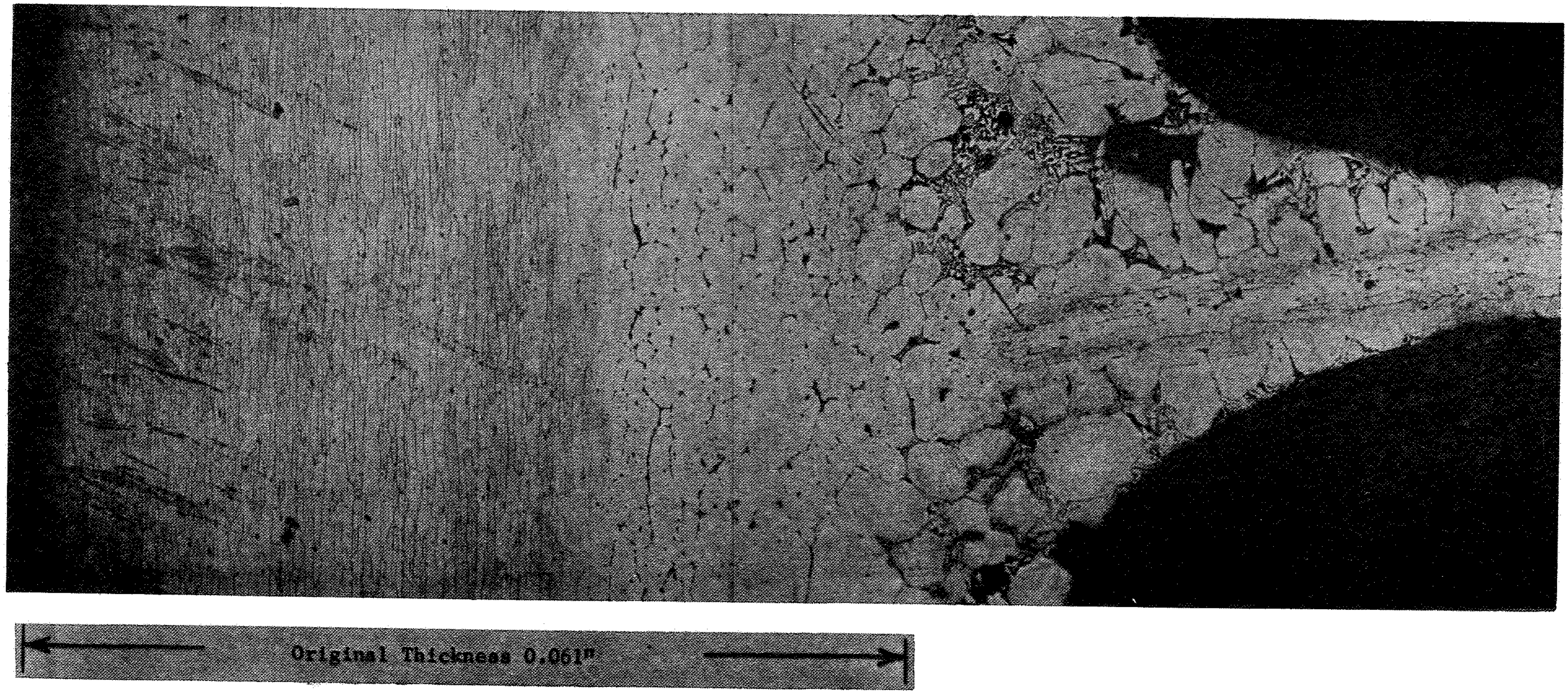


Figure 26 Cross-Section Photomicrograph of Core-to-Face Braze of a Specimen Sectioned from Panel No. 11. The core was X7005 and Face was X7106. The Brazing Alloy was 719 applied as an 0.010" Coating by Flame Spraying. The Brazing Cycle was approximately Ten Minutes at 1050°F in an Atmosphere of Argon.

Mag: 100X
Etchant: Flick's

Specimen	Gape	UTS KSI	YS KSI	Elongation Percent	Based on Original Thickness UTS KSI	YS KSI
X7005	0.071"	38.9	34.2	3	43.5	38.4
X7106	0.069"	40.0	36.0	5.5	44.5	40.2

Post-braze heat treatment significantly improved the strength of X7106, but only moderately affected X7005. Based on the strengths of the brazed panels reported previously and on the heat-treat study, post-braze heat treatment at 900°F, had not caused significant diffusion of the brazing alloys

The quenching rates that would be achieved in large panel brazing would be from 30" to 50°F/min. These rates are nearly adequate for X7005 (see above - as brazed versus post-brazed heat treatment), but too slow for X7106.

~~Metal~~lographic Analyses of Brazed Panels

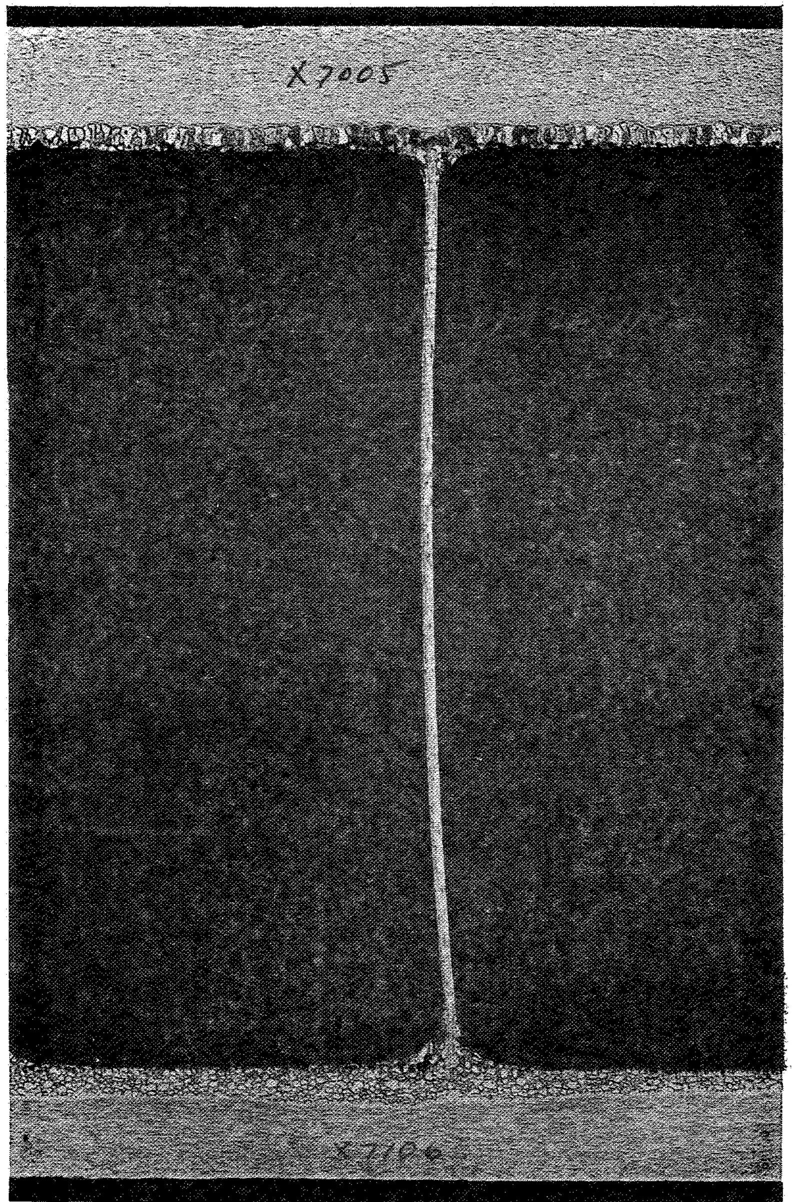
Portions of two brazed sandwiches were sent to the Alcoa research laboratories for their examination. The specimens were sectioned from the following two panels:

Panel No. 11 - X7005 and X7106 faces; X7005 core, 0.008" thick foil; and 719 brazing alloy brazed at 1050°F for ten minutes.

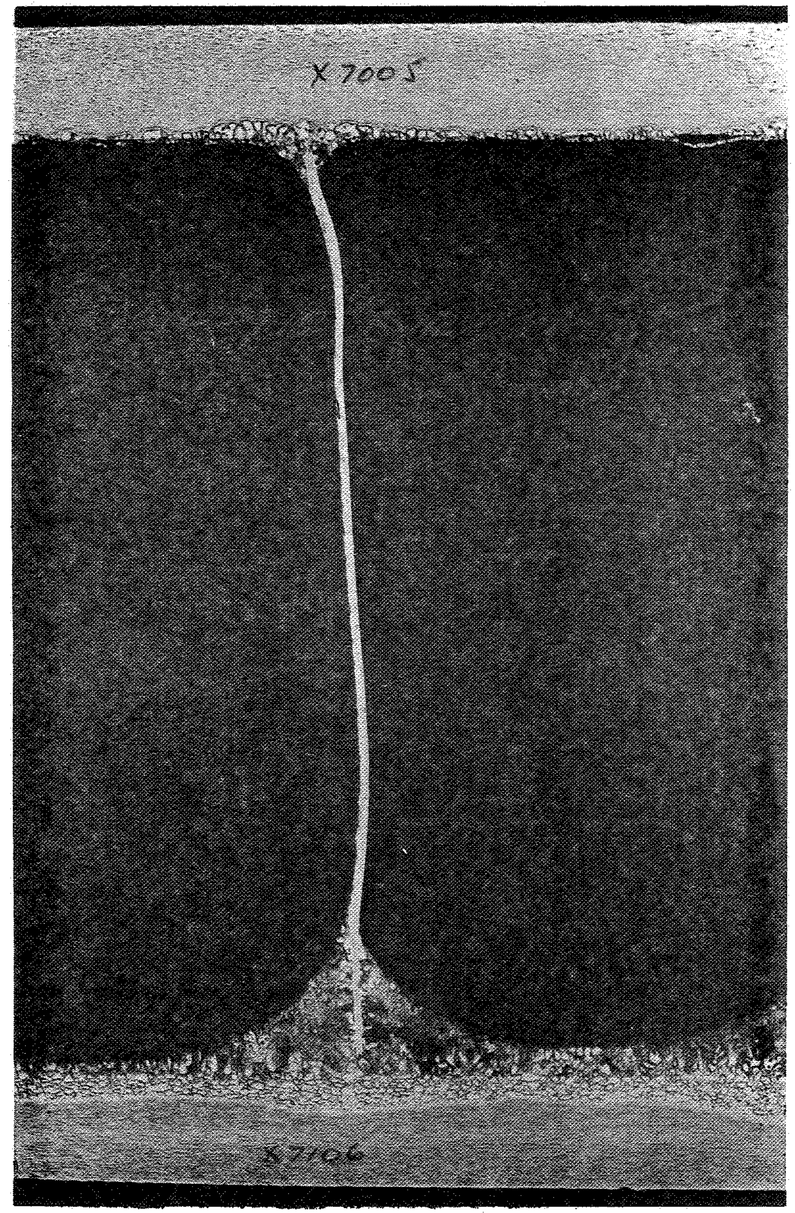
Non-numbered panel - 2" x 2" x 0.6", processed with panel no. 10 X7005 and X7106 faces, X7005 core, 0.008" thick foil, 716 brazing alloy applied as 0.010" thick sheet, brazed at 1080°F for ten minutes.

Macrophotographs of the two specimens, shown in Figure 27, were furnished by Mr. T. L. Corey, Alcoa.

It was evident that X7106 was more adversely affected by both brazing alloys than was X7005 and there was little difference between the two brazing alloys. Also, it was apparent that the amount of brazing alloy was excessive; but, the flame sprayed 719 was retained on the faces. The 0.010" 716 filler exhibited 'run-out' to the lower face of the panel.



Spec. No. 285960 Mag. 10X Keller's Etch
Panel No. 11



Spec. No. 285961 Mag. 10X Keller's Etch
Specimen Processed with Panel No. 10

Figure 27 Aeronca Brazed Sandwich Specimens. Macrophotographs furnished by Mr. T. L. Corey, Alcoa Research Laboratories. Note penetration of the Brazing Alloys into X7005 was less than that into X7106.

Panel Brazing and Tensile Data Conclusions

Alloy X7005 could be fluxless brazed with brazing alloys 718, 716, and 719. Nominal ultimate and yield strengths which could be expected from the as-brazed and aged condition were *40,000* psi and 35,000 psi, respectively, with 5% elongation. **All** of these brazing alloys diffused into X7005 to some extent but 718 had the most adverse effect on the thin X7005 core foil. X7005 core was substantially unaffected by brazing alloy 716 and 719. Alloy 719 would be preferred because its brazing temperature was lower than that of alloy 716. **As** a consequence the brazing temperature range would be broader and easier to control when' brazing large parts.

Alloy 7106 could be fluxless brazed with brazing alloys 716 and 719. Alloy 719 would be preferred because its brazing temperature was about 45°F below the solidus of X7106. Brazing alloy 716 brazed at 5° to 10" below the solidus of X7106. Both 716 and 719 diffused into and adversely affect the alloy X7106. Nevertheless, X7106 sheer brazed with either 716 or 719 could develop nominal ultimate and yield strengths of 50,000 psi and *40,000* psi, respectively, with 6% elongation.

The quenching rate of X7106 should be faster than that of X7005. High strengths were obtained only when brazed X7106 panels were poet braze heat treated.

Alloys 6951 and 6061 were substantially unaffected by any of the brazing alloys, except that 6061 requires a brazing temperature lower than 1100°F. The approved minimum ultimate and yield strengths were obtained when these alloys were water quenched and aged. However, elongations were reduced.

The experience in brazing large panels with some of the above metal systems is presented in Volume II. During the second year of the contract, brazing alloy No. 719 was obtained as foil and evaluated. In addition, a zinc-base alloy foil was evaluated and brazing alloy foils were roll clad onto X7005. The discussion of that work is presented in the next section.

2.3 MATERIALS AND PROCESSES OPTIMIZATION

2.3.1 The No. 719 Alloy

A 50 lb. cast ingot of the No. 719 alloy was sawed into four slabs measuring approximately 1" x 4" x 30" and rolled to 0.005" foil.*

The 0.005" foil was used to braze small sandwich specimens having .062" X7106 faces and No. 22 brazing sheet core, type 6-100 x .6" and 6-50 x .6". At a brazing temperature of 1050°F and a time of 15 min. at temperature, excellent appearing brazes were made. In addition, full node flow and core node joining was observed. Three separate sandwiches having 6-100 x .6" core were tested in flatwise tension and the results are reported below:

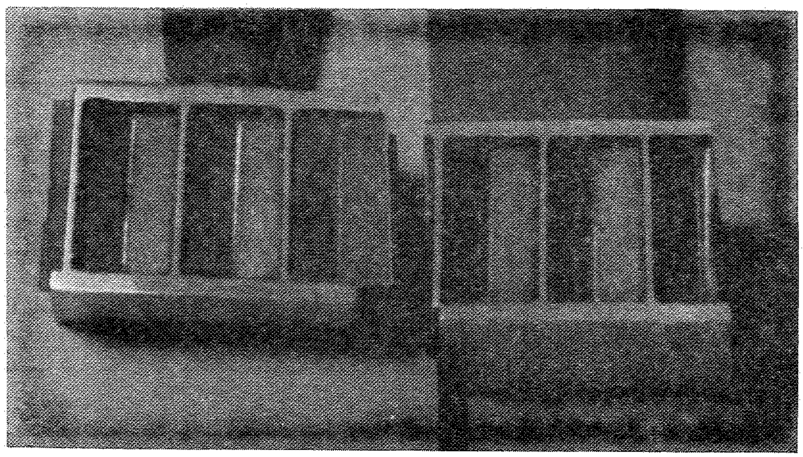
Specimen Number	Flatwise Tensile Strength psi	Failure Mode
T-719-1	490	50% Core Tear
T-719-2	770	100% Core Tear
T-719-3	800	50% Core Tear

These data show that the braze was equal in strength to the core.

Sections of one of the sandwiches are shown in Figure 28 . Note the uniformity of filleting and full node flow. The photomacrograph, Figure 28, right, again shows the extent of diffusion effect of No. 719 on X7106.

The diffusion of constituents of the No. 719 brazing alloy into X7106 was not significantly different whether the brazing alloy was placed as 0.005" thick foil, or flame sprayed onto the facing sheet.

*Work done at the Battelle Memorial. Institute, Columbus, Ohio.



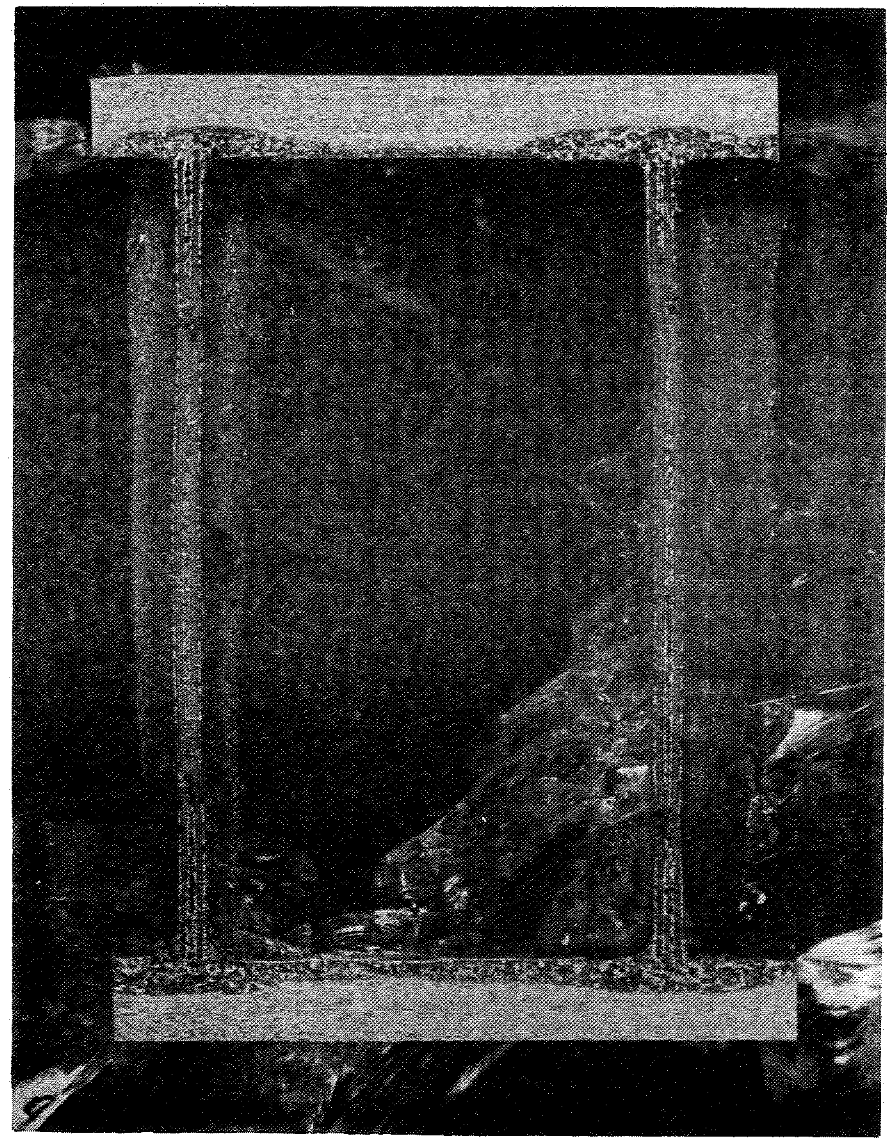


Figure 28 Left: Sections of a Brazed Sandwich Having X7106 Faces, .005" Thick No. 719 Brazing Alloy Foil, and No. 22 Brazing Sheet Core, Type 6-100 x .6".

Right: Photomacrograph of the Brazed Sandwich.

Mag: Approx. 7X

Prior to the work reported below, the thinnest honeycomb core foil which had been brazed on this program was 0.008" thick. That foil fabricated into hexagonal cell honeycomb core 3/8" cell size had a core density of 8.4 pounds per cubic foot. The decision was made that a lower density core would be selected for the Phase II brazing and testing program. Alloy X7005 was procured and rolled to a thickness of 0.0054". That foil fabricated into 3/8" cell size honeycomb core had a density of 6.2 pounds per cubic foot.

The selected brazing alloy was No. '719, available as 0.005" thick foil in 2" wide strips. There was a question whether that thickness of brazing alloy could be used to braze the thin X7005 core foil without dissolving it. Consequently, another series of laboratory tests were conducted and they are described below.

Sandwich specimens were brazed in the laboratory using the described core, X7005 faces and the No. 719 brazing alloy 0.005" thick. One group of specimens had brazing alloy placed only on the top side of the core; the other group had brazing alloy on the top and bottom. The brazing cycle was 10 minutes at 1050°F in an argon atmosphere. Both groups were well brazed and the 0.005" thick X7005 honeycomb core foil was not dissolved by the No. 719 brazing alloy. Macro and micro photographs of brazed specimens are shown in Figures 29 and 30.

A similar series of tests was conducted using magnesium to promote brazing alloy flow. Magnesium was applied to the brazing alloy foil by galling as is described subsequently. Figure 31 shows an example of the very large fillets which resulted from the magnesium addition when the brazing alloy was placed on the top and bottom of the core. Figure 32 shows a lower fillet which resulted from the magnesium coated brazing alloy placement at the top only. While magnesium did promote brazing alloy flow and wetting, it had the disadvantage of causing local erosion of the honeycomb core foil at the top side of the sandwich core blanket.

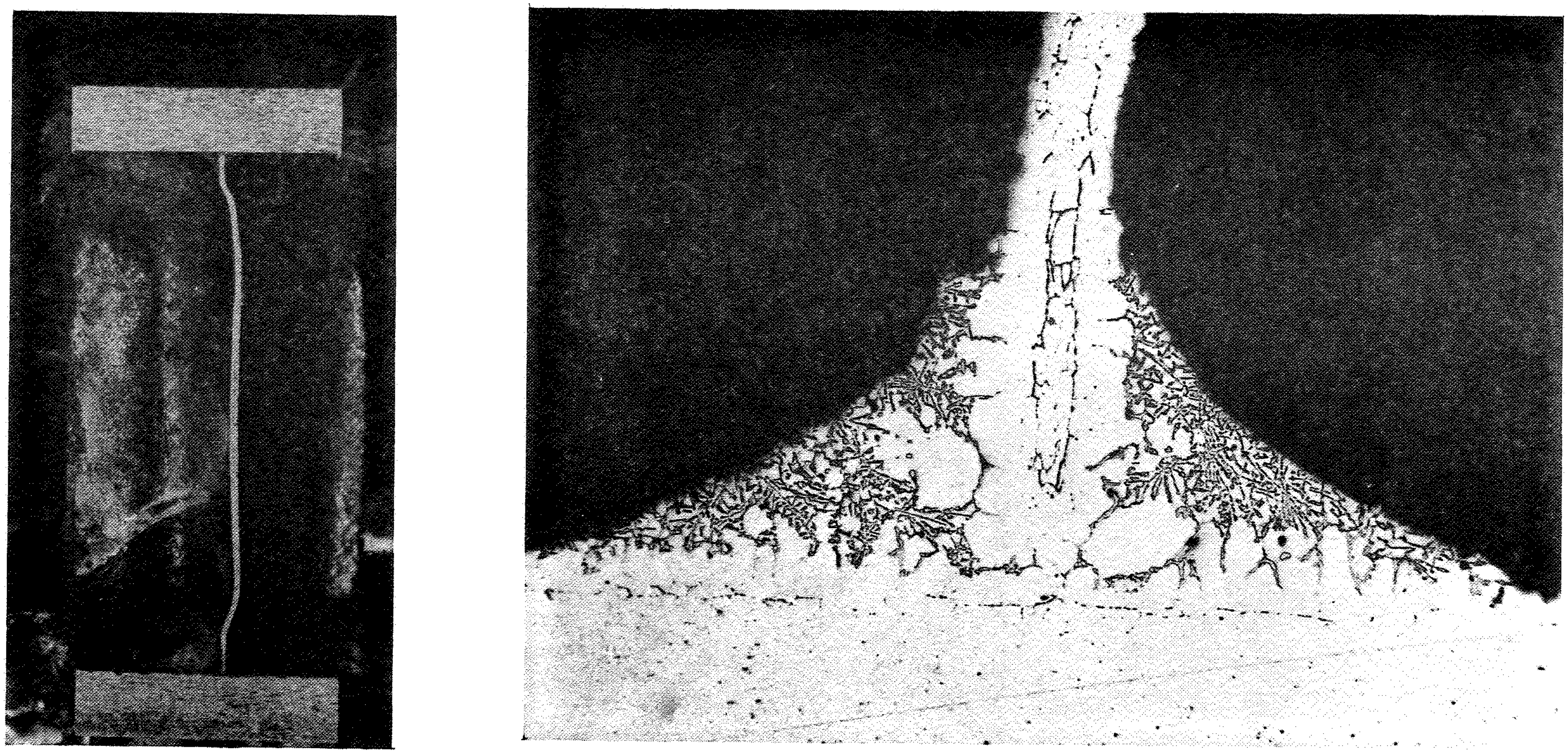


Figure 29 - Left: Section from a Laboratory brazed X7005 sandwich having 0.005" No. 719 filler placed on only the top side of the sandwich core. Mag. 6X

Right: Lower fillet of the macrograph

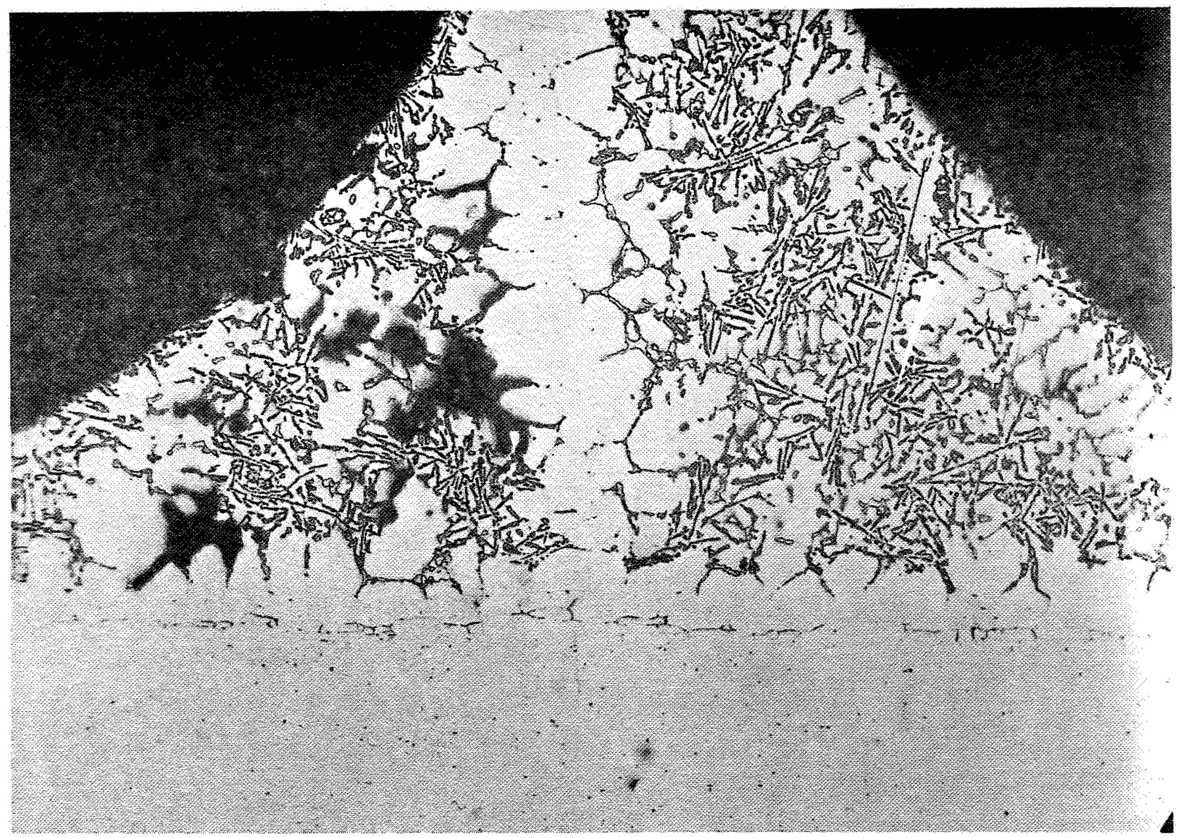
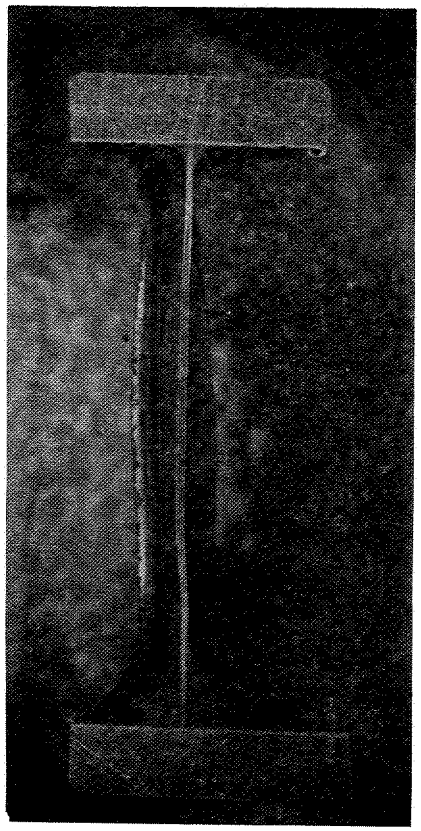


Figure 30 - Left: Section from a Laboratory brazed X7005 sandwich having 0.005" No. 719 filler placed on both sides of the sandwich core. Mag: 6X

Right: Lower fillet of the macrograph Mag: 100X



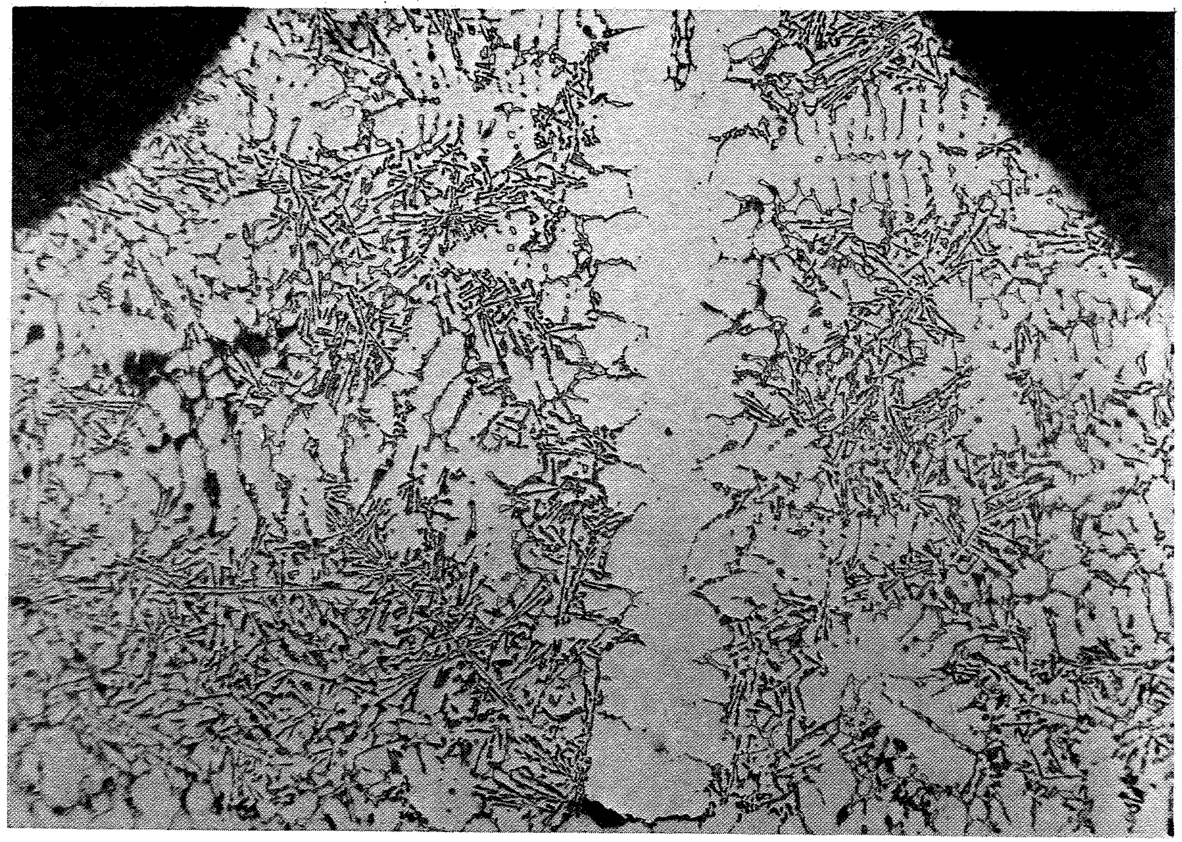


Figure 31 - Left: Section from a Laboratory brazed X7005 sandwich having magnesium coated 0.005" No. 719 filler placed on both sides of the sandwich core. Mag: 6X

Right: A portion of the lower fillet of the macrograph. Mag: 100X

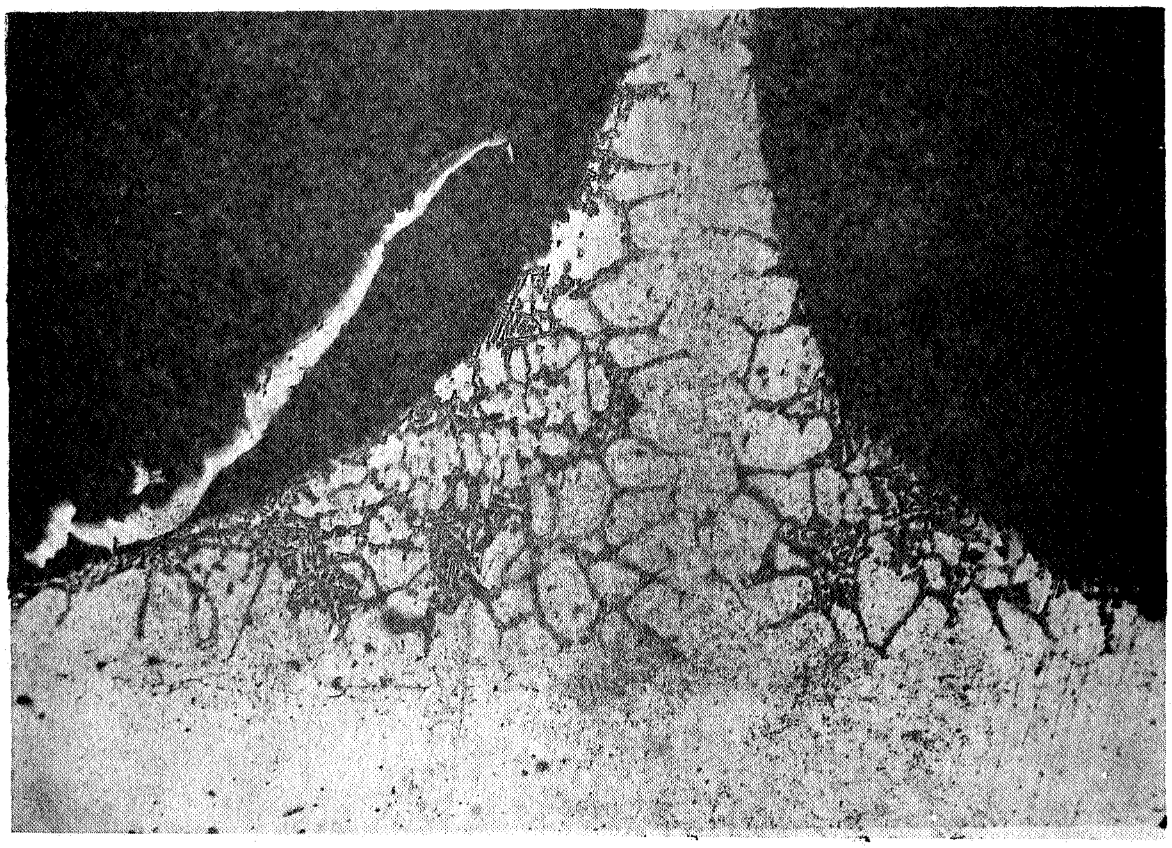


Figure 32 - The lower fillet of a Laboratory brazed X7005 sandwich having magnesium coated 0.005" No, 719 filler placed on only the top side of the sandwich core, Mag: 100X

Because of the success in brazing without flux or flow promoters and because the magnesium promoter made the brazing alloy aggressive, the large panel brazements (Volume II) were brazed without any added flow promoter. In addition, brazing alloy placement on the top and bottom of the sandwich was selected for the large panel brazements, because it was expected to offer greater assurance of a successful braze.

2.3.2 Roll - Ciad Brazing Alloys

Metals and Controls Division of Texas Instruments, Attleboro, Mass., was selected to roll clad sheet brazing alloys onto X7005 sheet. Brazing alloys and X7005 were strips approximately 2" wide x 30" long.

Two layers of 0.005" thick foil of 80 Zn-20Al+0.05Be were cold roll clad onto X7005 and one layer of 0.010" No. 716 alloy was clad onto another sheet of X7005. The brazing alloy thickness was reduced to approximately 0.006" during the roll cladding.

Brazing tests were conducted on small sandwich specimens in the laboratory furnace in an atmosphere of argon as described previously. The 80Zn-20Al+0.05Be clad X7005 was brazed at temperatures between 930' and 970°F. Eoth 6951 and X7005 core were used. The brazing alloy melted at 930° bnt did not fillet. At 970°, both flow and filleting were obtained, but uniformity was poor. The clad brazing alloy satisfactorily wet and adhered to the X7005 faces, but X7005 core was not wet as well as was the 6951 core. Generally, non-uniform filleting was obtained and the filleting appeared to occur, primarily, as a result of the run-down from the upper face.

Similar tests were conducted using the No. 716 clad X7005 brazed in the range of 1060" to 1100°F. The No. 716 alloy readily wet and filleted both 6951 and X7005 core at all temperatures tested.

Both cf the clad alloy systems were brazed as larger specimens as discussed in the next section.

Subsequently, the No. 719 alloy became available in the form of 0.005" thick foil. Metals and Controls Division was requested to undertake further cold rolling tests on both the No. 716 alloy and the No. 719 alloy with the aim of cladding honeycomb core foils. Metals and Controls Division declined to quote on the work because of their excessive work load. Because of timing and other requirements of the program, it was not considered desirable to develop another source for the roll cladding and no more cladding was done; although, braze clad substrates were shown to be far superior to other methods of placing alloys with respect to overall braze-ability and core node flow in particular.

Based on the results of the brazing teste using clad brazing alloy coating (as reported above and in the next section), the two most significant observations were: (1) brazing alloys 'can be cold roll clad onto structural aluminum alloys; and (2) effective fluxless aluminurn honeycomb sandwich brazing can be accomplished with only the core foil clad with the brazing alloy. In addition, full node flow and node joint brazes can be expected in the core blankets having brazing alloy clad core foils. These factors would make procurement and testing of experimental aluminum brazing alloys more economical and the system would not be size limited, thus it lends itself to scale-up. Only a small mill would be required to clad the core foil, whereas large production equipment would be required to clad sandwich facings. Moreover, the ingot cladding method used by the aluminum mills is not satisfactory for alloys No. 719, No. 716 and other experimental brazing alloys; but, cold roll cladding could be adopted €or cladding aluminum foils in small lots.

2.3.3 Powdered Brazing Alloys

Brazing alloys No. 719 and 53.0Al-45.0Ge-1.5Si were powdered by filing. Both of the powdered alloys readily wet and flowed on the faces of X7005 sandwich specimens, but did not fillet. The temperatures used were 1050°F for the No. 719 alloy and 1000°F for the Al-Ge-Si alloy. Other experimental alloys discussed within also were tested in the pcwdered form. Without flux, the powdered alloys did not coalesce and flow to form fillets. Some did wet the substrate and flow under a film of oxide, but they did not readily wet the adjacent aluminum alloy (core) nor form fillets.

The No. 719 powdered alloy was pressed to form small sheets, then used to braze X7005 sandwich specimens at 1050°F. Wetting and filleting were improved over that obtained with loose powder. To make larger brazing alloy sheets, No. 719 powder was pressed between two films of 0.0005" aluminum foil. Brazing with that composite alloy was successful, but the addition of pure aluminum foil raised the brazing temperature from 1050° to 1080°F.

Further btazing tests of the powdered No. 719 alloy are presented in the next section.

2.3.4 Magnesium, As A Brazing Flow Promoter

During the preliminary investigations it was demonstrated that magnesium significantly influenced and improved the flow and wettability of Al-Si brazing alloys on aluminum. Magnesium was applied to sandwich panel faces by painting a suspension of magnesium powder in a suitable binder. However, adequate control of the process proved difficult. If too much magnesium was present, the brazing alloy became aggressive and dissolved the thin honeycomb core foil. For that reason, magnesium was not used on the flat sandwich panel brazing and testing program (Volume II). It was concludad that the Al-Si brazing alloys, and the No. 719 brazing alloy in particular, wet aluminum adequately without any promoters.

Another series of brazing tests were performed in an attempt to obtain the benefits of magnesium while decreasing its aggressive characteristics. Aluminum powder, -600 mesh, was mixed with the magnesium powder in the following ratios by weight:

2 Mg: 1Al
3 Mg: 1Al
4 Mg: 1Al
5 Mg: 1Al

Aluminum additions decreased the aggressive characteristics, but none of the compositions gave satisfactory brazements and wetting and flow were retarded.

In other tests, honeycomb sandwich face sheets and core of X7005 were coated with magnesium by vacuum vapor deposition in an evacuated bell jar. Several small strips of magnesium foil, 0.004" x ¼" x 1" were suspended on a heating element which was operated at 2000°F. Aluminum specimens were suspended above the heating element at a distance of 10" and at ambient temperature. Bright coatings with a bluish tint were obtained.

Brazing tests on the magnesium coated aluminum were unsuccessful. The alloys used were No. 719, No. 716 and 80Zn-20Al+0.05Be. The brazing alloys were repelled from the magnesium coated surfaces to areas of bare aluminum.

Another series of tests were conducted using longer coating durations and higher element temperatures.

Operating conditions were the following:

a) Vacuum: tetter than 0.1μ

b) Heating Element: tantalum foil operated at 3500°F

c) Time: *3 to* 5 minutes

d) Magnesium: 0.5 gm .005" foil

Gray appearing coatings were deposited onto aluminum substrates (face and core) and onto zinc and Zn-alloy foils. The coatings gave an indication for magnesium in HNO_3.

During tests on brazing aluminum with zinc foils, the magnesium coatings appeared to neither aid nor surpress zinc brazing. In another test, two X7005 specimens were brazed with the No. 719 alloy; one X7005 sample was bare, the other had a magnesium coating. Both behaved identically and both were wet by the No. 719 alloy.

Another series of tests were conducted on magnesium coatings. In these tests, magnesium was galled onto X7005 aluminum sheet by simply rubbing a soft, pure magnesium rod over the surface of the clean aluminum alloy sheet. Sheet, coated in that manner, and bare sheet, were used as substrates for flow tests of the No. 719 brazing alloy foil and wire. Little difference was noted in brazing alloy flow from 1/8" diameter No. 719 wire, but the 0.005" No. 719 foil appeared to wet the magnesium coated aluminum sheet better than bare sheet. Small sandwich specimens of X7005, with the magnesium coated facing sheets showed significant improvements in brazing alloy flow and filleting characteristics, however erosion of the core occurred.

Additional investigztions on magnesium are reported in Section 3', Brazing Alloy Development.

2.3.5 Sandwich Erazing Tests

The previous section described cold roll cladding of two brazing alloys onto X7005. They were the No. 716 alloy clad onto X7005 and an experimental Zn-Al-Be alloy clad onto X7005. In addition, honeycomb core was fabricated from commerically available No. 22 brazing sheet*, type 6-100. Another honeycomb core which was available was X7005 (bare material), type 6-80. These materials and others were used for the sandwich brazements described below.

Brazing Parameters and Materials Combinations

Retort 1 - Aluminum Alloy 3003, containing the following sandwiches:

(1) .040" X7005 faces clad with No. 716 alloy, X7005 core, 6-80 x ½

(2) Same except that only the top face had brazing alloy

(3) .040" X7005 faces, No. 719 alloy powder pressed between aluminum foil, X7005 core, 6-80 x ½

The retort was positioned between two halves of an egg-crate type stainless steel fixture. Purging was done by evacuating and back filling with argon through ten cycles. For the brazing cycle, the argon pressure within the retort was adjusted to provide an atmospheric clamping pressure of 0.2 psi.

The brazing temperature was 1070°F, followed by water quenching. Quenching was done by submersion using the bottom-drop furnace and water tank, as previously described.

Retort 2 - Aluminum Alloy 3003, containing the following sandwich specimens:

(1) X7005 faces clad with 80Zn-20Al+0.05Be, 6951 core, 6-80 x ½

(2) Same, except that the brazing alloy was separate foil, .006" thick.

(3) X7005 faces, 6951 core, 6-80 x ½, and separately placed brazing foil comprised of .002" Zn and .005" Mg.

Purging and back filling were done as described above except that clamping pressure was adjusted to 0.5 psi. The retort was positioned between two halves of an egg-crate type fixture constructed of 'Transite'. The brazing temperature was 970°F followed by water quenching, as described.

*6951 clad both sides with the No. 713 alloy

<u>Retort 3</u> - Aluminum Alloy 3003, containing the following sandwich specimens:

(1) .040" X700.5 faces, bare, Core, Brazing Sheet No. 22, type 6-100 x 0.6"

(2) .040" X7005 faces, clad with No. 716 alloy, Core, same as (1)

(3) .040" X7005 faces, brazing alloy: .003" No. 718 and .002" Zn, Core, same as (1)

(4) .040" X7005 faces, brazing alloy: .003" No. 718 and .001" Cu, Core, same as (1)

The brazing temperature was 1080" - 1040°F.

Atmospheric clamping pressure on the panel was 0.4 psi. Following brazing, the retort was quenched into liquid nitrogen. However, prior to quenching the retort, but after the brazing cycle was completed, the gas and vacuum tubes inadvertently were pulied off rhe retort. Consequently, the panels were totally unrastrained and had no clamping pressure during the quench.

<u>Retort 4</u> - Carbon Steel, containing the following sandwich specimens:

(1) 0.060" X7005 faces, bare, Core, Erazing Sheet No. 22, type 6-100 x 0.6"

(2) 0.040" X7005 faces, with .003" No. 718 alloy, Core, same as (1)

The brazing temperature was 1080" to 1090°F and the atmospheric clamping pressure was 0.4 psi. The retort was quenched into liquid nitrogen.

<u>Retort 5</u> - Carbon Steel, containing the following sandwich specimens:

(1) 0.060" X7005 faces, bare, Core, Brazing Sheet No. 22, type 6-100 x 0.6"

(2) 0.060" X7005 faces, bare, 0.003" No. 718 alloy added, Core, same as (1)

The brazing temperature was 1110" to 1120°F and the atmospheric clamping pressure was 0.5". The retort was quenched into liquid nitrogen,

<u>Retort 6</u> - Carbon Steel, containing sandwich specimens identical to those in Retort No. 5.

The brazing temperature was 1090°F and the atmospheric clamping pressure during brazing was 0.3 psi. The retort vas air quenched.

Discussion of Brazed Panels

The panels within retort No. 1 were poorly brazed owing to atmospheric contamination. However, the panel with powdered No. 719 brazing alloy was partially well-brazed and had large fillets.

Retort No. 2 also had atmospheric contamination and the panels were not well brazed. Figure 33 shows a section of the panel which had X7005 faces clad with 80Zn-20Al-0.05 Be. Some filleting occurred on the bottom face as shown metallographically in Figure 33. Note that penetration of this zinc alloy into X7005 was limited to about 0.002".

The wetting aid provided by magnesium to zinc was evident in the panel where a lamination of magnesium foil and zinc foil was used as the brazing alloy. After forcibly removing one face of the sandwich, much of the brazing alloy adhered to the core. Unfortunately, this Mg-Zn alloy was brittle.

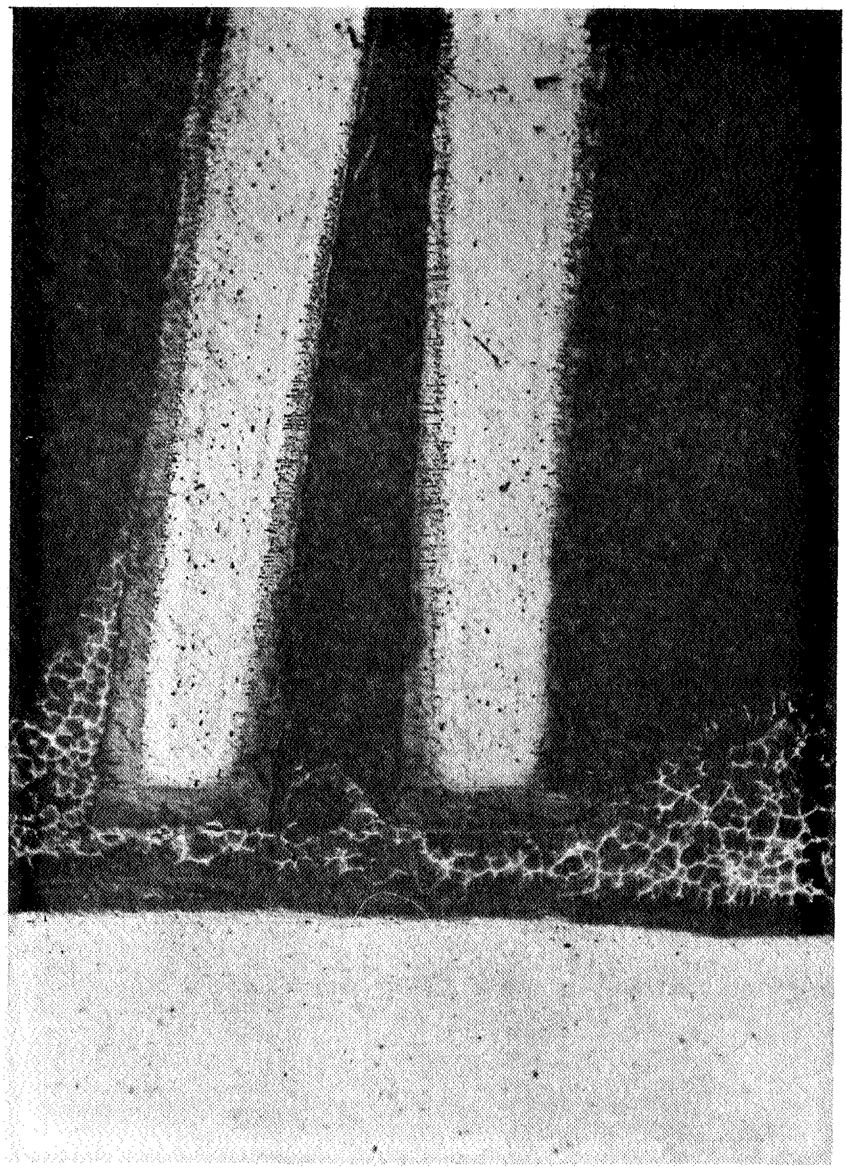


Figure 33 Cross Scctiun Photo.nicrograph of Core Nude-to-Face Joint for Sandwich Panel from Retort No, 2. Faces were X7005 Clad with a Zn-Al-Be Alloy. Core was X7005.

Mag. 100X

All of the panels in retort No. 3 were well brazed having good face-to-core fillets and nearly full node braze. Figure 34 shows a section of the panel which had hare X7005 faces and core fabricated from No. 22 Brazing Sheet. A cross section photomicrograph of a core node-Eo-face joint is shown in Figure 35.

A section of the panel with faces comprised of X7005 with roll clad No. 716 alloy is shown in Figure 36 and a photomicrograph of the core node-to-face joint is shown in Figure 37.

The No. 716 brazing alloy had little effect on the X7005 faces, based on metallographic examination.

The panels which had zinc or copper foil added to the No. 718 brazing foil are shown in Figure 38. The additions were made to depress the brazing alloy melting point and to increase flow, which occurred for both cases. However, the modified brazing alloys were aggressive and dissolved portions of the honeycomb core.

The panels described in this sectionwere aged 48 hrs. at 250°F, following brazing. Tensile data from the brazing alloy coated faces of several panels were obtained and reported below.

Sandwich Panel Facing	Ultimate Tensile Strength KSI	Yield Strength 0.2% Offset KSI	Elongation %
X7005 clad with No. 716 From Retort No. 1	42.5	33.8	9.3
	40.7	33.6	7.0
X7005 clad with No. 716 From Retort No. 3	38.8	32.9	8.5
	30.6	33.1	8.5
X7005 clad with Zn-Al-Be From Retcrt No. 2	34.5	30.8	3.0
	34.0	29.1	3.0
X7005 brazed with Zn-Mg foils from Retort No. 2	28.5	26.1	2.5
	31.8	30.0	1.0

The No. 716 brazing alloy moderately reduced the strength and ductility of X7005. Zinc alloys, and particularly the brittle Zn-Mg alloy, significantly reduced the ductility of X7005.

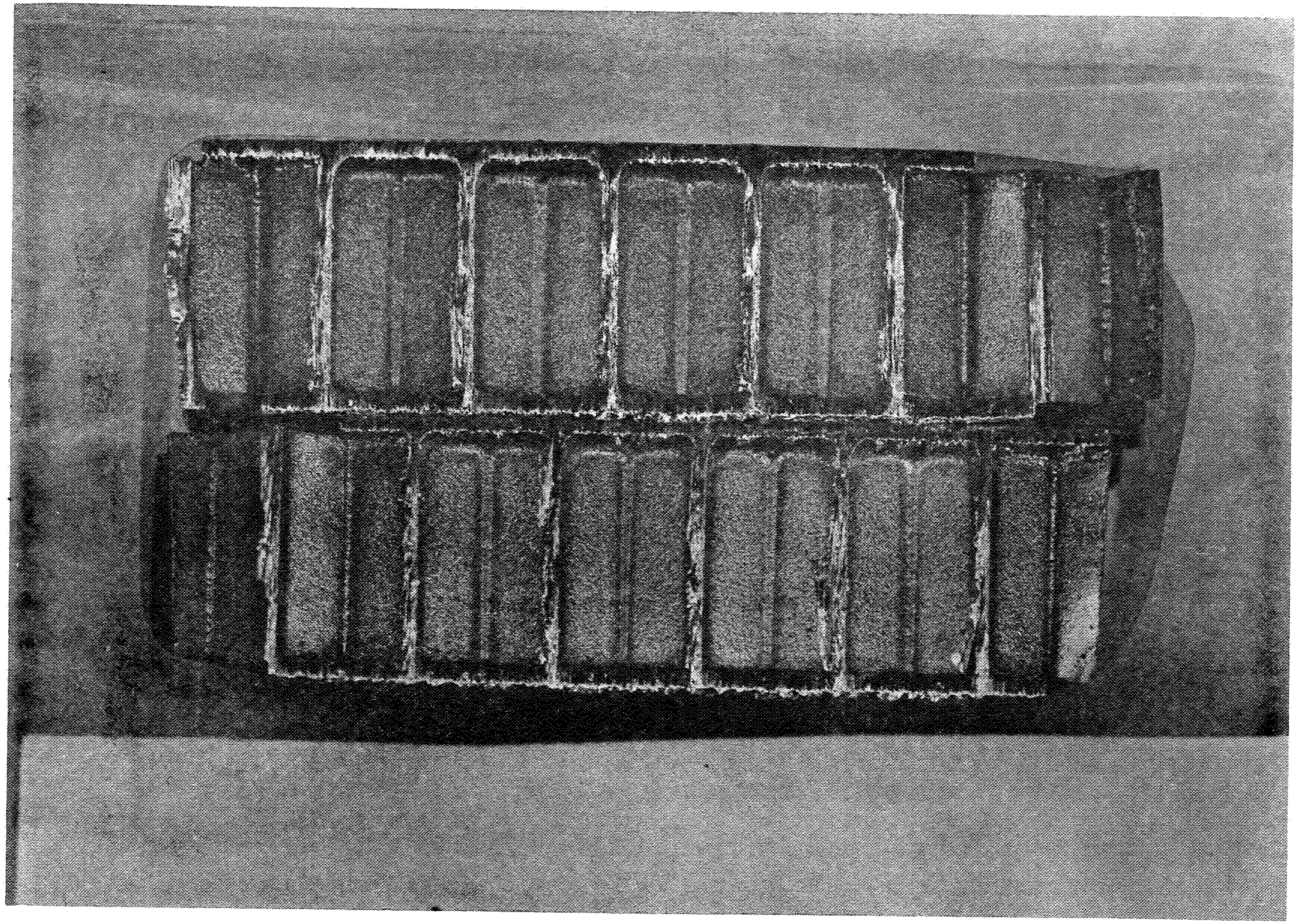


Figure 34 Sections of a Sandwich Panel from Retort No. 3. Faces were X7005 and Core was Brazing Sheet No. 22. No additional Brazing Alloy was Used.

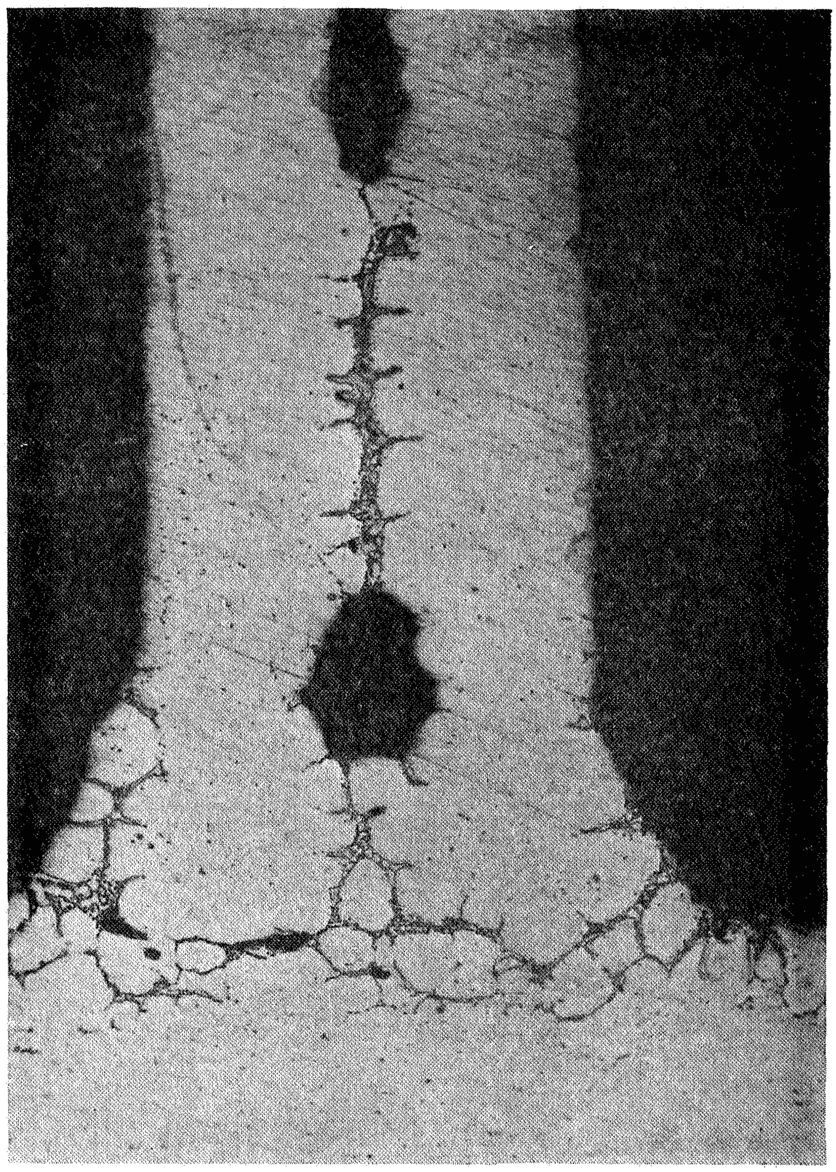


Figure 35 Cross Section Photomicrograph of Core Node-to-Face Joint for the Sandwich shown in Figure 18. Faces were X7005 and Core was Brazing Sheet No. 22

Mag: 100X

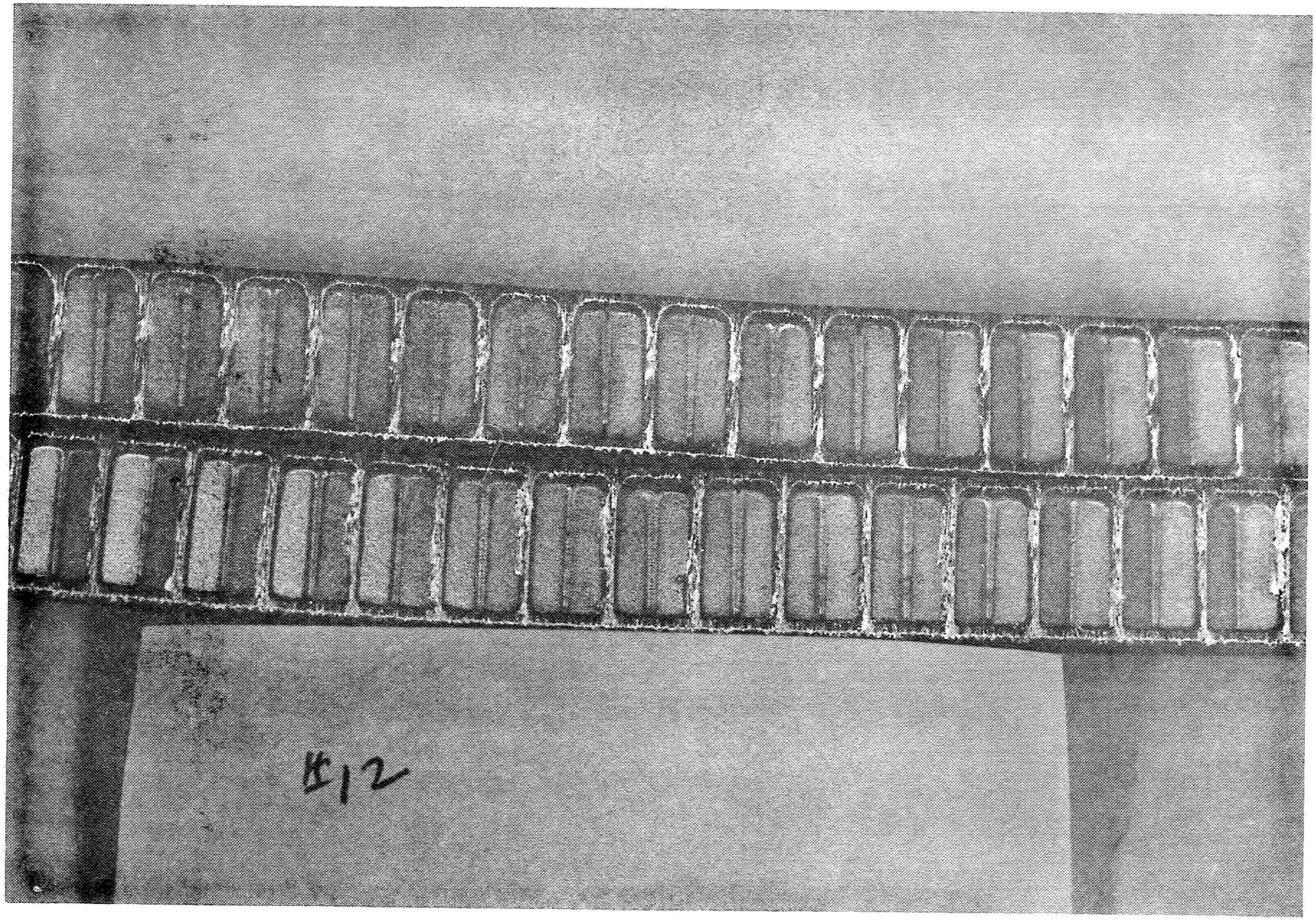


Figure 36 Sections of a Sandwich Panel from Retort No. 3. Faces were X7005 Cold Roll Clad with No. 716 Brazing Alloy. Core was Brazing Sheet No. 22.

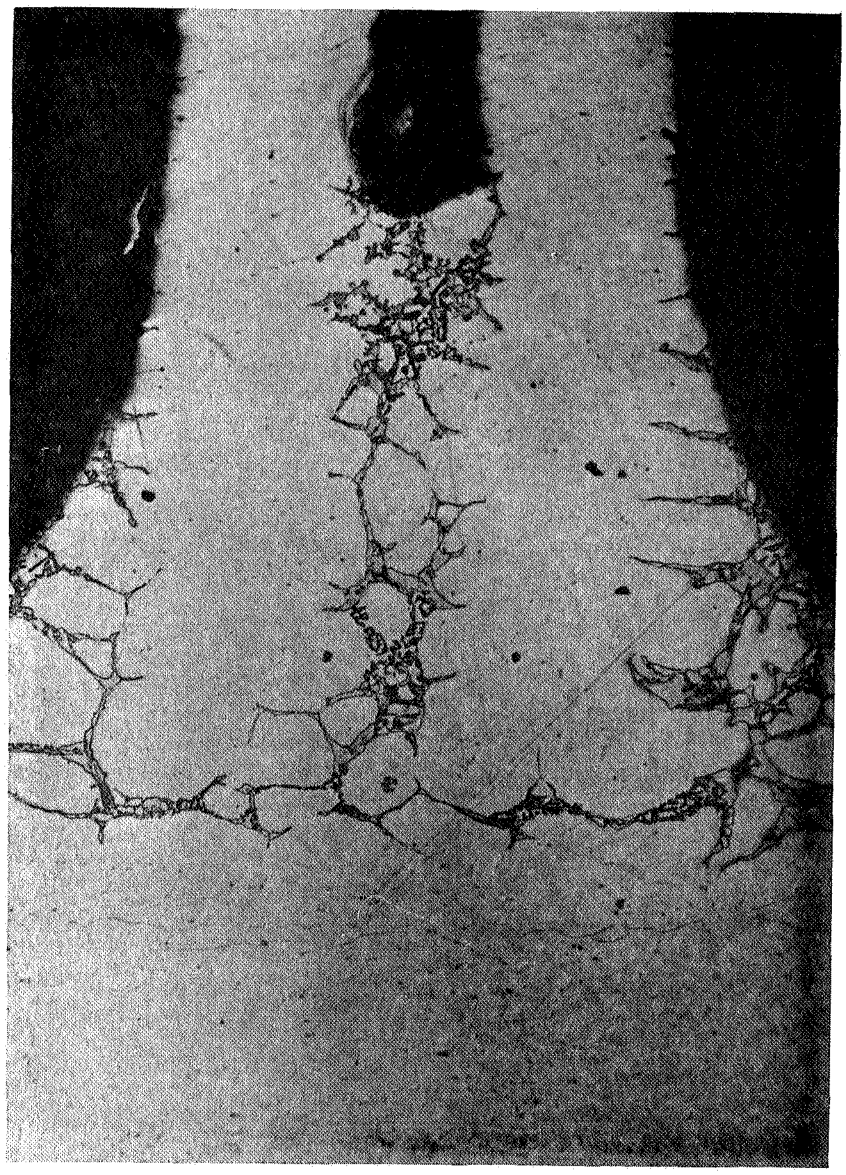


Figure 37 Cross-Section Photomicrograph of Core Node-to-Face Joint for the Sandwich Panel Shown in Figure —— & Faces were X7005 Clad with No. 716 Alloy. Core was Brazing Sheet No. 22.
Mag: 100X

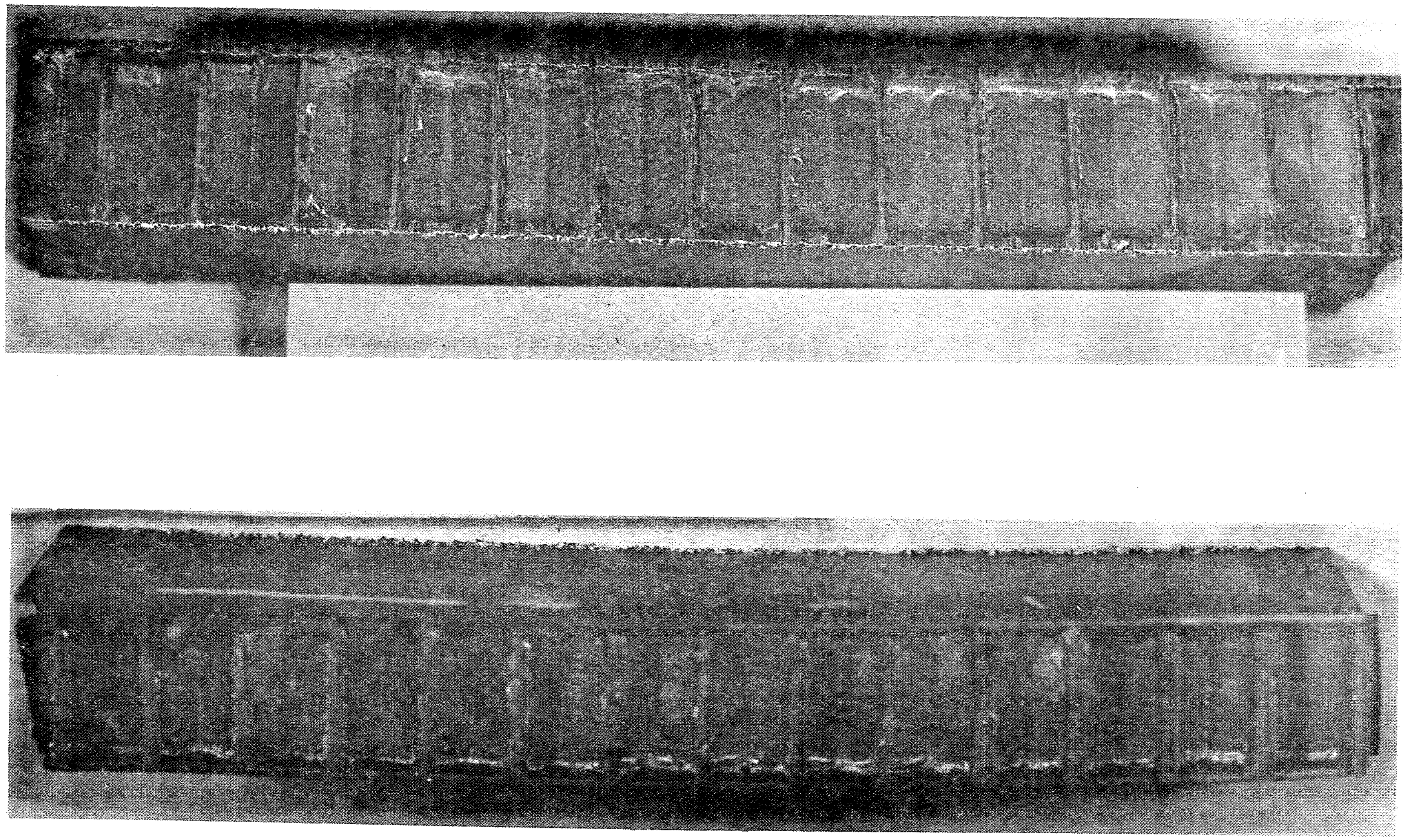


Figure 38 Sections of Two Sandwich Panels from Retort No. 3. Both had X7005 Faces and Brazing Sheet No. 22 Core. Brazing Alloy added was: Top: No. 718 Foil and Cu Foil; Bottom: No. 718 Foil and Zn Foil.

Retort No. 4 had external, rather than internal thermocouples, and is believed to have been brazed at a temperature 10" to 15" below optimum. Only small fillets were obtained, but the core node braze was nearly complete.

Figure 39 shows samples of brazed core, sectioned from panels brazed in retorts No. 3 and No. 4.

The fifth brazement (retort No. 5) was heated to the high side of the brazing range (1120°F) and atmospheric clamping pressure was increase to 0.5 psi. Excellent brazing alloy flow was achieved, but the core was crushed by the pressure used at the given temperature, Except for facing sheet tensile tests, no further tests were done on that panel.

The brazed panels from retort No. 6 appeared sound overall, except that the panel without additional brazing alloy filler had very small fillets.

Following brazing, the panels were aged 48 hrs. at 250.F, and sectioned for test specimens. In addition, mechanical tests were conducted on specimens sectioned from the panels brazed in retorts previously described.

Tensile data on the brazed sandwich panel facings are given in Table 5 and sandwich panel flatwise tensile data are given in Table 6.

The tensile data show that the No. 718 brazing alloy modestly reduced the strength and ductility of the X7005 faces. This had been reported previously and it had been shown that the No. 719 brazing alloy evidenced less diffusion into X7005.

The flatwise tensile data of Table 6 give *the* best measure of braze quality, The data show that the best test values were obtained when brazing alloy foil was added in addition to the brazing alloy clad core foil. Inspection of the specimens showed that failure occurred (for specimens without added filler) at the top face. The failure mechanism suggests that when using brazing alloy clad honeycomb core, it may be necessary to add additional brazing alloy on the top face of the sandwich,

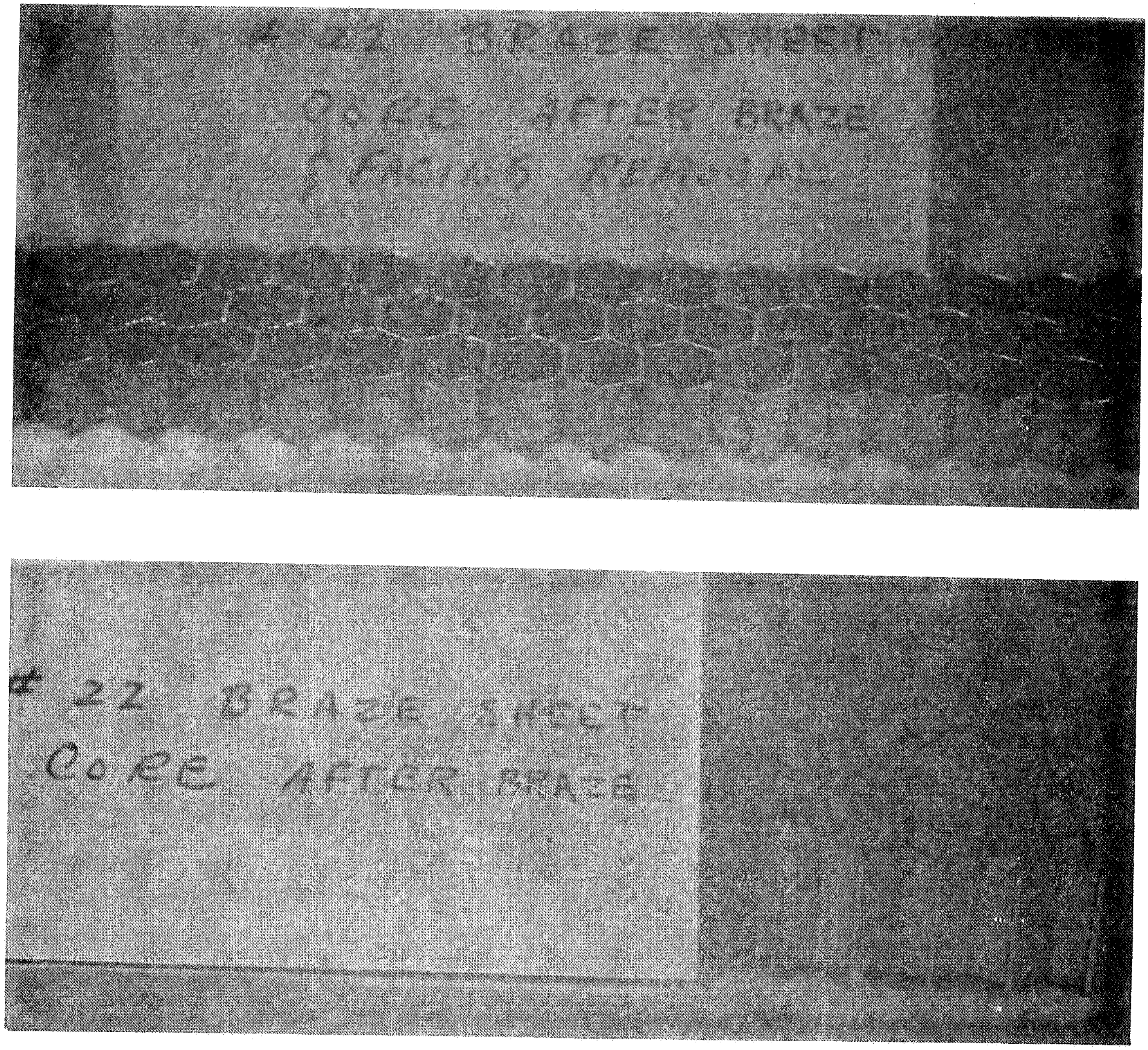


Figure 39 Brazing Sheet No. 22 Core Sectioned from Brazed Panels: Top, from Retort No. 3; Bottom, from Retort No. 4.

TABLE 5

ROOM TEMPERATURE TENSILE DATA - VARIOUS BRAZED SANDWICH PANEL FACINGS

Specimen Number	Specimen Identification	Facing Tensile Data: Tensile Strength ksi	Facing Tensile Data: Yield Strength 0.2% Offset ksi	Facing Tensile Data: Elongation Per Cent	Remarks
4-B 4-B	Bare X7005 Faces brazed to No. 22 Brazing Sheet core, retort No. 4	46.2 45.5	36.1 36.0	14.0 12.3	
4-718 4-718	Bare X7005 faces, .003" 718 filler added, brazed to No. 22 Brazing Sheet core, retort No. 4	42.3 43.9	36.5 33.0	7.0 7.0	
5-B 5-B	Bare X7005 faces brazed to No. 22 Brazing Sheet core, retort No. 5	42.2 41.8	33.0 34.4	11.0 8.0	Retort 5 was over brazed - 1120°F compared to about 1090° for retorts 4 & 6.
5-718 5-718	Bare X7005 faces, .003" 718 filler added, brazed to No. 22 Brazing Sheet core, retort No. 5	39.7 38.6	33.0 32.3	5.5 4.0	
6-B 6-B	Bare X7005 faces brazed to No. 22 Brazing Sheet core, retort No. 6	46.6 45.0	37.0 37.0	14.5 14.5	
6-718 6-718	Bare X7005 faces .003" No. 718 filler added, brazed to No. 22 Brazing Sheet core, retort No. 6	46.0 45.6	36.8 36.8	11.5 9.0	

TABLE 6

ROOM TEMPERATURE FLATWISE TENSILE DATA - VARIOUS BRAZED SANDWICH PANELS

All Specimens had X7005 Faces. The Brazing Alloy and Honeycomb Core are Identified Below.

Specimen Number	Specimen Identification	Flatwise Tensile Strength psi	Failure Mode
1-B-1 1-B-2	Bare X7005 Core 6-80 x .6", Powdered No. 719 brazing alloy laminated between 0.0005" aluminum, retort No 1	620 1660	50% Core Tear 100% Core Tear
3-B-2	No. 22 Brazing Sheet Core, 6-100 x .6", no additional brazing alloy, retort No.3	1280	50% Core Tear
3-B-1	.005" No. 716 rollclad onto X7005 faces, No. 22 Brazing Sheet core, 6-100 x .6", retort No. 3	1975 1930 1443	100% Core Tear 100% Core Tear 30% Core Tear
6-B-1 6-B-2	No. 22 Brazing Sheet Core, 6-100 x .6", no additional brazing alloy, Retort No. 6	845 225	Braze Failure Braze Failure
6-718-1	No. 22 Brazing Sheet Core, 6-100 x .6", .003" No. 718 brazing alloy added, Retort No. 6	1480 1570	Braze Failure Braze Failure

Conclusion

On the basis of sandwich flatwise tensile data and metallographic inspection, the best sandwich brazements were achieved with honeycomb core fabricated from No. 22 brazing sheet foil, and with the No. 719 foil positioned between facings and honeycomb core blankets. Section 2.2 of Volume II describes the brazing of large sandwich panels fabricated from that material system. Sound sandwich brazements were achieved and full node flow was obtained in the sandwich core blankets.

On the other hand, the testing program, Section 2.3, Volume II, was conducted on sandwiches containing bare X7005 honeycomb core. Alloy X7005 was selected in preference to Brazing Sheet No. 22, for the honeycomb core, in the interest of obtaining the highest possible core strength. Those panels, with bare X7005 core, evidenced little node flow, although core-to-face brazes were acceptable,

3. BRAZING ALLOY DEVELOPMENT

This section was aimed toward brazing those high strength aluminum alloys having solution heat treatments ranging from approximately 900" to 1000°F. It would include 2024, 2014 and 2219 in the 2000 series. In the 7000 series alloys, it would include 7075, but X7106 would be the more reasonable candidate, because of its less restrictive quenching rate and broader solution heat treatment temperature range.

The criteria established for an aluminum brazing alloy to satisfy the above requirements are the following:

1. Compatible with aluminum from the standpoint of erosion during brazing and subsequent corrosion resistance.
2. Brazing temperature of about 900°F.
3. Sufficiently malleable to be rolled to foil.
4. Room temperature and cryogenic ductility.

3.1 BACKGROUND

Based on information available early in the program, the alloy systems selected for preliminary study were:

Al-Si
Al-Ge
Al-Ag
Al-Mg
Zn

The literature survey identified two alloy systems ($1-Ge and Al-Ag) which were specifically developed for brazing the heat-treatable aluminum alloys at or near their melting points (B-1, B-2, B-3, B-4, B-5, B-6 and B-8). According to Miller*, both the Al-Ge and Al-Ag alloys were suitable alloys for brazing aluminum. The Al-Ge alloys were said to be equally

*Miller, M. A., Alcoa Research Laboratory, New Kensington, Fa., personal communication.

as corrosion resistant as Al-Si alloys, but were not commercially available because of the cost of germanium. The Al-Ag alloys were said to have decreased corrosion resistance. Both alloy systems were used for brazing in the presence of flux.

Preliminary tests were planned to define the limits of room temperature ductility in the Al-Ge system and the limits of cryogenic ductility in the Al-Zn system.

3.2 PRELIMINARY DUCTILITY TESTS ON CAST ALLOYS

To establish base-line data, pure aluminum, alloy No. 718 and alloy No. 719 were melted, cast, and tested for bending strength and bend angle*. Melting was done in air at 1400°F under cover of a molten flux comprised of equal parts by weight of KCl and NaCl to which was added 5% by weight of cryolite. Ingots were essentially chill cast by pouring 100 gr. heats into shallow steel molds at room temperature.

Test results on the three heats were the following:

Alloy - As Cast **	Bending Strength (psi)	Bend Angle (degrees)
Aluminum (99.5 purity)	30,000	> 25***
No. 718 (88Al-12Si)	26,000	8
No. 719 (76Al-10Si-10Zn-4Cu)	42,000	2

The No. 719 alloy lacked substantial ductility. However, it was believed that the No. 719 alloy ingot, which was rolled to .005" foil, (Section 2) had prior work at Alcoa (extrusion).

*Metals Handbook, 1948 Edition, page 125. Specimens were 0.25" x 0.25" x 1.1" span, using midspan loading.

**Compositions are given in weight percent.

***25° was the limit of travel

A section from that Alcoa ingot was tested in bending and had the following properties:

Alloy	Bending Strength (psi)	Bend Angle (degrees)
No. 719 alloy - Alcoa redraw stock	64,000	10

The next step was the determination of substantial room temperature ductility in the system Al-Ge. Alloys were melted and cast as described above. The test results follow:

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)
A-2	90Al-10Ge	24,000	7
A-1	83Al-17Ge	19,000	3
A-3	70Al-30Ge	22,000	2

These data showed that the limits of substantial ductility in the system Al-Ge would be in the range of 20-30% Ge.

Another purpose of the preliminary tests, was the establishment of the limits of substantial cryogenic ductility in the Al-Zn system. Zinc, 95Zn-5Al, and 50Zn-50Al were tested and found to be brittle at -320°F. Therefore a series of Al-Zn alloys was prepared and tested and the results follow:

Code*	Alloy - As Cast Intended Composition	Analyzed Composition	Room Temperature Bending Strength(psi)	Bend Angle (degrees)	-320°F Bending Strength(psi)	Bend Angle (degrees)
20-1	95Al-5Zn	4.6Zn	15,000	> 25	55,000	> 25
20-2	90Al-10Zn	8.9Zn	18,000	> 25	35,000	> 25
B-4	90Al-10Zn	9.4Zn	29,000	> 25	33,000	> 25
20-3	85Al-15Zn	13.9Zn	52,000	> 25	31,000	> 25
B-1	80Al-20Zn	23.8Zn	60,000	8	50,000	3
B-2	70Al-30Zn	29.2Zn	66,000	12	75,000	3
B-3	60Al-40Zn	37.4Zn	50,000	8	66,000	None

Apparently, Al-Zn alloys with up to about 30% Zn would be technically useful at -320°F.

*Most of the code numbers refer to pages in a laboratory note book. They have no other significance.

3.3 GROUP I BRAZING ALLOY SELECTION AND TEST RESULTS

The alloys listed in Table 7 were selected as the result of the literature survey. They were prepared by the Battelle Memorial Institute under subcontract to Aeronca. Battelle melted 200 gm. heats within a helium atmosphere and casts were made into a copper mold within the same atmosphere. Sample drillings were taken from the top, bottom, and middle of each ingot and analyzed by Battelle laboratories. The actual alloy compositions agreed very closely with the intended compositions.

The remainder of the tests reported in this section were conducted at Aeronca. The melting range or solidus of the alloys (Table I) was determined by submerging a chromel-alumel thermocouple into a molten pool of the alloy and stirring with the thermocouple while the alloy cooled to its freezing point. The reported solidus values (all tables herein) were observed to be reasonably accurate for eutectic alloys. For alloys having wide melting ranges, the reported solidus is not a true solidus, but represents some temperature between the solidus and liquidus, because the thermocouple was withdrawn from the melt when the alloy was in a mushy state. In addition, some alloys (such as those containing In or Cd) evidenced liquation at a temperature substantially below the reported solidus. As a check on the procedure, the solidus was determined for pure aluminum (99.5 purity) and alloy No. 719. For pure aluminum, a solidus temperature of 1210° to 1220" was determined reproducibly. For alloy No. 719 (melting range given as 960° to 1040°F by Alcoa), our solidus values ranged from 1000° to 1020°F. The solidus values for the various eutectic alloys reported in the tables (Al-Au, Al-Ce, Al-Ag, etc.) closely agree with accepted values.

TABLE 7

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

SELECTED CAST ALLOYS*

Code	Alloy -- As Cast	Bending Strength (psi)	Bend Angle (degrees)	Approx. Melting Range or Solidus (°F)
No. 1	54Al-45Ge-1Si	29,000	3	790-840
No. 2	68Al-27Ge-5Si	71,000	7	900-970
No. 3	73Al-12Ge-15Ag	55,000	5	1020
No. 4	28Al-55Ag-7Zn-10Cu	82,000	< 2	940
No. 5	17Al-39Ag-36Zn-8Cd	66,000	6	920-980
No. 6	28Al-57Ag-5Cd-10Cu	62,000	< 2	960
No. 7	30Al-68Ag-2Li	61,000	< 2	980
No. 8	88Al-10Mg-2Li	59,000	3	1050
No. 9	65Al-26Mg-9Cu	Not Tested-Very Brittle	-	830
No. 10	16Al-53Mg-31Ag	Not Tested - Very Brittle	-	-

Sections cut from the center portion of each experimental brazing alloy ingot (Table 7) were placed at' one end of ½" x 2" x .040" specimens of the alloy X7005. The X7005 specimens were cleaned with NaOH and HNO_3 prior to testing, but experimental brazing alloys were degrcased only. The X7005 specimens and brazing alloys were heated, one at a time, to 1000°F for 10 minutes in a pure argon atmosphere. Based on observed melting and flow, the tests were repeated at either higher or lower temperatures. The results are listed in Table 8.

Alloys 1 and 2 showed the most promise. Cross-section photomicrographs of these brazing alloy-substrate interfaces are shown in Figure 40.

Alloy 2 penetrated the substrate to approximately one-third the thickness of the 0.40" sheet, while alloy 1 flowed over the surface without appreciable penetration.

Of the ten experimental alloys tested, only No. 1 appeared promising without additional modification. It would be possible to braze at temperatures lower than 975°F, thus making it useful for 2219, 6061 arid other heat treatable alloys having a solution heat treat temperatures and/or solidus above about 950°F. Alloy No. 2 was similar, but brazing at about 1050°F would be required.

TABLE 8

MELTING AND FMW TEST OF TEN EXPERIMENTAL BRAZING ALLOYS
Time was Ten Minutes At The Test Temperature
Substrate was X7005

Alloy No.	Test Temperature	Remarks
Al-41.3Ge-1.5Si 1	1000°F	Melted and flowed over entire specimen. Specimen was ductile.
1	975	Melted and flowed over ½ the specimen. Specimen was ductile.
1	950	One-half the alloy melted and flowed over one-half the specimen. Braze metal brittle in thick section.
Al-27Ge-5.3Si 2	1000°F	One-third of the alloy melted and flowed over one-fourth of the specimen. Braze metal brittle in thick section.
2	1050	Melted and flowed over entire specimen. Specimen was brittie where thickly coated; ductile with thin coating.
Al-15.3Ag-11.9Ge 3	1020°F	Slight amount of liquid phase separated and flowed over one-third of specimen. Coated specimen was ductile.
3	1050	Slight amount of liquid phase separated and flowed over one-third of specimen. Thickly coated specimen was brittle; ductile with thin coat.
3	1100	One-third of the alloy melted and flowed over me-third of the specimen. Braze metal brittle in thick sections.
Al-55.2Ag-6.7Zn-10.2Cu 4	1020°F	Melted, but balled-up without wetting or flow.
Al-39.1Ag-35.7Zn-8.0Cd 5	1020°F	Melted, but balled-up without wetting or flow. Wet when specimen was vibrated.
Al-57.4Ag-4.6Cd-10.2Cu 6	1010"F	Same as Alloy No. 5
Al-68.2Ag-1.7Li 7	1020"F	Wet and adhered but did not melt.
7	1050	Slight melting. Adhered and penetrated specimen but did not flow.
7	1100	Two-thirds melted and flowed over two-thirds of specimen. Specimen brittle.
Al-10.1Mg-1.8Li 8	1020"F	Wet and adhered, but did not melt.
8	1050	Wet and adhered, but did not melt.
8	1100	Slight melting--wet and flowed.
Al-25.6Mg-9.5Cu 9	1015°F	Melted, balled-up, wet under center of brazing alloy lump, No flow.
10 Al-31Ag-5~ M E	1015°F	Melted, ballad-up, wet and penetrated the specimen. No flow.

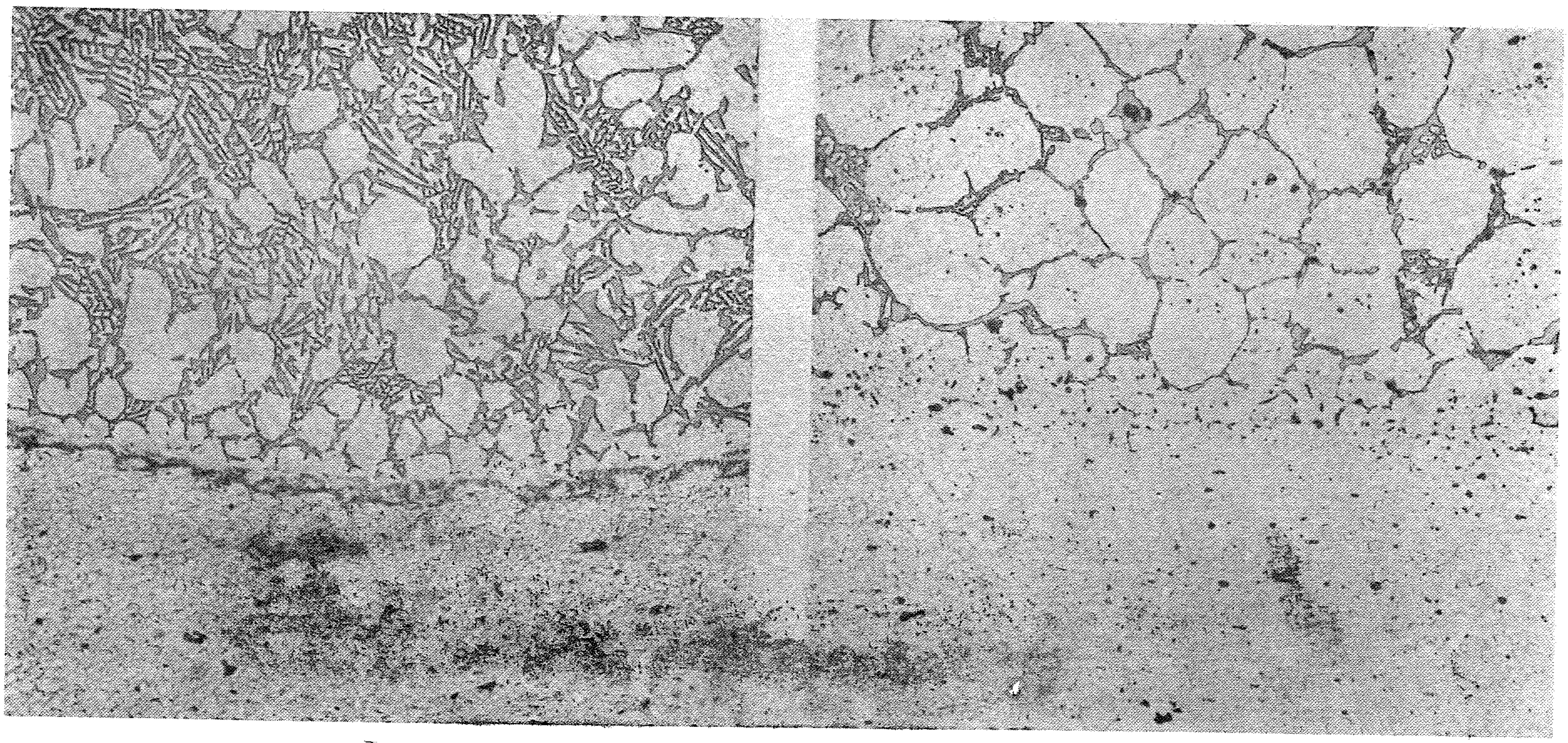


Figure 40 Left: The Alloy 53.5Al-45.0Ge-1.5Si Fused onto X7005 at 975°F for 10 Minutes. Note Narrow Diffusion Zone and no Penetration into the X7005.

Right: A Portion of the Wide Diffusion Zone produced by Fusing the Alloy 67.5Al-27Ge-5.5Si onto X7005 at 1050°F for 10 Minutes.

Mag: 250X
Etchant: Flick's

The Al-Ag-Li and Al-Mg-Li alloys were disappointing, because they had melting points higher than anticipated and nay have had the undesirable film formation characteristic of lithium containing alloys*.

The Al-Ag and Al-Mg alloys containing Cu, Cd or Zn, respectively (4, 5, 6 and 9, Table 7) had melting points of 1000°F, or lower, but did not wet nor flow adequately.

Alloys Nos. 3 and 10 had melting points much higher than anticipated.

Based on the experimental results listed in Table 8, alloy No. 1 was selected for additional tests. Battelle was contracted to cast a 4 lb. ingot and to conduct tests aimed toward reducing the ingot to 0.005" thick foil. Both hot and cold rolling tests were conducted, but the alloy was found to be unsuitable for reduction by rolling. Severe edge cracking occurred during cold rolling tests and lamellar cracking occurred during hot rolling.

3.4 GROUP II BRAZING ALLOY SELECTION AND TESTS

An extensive experimental program was planned in which ten aluminum-base binary systems would be evaluated: first, with moderate (20 to 30%) levels of additive elements; secondly, with increased additive elements, as required to depress melting points below 900°F. The alloys listed in Tables 9 through 17, having code numbers lower than 38 constitute that first group. The second, and more highly alloyed groups, are listed in the same Tables, but have the higher code numbers.

Discussion

The following conclusions pertain to the first group of alloys (code numbers lower than 38) and give equal importance to ductility and melting range:

*See N. Bredzs, U.S. 3,081,534.

TABLE 9

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING GERMANIUM

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Melting Range or Solidus (°F)
A-4	78Al-10Ge-12Si	33,000	8	1000
15-2	80Al-10Ge-10Zn	22,000	4	1000
15-1	70Al-10Ge-10Si-10Zn	17,000	4	970
16-1	85Al-10Ge-5Ag	22,000	5	1100
16-2	80Al-10Ge-10Ag	26,000	7	1060
16-3	70Al-10Ge-20Ag	43,000	4	1080
19-1	85Al-10Ge-5Cu	18,000	6	1060
19-2	80Al-10Ge-10Cu	49,000	6	1000
19-3	70Al-10Ge-20Cu	40,000	3	950
21-2	85Al-10Ge-5Au	15,000	4	1120
21-3	80Al-10Ge-10Au	16,000	7	1100
21-4	75Al-10Ge-10Zn-5Cu	30,000	3	1010
21-5	70Al-10Ge-10Zn-10Cu	41,000	None	1020
21-7	80Al-10Ge-10Mg	35,000	7	1070
50-5	60Al-30-Ge-10Cu	33,000	None	800-880
50-6	55Al-27Ge-18Cu	36,000	None	830-870
50-7	50Al-25Ge-25Cu	11,000	None	890-970
48-1	63Al-32Ge-5Si	34,000	7	880-910
44-1	54Al-40Ge-6Si	24,000	None	850-920
50-2	62Al-31Ge-5Si-2Cu	27,000	< 2	860-900
48-2	60Al-30Ge-5Si-5Cu	25,000	< 2	860-910
* 44-2	51Al-38Ge-6Si-5Cu	28,000	None	820-840
50-1	62Al-31Ge-5Si-2Zn	33,000	2	880-925
48-3	60Al-30Ge-5Si-5Zn	21,000	2	860-900
44-3	49Al-36Ge-5Si-10Zn	30,000	< 2	820-870
48-4	60Al-30Ge-5Si-5Ag	40,000	None	890-930
44-4	49Al-36Ge-5Si-10Ag	33,000	< 2	850-890
48-5	62Al-31Ge-5Si-2Mg	9,000	None	930-1010

TABLE 9 (continued)

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Melting Range or Solidus (°F)
44-6	52Al-35Ge-13Mg	17,000	None	1080-1200
44-7	57Al-38Ge-5Mg	12,000	None	1030-1080
44-5	49Al-36Ge-5Si-10Au	23,000	< 2	870-1040
50-3	52Al-27Ge-4Si-17Ag	35,000	None	880-910
50-4	48Al-24Ge-4Si-24Ag	38,000	2	880-900
52-4	51Al-43Ge-1Si-5Ag	49,000	None	790-820
52-5	38Al-32Ge-1Si-29Ag	48,000	2	810-940
52-1	51Al-43Ge-1Si-5Cu	38,000	None	800-860
52-2	51Al-43Ge-1Si-5Zn	34,000	None	780-820
52-3	49Al-41Ge-1Si-9Zn	31,000	None	760-820

TABLE 10

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING ZINC

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Solidus (°F)
22-1	70Al-10Zn-20Cd	52,000	20	1100
22-2	80Al-10Zn-10Cd	24,000	16	1100
23-1	80Al-10Zn-10Mg	12,000	None	1040
23-2	75Al-10Zn-15Mg	43,000	None	980
23-4	85Al-10Zn-5In	8,000	None	1100
23-5	80Al-10Zn-10In	27,000	12	1080
24-1	85Al-10Zn-5Sb	21,000	11	1110
24-2	70Al-10Zn-20Sb	25,000	7	1120

TABLE 11

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING SILVER

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Melting Range or Solidus (°F)
23-3	70Al-30Ag	57,000	10	1050
24-3	80Al-20Ag	59,000	9	1080
25-1	70Al-23Ag-7Au	57,000	6	1060
25-2	30Al-56Ag-14Ge	32,000	None	940
25-3	62Al-24Ag-14Cu	32,000	None	930
25-4	69Al-30Ag-1Be	34,000	10	1040
25-5	68Al-26Ag-6Mg	14,000	None	1020
25-6	62Al-24Ag-14Mg	16,000	None	910
26-1	67Al-25Ag-8Pb	73,000	>10	1070
26-2	62Al-23Ag-15Pb	63,000	15	1080
26-3	67Al-25Ag-8Pd	52,000	None	1050
26-4	71Al-25Ag-4Si	62,000	8	1010
26-5	67Al-25Ag-8Si	65,000	7	970
26-6	69Al-26Ag-5Zn	60,000	7	1075
26-7	66Al-24Ag-10Zn	66,003	9	1060
26-8	58Al-21Ag-21Sb	26,000	8	1120
46-1	60Al-30Ag-10Si	33,000	2	1000-1040
48-6	50Al-40Ag-10Si	31,000	3	1010-1030
46-2	55Al-27Ag-18Si	weak and brittle		1000-1200
46-3	50Al-33Ag-17Si	21,000	None	1000-1100
47-2	60Al-30Ag-10Ge	14,000	4	980-1030
47-3	55Al-27Ag-18Ge	38,003	< 2	920-990
49-1	50Al-40Ag-10Ge	38,000	2	930-980
47-4	55Al-27Ag-18Mg	8,000	None	960-990
47-5	50Al-25Ag-25Mg	7,000	None	910-940
48-9	50Al-33Ag-17Mg	5,000	None	970-1000
49-7	30Al-70Ag	65,000	6	1030
49-2	27Al-64Ag-9Ge	46,000	2	930-1040
49-5	29Al-66Ag-5Ge	50,000	2	980-1020

TABLE 11 (continued)

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Melting Range or Solidus (°F)
49-3	29Al-66Ag-5Si	52,000	2	1010-1060
49-6	18Al-41Ag-41Pb	54,000	8	1020-1030
49-8	18Al-41Ag-41Bi	57,000	10	~ 1020

TABLE 12

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING MAGNESIUM

Code	Alloy - As Cast Intended Composition	Analyzed Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx, Melting Range or Solidus (°F)
'0-2	93Al-7Mg	7.9 Mg	37,000	6	1060 Not tested
42-4	90Al-10Mg	10.7 Mg	'35,000	< 2	
30-1	88Al-12Mg	13.5 Mg	20,000	4	Not tested
42-5	80Al-20Mg	20.0 Mg	8,000	None	980
27-1	82Al-11Mg-7Ag		19,000	None	1040
27-2	75Al-10Mg-15Ag		25,000	None	1030
27-3	86Al-12Mg-2Au		15,000	None	1020
27-4	83Al-11Mg-6Au		23,000	None	1030
27-5	88Al-11Mg-1Be		18,000	None	960
27-6	85Al-11Mg-4Ge		22,000	3	1020
27-7	80Al-11Mg-9In		42,000	3	970
27-8	73Al-10Mg-17In		50,000	4	980
28-1	84Al-12Mg-4Sn		19,000	None	1000
28-2	86Al-12Mg-2Sn		23,000	None	960
38-7	66Al-27Mg-7In		12,000	None	880
38-2	58Al-24Mg-18In		12,000	None	900
38-3	56Al-21Mg-23In		17,000	< 2	950
39-1	67Al-17Mg-16In		36,000	2	960
39-2	61Al-16Mg-23In		51,000	7	1000
38-4	68Al-28Mg-4Ge		8,000	None	890
38-5	67Al-24Mg-9Ge		9,000	None	1000
38-6	61Al-25Mg-14Ge		Solid constituents at 1400°F		
39-3	62Al-16Mg-6Ge-16In		30,000	4	1000
39-4	58Al-14Mg-6Ge-22In		53,000	4	1020

TABLE 12 (continued)

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Melting Range or Solidus (°F)
40-1	60Al-30Mg-10Zn	weak and brittle		830
40-2	55Al-25Mg-20Zn	5,000	None	850 - 900
40-3	50Al-35Mg-15Zn	weak and brittle		840 - 900
42-6	50Al-20Mg-30Zn	11,000	None	870
40-4	30Al-40Mg-30Zn	weak and brittle		840 - 890
40-5	20Al-55Mg-25Zn	10,000	None	760 - 800
42-8*	2Al-43Mg-55Zn	28,000	None	680
42-7	45Al-14Mg-27Zn-14In	16,000	None	960
42-2	15Al-50Mg-35Pb	30,000	None	790
42-3	25Al-40Mg-35Pb	weak and brittle		Not Tested
42-1	35Mg-65Pb	10,000	None	Not Tested
41-1	20Al-60Mg-20Ag	13,000	None	790
41-2	10Al-55Mg-35Ag	11,000	None	810
41-3	30Al-35Mg-35Cd	9,000	None	800
41-4	20Al-25Mg-55Cd	21,000	None	880
41-5	5Mg-95Cd	19,000	5	Not Tested
41-6	10Mg-90Cd	weak and brittle		Not Tested
41-7	45Mg-55Cd	3,000	None	Not Tested
40-6	64Al-27Mg-9Au	weak and brittle		860
40-7	58Al-25Mg-17Au	10,000	None	850

* Dow alloy GA 432 powder, melted under Dow flux 452. Melting range given as 625" to 675°F with a brazing range of 925" to 940°F (for brazing magnesium alloys).

TABLE 13

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING COPPER

Code	Alloys - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Solidus (°F)
28-3	90Al-10Cu	22,000	2	1090
28-4	80Al-20Cu	27,000	None	1000
29-1	85Al-10Cu-5Ag	28,000	None	1050
29-2	87Al-10Cu-3Ag	23,000	None	1080
29-3	89Al-10Cu-1Be	33,000	None	1090
29-4	85Al-10Cu-5Ge	27,000	None	1050
29-5	85Al-10Cu-5Mg	27,000	None	1020
29-6	85Al-5Cu-10Mg	33,000	None	960
29-7	75Al-10Cu-15Si	44,000	None	980
29-8	70Al-10Cu-20Si	29,000	None	980
29-9	85Al-10Cu-5Cd	34,000	5	1050
29-10	75Al-10Cu-15Cd	40,000	6	1070

TABLE 14

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING GOLD

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Melting Range or Solidus (°F)
31-1	94Al-6Au	32,000	> 25	1190
32-1	90Al-6Au-4Ge	24,000	15	1130
32-2	85Al-10Au-5Si	17,000	13	1060
32-3	90Al-6Au-4Si	27,000	20	1110
32-4	90Al-6Au-4Mg	20,000	None	1130
32-5	92Al-6Au-2Mg	14,000	8	1160
32-6	92Al-6Au-2Sb	35,000	> 25	1150
32-7	86Al-10Au-4Sb	24,000	20	1130
32-8	87Al-10Au-3Sn	25,000	22	1180
32-9	90Al-6Au-4Sn	22,000	> 25	1150
45-1	80Al-10Au-10Si	41,000	7	1040 - 1180
45-2	70Al-20Au-10Si	31,000	3	1030 - 1050
48-7	60Al-30Au-10Si	9,000	None	1050 - 1240
48-10	50Al-40Au-10Si	7,000	None	1070 - 1200
45-5	70Al-20Au-10Ge	17,000	3	1080 - 1150
48-8	60Al-30Au-10Ge	16,000	2	1080 - 1120
45-3	64Al-18Au-9Ge-9Si	30,000	4	970 - 1100
45-4	44Al-30Au-20Ge-6Si	8,000	None	1050 - 1300

TABLE 15

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING PALLADIUM

Cade	Alloy - As cast ~~Intended Composition~~	Bending Strength (psi)	Bend Angle (degrees)	Approx. Solidus (°F)
31-2	82Al-18Pd	33.000	2	1100
33-2	80Al-15Pd-5Mg	38,000	None	1070
33-3	80Al-15Pd-5Zn	43,000	9	1090
33-4	85Al-5Pd-10Sb	45,000	12	1130

TABLE 16

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS

OF

CAST ALLOYS CONTAINING CERIUM

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Solidus (°F)
34-1	90Al-10Ce	28,900	14	1140
36-1	85Al-5Ce-10Mg	37,000	2	1040
36-2	80Al-10Ce-10Mg	29,000	< 2	1030
36-3	85Al-5Ce-10Cu	31,000	4	1100
36-4	80Al-10Ce-10Cu	34,000	5	1100
36-5	85Al-10Ce-5Cu	39,000	11	1110
37-2	80Al-15Ce-5Cu	27,000	4	1120
37-1	84Al-10Ce-6Au	26,000	11	1150

TABLE 17

ROOM TEMPERATURE BEND TESTS AND MELTING TESTS OF CAST ALLOYS CONTAINING LANTHANUM

Code	Alloy - As Cast Intended Composition	Bending Strength (psi)	Bend Angle (degrees)	Approx. Solidus (°F)
34-2	90Al-10La	25,000	13	1140
37-3	86Al-10La-4Au	18,000	8	1140
37-4	85Al-10La-5Ag	35,000	5	1150
37-5	85Al-10La-5Cu	26,000	6	1120
37-6	85Al-10La-5Mg	30,000	5	1080

The Al-Ge group of alloys, Tables 7 and 9 , appeared to merit further work. The most promising system was the Al-Ge-Si ternary and the most promising addition elements were thought to be Cu and Zn. Other, possibly useful addition elements were Au and Gg.

The Al-Zn group of alloys (Table 10) could have been re-evaluated at higher Zn levels; however, even at 70Al-30Zn, the liquidus would be above 1100°F. Accordingly Al-Zn systems were not, planned to be evaluated further, except that Zn might be an addition element to other systems.

The Al-Ag group of alloys (Table 11) showed several promising possibilities, such as:

1. Al-Ag-Si - Increase Ag and *Si.* Possibly add Pb.
2. Al-Ag-Mg - Vary the composition, add Pb or In to improve ductility. (See Al-Mg alloys below)
3. Al-Ag-Ge - Vary the composition, add Si and/or Au.
4. Increase Ag content on entire series.

Tests on the Al-Mg group alloys (Table 12) and the Al-Cu group alloys (Table 13), showed that it would be difficult, if not impossible, to achieve substantial ductility in those alloys having high enough Cu or Mg to sufficiently depress the melting ranges. The Al-Cu system would not be evaluated further except that Cu might be considered as an addition element €or other systems. The Al-Mg system was evaluated in the second series of rests by increasing the Mg content and by attempting to retain ductility with In and Ge additions. Secondly, the ternary phase diagrams available for Al-Mg-Zn, Al-Mg-Ag, Al-Mg-Cd, and Al-Mg-Pb suggested possible candidate alloys. Several alloys from each system were prepared and evaluated.

Table 14 on Al-Au alloys shows both high melting points and high ductilities. Reference to their respective binary phase diagrams shows that Au greatly depresses the melting points of Ge and Si. Consequently, a second series of tests were planned on Al-Au-Si and Al-Au-Ge alloys with progressively higher precentages of Au, Si, and Ge.

Aluminum alloys containing Pd, Ce, and La (Tables 15 through 17) would not be evaluated further.

The second group of tests (code numbers greater than 37) were begun by determining the effects of In and Ge additions on Al-Mg alloys having higher Mg percentages than those discussed above. The results are listed in Table 12. Neither system offered enough merit for further work. In addition to failing to pass the ductility and melting point tests, all of the second group Mg-alloys were observed to have poor corrosion resistance. The poor corrosion resistance of some Mg-Ge alloys is well known (oxidize in dry air at room temperature). It was interesting to observe that the 81-rich, Al-Ge-Mg alloys also had very poor corrosion resistance.

Alloys from the systems Al-Mg-Zn, Al-Mg-Ag, AL-Mg-Cd, and Al-Mg-Pb, were selected on the basis of the liquidus in their respective ternary equilibrium diagrams*. The data, Table 12 , showed little promise for meeting the goals of the program with those alloy systems. Other alloys, containing Mg-Pb, Mg-Cd, and Mg-Au, also showed negative results.

A few additional brazing tests were planned on Al-Mg-Cu alloys because of their flow characteristics. Unless those tests provided unexpected results, no further work would be done on alloys containing substantial amounts of magnesium.

Alloys based on the systems Al-Ge and Al-Ag are listed in Tables 9 and 11 , respectively. The results in the Al-Ge system are self-evident and selection of one or more specific alloys would depend upon brazing and working tests as described subsequently. Interestingly, the addition of rather large

*Metals Reference Book, 3rd Edition, Vol. 1, Smithells, C. J. Butterworths, 1962.

amounts of Ag to Al-Ge-Si alloys imparted more ductility than that obtained with Al-Ge-Si alloys having only small amounts of Ag. It appeared that Al-Ge-Si alloys would require about 35% Ge to meet the program requirements.

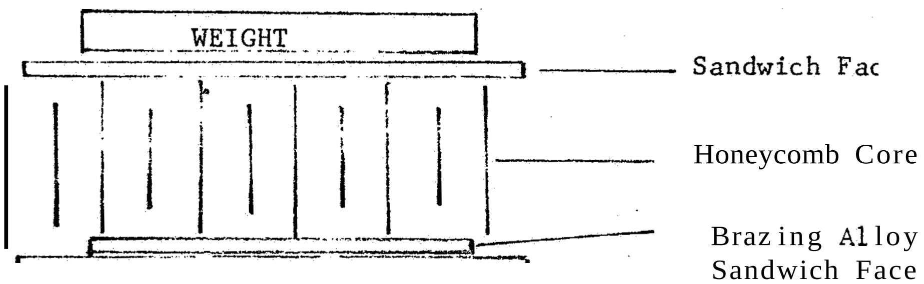
The selected Al-Ag-Si alloys (Table 7) did not evidence adequate melting point depressions. On the other hand, the Al-Ag-Ge alloys more closely approached the requirements.

Alloys based on the Al-Au system did not offer sufficient promise for further work,

3.5 BRAZING TESTS

Small sandwich brazing tests were conducted in the laboratory tube furnace within an argon atmosphere to determine the flow, wetting, and erosive characteristics of selected experimental brazing alloys.

The specimen configuration is shown below.



The brazed sandwich specimens were sectioned, etched, and examined following brazing. The observed results are listed in Table 18 . The alloys showing the most promise at this time were in the system Al-Ge-Si-Ag and the system Al-Ge-Si-Zn. Both of those alloy systems also showed good strength and appreciable ductility in bend tests.

3.5 BRAZING ALLOY EVALUATION

From Table 18 above, the following alloys were selected for further evaluation:

Code	Intended Composition	Approx. Melting Range - °F
58-1	47Al-33Ge-20Zn	760-850
44-3	49Al-36Ge-5Si-10Zn	820-870
52-3	49Al-41Ge-1Si-9Zn	760-820
52-4	51Al-43Ge-1Si-5Ag	790-820
53-1	43Al-36Ge-1Si-20Ag	810-820
50-4	48Al-24Ge-4Si-24Ag	880-900

In addition, the alloy 65Al-26Mg-9Cu (Code No. 9) was promising in brazing tests; however, it was too brittle to be considered further at this time.

3.5.1 Foil Cladding and Brazing Tests

Foil of alloy 2024, 0.005" thick and 0.55" wide, was drawn through molten 200 gm heats of each of the above brazing alloys with the alloys maintained at a temperature of 900°F. Final thickness of the 2024 foil ranged

TABLE 18

ALUMLNUM ALLOY SANDWICH

SELECTED EXPERIMENT

Code	Brazing Alloy Intended Composition	Approx. Melting Range °F	Sandwich Faces & Core	Brazing Temperature °F (for 10 min.)
No. 9	65Al-26Mg-9Cu	830-880	2024	915
No. 5	17Al-39Ag-36Zn-8Cd	920-980	X7005	980-1010
No. 1	54Al-45Ge-1Si	790-840	2024	920-940
No. 1a*	54Al-45Ge-1Si	790-840	2024	900-930
44-1	54Al-40Ge-6Si	850-920	2024	915
48-1	63Al-32Ge-5Si	880-910	2024	920
56-3	50Al-29Ge-21Zn	790-900	2024	930
58-1	47Al-33Ge-20Zn	760-850	2024	930
50-1	62Al-31Ge-5Si-2Zn	880-925	2024	930
48-3	60Al-30Ge-5Si-5Zn	860-900	2024	920
44-3	49Al-36Ge-5Si-10Zn	820-870	X7005	900-930
52-2	51Al-43Ge-1Si-5Zn	780-820	2024	900-930
52-3	49Al-41Ge-1Si-9Zn	760-820	2024	890-910
50-5	60Al-30Ge-10Cu	800-880	2024	920
50-6	55Al-27Ge-18Cu	830-870	2024	900
50-2	62Al-31Ge-5Si-2Cu	860-900	2024	915
48-2	60Al-30Ge-5Si-5Cu	860-910	2024	925
44-2	51Al-38Ge-6Si-5Cu	820-840	2024	900-925
52-1	51Al-43Ge-1Si-5Cu	780-820	2024	900-930
52-4	51Al-43Ge-1Si-5Ag	790-820	2024	900-910
44-4	49Al-36Ge-5Si-10Ag	850-890	2024	900-920
44-4	49Al-36Ge-5Si-10Ag	850-890	2024	930
53-1	43Al-36Ge-1Si-20Ag	810-820	2024	900
50-4	48Al-24Ge-4Si-24Ag	880-900	2024	900-930
52-5	38Al-32Ge-1Si-29Ag	810-940	X7005	990
47-3	55Al-18Ge-27Ag	920-990	X7005	1000

* Four pound ingot. Same intended composition as Code No. 1.

AZING TESTS USING

BRAZING ALLOYS

Wetting of andwich Face	Condition of Core Root	Remarks
Complete	Unaffected	Good flow and filleting.
Poor	Dissolved	
Complete	Dissolved	Slight penetration of face.
Complete	Dissolved	Slight penetration of face.
Fair	Unaffected	Incomplete melting, some filleting.
eparated	Unaffected	.In complete melting.
eparated	Unaffected	Flow on core walls. Incomplete melting.
Complete	Local attack	Good flow and fair filleting.
Poor	Unaffected	Incomplete melting.
Poor	Unaffected	Incomplete melting.
Complete	Local attack	
Complete	Local attack	
Complete	Local attack	
Poor	Unaffected	Incomplete melting.
Separated	Local attack	Flow on core walls. Incomplete melting.
Separated	Unaffected	Incomplete melting,
Separated	Unaffected	Incomplete Melting.
Complete	Dissolved	Slight penetration of face.
Door	Local attack	Local penetration of face.
Complete	Local attack	Slight penetration of face.
Separated	Unaffected	Incomplete melting.
Poor	Unaffected	Rolled brazing alloy. See Table V.
Complete	Local attack	Slight penetration.
Complete	Unaffected	Good flow without penetration.
Complete	Local Attack	Excellent node flow.
Separated	Unaffected	Rolled brazing alloy. See Table V.

from 0.007" to 0.010". The clad foil was corrugated and resistance welded to form small core blankets.

Laboratory brazing tests were conducted by brazing sandwich specimens having the clad core and bare 2024 faces. The brazing schedules were 10 minutes within the temperature range 900-930°F in an argon atmosphere.

The results indicated that there was an insufficient amount of brazing alloy. Only small fillets were obtained and the top faces of the sandwiches could be separated from the core.

Further dip cladding tests were no more promising. Attempts to build-up heavier coatings resulted in melting of the 2024 honeycomb core ribbon. When the brazing alloy melt was cooled somewhat, coatings were irregular and contained varying amounts of dross.

This method of foil cladding was discontinued.

3.5.2 Brazing Alloy Flow and Corrosion Testing

Brazing alloy flow tests were conducted within argon atmospheres. The brazed specimens, their temperatures and substrate materials are listed in Table 19. Brazing alloys Nos. 718 and 719 were included to provide a basis for comparison. The brazed specimens are shown in Figure 41. Sections of each specimen were examined metallographically and photomicrographs are shown in Figures 42 through 45. Note that alloys 52-3 and 50-4 behaved much like alloys 718 and 719. Some of the brazing alloys showed remarkable fluidity as demonstrated by the photographs of the reverse side of the specimens. They included alloys 53-1 and 58-1. While the behavior of 52-4 appeared similar, the flow to the reverse side of the coupon was caused by penetration through the substrate. Alloy No. 1 also penetrated the substrate. The remainder of the specimens were corrosion tested 96 hours in a salt spray (5% solution) per Federal Test Method Standard No. 151a.

TABLE 19

BRAZING ALLOY FLOW TESTS

Code	Brazing Alloy	Other Brazing Alloy Description	Substrate	Brazing Temperature
74-1	88Al-12Si	No. 718	X7005	1095°F
74-2	76Al-10Si-4Cu-10Zn	No. 719	X7005	1050
74-3	43Al-36Ge-1Si-20Ag	53-1	2024	930
74-4	49Al-41Ge-1Si-9Zn	52-3	2024	930
74-5	51Al-43Ge-1Si-5Ag	52-4	2024	930
74-6	47Al-33Ge-20Zn	58-1	2024	900
74-7	54Al-45Ge-1Si	No. 1	2024	930
74-8	48Al-24Ge-4Si-24Ag	50-4	2024	930

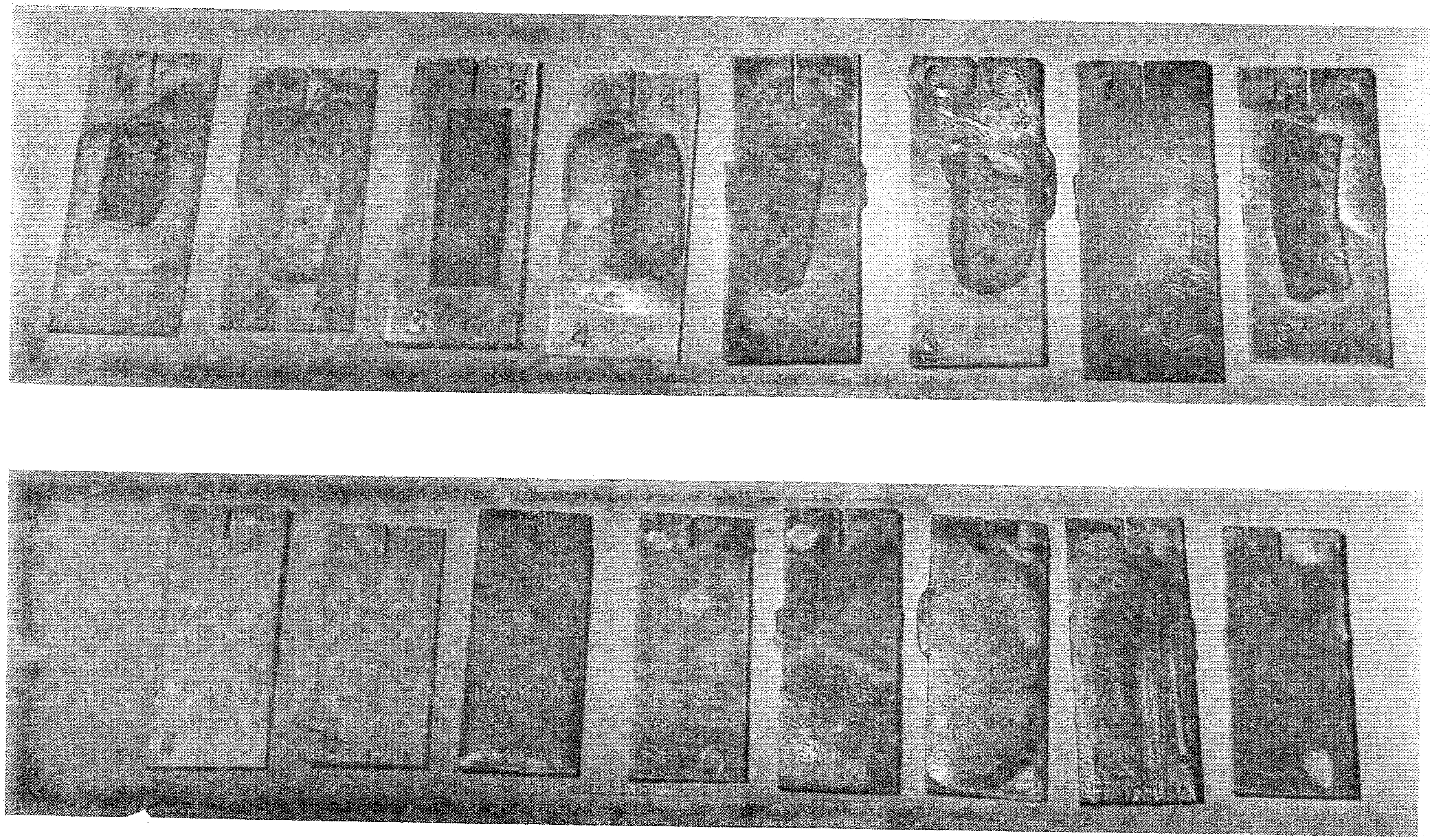


Figure 41 - Brazing Flow Tests 74-1 through 74-8 (see Table 17) showing Top Side and Reverse Side of the Coupons.

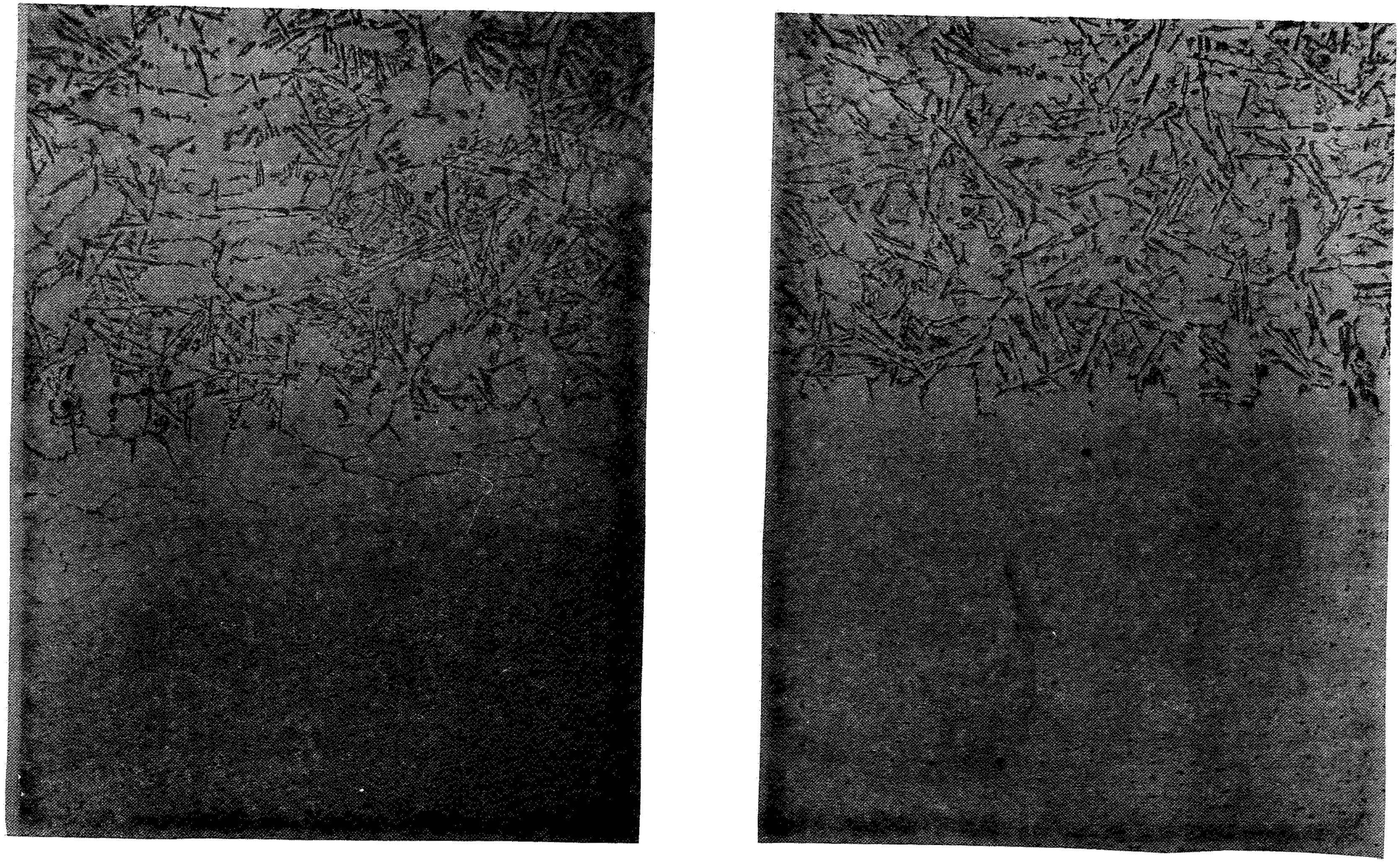
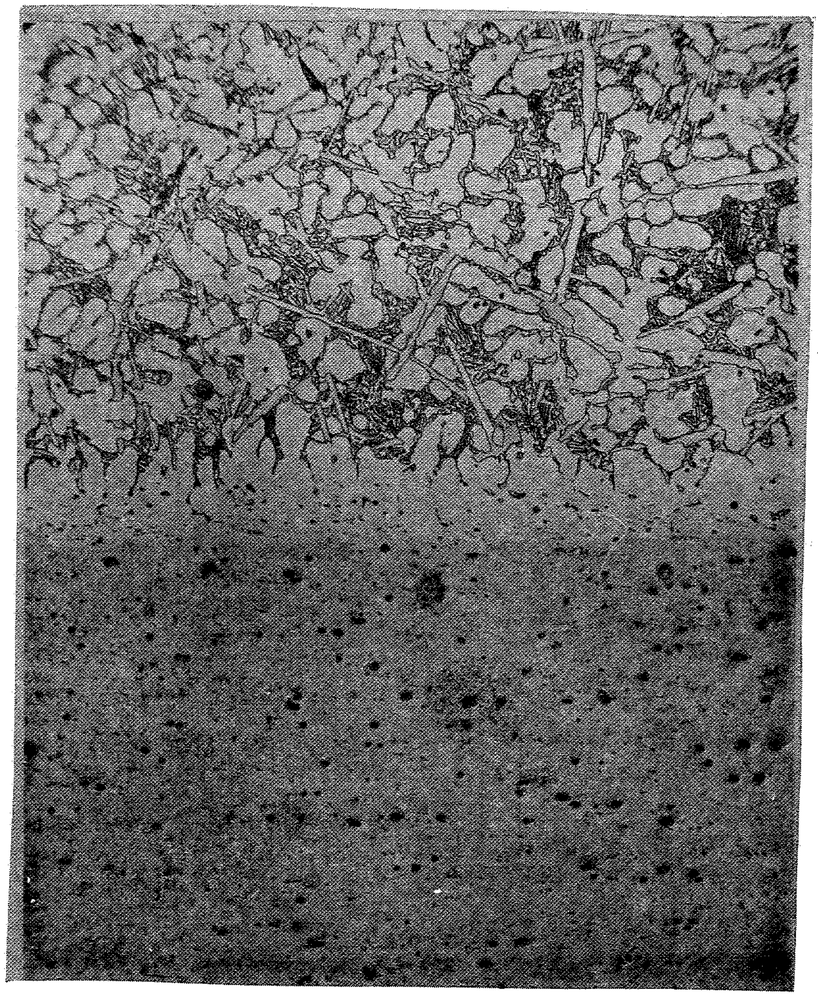


Figure 42

Left: Alloy No. 718 Fused to X7005 at 1100°F in an Atmosphere of Argon

Right: Alloy No. 719 Fused onto X7005 at 1050°F in an Atmosphere of Argon

Mag: 100X



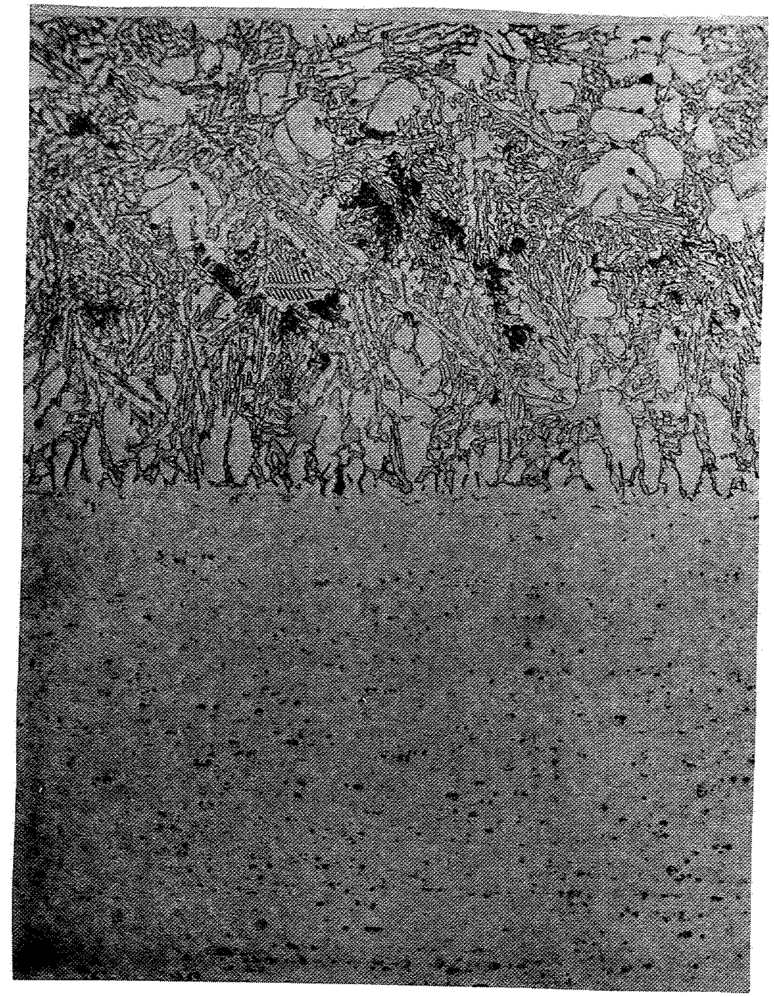


Figure 43

Left: The Alloy 43Al-36Ge-1Si-20Ag Fused onto 2024 at 930°F in an Atmosphere of Argon

Right: The Alloy 49Al-41Ge-1Si-9Zn Fused onto 2024 at 930°F in an Atmosphere of Argon

Max: 100X

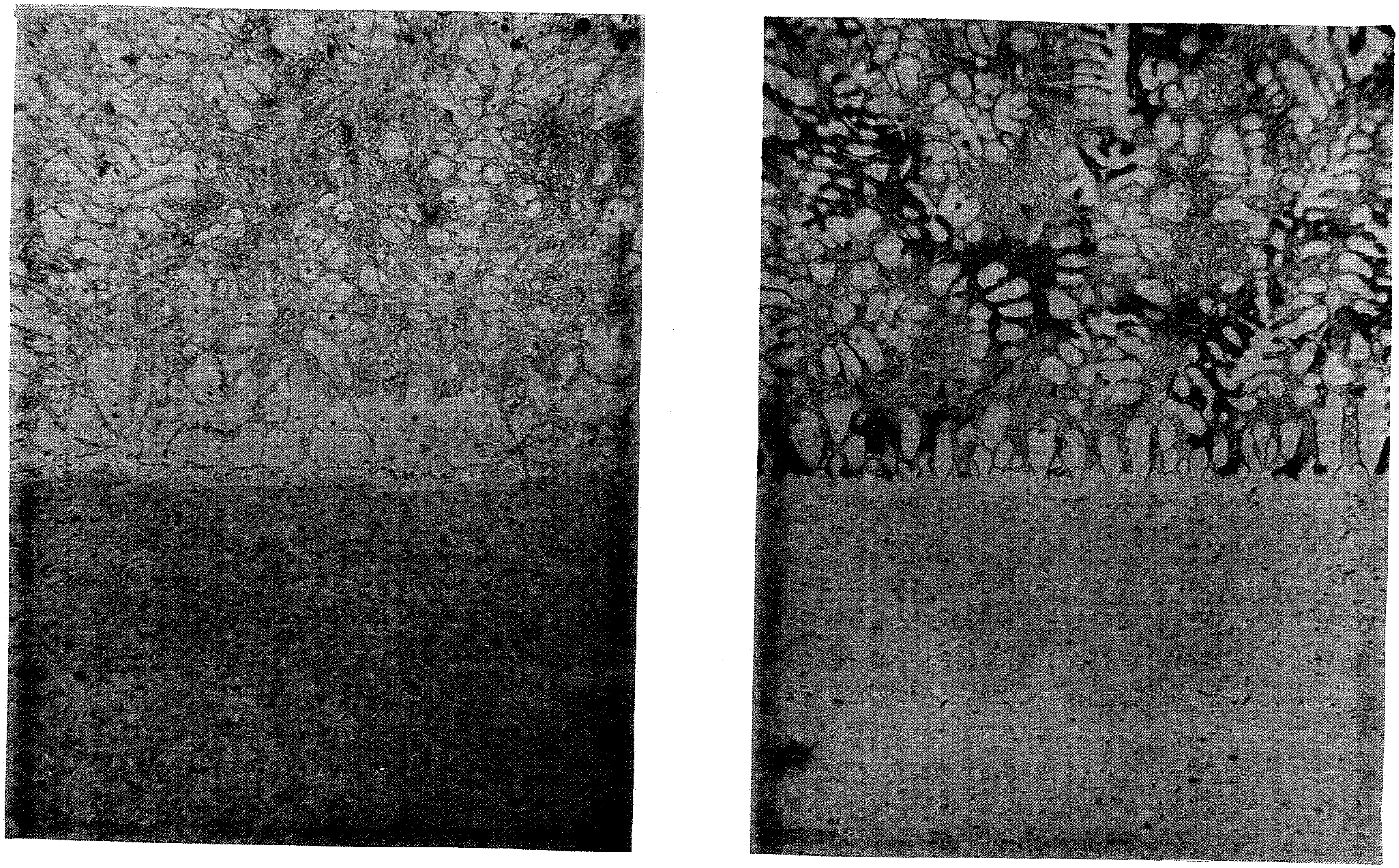


Figure 44

Left: The Alloy 51Al-43Ge-1Si-5Ag Fused onto 2024 at 930°F in an Atmosphere of Argon

Right: The Alloy 47Al-33Ge-20Zn Fused onto 2024 at 930°F in an Atmosphere of Argon

Max: 100X

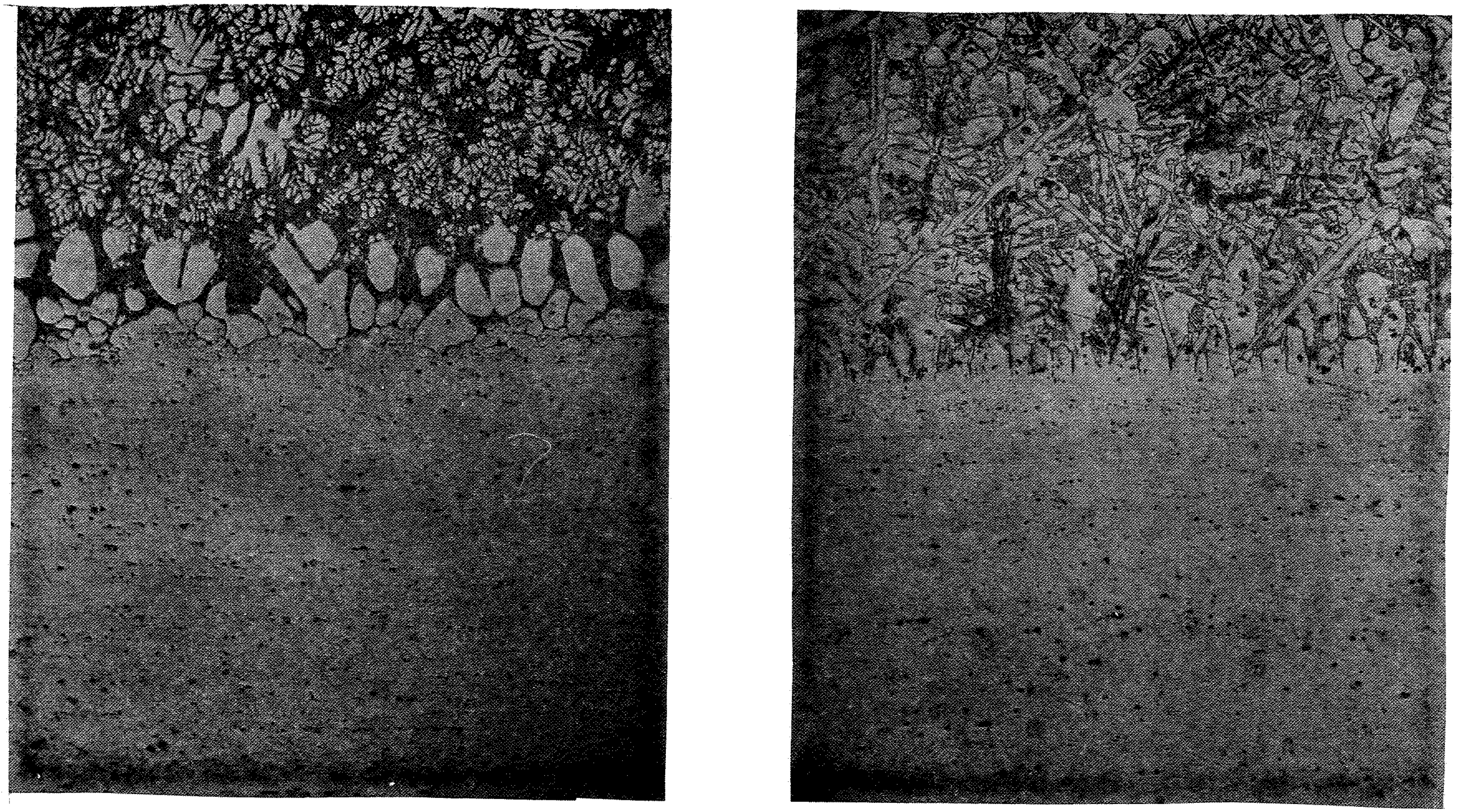


Figure 45

Left: The Alloy 54Al-45Ge-1Si Fused onto 2024 at 930°F in an Atmosphere of Argon

Right: The Alloy 48Al-24Ge-4Si-24Ag Fused onto 2024 at 930°F in an Atmosphere of Argon

Max: 100X

Metallographic examination of the exposed specimens revealed a moderate amount of general corrosion, but no crevice corrosion at the brazing alloy-substrate interface, Few differences were noted among the specimens, except for the 2024 coupon coated with the alloy 43Al-36Ge-1Si-20Ag, (Code 53-1), where there was a greater amount of substrate corrosion.

Similar corrosion tests were conducted on brazed sandwich flatwise tensile specimens from panels F(X7005 faces and core, No. 719 brazing alloy) and G (X7106 faces, X7005 core, No. 719 brazing alloy). After the 96-hour salt spray exposure, the six specimens were tested in tension at room temperature and they failed at a stress between 0 and 100 psi. Non-corroded specimens had a typical flatwise tensile strength of 1100 psi at room temperature (Ref: Volume II). The predominate corrosion mode was perforation of the 0.005" thick X7005 honeycomb core foil at the junction of the brazing alloy fillet and the core cell wall. The corrosion perforation of the honeycomb core was general throughout the 2" x 2" specimens.

Although the salt spray corrosion test is only qualitative, it suggests a requirement for external protection of exposed panel edges and/or the desirability of a closed cell configuration in the honeycomb core blankets.

3.5.3 Hot and Cold Rolling Tests of Selected Alloys

Rolling tests were conducted on the alloys listed in Table 20 . Some of the alloys could be reduced up to 50% at 500°F, but only about 5% at room temperature. Before starting a hot rolling program, other means of brazing alloy placement were sought.

3.5.4 Flame Sprayed Brazing Alloy Placement

Brazing tests of flame sprayed brazing alloy coatings on 2024 honeycomb core sandwiches were conducted. Alloys 58-1, 52-3, and 53-1 were

TABLE 20

ROLLING TESTS OF SELECTED ALLOYS

Alloy Code	Rolling Temperature °F	Reduction in Mils Before Significant Edge Cracking (Original Thickness .10" to .12")
44-2	70	22
	500	
-44-3	70	46
	500	
44-4	70	59
	500	
47-3	70	40
	500	
48-1	70	18
	500	
48-2	70	10
-50-4	70	5
	500	22
50-6	70	10
	500	18
52-2	70	3
	500	55
-52-3	70	5
	500	87
52-5	70	9
-52-4	70	6
	500	25
-53-1	70	3
	500	23
-58-1	70	10
	500	48

- Showed most promise in brazing tests.

crushed to powder and sprayed using an oxy-acetylene metal powder flame spray gun. In addition, alloys 58-1, 53-1, 52-3 and 52-4 were cast into rod molds, centerless ground to 3/16", and sprayed using a rod type oxy-acetylene flame spray gun. Brazing tests employing the flame sprayed brazing alloy coatings were unsuccessful. The sprayed coatings did not fillet and flow adequately when brazing was attempted at 930°F. Honeycomb core cell walls were coated with the brazing alloys but filleting characteristics were unsatisfactory. In every case the top face of the brazed sandwiches could be separated from the core.

3.5.5 Thin Sheet Casting

A method was developed to cast brazing alloys into thin sheets. It involved pouring a molten 100 gm heat of brazing alloy onto a ceramic plate followed by spreading and quenching it with a 15" diameter steel roll. Foils as thin as 0.003" could be produced by that method; but typical thicknesses ranged from 0.010" to 0.015". The six candidate alloys, page 102, were cast into foil by this method and their respective brazing tests are discussed below.

3.5.6 Brazing Tests Using Cast Thin Sheet Brazing Alloys

Each one of the six candidate alloys was cast in thin sheet, approximately 0.01" thick and used to braze 2024 sandwiches at 930°F in an argon atmosphere. With the exception of alloy 50-4, which was incompletely melted, all of the alloys evidenced excessive run-down to the lower sandwich face and poor filleting characteristics.

Alloy 50-4 was modified by increasing the germanium content to 30% and a brazing test on a 2024 sandwich was repeated at 920°F. Although the sandwich was brazed, there was no node flow and little filleting. Its flatwise tensile strength was 100 psi, with the failure at the bottom face core root.

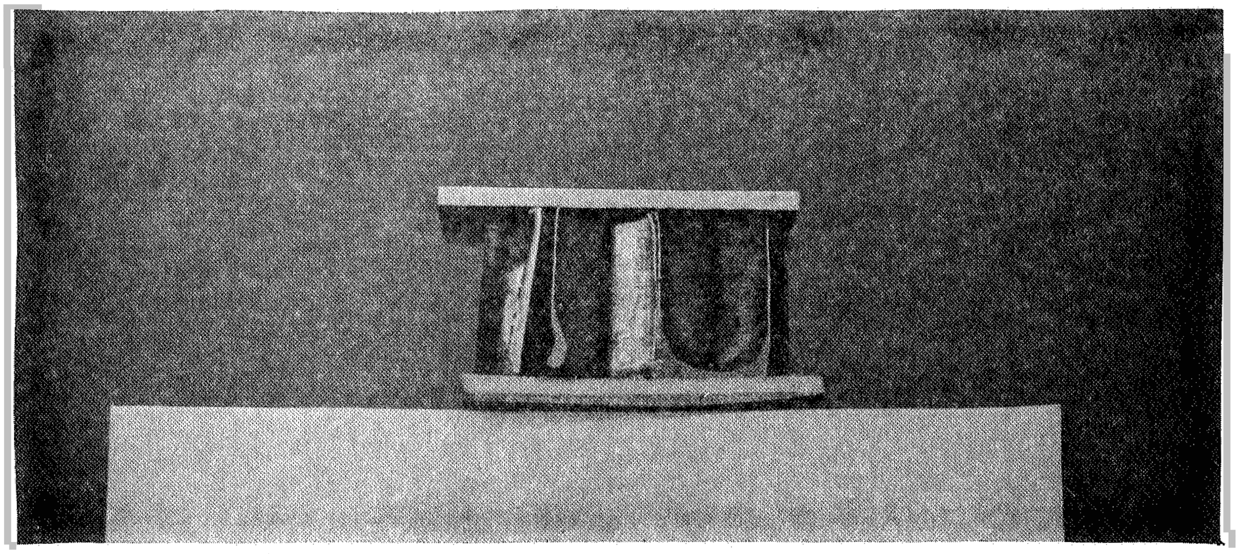
Alloy 53-1 was similar in composition to 50-4, but had a lower flow temperature. Accordingly, sandwich brazing tests of alloy 53-1 were conducted at 850°F and 860°F. Incomplete melting and facing separation was observed for the 850°F brazing temperature. The specimen brazed at 860°F appeared to have flowed and wetted adequately, but there was no filleting. Its flatwise tensile strength was 50 psi.

Two sandwich brazing tests of alloy 44-3 were conducted at 900°F. In both cases, the braze appeared sound, but filleting was poor, and the sandwich faces could be separated manually; consequently, flatwise tensile tests were not conducted.

Alloy 58-1 was used to braze sandwich specimens at 880°F and 890°F. In both cases, filleting was poor, and the sandwich faces were separated manually.

A re-examination of the above specimens, and other similar specimens brazed previously, revealed that wetting and flow were adequate. Sandwich faces and core cell walls were fully coated with the respective brazing alloys, but the filleting characteristics were poor. Excess fluidity appeared to be a problem. In some cases, the brazing alloys ran off the upper surfaces of the sandwiches and fully coated the under side of the lower faces; for example, Figure 46, top. Several of the sandwiches evidenced erosion of the honeycomb core (alloy 2024). It was noted that when the core was dissolved, large fillets were formed. Consequently, alloys 53-1 and 58-1 were modified by adding 2024 to the respective melts.

Alloy 53-1 + 10% 2024 was used to braze a 7075 sandwich at 880°F. Although the brazing alloy was incompletely melted, the brazed sandwich flatwise tensile strength was 300 psi. Alloy 58-1 + 10% 2024, brazed



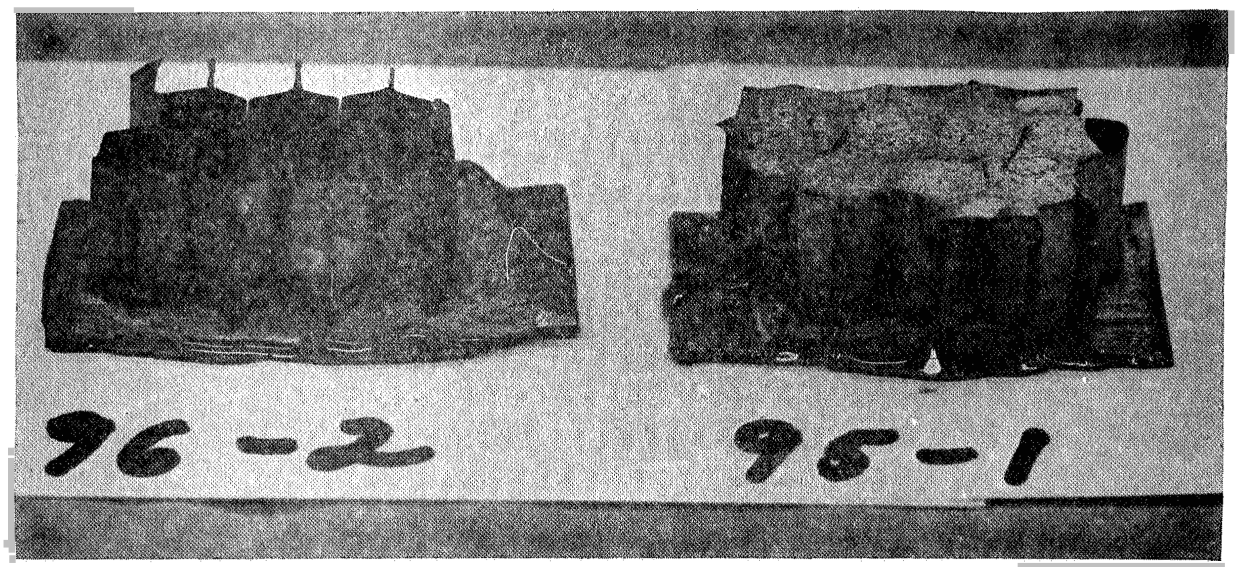


Figure 46

Two 2024 sandwiches brazed at 920° *to* 930°F shown after flatwise tensile testing. Note brazing alloy flow on core cell walls, but there was no filleting.

identically, also was incompletely' melted. Its sandwich flatwise tensile strength was 140 psi.

Additional modifications of alloys 53-1 and 58-1 were made and they were used to braze *2024* sandwiches at *920°F.* The sandwich brazed with alloy 53-1 + 20% *2024* had a flatwise tensile strength of 170 psi. Alloy 53-1 + 10% 7075 yielded a sandwich with a flatwise tensile strength of 360 psi. A modification of 58-1 with *20%* 7075 yielded a sandwich flatwise tensile strength of 600 psi, when brazed at *930°F.* Two of these specimens are shown in Figure 46 , bottom. Note that the honeycomb core was fully coated with brazing alloy, but there was no filleting in the nodes and no face-to-core fillets. Additional tests were conducted and either brazing alloy run-down, or incomplete melting continued to be problems and the filleting characteristics of the alloys were not satisfactory, compared with AI-Si type alloys, Better appearing results were obtained with a duplex brazing cycle, in which the specimens were inverted after the first brazing operation and rebrazed.

A scale-up brazing test was done with a *2024* alloy sandwich panel, approximately 0.6" x 12" x 12". A modification of brazing alloy 58-1 was used for one-half of the panel and a modification of alloy 53-1 for the other half. The two brazing alloy compositions were the following: Code 58-1 plus *20%* 7075; and Code 53-1 plus 10% *2024.*

After weld sealing and purging the retort, the panel was brazed within the range 900" to *940°F.* During the brazing cycle, the retort was removed from the brazing die, inverted, and replaced within the die for the remainder of the brazing cycle.

The panel was sectioned for examination and flatwise tensile testing, but it was evident that it was not adequately brazed. Although the core cell walls and faces were wet by both of the brazing alloys, there were no fillets. The faces could be separated from the core manually; consequently, no mechanical tests were conducted.

After another review of the previous brazing and flow tests, the alloy 65Al-26Mg-9Cu (Code No. 9) was tested by brazing a 2024 sandwich at 930°F. Excellent filleting and flow characteristics were obtained and there was no erosion of the core foil, nor penetration of the facing sheet. The flatwise tensile strength of the specimen was 750 psi, but the failure mode was fracture of the fillets as shown in Figure 47 . Because of its weak and brittle nature, the alloy 65Al-26Mg-9Cu was eliminated from further consideration.

3.5.7 Brazing Alloy Optimization

From Tables 7 through 17 , the strongest and most ductile brazing alloys, with the lowest melting ranges, were selected and they are listed in Table 21 . From that list, three alloys were selected, remelted, cast into thin foil, and used to braze sandwiches at approximately 1000°F. The sandwich materials were X7106 faces and X7005 honeycomb core, type 6-50 x ½".

Table 22 lists the alloys selected, the brazing temperature, and the results, Although none of the brazements were without defects, they showed more promise than those alloys tested on 2024 at 900" to 930°F, (Fig. 48, top) Consequently, tests were conducted to further reduce the Ge content of the brazing alloys, but hold the brazing temperature at or below 1000°F. Those alloys tested are listed in Table 23 . One of the better specimens is shown in Figure 48 , bottom, after flatwise tensile testing. That specimen' was brazed with the alloy 68Al-7Si-15Ge-10Zn at 1010° - 1020°F. It had

TABLE 21

SELECTED × × S ENGTH, DUCTI[illegible], EXPERIMENTAL ALLOYS

CODE	COMPOSITION	BENDING STRENGTH PSI	BEND ANGLE (DEGREES)	APPROX. MELTING RANGE OR SOLIDUS - °F
49-7	30Al-70Ag	65,000	6	1030
23-3	70Al-30Ag	5[illegible],000	10	1050
26-1	67Al-25Ag-8Pb	73,000	> 10	10[illegible]0
26-2	62Al-23Ag-15Pb	63,000	15	1080
26-5	67Al-25Ag-8Si	65,000	7	970
49-6	18Al-41Ag-41Pb	54,000	8	1020-1030
49-8	18Al-41Ag-41Bi	57,000	10	1020
No. 2	68Al-27Ge-5Si	71,000	7	900-9[illegible]0
48-1	63Al-32Ge-5Si	34,000	7	880-910
39-2	61Al-16Mg-23In	51,000	7	1000
29-10	75Al-10Cu-15Cd	40,000	6	1070

TABLE 22

SANDWICH BRAZING TESTS ON X7106

CODE	BRAZING ALLOY	BRAZING TEMPERATURE	RESULTS
118-1	68Al-7Si-25Ag	1020	Heavy fillets, both faces brazed, some penetration into facing sheets.
118-2	68Al-7Si-25Ge	970	Incomplete melting.
118-2a	68Al-7Si-25Ge	1020	Heavy lower face fillets, some core erosion.
118-2b	68Al-7Si-25Ge	970-1000	Incomplete melting, s[illegible] flow.
118-2c	68Al-7Si-25Ge	1010	Fillets top and bottom, some core erosion.
118-3	61Al-16Mg-23In	1000	Fillets top and bottom, some core erosion, poor corrosion resistance.

TABLE 23

SANDWICH BRAZING OPTIMIZATION TESTS ON X7106

CODE	BRAZING ALLOY	BRAZING TEMPERATURE	RESULTS
119-1a	68Al-7Si-20Ag-5Ge	1050	Heavy flow, temperature too high.
119-1b	68Al-7Si-20Ag-5Ge	1030	Heavy flow, temperature too high.
119-1c	68Al-7Si-20Ag-5Ge	990	Imcomplete melting.
119-1d	68Al-7Si-20Ag-5Ge	1010	Sufficient flow, poor filleting, agressive.
120-1	68Al-7Si-15Ag-10Ge	1000	Sufficient flow, poor filleting characteristics.
120-2a	68Al-7Si-15Zn-10Ge	1015	Excessive flow.
120-2b	68Al-7Si-15Zn-10Ge	1005	Excessive flow.
120-2c	68Al-7Si-15Zn-10Ge	1000	Heavy lower face fillets, small top face fillets.
120-2d	68Al-7Si-15Zn-10Ge	990	Little melting.
121-2	68Al-7Si-20Zn-5Ge	1015	Incomplete melting, faces separated.
121-3	68Al-7Si 10Zn-15Ge	1010	Excellent braze with node flow.
122-1a	66Al-7Si-10Zn-17Ge	990	Small fillets, top and bottom.
122-1b	66Al-7Si-10Zn-17Ge	1000-1010	Heavy bottom face fillets, partial filleting top face.
123-1	66Al-7Si-12Zn-15Ge	1000-1020	Excellent braze, but no node flow.
123-2	64Al-7Si-14Zn-15Ge	1000-1020	Poor flow, no filleting, faces separated.
123-3a	63Al-7Si-10Zn-20Ge	1000	Fair braze, small fillets, no node flow.
123-3b	63Al-7Si-10Zn-20Ge	1020	Excess flow, coated lower side of bottom face.

TABLE 23 (CONTINUED)

CODE		BRAZING TEMPERATURE	RESULTS
124-1 (New heat of 121-3 to check reproducibility)	68Al-7Si-10Zn-15Ge	1000-1020	Excellent braze with node flow.
125-2	68Al-7Si-10Ag-15Ge	1000	Poor flow, top face separated.
126-2	Same with brazing alloy in nodes.	1020	Excellent braze with node flow.

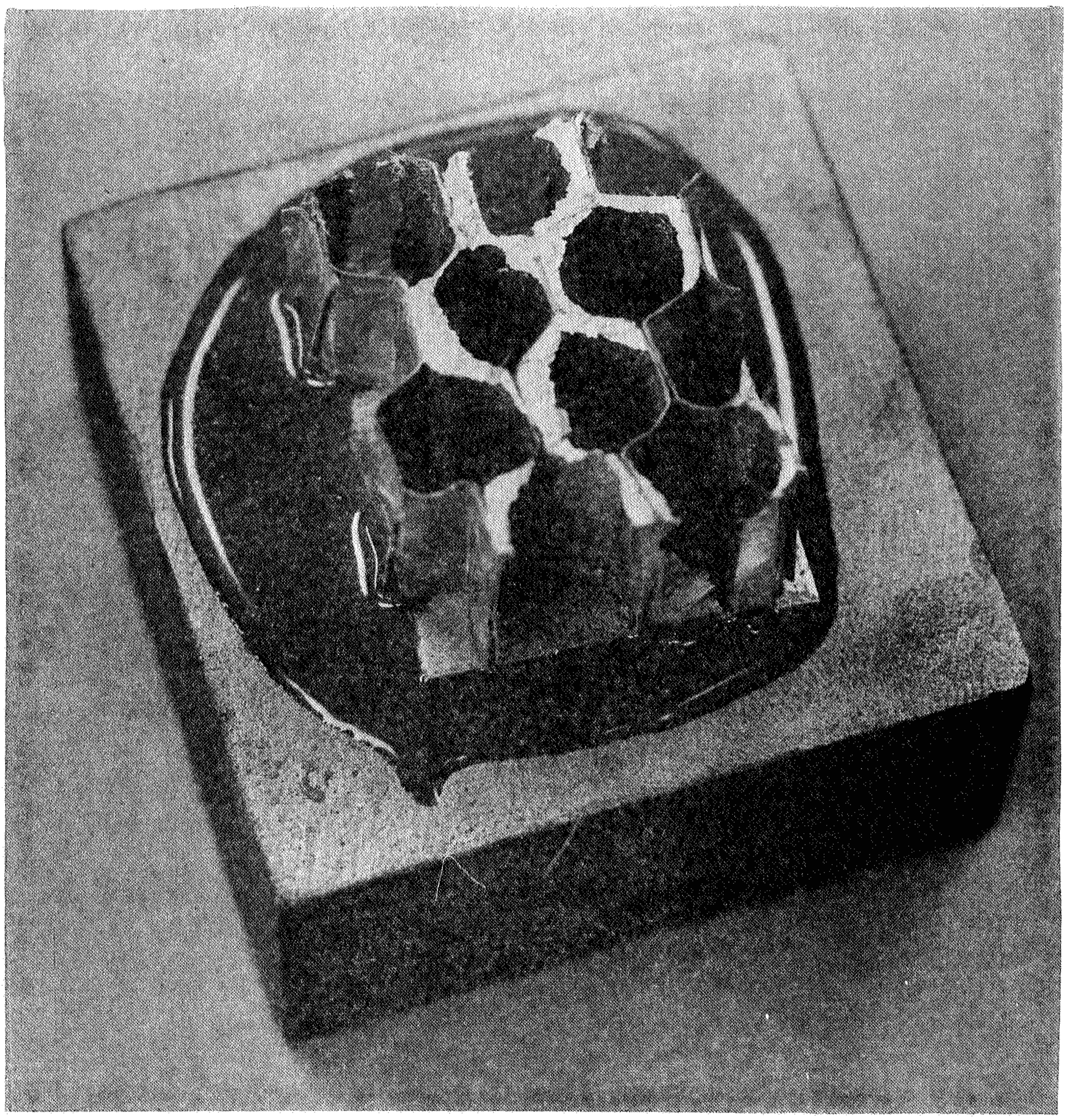
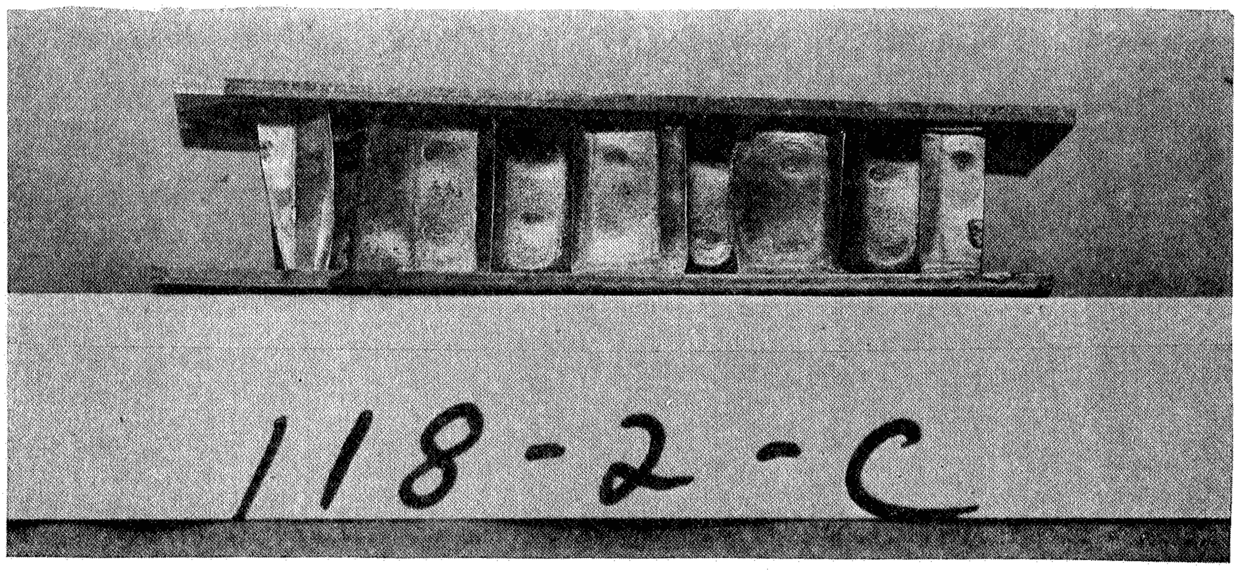


Figure 47

Flatwise Tensile Tested Sandwich comprised of 2024 Faces and Core and the Brazing Alloy 65Al-26Mg-9Cu. Note Fracture of the Fillets.



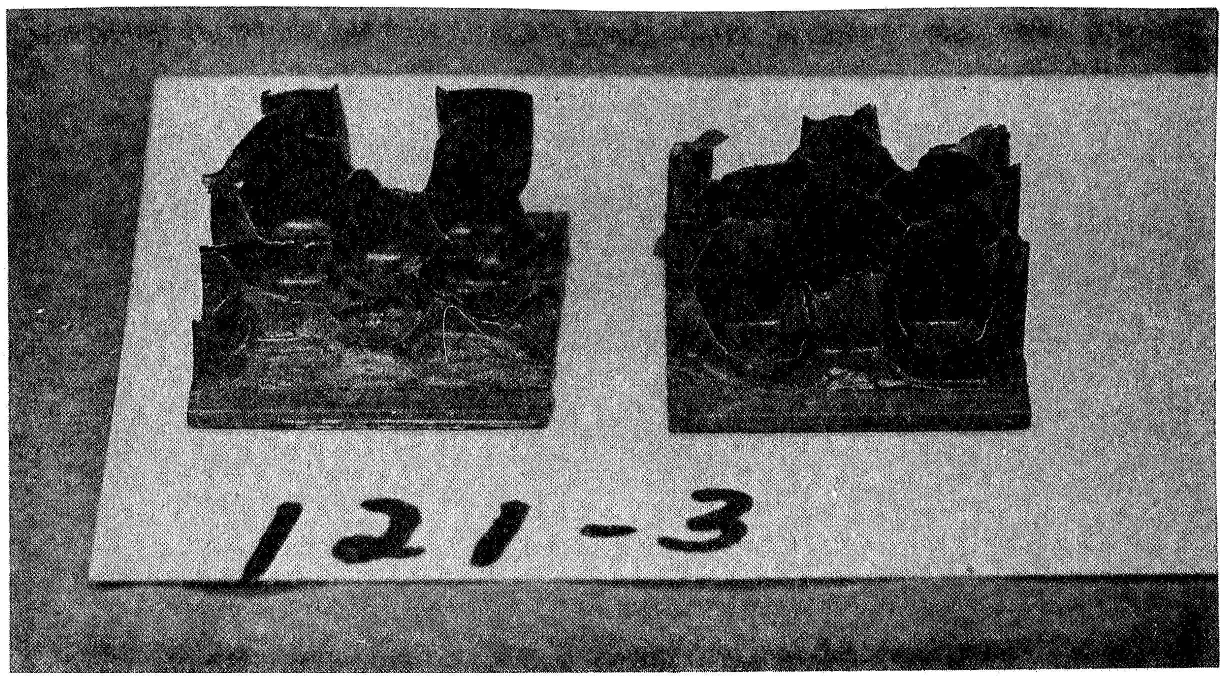


Figure 48

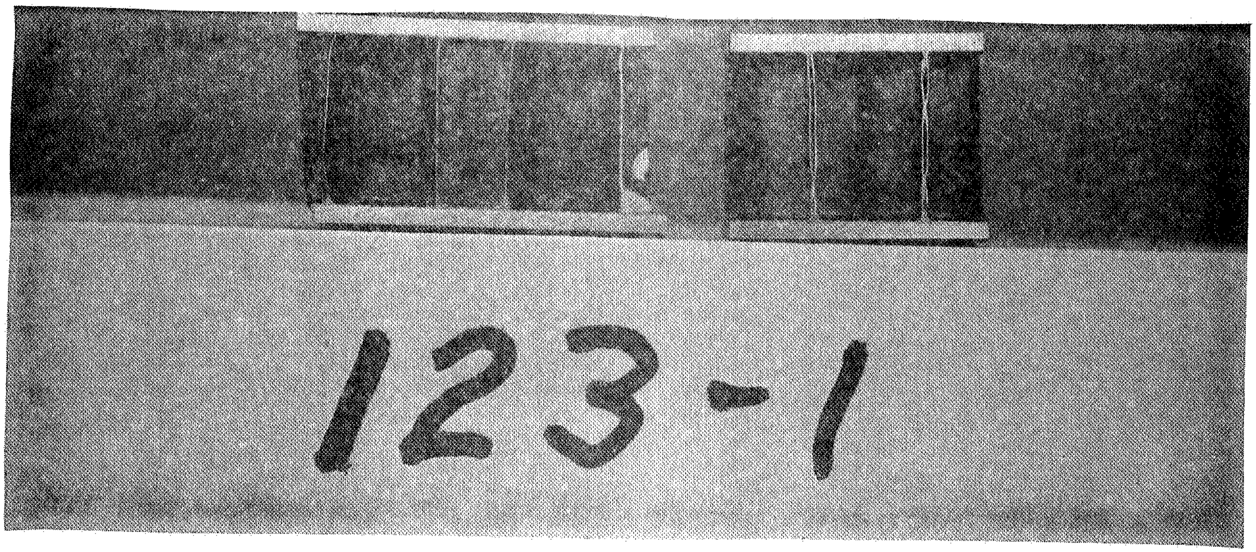
Top: X7106 sandwich brazed at 1010°F with an Al-Ge-Si Alloy

Bottom: X7106 sandwich brazed at 1010°F with an Al-Ge-Si-Zn alloy, shown after flatwise tensile testing. Note uniform filleting, both faces, and full node flow uniform fillets on both faces and full node flow. The flatwise tensile strength was 830 psi with core tear as the failure mode.

Additional specimens are shown in Figures 49 and 50. Specimen 123-1, Figure 49 top, was brazed within the range 1000°F-1020°F and shows small fillets on both faces but no node flow. Figure 49, bottom, shows a similar specimen which had magnesium galled onto the sandwich faces. Although the magnesium improved the brazing alloy flow characteristics, it caused pitting and brazing alloy diffusion into the sandwich faces.

Figure SO shows a specimen which had brazing alloy foil prepositioned in the honeycomb core nodes during the core blanket fabrication. Excellent filleting and core node joining was achieved and there was no brazing allay diffusion into the facings.

Because of schedule requirements, it was necessary to make the brazing alloy selection at this time for the brazing and testing program reported in Volume IT, Section 2. The alloys selected were 68Al-7Si-15Ge-lOZn and 68Al-7Si-15Ge-10Ag, each of which would have a brazing temperature of approximately 1020°F. The sandwich panel materials would be X7106 faces and X7005 honeycomb core.



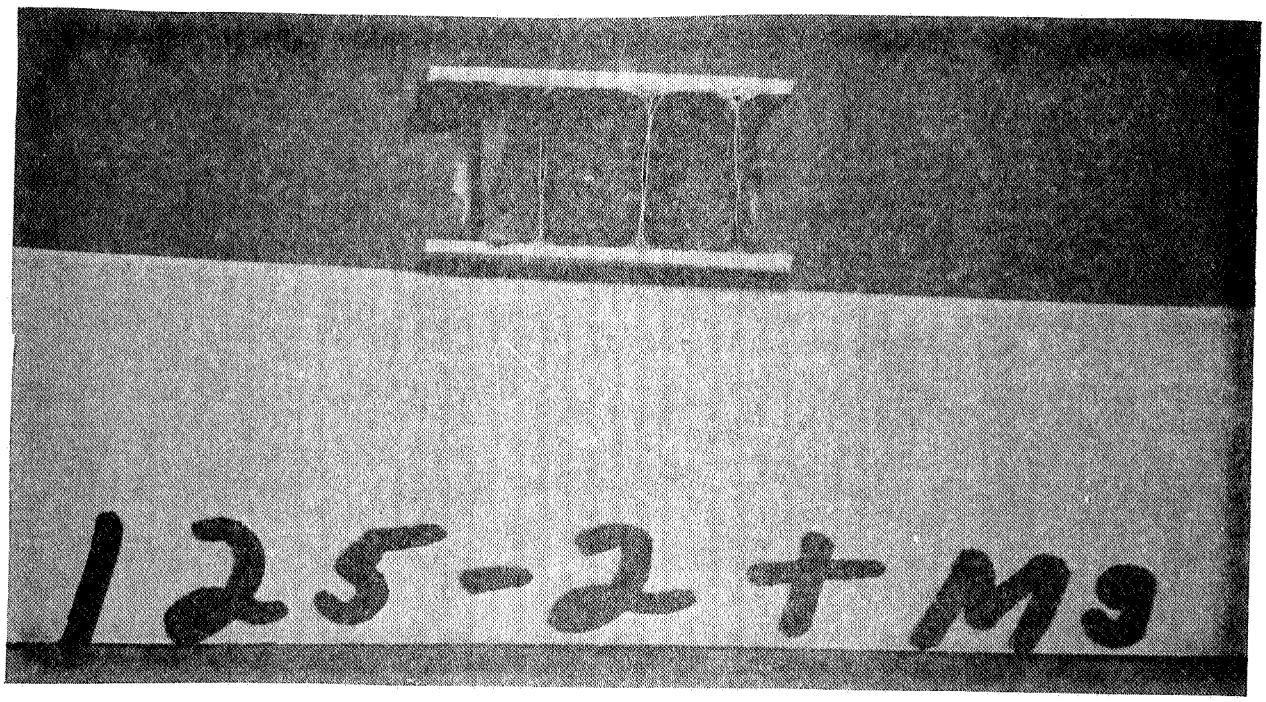
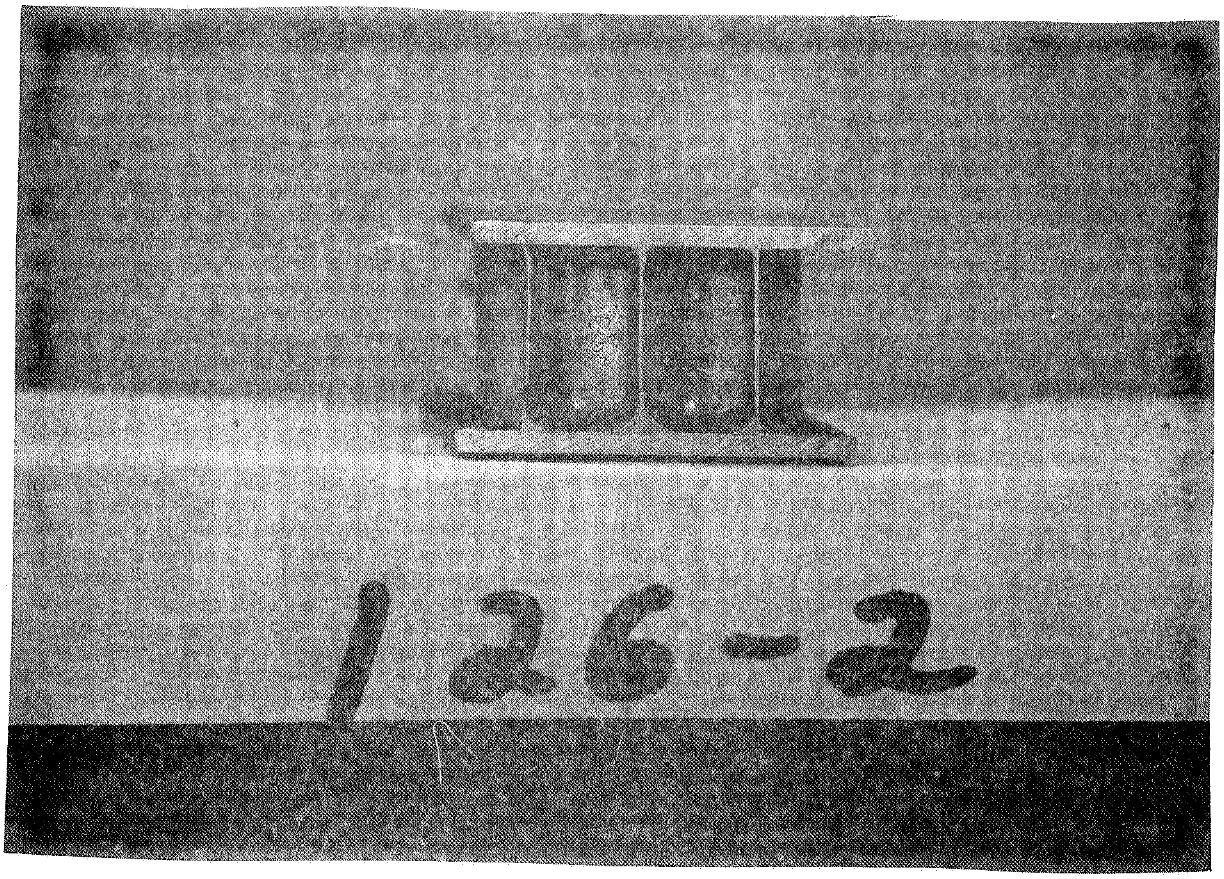


Figure 49

Top: X7106 sandwich brazed at 1000° to 1020°F with an Al-Ge-Si-Zn alloy. Note small, uniform fillets on both faces, but absence of node flow.

Bottom: X7106 sandwich which had magnesium applied to the sandwich faces and was brazed at 1020°F with an Al-Ge-Si-Ag alloy. Note pitting and diffusion into faces. Compare with Figure 50.



Figure? 50

X7106 sandwich brazed at 1020°F with an Al-Ge-Si-Ag alloy. Note large fillets and full node flow.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Alloy systems which might be useful for fluxless brazing of aluminum alloys at 900°F were identified. They are: Al-Ge, Al-Ag, Al-Mg, and Af-Zn. Because it was found that Al-Zn alloys with more than 30% Zn would lack cryogenic ductility, the Al-Zn system was not considered suitable for this program. In the Al-Mg system, the alloy 65Al-26Mg-9Cu was found to braze 2024 honeycomb core sandwiches within the temperature range 900°-930°F. Soundbrazements were achieved with excellent. fFlleting characteristics. However, that brazing alloy lacked appreciable ductility. The fillets fractured when brazed sandwiches were tested in flatwise tension; consequently, experiments on the Al-Mg system were discontinued. In the Al-Ag system, an Al-Ag-Cd-Zn alloy and an Al-Ag-Zn-Cu alloy were tested within the brazing range of 900" to 1000°F, but their wetting characteristics were poor. The Al-Ge system was tested extensively with additions of Si, Zn, Cu, Ag, Mg, and Au. Numerous specific alloys, which flowed on and wet 2024 aluminum within the temperature range 850" to 950°F, were identified and tested for brazeability on 2024 honeycomb sandwiches. None of those alloys filleted nor brazed honeycomb core sandwiches acceptably. The lack of brazeability at 900°F is unexplained; because, similar alloys would fillet and braze at 1000°F when the Ge content was decreased appropriately.

The two specific alloys chosen for sandwich brazements were 68Al-7Si-15Ge-10Zn and 68Al-7Si-15Ge-10Ag, which brazed aluminum alloys at approximately 1000°F. It will be noted that any binary combination in those two respective alloys (except Ag-rich Al-Ag alloys) yields a relatively simple alloy, free from intermetallic compounds. A continuous series of solid solutions is formed by coinbinations of Si and Be while Si and Zn are insoluble.

All other binary combinations in those respective alloys have eutectics. It is suggested that among the possible alloys in the system Al-Si-Ge-Zn-Ag, there may exist solutions to the problems of brazing at 900°F. A statistically designed experiment would be useful for that purpose,

On the other hand, test results on quenched X7106 and 2024 indicated that brazed sandwiches fabricated from 2024 would be only marginally useful because they would have to be re-heat treated after brazing to develop condition T-6 mechanical properties. When X7106 sandwiches were contained within retorts and the assemblies were quenched into liquid nitrogen, the quenching rates were not fast enough. The post-braze heat treatments of X7106, 7039 and X7005 can be accomplished because their unique combination of properties provide more than 150°F differences between brazing temperatures and minimum solution heat treatments. In contrast, alloys such as 2024, 2014 and 2219 would have to be post-braze heat treated at temperatures within or above the brazing temperature range.

The advantages of the two newly developed brazing alloys (Al-Ge-Si-Zn and Al-Ge-Si-Ag) for X7106 or 7039, are their decreased diffusion into the substrates, compared with the commercial brazing alloys, and their lower brazing temperatures which would improve producibility, because of the wider permissable brazing temperature range.

APPENDIX A

NOMINAL COMPOSITION AND MELTING RANGE OF BRAZING FILLER ALLOYS *

Alloy	AWS-ASTM Class	Silicon	Copper	Zinc	Approx. Melting Range--°F
4043 Wire	BAlSi-1	4.0-6.0	0.30	0.10	1070-1165
No 713 Brazing Sheet	BAlSi-2	6.8-8 2	0 25	0 20	1070-1135
No. 714 Brazing Sheet	-------	10 0	----	----	1070-1100
No. 716 Brazing Wire and Flattened Wire	BAlSi-3	9 3-10 7	3 3-C 7	0 20	970-1085
No 718 Brazing Wire and Sheet	BAlSi-4	11.0-13 0	0 30	0 20	1070-1080
No 719 Brazing Wire	-------	9.5-10.5	3 5-C.5	9.5-10.5	960-1040
No 805 Solder	-------	----	----	95	720
No 80? Solder	-------	----	----	100	787

* alance Aluminum